ANZCA

AUSTRALIAN AND NEW ZEALAND
COLLEGE OF ANAESTHETISTS

AUSTRALASIAN ANAESTHESIA 2015

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Invited papers and selected continuing education lectures

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Preface

Welcome to the 2015 edition of *Australasian Anaesthesia* (the Blue Book).

This edition of the Blue Book provides a diverse range of topics for your interest and I thank the authors and regional editors for their valuable contributions.

Please remember that bonus materials may be found on the ANZCA website (www.anzca.edu.au/resources/collegepublications or use the QR code with your digital device). The authors have generously allowed their articles to be available in this way to maximise distribution of their work.

We have again produced the Blue Book in both digital and hard copy formats. While anecdotally many anaesthetists favour the digital format as they amass vast electronic libraries on their portable devices, there are still a number of you who prefer a hard copy. It is wonderful to be able to offer both formats. ANZCA and other medical colleges are constantly faced with the challenges of providing access to the latest medical information. Publications provide a more traditional means of educating and informing and more recently social media has been used to communicate with members about meetings, drug alerts, employment opportunities and other events. Perhaps we may have an article on this very topic in 2017!

I hope you enjoy this edition and I'd also like to thank ANZCA's Publications Manager Liane Reynolds for her support.

Please thank our authors personally if you can – and also consider writing yourself for a future edition.

Dr Richard Riley
Editor, *2015 Australasian Anaesthesia*

Re-examining rapid sequence induction

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INTRODUCTION

Rapid sequence induction (RSI) is an anaesthetic technique that is used to minimise the risk of pulmonary aspiration during induction of anaesthesia.

It has traditionally involved:

- Preoxygenation.
- Cricoid pressure.
- Predetermined doses of thiopentone and suxamethonium.
- Intubation as soon as the suxamethonium has caused paralysis (often indicated by fasciculations).
- No bag and mask ventilation before intubation.
- Inflation of the tracheal cuff and confirmation of tracheal intubation by end tidal CO_2 before removal of cricoid pressure.

The proposed advantages of RSI include:

- Reduced likelihood of aspiration.
- If the patient's trachea cannot be intubated, then there is a relatively rapid return of spontaneous ventilation due to the short duration of action of the drugs used.

The disadvantages of RSI include:

- Increased risk of awareness due to the dosage of induction agent being predetermined and not titrated[1].
- Haemodynamic instability due to non-titration of drug doses.
- Some specific disadvantages/contraindications of using suxamethonium (spinal cord injuries, burns, cholinesterase deficiencies).

The risk of aspiration can vary between high and remote, even in emergency situations, so the reduction in risk of aspiration by RSI must be weighed against other risks and disadvantages of the technique.

With the introduction of new drugs, particularly propofol, rocuronium and sugammadex, and with thiopentone falling into disuse, various modifications of the RSI technique are increasingly being used, depending on circumstances and personal preferences.

In this article we discuss the various combinations of drugs that are used in modified rapid sequence induction and the evidence for any advantage or disadvantage:

- Propofol versus thiopentone.
- Suxamethonium versus rocuronium.
- The use of short-acting opioids to supplement induction agents.

The studies we have looked at all suffer from the problem of comparing two drugs for efficacy in doses that are decided arbitrarily. If a study shows one drug to be superior to another in achieving an end point at two particular doses, it does not mean that if the doses were altered, the results might not be reversed. Having said that, some studies do use a range of doses and a fundamental of ANZCA training is to know what dose ranges to use in order to achieve the desired effect while minimising unwanted side effects.

PROPOFOL VERSUS THIOPENTONE

Hypotension is a side effect of both thiopentone and propofol induction. Indeed, it may be seen with induction of anaesthesia in general, and is of particular concern in RSI due to the non-titration of induction doses and the haemodynamic instability of many emergency patients.

Thiopentone has traditionally been thought to cause less hypotension compared with propofol post-induction, and this is probably true when 5mg/kg of thiopentone is compared with 2.5mg/kg of propofol[2-5]. Some recent studies comparing 2mg/kg of propofol with 5mg/kg of thiopentone[6,7] showed less haemodynamic effect from the propofol, highlighting the difficulty in comparing two drugs with dose-dependent side effects.

A systematic review examined a number of studies that compared the use of rocuronium with either propofol or thiopentone and found that satisfactory intubation conditions are possible with either combination[8]; however, the dose of rocuronium required was increased when thiopentone was used. It is not surprising that the laryngoscopic views attained are comparable when there is sufficient neuromuscular blockade. However, in the absence of complete neuromuscular blockade, propofol appears to be more effective at blunting airway reflexes and improving laryngoscopy grade[9].

Regarding speed of onset, although studies have found that both propofol and thiopentone have a similar time to loss of consciousness[9], time to BIS <50 may be quicker with thiopentone (52 seconds vs 65 seconds, p = 0.01)[10]. However, lower BIS scores were noted with the use of propofol[10,11]. This deeper level of anaesthesia may represent a reduced risk of awareness during rapid sequence induction with propofol compared with thiopentone[1].

Thiopentone is no longer manufactured in Australia. It is imported and although the imported product is not registered in Australia, it is distributed under an exemption granted by the TGA and will likely be available for the foreseeable future. There is currently a 13-fold price differential between thiopentone ($9.73 per 500mg vial) and propofol ($0.76 per 200mg vial), which makes an economic argument in favour of the use of propofol.

In spite of the limited availability, obstetric anaesthesia appears to be the last area of practice in which thiopentone is used regularly. Despite fewer anaesthetists using thiopentone outside of obstetric practice[12], it remains the obstetric induction agent of choice for many anaesthetists in the UK. There is, however, growing evidence for the safety of propofol in obstetric anaesthesia,[13-15]. Despite ongoing use in obstetrics, ANZCA trainees are often unfamiliar with the use of thiopentone[16], which may be due to its limited availability and expense. This lack of experience may result in improper use[17] and drug errors if thiopentone is used. Common drug errors reported during obstetric anaesthesia involve confusion between thiopentone and antibiotic syringes[16-18]. The NAP5 recommendation 16.5 suggests the use of propofol for induction in obstetric anaesthesia to mitigate the risk of such drug error[17].

SUXAMETHONIUM VERSUS ROCURONIUM

Suxamethonium is a depolarising muscle relaxant characterised by a rapid onset that is defined by muscle fasciculations, and a quick offset that theoretically precedes haemoglobin desaturation in the apnoeic patient[19]. It is, however, the only depolarising muscle relaxant available, and its utility is supported by a long history of use, and if paralysis is not required post-induction, then the use of neostigmine and an anticholinergic can be avoided.

There are several potential benefits in avoiding suxamethonium in RSI. These are due to the incidence of muscle pains (50 per cent[20]), allergy (estimated at 1:5,500[21]), malignant hyperpyrexia (incidence 1:50,000 – 1:150,000[22]) and the presence of phenotypes with atypical anticholinesterases (0.01 per cent, with varying prevalence among specific groups[23]).

Suxamethonium is contraindicated in burns, recent spinal injuries and penetrating eye injuries, so avoidance of suxamethonium in some situations is not controversial.

The use of non-depolarising muscle relaxants has also been avoided in the past, due to problems caused by the relatively large doses required to reproduce the onset time of suxamethonium and the time taken for spontaneous respiration to return in the event of the trachea being difficult to intubate and ventilate.

A recent Cochrane Review comparing suxamethonium and rocuronium found that suxamethonium facilitates excellent intubation conditions more reliably than rocuronium, although at higher doses rocuronium (0.09-1.2mg/kg) does provide acceptable views[24]. As such, they recommended rocuronium as a second-line treatment.

The concern regarding the use of high doses of rocuronium to achieve intubation conditions comparable to those achieved by suxamethonium is due to the duration of action, which may delay return of spontaneous respiration in “can’t intubate, can’t oxygenate” (CICO) scenarios. The relatively recent introduction of sugammadex, a cyclodextrin derivative, provides safe and effective reversal, even from profound neuromuscular blockade with rocuronium[25], mitigating this concern. However, sugammadex requires appropriate dosing and time to draw up and administer, which may be prolonged in an emergency, reducing the time advantage[26].

Physiological modelling of haemoglobin desaturation following paralysis with 1mg/kg of suxamethonium suggests that critical desaturation will occur before functional recovery from neuromuscular blockade (~50 per cent twitch height at adductor pollicis)[27,28]. However, dose adjustment of suxamethonium may still provide acceptable views while significantly reducing time to functional recovery[29,30], potentially enhancing its safety.

SHORT-ACTING OPIOID USE TO SUPPLEMENT INDUCTION AGENT

Due to the relatively slow onset of fentanyl – until 20 years ago the most rapidly acting opioid available in Australia – compared with the onset of induction agents, opioids have not been a component of traditional RSI, though many use them in modified techniques. This was because if they were given at the same time as the induction agent, they would have no effect by the time of intubation and would further slow emergence if airway problems ensued. If they were given prior to the induction agent, so that the effects coincided, there was a risk of impairment of airway reflexes prior to paralysis and securing the airway.

Alfentanil has an onset time in the same order as induction agents and its use may increase depth of anaesthesia without the same haemodynamic instability[31], as would occur with larger induction drug doses, while making intubation conditions better and awareness less likely.

Due to the low incidence of awareness it is not surprising that there are no studies showing the use of alfentanil or any other short-acting opioids at RSI reduces the likelihood of awareness. However, there are several studies that show it does improve intubation conditions, particularly when the muscle relaxant used is rocuronium[32,33].

Although there are many reports describing severe bradycardia associated with the use of propofol and suxamethonium, there does not appear to be any evidence that the addition of alfentanil increases this risk[34].

CONCLUSION

RSI remains an important tool in protecting the airway during induction in emergencies and other situations in which aspiration of gastric contents is likely.

The principles of the traditional RSI still hold true, but today there are options of induction agents, muscle relaxants and whether or not to include short-acting opioids, which means that one type of RSI is not suitable for all situations.

When there are no contraindications to suxamethonium, a rapid-sequence induction using a predetermined dose of propofol and suxamethonium is probably the first choice for most anaesthetists in most situations and the bulk of evidence in the literature supports this.

There is also evidence that the addition of alfentanil to this regimen has some advantages, though less so if suxamethonium is used and not rocuronium.

In situations where there is absolute, or even relative, contraindications to the use of suxamethonium, then rocuronium has been shown to be a good substitute.

Similarly, where propofol is contraindicated due to allergy or preference, then there is still a role for thiopentone. However, with thiopentone having limited routine use and limited availability, the experience in its favour and the preference of some traditional anaesthetists will become easier to ignore.

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Which videolaryngoscope do you choose?

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INTRODUCTION

Since the introduction of the Weiss video-intubating laryngoscope[1], there has been a proliferation in number and type of videolaryngoscopes. Anaesthetists, other providers of critical care and managers need to consider multiple factors when purchasing these devices. These considerations can be broadly divided into those affecting the success of the device in the hands of the laryngoscopist and device technical considerations.

Selection considerations for videolaryngoscopes include:

1. Type of blade.
2. Operating environment.
3. Portability – size, power source, video display.
4. Reliability.
5. Robustness.
6. Integration.
7. Expense – capital, disposables and maintenance.

BLADE SELECTION

Videolaryngoscope are available with Macintosh or hyper-angulated type blades, which can be further subdivided into channelled and non-channelled blades[2].

Laryngoscopists are generally comfortable using a Macintosh blade. Using a familiar technique, the Macintosh-style videolaryngoscopes provide an improved view, with additional benefits in a difficult intubation scenario[3]. In an educational setting, Macintosh-style blades can enhance learning for trainee or inexperienced personnel, while reinforcing standard Macintosh intubation techniques[4,5]. Learning and reinforcing basic intubation skills may be becoming more difficult. Exposure to intubations is decreasing for many trainees due to constraints relating to safe working hours[6-9], increased use of alternative airway devices, such as laryngeal mask airways, and increasing out-of-theatre clinical requirements. For training purposes, the laryngoscopist uses the standard direct view of the larynx, while the educator views the video screen, enabling appropriate discussion on blade handling and tube manipulation techniques to optimise the intubation.

The hyper-angulated videolaryngoscope is the device of choice as the secondary blade after a failed intubation with a Macintosh-type blade and bougie[10,11]. It may be the device selected as the primary blade in a suspected difficult intubation. Hyper-angulated devices are less familiar to most users. For optimal success these require a different intubation technique[2]. Rather than entering the right side of the mouth and sweeping the tongue across to the left, they use a midline "point and shoot" technique with a channelled device or a midline, guided technique with a styletted angulated endotracheal tube in an un-channelled device. It may be difficult to use a bougie in the

un-channelled hyper-angulated device and novice users should avoid this. Subjectively, the hyper-angulated blade can make intubation harder in easy intubation cases (Cormack and Lehane grade 1 and 2).

Both types of videolaryngoscopes can be used in the advanced two-person videolaryngoscope fibrescope intubation techniques[12].

DISPOSABLE VERSUS REUSABLE SYSTEMS

There are options of reusable or disposable blades and, if optical laryngoscopes are included, a completely disposable single-use option. Infection-control issues, including costs, appropriate resources and turn-around time for the decontamination and sterilisation processes need to be considered. With the reusable option, turn-around time has implications to the number of units required. Total cost, including disposables, cleaning, and training, may limit the options.

IMAGING

Image and/or video recording, can be considered in purchasing these devices. This facilitates airway documentation in the hospital's electronic medical records; education in demonstrating optimal and suboptimal laryngoscopy; and as part of medico-legal record of airway morbidity, such as pharyngeal injury. Some devices have options for real-time remote viewing, for example, using wi-fi.

Clinicians need confidence in the reliability of airway equipment and knowledge of how to use the specific types of videolaryngoscopes appropriately, especially when using it as a rescue device. Screen failures, device breakage and power-source issues have all been described during intubation, either due to equipment failure or lack of training in how to use the device[13,14]. Devices must be robust enough to stand the rigours of everyday use. This becomes more important as the number of personnel using the device increases, with a corresponding increase in range of familiarity and skill levels with the device.

STANDARDISATION

Some clinical areas have particular requirements. An academic anaesthetic department will require equipment to teach junior staff, to be used by multiple users of varying ability and to be able to tackle a wide range of airway issues on and off the operating room floor. Integration and compatibility into an airway-intubation system, with the ability to swap between different types of videolaryngoscope blades and other compatible devices, such as rigid stylets and videoscopes, may be beneficial. Complete systems, with a full range of devices, either reusable or single use, are available. Off-the-floor locations and emergency-response packs should use the same videolaryngoscope as the main theatre to standardise and increase familiarity with the videolaryngoscope.

Thought needs to be to given to battery life and power sources, and the required cables and monitors, as this may limit portability.

There are opinions suggesting availability of a cheap single-use hyper-angulated device on every anaesthetic machine for immediate use as a secondary intubating device[15]. The cost effectiveness, compared to having an all-in-one system available on the difficult-airway trolley, is unclear. This could depend upon the number of theatres being equipped, the training required to obtain competency with the device and the number of times a secondary device is likely to be used.

Hospitals should provide appropriate equipment, rather than it being the responsibility of the anaesthetist. This includes private, standalone day centres. Stand-alone centres should have a hyper-angulated device in addition to the standard MacIntosh laryngoscope. If laryngoscopists have concerns about their proficiency, a channelled hyper-angulated device is probably a better option as the secondary blade. Some individuals may prefer to have their own system, for which they have familiarity and responsibility. In this case, a disposable hyper-angulated device with both channelled and non-channelled blades has advantages, as most intubating environments have a Macintosh-type device. However a single-use device may be more appropriate if there is concern about contamination between different locations. Disposable devices, as opposed to disposable-blade devices, may be more expensive over time.

PRE-HOSPITAL CARE

The benefits of videolarygnoscopy are permeating into the pre-hospital environment[16]. A number of studies have been undertaken comparing devices and their suitability to the trauma and pre-hospital setting[17-18]. Published literature focuses mainly on comparisons of the speed of intubation and rates of successful intubation between different devices. The pre-hospital environment is one of the more diverse environments in clinical practice, both with respect to the environment and the personnel who work in it. A winter aero-medical trauma response in the high latitudes of North America is an entirely different scenario to a summer's road primary response in metropolitan Sydney.

A pre-hospital device should be fit for purpose, including reliability in all relevant weather conditions. It should present the laryngoscopist with an adequate view in direct sunlight and should not fog in winter[18], although environmental manipulations, such as darkening the environment, may be needed. It should continue to function, unimpeded, in rain and sub-zero temperatures. It should be lightweight, compact, with enhanced shock resistance, capable of tolerating the vibration of rotary-wing aircraft and the shock of being dropped. It should have a rapid start-up time, with batteries that are easily available and changeable, and be resistant to the potential damage caused by battery leakage over time. It should be reliable, even after long periods between uses. The device design

should ensure that even if the electronics fail, it could still continue to function as a standard laryngoscope. Ideally, it should be suitable for both paediatric and adult populations with the minimum degree of duplication.

One of the challenges in hospital and pre-hospital medicine is maintaining the currency of skills. The techniques required to use the ideal scope should therefore be easily mastered and maintained, with the progression from novice to master laryngoscopist being rapid. Ideally, this would mean the minimum volume of practice is required to make and maintain that transition[19,20]. As a consequence, there is a tendency for pre-hospital organisations to use a conventional Macintosh-blade device in the knowledge that the technique is familiar to many and that the required skills are being maintained in other areas of the larygnoscopist's clinical practice. Unfortunately, a single device to handle a difficult intubation in all these conditions and their associated challenges is currently not on the market. As clinicians feed back their experiences to manufacturers, there is progress towards that ideal.

We believe every intubating area should have access to both a Macintosh-type and hyper-angulated-type videolaryngoscope. This may be as one device system with interchangeable blades or as a standard Macintosh laryngoscope and a hyper-angulated videolaryngoscope. In addition, we recommend having a work-based training program with the devices to overcome the learning curves, as there may be limited experience with appropriate use of the devices, even by senior staff[21-22]. Specifically, the look in the mouth-screen-mouth-screen four-step approach[23] should be taught for insertion of the videolaryngoscope and endotracheal tube to minimise the risk of iatrogenic injury[24-26]. Critically, portable capnography should be seen as an essential piece of equipment to complement any out-of-theatre usage of the videolaryngoscope.

PERSPECTIVES

We offer a word of caution not to forget awake techniques when supraglottic oxygenation is anticipated to be difficult, in addition to a potentially difficult intubation. Also we add a plea, that it should be clearly documented what type of device is used and the grade of view obtained, so that there can be no confusion with a standard MacIntosh intubation. There have been a number of letters to scientific journals addressing this very issue, which offer solutions including the POGO scoring system and the Fremantle score for videolaryngoscopy[27-31].

CONCLUSION

There has been rapid change in the variety and sophistication of videolaryngoscopes available. As anaesthetists and airway experts, we should be actively advising on the airway-equipment choices required both at hospital and departmental level. Ideally, the decision-making should involve the best available evidence and local airway-management experts to advocate the most appropriate devices to the hospital departments that undertake airway management. They should standardise the devices between the departments and running training courses in their use.

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Tracheal extubation: Strategies for predicting and managing extubation of the difficult upper airway in the non-obstetric adult patient

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INTRODUCTION

Most research and algorithm development in airway management has focused on facilitating safe tracheal intubation, with relatively little attention paid to extubation. According to the latest American Society of Anesthesiologists (ASA) closed claims report, the odds of death or brain damage from airway management associated with induction of anaesthesia decreased by 27 per cent in 1993-99 compared with 1985-93. In contrast, death or brain damage associated with emergence or recovery did not change significantly between the same periods[1]. The incidence of complications associated with extubation may actually now exceed those occurring during intubation[2].

Extubation complications of the "normal" airway are uncommon. However, occurrence is increased with procedures in proximity to the airway, particularly with emergency surgery. Case reports of potentially preventable post-operative airway compromise leading to death or severe disability in conditions such as Ludwig's angina highlight deficiencies in understanding by medical and nursing staff of the sequence of clinical parameters indicative of the compromised airway[3,4], and lack of practical and effective plans to appropriately address them[5]. In the field of critical care, a higher rate of extubation complications occurs with reports between 2 and 25 per cent[6]. This may be attributable to other factors, including duration of intubation and ventilation, severity of underlying disease, prolonged sedation, generalised weakness (endogenous or iatrogenic) and cardio-respiratory or neurologic compromise[6,7].

The ASA Task Force on the Management of the Difficult Airway[8] regards the concept of an extubation strategy as a logical extension of the intubation strategy and strongly supports developing a preconceived plan for extubation of the difficult airway. This strategy depends on the type of surgery, the condition of the patient and the skills and preferences of the practitioner[8]. The focus should ideally be towards assisting the practitioner to identify potentially difficult extubations based on patient history, anatomy, possible functional impairment, oedema and type of surgery. This approach should include tests to identify patients who are suitable for extubation and use devices that allow safe re-intubation as required.

The Difficult Airway Society (DAS) published its landmark consensus papers on tracheal extubation[9]. It has a very comprehensive overview of the patho-physiology of problems arising during emergence and extubation period and highlights the importance of advanced planning for extubation. The stepwise approaches appear in three self-explanatory flow charts, "basic algorithm", "low-risk algorithm" and "at-risk algorithm", which describe the process in four steps: plan for extubation; prepare for extubation; perform extubation and post-extubation care. This work provides practitioners with useful guidelines and a valuable resource for future research[9].

The use of the three-column model may further assist the anaesthetists and trainees to understand the different nature of airway anatomy in difficult airway and help them to incorporate this knowledge in the context of the clinical scenarios to plan for extubation.

MATERIALS AND METHODS

The PubMed database was used to identify publications relevant to tracheal extubation of the difficult airway between the years 1980 to 2011. "Extubation" is not a MeSH term so the following key words were used for the literature search:

- Intubation, intratracheal/adverse effects.
- Intubation, intratracheal/complications.
- Intubation, intratracheal/contraindications.
- Intubation, intratracheal/instrumentation.
- Tracheal extubation.
- Extubation criteria.
- Extubation failure.
- Extubation readiness.

Any articles involving paediatric or obstetric patients were excluded. Articles involving pathophysiology of the lower airway were excluded (for example, bronchospasm or desaturation post-extubation in the intensive care unit). Articles involving extubation of patients without known difficult upper airway problems were excluded.

DEVELOPING A STRATEGY FOR SUSPECTED HIGH-RISK EXTUBATION

The need for a stepwise strategy for safe extubation has been outlined previously[8,9]. Such a strategy should aim to maintain oxygenation, minimise complications and reduce the risk for re-intubation, but include a safe plan to do so if necessary.

Rescuing the airway following tracheal extubation can be extremely difficult for several reasons. Firstly, it is difficult to predict when respiratory compromise may develop. This is a particular problem outside normal working hours or in remote locations when airway expertise may not be immediately available or the provision of airway management equipment may not be ideal. Secondly, patients may have already experienced an episode of respiratory compromise resulting in depletion of their oxygen reserve, which limits the time available to secure the airway. Finally, airway distortion may render intubation challenging, especially in an already anxious and hypoxic patient[10].

An extubation strategy should aim for adequate oxygenation, minimal complications and a safe plan to secure the airway in case of airway compromise after extubation. This strategy will depend on the surgical and medical condition of the patient and the airway status, as well as on the skills and preferences of the practitioner[11].

The extubation plan should include:

1. A method for predicting patients at high risk for extubation.
2. Physical assessment of the airway.
3. Airway monitoring after extubation.
4. Development of an airway management plan, including airway devices to facilitate oxygenation and possible re-intubation.

The purpose of many guidelines and algorithms is to direct the clinician on a management pathway that minimises judgment and adverse results[8,12]. However, the clinician's judgment at the time is still important in the provision of optimal patient care[13].

1. PREDICTING WHICH PATIENTS ARE AT HIGH RISK FOR EXTUBATION

Prevention of extubation complications cannot be over emphasised. Fortunately, patients who are likely to develop post-extubation problems often can be identified based on patho-physiological and anatomical factors.

Patho-physiological predictors:

A successful extubation plan initially depends upon the fulfilment of conventional extubation criteria. Francon and colleagues defined these prerequisites as haemodynamic stability, adequate respiratory strength and airway patency, normothermia and a conscious level enabling clearance of secretions and airway protection (Table 1)[14]. If these criteria are not met or are borderline, the patient is likely to be at high risk for post-extubation complications. If extubation is attempted, an appropriate plan, including a period of close monitoring with clear criteria and planning for safe re-intubation, will be needed.

Table 1. Conventional extubation parameters (modified from Francon D et al[14].)

Respiratory criteria	Patent airway, spontaneous and regular breathing, no inspiratory chest wall retraction Tidal volume >5-8 $ml.kg^{-1}$ Minute ventilation <10 $l.min^{-1}$ Respiratory frequency 12-25$breaths.min^{-1}$ Negative inspiratory pressure >-20cmH_2O against a closed glottis Swallowing/cough reflexes intact
Gas exchange	Spo2 >95 per cent with Fio2 <0.5 and Peep <5cmH_2O PaO2 >60mmHg Or values appropriate for the individual patient
Neuromuscular	Awake, following simple order commands, obtain a verbal response Reversal of neuromuscular blocking agent (T4/T1 >0.9)†
Cardiovascular	Haemodynamic stability (blood pressure and pulse rate ±20 per cent of preintubation levels) No vasopressor or inotropic support
General	Core temperature ≥36 degrees Celsius Normoglycaemia Good analgesia (VAS ≤3)* Absence of anaesthetic or surgical complications

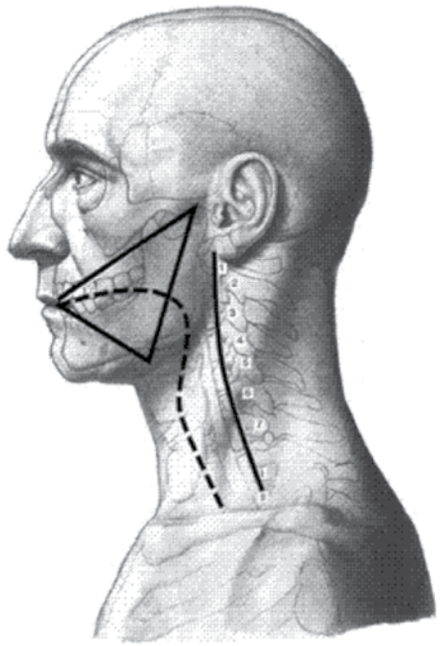
*VAS; visual analogue score
†T4/T1; train-of-four ratio

Anatomical predictors

Over time, many operators gain experience in difficult airway management and incorporate this into their teaching. However, the learning experience of many clinicians remains haphazard and is difficult to pass on to future generations. Airway management for both routine and difficult conditions requires reappraisal of this situation and the establishment of a structured approach to the cause of the difficult airway.

One such approach classifies the difficult airway anatomically into problems of the posterior, middle or anterior columns based on the three-column model[15]. The posterior focuses on the cervical spine (in particular the occipito-atlanto-axial complex), the anterior is the mandible, tongue and submandibular tissues and the middle column is the airway passage (Figure 1).

Figure 1. Three-column model for direct laryngoscopy



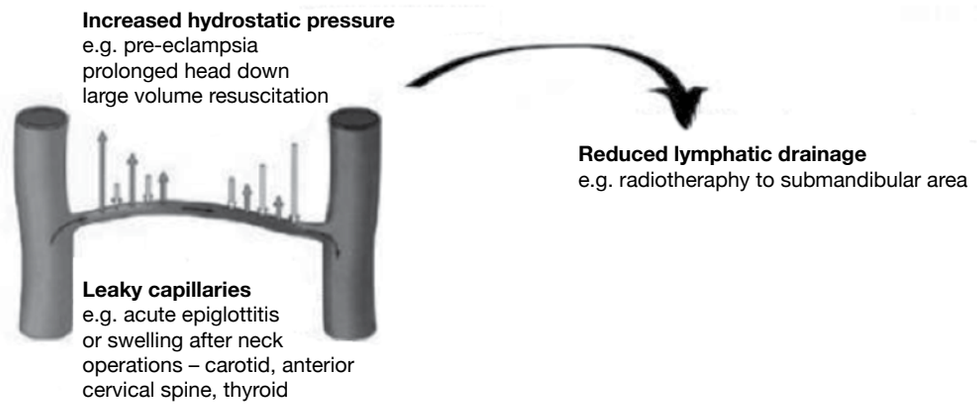
Modified from Greenland, K.B. Reappraisal of adult airway management, *Australasian Anaesthesia*, a publication of the Australian and New Zealand College of Anaesthetists. The anterior (triangle) and posterior (solid line) columns of the model for direct laryngoscopy influence the shape of the middle (airway passage) column (dotted line). In addition, the middle column may have intrinsic changes where the configuration is distorted by loss of pharyngeal muscle tone (due to sedative drugs or muscle relaxants), mucosal oedema or airway tumours.

An extubation strategy based on this anatomical definition and the nature of the changes in configuration of the columns, allows the prediction of high-risk patients and the development of specific management strategies. However, difficulty of intubation based on anatomical landmarks is not the sole predictor in the decision for extubation. For example, a patient with either an anterior (for example, retrognathia) or a posterior (for example, ankylosing spondylitis) column problem during intubation may still be suitable for immediate extubation after uncomplicated surgery if the risk of airway compromise is otherwise deemed low. A useful strategy is to insert a laryngeal mask airway (LMA) behind the ETT before tracheal extubation[16]. The ETT can then be removed and the supra-glottic airway becomes an airway conduit. The placement of the supra-glottic device is performed prior to removal of the ETT so it can be correctly sited prior to extubation. The LMA is left in place until the patient can maintain his or her own airway[17-19].

Delayed extubation is often recommended in situations where there is a middle column problem. There are two broad situations following anaesthesia when this may occur. Firstly, patients with difficult airways undergoing prolonged anaesthesia and requiring moderate to large doses of long-acting opioids. Hypnotic drugs and opioids separately and in concert depress genioglossus and pharyngeal muscle tone and diminish airway protective reflexes. This loss of tone impacts on the middle column configuration and, when combined with anterior and/or posterior column problems, may make immediate extubation dangerous. Ventilation in the intensive care unit post-operatively allows time for the effects of the anaesthetic drugs to dissipate and provides safer extubation conditions.

The second is when anaesthetic and/or surgical factors, such as prolonged head-down position, massive fluid resuscitation, airway soft tissue trauma or submandibular abscess, may cause airway mucosal swelling. This anatomical distortion of the middle column requires delay of extubation until the swelling has resolved (Figure 2).

Figure 2. Causes of airway mucosal swelling based on Starling forces and reduced lymphatic drainage



2. PHYSICAL ASSESSMENT OF THE AIRWAY

Evaluation and preparation of the patients considered a possible risk for extubation failure should be methodical and comprehensive. Physical assessment of the airway should include: 1. direct laryngoscopy; 2. cuff-leak test; 3. fibreoptic visualisation or often a combination of these tests.

Direct laryngoscopy

Direct laryngoscopic visualisation of the airway may provide useful information about supra-glottic and glottic structure and function, particularly in cases with suspected change in the airway configuration due to surgery or underlying pathology. With head and neck surgery, sub-mandibular infection and thermal injury to the airway, post-operative airway mucosal swelling may occur insidiously and present a problem for monitoring and re-intubation. The Cormack and Lehane laryngoscopy grading should be considered as a "snap shot" of the upper airway at intubation, but may not correlate with ease of re-intubation at a later time. In addition, a Magill-shaped tracheal tube (ETT) may push the glottic opening posteriorly giving a deceptively better laryngoscopic view compared to the view after it is removed. This may contribute to difficulties should re-intubation be required. Finally, the tube may compress airway mucosal swelling so that the airway is stented open. After the tube is removed, the oedema fluid may redistribute leading to delayed airway occlusion.

Cuff-leak test

Several authors have suggested conducting a cuff-leak test before extubation as an assessment of airway patency[20-25]. Careful suctioning of the sub-glottic and supra-glottic areas should precede this test. The cuff is deflated and the tube lumen is occluded in order to assess the air leak around the tube during spontaneous ventilation.

The cuff-leak test may be performed quantitatively, by measuring the volume of the leak, or qualitatively by listening for an audible leak. The flow around the tube may be generated by respiratory effort in a conscious patient or by a positive pressure of 20mmHg through the ETT. Leak is calculated by measuring the difference between the inspiratory tidal volume with the cuff inflated and the expiratory tidal volume when deflated. The test is positive (failed) when the leak volume is less than 110ml. A positive predictive value of 80 per cent for failed extubation occurs when the test is conducted 24 hours prior to the extubation after extended critical care intubation[14]. This may suggest the necessity for surgical access to the airway as a longer term bridging measure before final extubation[14]

A failed cuff-leak test does not necessarily indicate the extubation will fail and, if used as a sole indicator for extubation, may lead to unnecessary delays[26]. Judicious fluid management and intravenous corticosteroid therapy may be beneficial in suitable cases[27-30].

Evaluation via fibreoptic bronchoscopy and nasendoscopy

The fibreoptic bronchoscope (FOB) is useful for visualising airway anatomy and function at several levels[31-33]. With distorted airway anatomy, vocal cord paralysis or tracheomalacia, FOB can assist the operator to assess the airway prior to extubation. There has been a report of tube entrapment (surgical suture through the ETT cuff) complicating the extubation process identified and remedied with FOB[32].

Nasendoscopy also can be used to assess supra-glottic swelling and oedema[34], although interpretation is subjective and somewhat dependent on operator experience. This can be particularly useful with a borderline cuff-leak test.

Appropriate patient selection and explanation, upright positioning and administration of an anti-sialagogue may assist FOB assessment of the upper airway. Unfortunately, the presence of the ETT may limit adequate inspection of the surrounding structures.

3. DEVELOPMENT OF AN AIRWAY MANAGEMENT PLAN

The airway management plan must include an extubation strategy that specifically focuses on allowing continuous oxygenation and ventilation while facilitating early and safe re-intubation if required. Options for management of a high-risk extubation may include the placement of an extraglottic device or an airway exchange catheter.

Extubation of the trachea with an extraglottic device in place:

An extraglottic device may be used as an airway conduit following extubation. A flexible bronchoscope can then be advanced through the device allowing inspection of laryngeal anatomy and function[35,36]. This method is particularly useful when fibreoptic assessment of vocal cord function is required. Airway access can be achieved if the fibreoptic bronchoscope is loaded with an Aintree catheter™ (Cook Critical Care, Bloomington, IN) and directed through the extraglottic device. The FOB and the extraglottic device are then removed and an ETT is railroaded over the Aintree catheter[37]. The safety of this method is questionable with suspected peri-glottic oedema, as resulting distortion of the middle column, may make placement of the extraglottic device difficult.

Airway exchange catheter:

Airway exchange catheters (AEC; Cook Critical Care, Bloomington, IN) are small hollow semi-rigid tubes made of radio-opaque polyurethane. They are designed to increase safety while changing an ETT and maintain oxygenation. They have also been used to maintain airway access after extubation, allowing re-intubation if needed. The concept of re-intubation of the trachea using this technique after a failed extubation is not new[38-40]. Bedger and Chang described successful use of a "jet-stylet" as an airway conduit to facilitate re-intubation in 1987[41]. Bemunof also recommended extubation over a jet stylet in order to maintain airway access in case re-intubation was required[42]. Loudermilk and colleagues used an AEC in extubation of 40 patients with risk factors, three of whom developed respiratory distress requiring tracheal re-intubation[10].

The efficacy of the AEC as part of a staged extubation strategy also has been addressed in a study of re-intubation rate, reason for re-intubation and complications in 354 patients over a nine-year period[11]. The investigators compared the size 3.7mm E.D. 11French gauge (FG), 4.7mm E.D 14FG and 6.3mm E.D. 19FG AECs. Fifty-one patients with indwelling AEC required re-intubation. Forty-seven of these 51 patients were successfully re-intubated over the AEC (92 per cent) with 41 being on the first attempt. In three of the four failures, the AEC was inadvertently removed during re-intubation and the remaining patient had significant laryngeal swelling preventing ETT advancement. The successful re-intubation group suffered significantly fewer complications compared to those in whom the AEC was displaced. The successful group had a lower incidence of hypoxaemia (8 per cent versus 50 per cent, $p < 0.01$), bradycardia with hypotension (4 per cent versus 14 per cent, $p < 0.05$) and oesophageal intubation (0 per cent versus 18 per cent).

It has been suggested that AEC should be an integral component of any difficult airway extubation strategy[37,38]. Most studies have examined the size 11 and 14 FG AEC and showed both to be well tolerated by patients. The largest AEC (19 FG), although an excellent conduit for airway access, is tolerated by only 50 per cent of patients[11].

Following the decision to use an AEC assisted extubation, after conventional criteria for extubation are met, a lubricated AEC should be carefully inserted through the ETT to the same depth as the tip of the ETT to avoid stimulation of the carina. The ETT can then be removed over the AEC, while maintaining the exchange catheter at the same depth in the trachea. High concentration oxygen can be administered via a modified oxygen mask or through the AEC lumen. The proximal AEC should be secured to the patients' forehead with adhesive tape to reduce the risk of dislodgement. The tip should be occluded with tape and clearly labelled to ensure it is not mistakenly used for enteral feeding. Patients should remain fasted while the AEC is in-situ.

Optimal duration of placement of an AEC

The ideal duration of continuous airway access post-extubation is variable and depends on the patient's clinical status. Removal is often based solely on the clinician's assessment of the patient. In Mort's study, 36 out of 354 patients in whom the AEC was removed, subsequently required re-intubation within seven hours[11]. Eighteen of these 36 patients were intolerant of extubation within 120 minutes, four patients between two and four hours, and 14 patients required re-intubation beyond four hours. The majority of these patients required three or more laryngoscopy attempts and the use of accessory devices and/or techniques during re-intubation. This contrasts with only one patient with the indwelling AEC who required three attempts.

A study in 2004 examined 36 patients after maxillofacial and neck surgery where an AEC was left in-situ for a mean of 10.4 hours (range four-24 hours)[38]. Four of the 36 cases required re-intubation and all were successful using an 11 FG airway exchange catheter.

Although peri-glottic oedema contributing to airway compromise usually develops within the first 45 minutes after extubation, laryngeal oedema as late as eight hours post-extubation has been reported[11]. It may be advisable to extend the duration of continuous airway access to 12 hours or even longer in patients with cardiopulmonary or neurological compromise[11]. At this point, there is not enough evidence to confidently recommend a specific duration for leaving an AEC in-situ post-extubation.

Advantages

It has been suggested that by facilitating safer re-intubation after earlier extubation the AEC may reduce complications related to prolonged intubation. This also may be more cost effective[10-11]. The AEC also provides a method for the continuous administration of oxygen with less hypoxic episodes during re-intubation when compared with other techniques[11]. Several studies have shown improved cardio-respiratory stability during re-intubation when the AEC is used[10,38,39]. The AEC also has been used for jet ventilation and for CO2 monitoring[37].

Disadvantages

Inadvertent removal of AECs has been reported requiring the use of other methods to secure the airway[10,11]. Inability to advance an ETT over the AEC due to excessive airway oedema also has been reported[11]. Barotrauma occurred in five out of 45 patients when jet ventilation was used via the AEC[39]. Other reported complications include lung abscess, direct airway trauma and lung laceration[2,43-47].

Other methods:

Cannula cricothyroidotomy is recommended for emergency tracheal oxygenation and/or ventilation in the current ASA Practice Guideline for management of the difficult airway[8]. Accurate identification of the cricoid membrane is reportedly poor, possibly due to the infrequent practice[48]. This makes the routine use a problem unless training can be improved.

Elective insertion of a cricothyroid cannula prior to intubation[49] and securing it in place in a controlled environment may be beneficial for the management of a difficult airway during both intubation and extubation by providing a route for oxygenation and the possibility of airway access via the Seldinger manoeuvre[50]. However, subsequent use of the cannula may be a problem due to cannula displacement after intubation. Further work is required in this area.

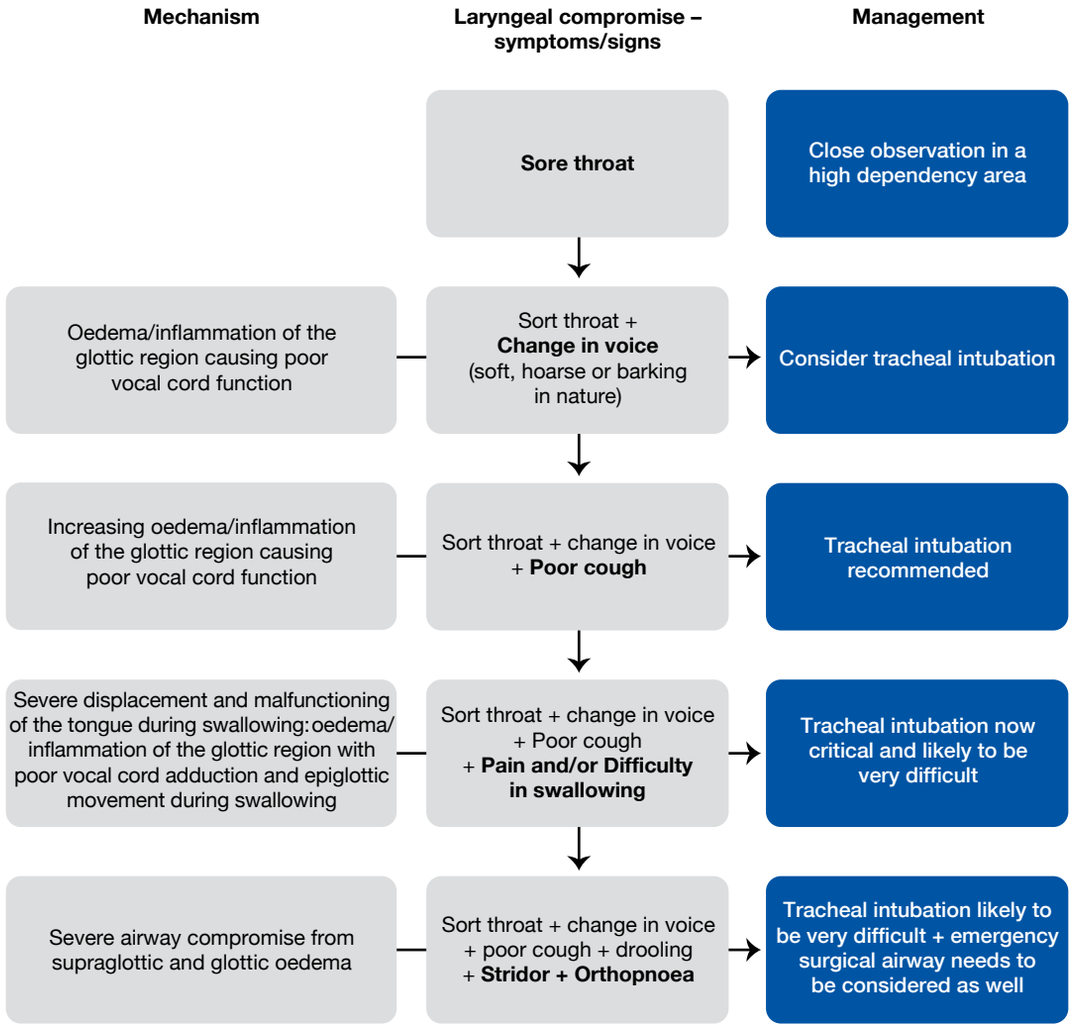
4. AIRWAY MONITORING FOLLOWING EXTUBATION

For every potentially difficult airway, extubation should be considered a trial with a clear plan for how and when re-intubation should occur.

Previous work[6,51-53] has shown an association between ineffectual cough and poor swallow in the post-extubation period with the need for re-intubation of patients following prolonged ICU ventilation. Early detection of symptoms and signs of post-extubation airway compromise relies on appropriate monitoring. Clear parameters in airway monitoring in the post-operative period may not be recognised by inexperienced staff[5].

Coronial inquests into deaths secondary to Ludwig's angina in Australia revealed that detection of early signs and prompt management of the threatened airway was poor by both medical and nursing staff. Emphasis is usually on late signs such as stridor and respiratory distress, which are, unfortunately, associated with imminent respiratory arrest[5,54]. Based on these inquests, a chronological sequence of symptoms and signs was determined (Figure 3). Early indicators were sore throat, hoarse or weak voice, poor cough and dysphagia or drooling. Stridor and orthopnoea were late signs indicating near complete airway obstruction with tracheal re-intubation likely to be very difficult.

Figure 3. Signs and symptoms of laryngeal compromise with suggested clinical management

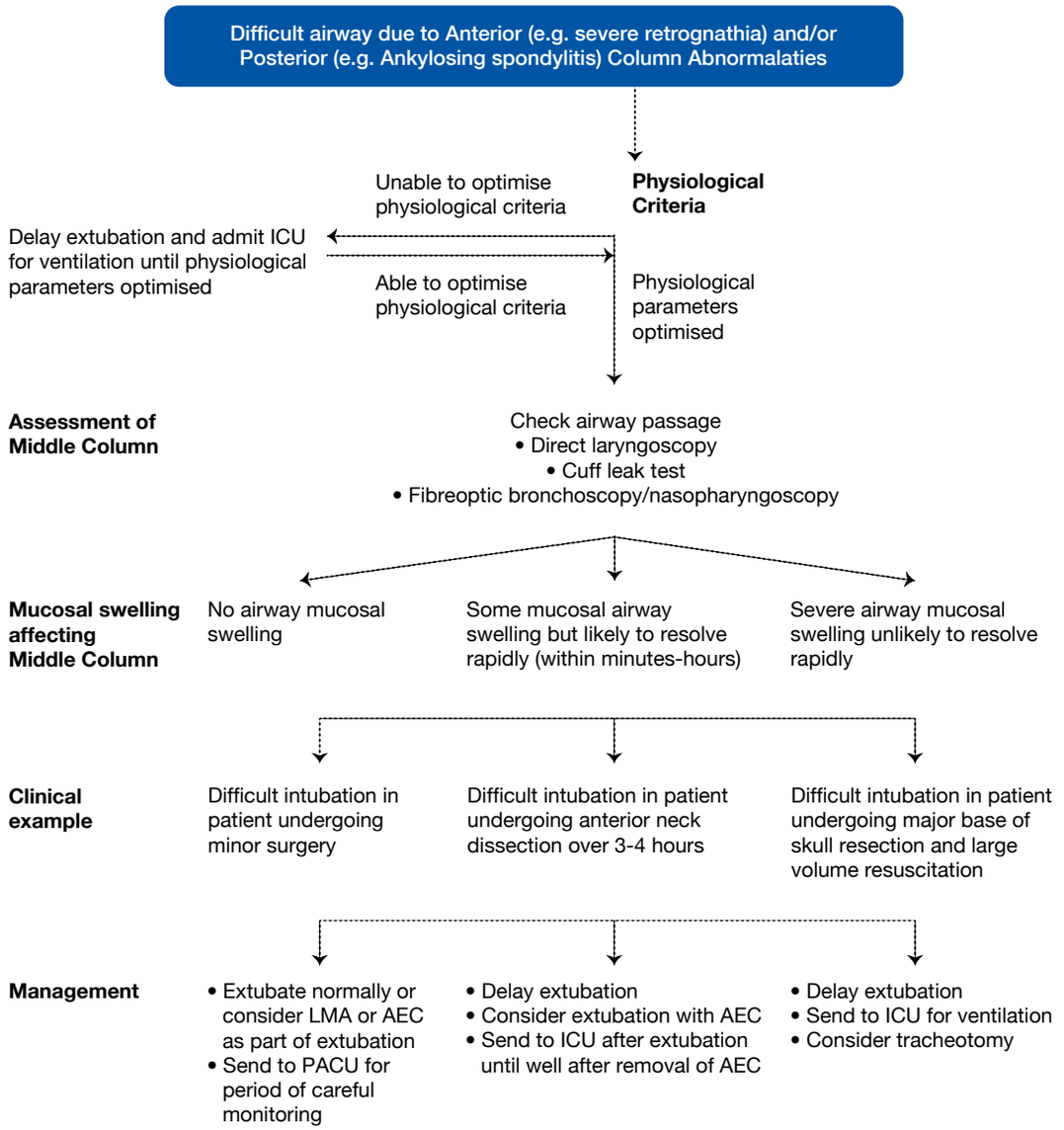


From Greenland KB et al. Anaesthesia and Intensive Care. 2011; 39: 506-8[5].

The recent fourth National Audit Project (NAP4) states "reviewers judged that the use of capnography in the recovery area (and its appropriate interpretation) would have led to earlier identification of airway obstruction in several cases"[55]. This highlights the need for capnography in the post-anaesthesia recovery area to assist in earlier identification of airway obstruction. An acoustic device for measuring breath sounds in the trachea has recently been commercially launched and is called Acoustic Respiration Rate (RRa™, Masimo Corporation, US). It non-invasively and continuously measures respiration rate using an adhesive sensor with an integrated acoustic transducer applied over the patient's trachea in the neck. Using acoustic signal processing, the respiratory signal is separated and processed to display continuous respiration rate. This is an interesting development that shows some promise, but clinical acumen is still the best tool for early detection of the obstructing airway.

Suggested extubation strategy:
The flow diagram below has been constructed based on the principles of the extubation strategy outlined above (Figure 4). It assesses the patient based on their pathophysiological and anatomical parameters, as well as whether they had a pre-existing difficult airway. The airway assessment represents the point at which the airway is assessed by direct laryngoscopy, leak test or fibreoptic visualisation. The authors favour the use of the AEC due to its relative ease of use, ability to deliver oxygen, its use as a conduit for re-intubation and its tolerance by the patients over extended periods of time. Patients with an AEC in-situ should be observed in a high dependency unit/intensive care unit environment where their airway status can be continuously assessed and there is expertise to intervene should the patient's condition change.

Figure 4. A suggested difficult airway extubation decision-making process illustrating the inter-relationship of key issues



CONCLUSION

The overwhelming attention paid to difficult airway during intubation has led to difficult extubation being neglected. The development of staged strategies for the identification and management of difficult airways during emergence and recovery from anaesthesia or in intensive care may improve patient safety and is strongly recommended[1]. Airway assessment with the identification of early warning signs, and the need for close monitoring in a high dependency unit with staff who can effectively diagnose and manage early upper airway obstruction with difficult airway equipment, are integral components of an effective extubation strategy.

Maintaining continuous airway access with the AEC can be an important component of an extubation strategy. The AEC appears to increase the first-pass success rate of tracheal re-intubation and decrease the incidence of complications. It also may be cost effective, allowing a margin of safety for earlier extubation and reducing prolonged intubation with its associated complications. However, the incidence of AEC facilitated re-intubation failure and complications, although low, does still exist.

Aintree™ assisted fibreoptic intubation through extraglottic devices and cricothyroidotomy may have a role as alternative management strategies. Well-designed prospective randomised trials are needed to develop effective and practical extubation strategies, techniques and training[42,56,57].

Staff education focusing on airway monitoring, early detection of airway compromise, and familiarity with rescue equipment is crucial for successful management. Problems often develop in an unfamiliar and suboptimal environment with anxious and/or hypoxic patients. Occasional use of specialised equipment by inexperienced staff is closely correlated to poor patient outcomes[55]. Consequently, there is a need for education and training of medical and nursing staff working in such environments. This should include familiarisation with difficult extubation algorithms, teaching of clinical signs, and use and interpretation of equipment such as AEC and capnography. Regular simulation workshops further reinforce the practical application of this knowledge[55].

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FA Ajvadi, MJ Edwards and KB Greenland purchase emergency surgical airway equipment from Cook Medical Pty Ltd for teaching purposes.

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Muscle relaxation in laparoscopic surgery: How deep is deep enough?

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CONFLICT OF INTEREST DISCLOSURE

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INTRODUCTION

Harold Griffith and Enid Johnson famously were the first to describe the routine use of a neuromuscular blocking agent (NMBA), curare, in anaesthesia practice[1]. Three years later, when reviewing 1000 cases of curare use at the Homeopathic Hospital in Montreal, Griffith described the new drug as "dramatically successful"[2].

However, despite being hailed the "second revolution in anaesthesia" by many, NMBAs also became notorious for their predominant side effect, the impairment of respiratory function[2]. Though this was initially thought to be a problem only during the operation, Beecher and Todd[3] soon described a sixfold increase in postoperative mortality after the use of NMBAs. Despite this evident problem, NMBAs have remained in our portfolio until today, not at least because they allowed surgical techniques previously thought to be impossible[4]. However, from the outset Griffith suggested to avoid curare-related side effects by reducing its dose, recommending the combination with cyclopropane anaesthesia[2].

Though the anaesthetic technique has certainly changed since the days of Griffith and Johnson, the idea to "balance" anaesthesia between hypnosis, analgesia and muscle relaxation has remained nearly unchanged. In this context, NMBAs usually play only a minor part, and most anaesthetists (if monitoring the depth of neuromuscular block at all) aim for a moderate depth of block of one to four twitches in the train-of-four (TOF). The latter also applies to the field of laparoscopic surgery – although most anaesthetists seem to agree that some degree of paralysis is necessary to achieve adequate surgical conditions, the depth of muscle relaxation required is largely unknown. As a result, most laparoscopic procedures are likely performed under moderate or shallow neuromuscular block.

Lately, however, some studies have suggested that only deep neuromuscular blockade may achieve best operating conditions during laparoscopic surgery. As deep neuromuscular block cannot be safely reversed with neostigmine, the technique has clear implications for the method of reversal (sugammadex) and may thus also impact on healthcare economics.

Therefore it is the aim of this short review to investigate what depth of neuromuscular block may achieve optimum surgical conditions and best patient outcomes.

DEFINITIONS

According to the revised guidelines for *Good clinical research practice in pharmacodynamic studies of neuromuscular blocking agents*[5] the following definitions apply for the description of the depth of neuromuscular block:

- Intense neuromuscular block is reflected by no twitch in neither TOF nor post-tetanic count (PTC) stimulation pattern. The depth of intense block can currently not be adequately monitored.
- Deep block results in ≥1 twitch in the PTC, but no twitch in the TOF.
- Moderate block, frequently also called "surgical depth of block" will allow one to three twitches in the TOF to be elicited.
- Shallow block (>3 TOF twitches) will seamlessly progress into recovery from NMBA, with a TOF ratio of >0.7 signifying recovery of the diaphragm and >0.9 recovery of the pharyngeal muscles. A TOF ratio >0.9 is therefore defined as the threshold for sufficient neuromuscular recovery.

HOW DEEP IS DEEP ENOUGH?

Two recent review articles have investigated the matter[6,7], with conflicting results. While a systematic review by Madsen et al.[7] concluded that neuromuscular block *per se* marginally improved operating conditions, and that deep block was superior to a moderate level of block, the second review by Kopman and Naguib[6] found little or no evidence for improved surgical conditions under deep neuromuscular blockade. This apparent contradiction is largely resolved when only studies fulfilling certain inclusion criteria are analysed.

When investigating the effect of NMBA on laparoscopic operating conditions, it is important to distinguish between studies comparing "no" versus "moderate" or "deep" block and those comparing different depths of block (usually "moderate/shallow" versus "deep") without using a "no" block group as control. It is also critical to note whether a specific study used a clear description of outcome parameters (that is, surgical conditions on numeric

rating scale) and whether the depth of neuromuscular block was monitored at all. The allocation to treatment arms should also be randomised as well as observers ideally be blinded. In view of many old studies which are still quoted in current reviews it is desirable to only include publications in which the described anaesthetic is comparable with today's standard practice.

Disappointingly, the above excludes >95 per cent of all trials published about the topic.

Only six studies ultimately qualify for further analysis[8-13], with three aiming to compare "no" versus "deep" block[8,10,13] and three comparing "moderate" versus "deep" block[9,11,12].

NO BLOCK VERSUS DEEP BLOCK

Summary

Three studies invested surgical conditions under "no" versus "deep" block. Deep muscle relaxation improved surgical space at a given intra-abdominal pressure (IAP), or allowed a reduction of IAP without impairing operating conditions. Deep block also resulted in less undesirable events, such as sudden movement or coughing.

In the largest and probably best-designed of the three studies, Blobner et al[8] examined the impact of deep paralysis on surgical conditions during laparoscopic cholecystectomies. Fifty patients were randomly assigned to receive either no or deep neuromuscular block. Investigated outcome parameters were signs of inadequate muscle relaxation (movement of diaphragm or abdominal muscles, inadequate visibility, or breathing and coughing against the ventilator), the frequency of rescue doses of rocuronium (0.3mg/kg) and the overall rating (0-100 numeric rating scale) of operating conditions by the surgeon at the end of the procedure. All patients received depth of anaesthesia monitoring with bispectral index under desflurane/opioid anaesthesia. Signs of inadequate anaesthesia were significantly more often found in the "no" block group (12/25 patients versus 1/25 patients; p<0.001), resulting in an absolute risk reduction of 0.44 (0.23-0.65) and a number needed to treat of 2.3 (1.5-4.4). Rescue rocuronium was given in 40 per cent of "no" block cases, but no patient during "deep" block. Operating conditions were a median of 36 points better in "deep" versus "no" block patients (p< 0.001).

An investigation by Lindekaer et al[10] studied 15 patients scheduled for laparoscopic gynaecological procedures. Intraoperatively, intra-abdominal space (distance from trocar insertion at the skin to the promontory) was assessed by the surgeon at two different levels of IAP of 8 and 12mmHg and at non-paralysed versus deep block respectively. Independent of the level of IAP, muscle relaxation resulted in a significant increase of intra-abdominal space. Intra-abdominal space at the higher IAP level (12mmHg) was still significantly smaller than in paralysed patients at an IAP of 8mmHg[10]. This study seemingly confirms that an increase in IAP in itself may not be as effective as muscle relaxation. However, the study should be viewed in the context of a low number of included subjects and the fact that the surgeon was not blinded to the state of muscle relaxation.

A similar study by Van Wijk et al[13] investigated the influence of "deep" versus "no" neuromuscular block on the lowest acceptable IAP needed to achieve adequate operating conditions during laparoscopic cholecystectomies (n=20). After induction of anaesthesia with succinylcholine for muscle relaxation, patients had fully recovered at the start of surgery. Surgeons titrated the IAP to the lowest pressure, allowing adequate operating conditions. Thereafter, patients were paralysed with rocuronium to achieve a deep neuromuscular block (PTC < 2). Surgeons were then asked to titrate to the lowest acceptable IAP directly after the onset of the block and every 15 minutes thereafter until the end of surgery. Without muscle relaxation, a mean IAP of 12.75 (± 4.49) mmHg was required to maintain adequate operating conditions. Immediately after achieving a deep NMB, this significantly dropped to an IAP of 7.20 (± 2.51; P < 0.001). The initial pressure difference of mean 5.55 mmHg dropped to a mean of 3.00 mmHg after 15 minutes, despite the PTC still being < 2 at the second time point.

Similar to the study by Lindekaer et al[10], this study confirms that deep muscle relaxation may provide the same exposure of the surgical field at a lower IAP. However, similar limitations apply (low number of subjects, surgeons not blinded).

MODERATE/SHALLOW VERSUS DEEP BLOCK

Summary

Three studies compared "moderate-shallow" (possibly the standard depth of block during laparoscopic surgery, see above) versus "deep" block. All studies found better operating conditions under "deep" versus. "moderate" or "shallow" block. Though the described differences were relatively small, they may be important in high-risk patients (such as bariatric, or those with significant adhesions from previous surgery) or procedures (such as robotic surgery), where even small movement may have catastrophic consequences.

Staehr-Rye et al[14] randomly allocated 48 laparoscopic cholecystectomy patients into either "deep" (maintenance of deep block via infusion of rocuronium) or "moderate" (rocuronium only for intubation, thereafter spontaneous recovery if no complaint by surgeon) neuromuscular block. Anaesthesia was performed with propofol and remifentanil. The attempt was made to perform all procedures at an IAP of 8 mmHg. Surgical space ratings were done by blinded assessors using a four-point scale. Optimum conditions throughout the duration of the procedure were found in 7/25 patients in the deep block, but only 1/23 in the moderate block group (P < 0.05). Though the study failed to demonstrate a significant difference between groups in the number of procedures performed at an IAP of 8 mmHg (p = 0.08), a potential trend was observed towards a higher success rate with "deep" block: 15/25 versus "moderate" block 8/23). Furthermore, operating conditions during dissection of the gall bladder rated about 10 per cent better when "deep" block was performed. The authors concluded that "deep" block marginally improved surgical conditions for laparoscopic cholecystectomy.

A similar investigation is reported by Martini et al[11]. Twenty-four patients were randomised into either "deep" or "moderate" neuromuscular blockade for a laparoscopic prostatectomy or nephrectomy. One surgeon rated the operating conditions into five categories – excellent being 5 and unacceptable being 1. Overall, significantly better ratings were obtained in the deep block group (4.7 versus 4.0; P < 0.001). Moderate block resulted in 18 per cent of scores at the low end of the scale (scores 1-3); deep block resulted in 99 per cent of scores at the high end of the scale (scores 4 and 5). The authors also asked 12 experienced anaesthetists to rate operating conditions based on video images from the study according to the 1-5 scale used by the surgeon. Interestingly, there was a very poor agreement between ratings of the same images by anaesthetists and surgeon. Although the study was well designed, it was relatively small. Furthermore, the described differences appear – at least on first sight – relatively small, with 80 per cent of operating conditions in the "moderate" group still rated as "good" ("…a wide laparoscopic working field with sporadic muscle contractions, movements, or both"[11]). However, since conditions rated as "good" did allow a certain degree of sudden movements, they may be found unacceptable for high-risk procedures (for example, robotic prostatectomy). Deep versus moderate block may therefore be of significant benefit in cases where even slight patient movement has to be completely excluded.

The third study in this context was published by Dubois et al[9]. The authors randomised 105 patients scheduled for laparoscopic hysterectomies into either "deep" block (TOF maintained < 2) or "shallow" (initial bolus of rocuronium 0.45mg/kg-[1] and further relaxant only if surgical conditions unacceptable) block. The surgeon scored the quality of the surgical field every 10 minutes as excellent (1), good but not optimal (2), poor but acceptable (3), or unacceptable (4). For the "shallow" and "deep" groups respectively, the maximum surgical field scores were 1 in 21 and 34 patients, 2 in 11 and 11 patients, 3 in 4 and 5 patients and 4 in 14 and 0 patients. A trend towards higher scores (= worse conditions) was demonstrated in "shallow" block group (P < 0.001). Surgical field scores of 2, 3 and 4 (= non-excellent ratings) occurred only when the TOF was at least 1, 2 and 3 respectively.

Although this study was principally well conducted, it ultimately did not achieve a "deep" block group as per the definition above[5]. This might reflect real life, since most anaesthetists may not attempt to meticulously maintain a certain level of neuromuscular block, but rather a wider range. However, though the design of the "deep" block group may limit conclusions about the value of "deep" block by definition, it allows the conclusion that maintenance of a "deep to moderate" block throughout laparoscopic surgery may be superior to a one-off bolus of NMBA at induction with subsequent neuromuscular recovery.

Effects on postoperative patient outcome

All studies mentioned above investigated effects of muscle relaxation on operating conditions, but not on postoperative patient outcome. As outcome is influenced by a plethora of variables, it is naturally much more difficult to assess, and suitable studies usually require large cohorts of patients. However, one relevant parameter of laparoscopic surgery, intra-abdominal pressure (IAP), has been relatively well investigated[14-34]. High IAP may have adverse haemodynamic effects[17,18,33,34], but beyond this, high or prolonged IAP has also been found to impair organ perfusion via either macro-[15,31] or micro-vascular changes[22,24,25,27,30,32]. The latter may result in organ dysfunction, with the effect of renal[19,22,24,25,27]), hepatic[31,32] or cardiac[18,29] impairment. Furthermore, it may cause a decrease in splanchnic perfusion[23] and trigger an increased oxidative stress response, with ovarian damage as a potential consequence[21]. Mesothelial hypoxia may also contribute to the formation of postoperative adhesions[30].

Correspondingly, low IAP of 8-10 mmHg has been found to significantly reduce problems such as renal[35] and liver dysfunction[36], splanchnic hypoxia[39-39], cardiac dysfunction[40], haemodynamic suppression[41,42], autonomic[43] and general inflammatory stress response[44] when compared to higher pressures (10-15 mmHg).

Furthermore, post-laparoscopy pain has been linked to high IAP and a reduction of pressure has been shown to significantly reduce postoperative pain[42,45–49].

Discussion

When Griffith and Johnson set out to use curare, neuromuscular monitoring did not exist. However, due to the limited abilities to deal with the consequences of deeper neuromuscular block, patients were usually kept at a modest depth of block. The latter is confirmed by the description of the return of spontaneous ventilation at around 15 minutes post-curare injection[1].

The "classic" level of surgical block, a 90-95 per cent depression of a single twitch, was first described in detail by Ali and Savarese[50]. However, the recommendation was largely based on assumptions, as the authors quoted only one paper that actually examined the matter directly[53]. Though "cutting edge" at the time of publication, the anaesthetic technique (suxamethonium infusions) described in this paper by De Jong et al[51] would today qualify as seriously awkward. Conclusions drawn from this publication about patient care in 2015 should hence be viewed with some concern.

Furthermore, it has since been recognised that nerve stimulation at the adductor pollicis brevis muscle may satisfactorily reflect pharyngeal muscle function (which anaesthetists are most concerned about), but is a much poorer descriptor of diaphragmatic muscle relaxation (which surgeons are most concerned about). This is mainly due to the significant difference in NMBA sensitivity between the different muscle groups. After full paralysis with rocuronium, recovery of the adductor pollicis brevis muscle may take significantly longer (return of 10 per cent recovery at the diaphragm after 10 minutes versus 34 minutes at adductor pollicis brevis)[52]. Even at a PTC of just 5 (adductor pollicis brevis) the diaphragm may have already regained about 20 per cent of baseline strength[53]. Thus, diaphragmatic contractions may impair surgical working conditions at much deeper levels of neuromuscular block than usually maintained.

Based on the need for an (ideally) paralysed abdominal wall and diaphragm during laparoscopic surgery, and based on the "deeper than usual" level of neuromuscular block needed to achieve this goal, many anaesthetists aim to combine a modest-shallow depth of block with deep anaesthesia in order to facilitate NMBA reversal at the end of surgery. As propofol has no significant muscle-relaxing properties[54], NMBA would ideally need to be combined with volatile anaesthetic agents that are known to have significant muscle relaxing properties, both by direct action on skeletal muscle as well as by an interaction with NMBA[54-64]. This would principally follow Griffith's advice to combine curare with cyclopropane anaesthesia[2]. Though volatile anaesthetic agents will "boost" the effects of NMBA by about 20-30 per cent, a study by Tammisto and Olkkola[65] suggests that this may less reliable than it appears. Though the authors concluded that "as anaesthesia deepened, less intense block was required", they also stated "…due to huge inter-individual variation, certain 'overdosing' of neuromuscular blocking drugs is necessary to guarantee adequate muscle relaxation of abdominal muscles during all stages of upper abdominal surgery"[65]. Depth of anaesthesia appears therefore not to be sufficiently predictive to maintain satisfactory surgical conditions. In light of ongoing intense research into the possible side effects of "too deep" anaesthesia[66], deep anaesthesia may be a somewhat counter-intuitive strategy to save on the dose of NMBA and improve surgical conditions.

CONCLUSION

Good evidence exists for the beneficial effect of deep (versus no) muscle relaxation on surgical working conditions during laparoscopic surgery. However, the ideal depth of neuromuscular block has still not been defined. Recent publications have shown a small but significant benefit for deep vs. moderate-shallow depth of block. A continuously monitored and maintained deep-to-moderate neuromuscular block appears superior to a one-off dose of an NMBA with subsequent spontaneous recovery. Whether such differences are crucial for everyday routine surgery is yet unknown. However, deep block may be advisable for difficult cases or when sudden patient movements could have catastrophic consequences.

The impact of deep block on postoperative patient outcomes has been much less investigated. However, lower IAP has shown to have significant outcome benefits (such as less organ damage and less postoperative pain), and continuously maintained deep-moderate block may assist in keeping the IAP as low as possible.

Whether or not deep vs. moderate block is used in a specific case ultimately remains a point of discussion between surgeon and anaesthetist. Continuous neuromuscular monitoring, as well as ongoing communication between the involved parties, remain of utmost importance.

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Perioperative iron deficiency anaemia – a review with a regional flavour

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INTRODUCTION

Launceston General Hospital (LGH) is a public, regional tertiary referral hospital and the second-largest in Tasmania. It has a catchment of some 150,000 patient population, with some specialties servicing a total of 250,000 – the entire north of the state. It has an obstetric unit delivering about 1500 women a year and most surgical specialties are represented, with the exception of cardiac and neurosurgery. Tasmanians suffer a greater burden of comorbid disease, and have a lower life expectancy than residents of most other Australian states and territories[1].

This article aims to summarise the epidemiology and pathophysiology of iron deficiency anaemia (IDA), the therapeutic options, rationale for our process of haematinic optimisation in the perioperative and maternity setting and our prospects for the future in promoting a system for appropriate patient blood management in obstetrics and surgery at the LGH.

WHY PATIENT BLOOD MANAGEMENT?

The goal of patient blood management (PBM) is to improve patients' clinical outcomes. While not the primary aim, minimising or avoiding blood transfusion can be considered another desirable result[2].

Red blood cell transfusion in the perioperative period is associated with increased mortality following cardiac and non-cardiac surgery[3]. This has been demonstrated in short-term outcomes as well as in five-year follow-up data. There has been much debate about the cause of this and it is still not clear whether blood transfusion *per se* or the series of physiologic insults that lead to blood transfusion are the cause of the increased mortality.

Blood transfusion is associated with increased morbidity; there is a clear association with postoperative infections and increased length of hospital stay[3,4]. The term transfusion-associated immune modulation (TRIM) has been coined to describe the range of immune changes that occur due to blood transfusion. TRIM encompasses changes to cellular immunity, as well as alteration of cytokine expression, such that malignant tumour growth is favoured. Observational evidence suggests that there is a link between cancer recurrence and administration of blood products[5].

Blood transfusion is expensive. Figure 1 outlines the list prices for some commonly used blood products. These costs are list prices only, and the true cost of administration is much higher. The average cost of administration of a unit of packed red blood cells is estimated to be three to four times the unit cost of the product.[6,7] The cost of blood transfusion is shared between the States and Commonwealth of Australia. The Commonwealth funds the majority (63 per cent) of the cost of procurement and distribution of blood, with the states and territories responsible for the remainder. The state services are also responsible for the costs of administration and any complications.

There has been a paradigm shift away from blood transfusion across Australia, with many hospitals implementing transfusion management programs to meet National Blood Authority Guidelines introduced in 2012. PBM programs have implemented preoperative, intraoperative and postoperative strategies built on three conceptual "pillars" promoting an approach aimed at "optimising red cell mass", "minimising blood loss and bleeding" and "harnessing and optimising physiological reserve of anaemia"[2]. Most of this article pertains to "optimising red cell mass".

Figure 1. List price per unit of some commonly used blood products

Product	Cost per unit (AUD)
Red blood cells	365
Fresh frozen plasma	296
Platelets	391
Cryoprecipitate	40

ANAEMIA AND IRON DEFICIENCY

Defined values for normal haemoglobin (Hb) level may vary by laboratory and population; however, most authors agree anaemia should be defined as Hb <120g/L for non-pregnant women. In a pregnant woman at greater than 20 weeks gestation, a Hb of <110g/L is considered anaemic[8]. In adult men at all ages, anaemia is defined as Hb less than 130g/L[9,10].

Figure 2 shows the rate of anaemia in the non-pregnant Australian population. Under the age of 65, the anaemia rate is less than 4 per cent – about 6 per cent in females and 2 per cent in males. This risk increases to 16 per cent over the age of 75[11]. The rate of anaemia among patients presenting for major elective surgery is unclear. In pregnant women, the prevalence of IDA is estimated to be about 15 per cent in the developed world[12].

Anaemia is an independent risk factor for morbidity, mortality, hospitalisation and a decreased quality of life[3]. Preoperative anaemia is an independent risk factor for postoperative morbidity and mortality, as well as being associated with an increased likelihood of blood transfusion[3].

Iron deficiency is the most common cause of anaemia in patients presenting for major elective surgery. This cohort of patients is typically elderly with multiple comorbid conditions. Diabetes, cardiac failure, cancer and chronic renal impairment are associated with a greater risk of concurrent anaemia than are other comorbidities[3].

It is important to recognise that IDA is only a late feature of iron deficiency, which should itself be considered a pathologic state. Insufficient stored iron due to lack of intake progresses to iron deficient erythropoiesis that can ultimately lead to IDA[3,14]. Pathogenesis of IDA due to chronic blood loss is explained, as most stored iron in the form of ferritin is used in hyperactive erythropoiesis. When iron stores become severely depleted, erythropoiesis becomes inadequate, leading to IDA[13,14].

Figure 2. Population risk of anaemia by age group, persons 12 years and over

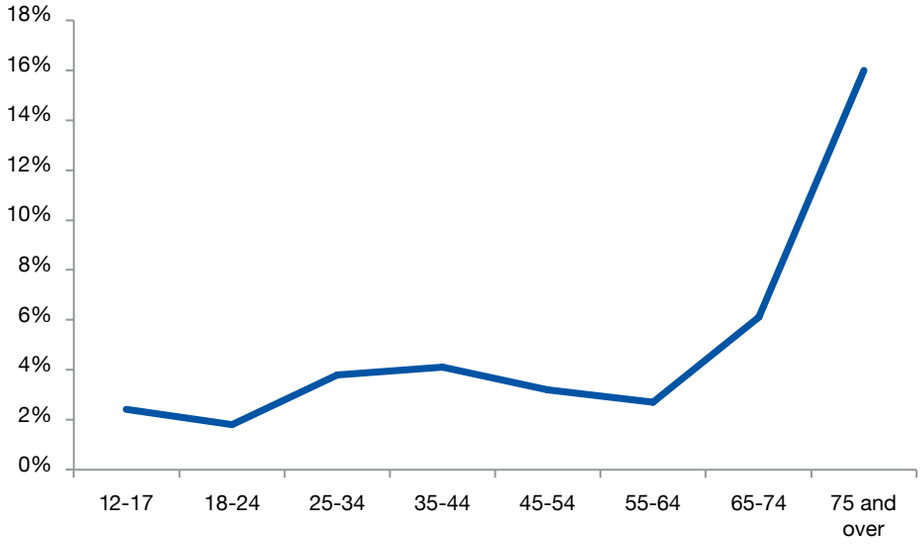


Figure adapted from Australian Health Survey: Biomedical Results for Chronic Diseases, 2011-12

CURRENT STRATEGY TO ASSESS IRON DEFICIENCY

Full blood count including Hb and blood film, as well as blood indices such as mean corpuscular volume (MCV), mean corpuscular Hb concentration (MCHC) and red cell count (RCC) values allowing the diagnosis of microcytic anaemia is considered a good screening tool for IDA. However, in areas of the world where haemoglobinopathies are prevalent, these indices will indicate microcytosis, so iron studies (in particular the ferritin level) remain the surrogate marker for IDA.

The degree of iron deficiency is classified according to ferritin level into:

- Severe iron deficiency if the serum ferritin level is below 15 or 30μg/L (some variation between laboratories).
- Moderate iron deficiency if the serum ferritin level is 30-50μg/L.
- Mild iron deficiency if ferritin is 50-100[12,15].

A low transferrin saturation <20 per cent (or <15 per cent in some studies) also indicates iron deficiency. Ferritin can be considered the surrogate marker for iron deficiency, but serum ferritin is an acute phase reactant often raised in cases of inflammation or infection.

Therefore, a concurrent test for inflammatory markers such as C-reactive protein (CRP) is advisable in cases of anaemia with raised ferritin, to exclude reactive causes. Iron deficiency is unlikely if the ferritin level is above 100μg/L[16,17].

In conditions associated with inflammation, the expression of the plasma protein, hepcidin, is increased. Hepcidin impairs absorption of dietary iron and inhibits the use of stored iron. Hepcidin expression associated with inflammation thus can cause an iron sequestration disorder in which iron storage may be normal as assessed by ferritin level, but the transferrin saturation is low. These patients are not iron deficient per se, but are unable to access their iron stores appropriately. There is no benefit from oral iron (due to expression of hepcidin), but intravenous iron therapy might help[18].

Other complementary tests in iron studies, such as serum iron and iron-binding capacity, are helpful in confirming the diagnosis of IDA and are outlined in Figure 3.

Figure 3. Laboratory evaluation of iron status

Test	Normal range/ diagnostic values	Details	Access	Other details
Ferritin	30-300 mcg/L and it is lab-specific.	Ferritin is an acute phase reactant and can be increased in patients with inflammation, liver disease, chronic infection, autoimmune disorders, and some types of cancer.	Readily available in most laboratories.	Acute phase reactant.
Transferrin saturation (TSAT), iron binding capacity and serum Iron	In healthy people, about 20-40% of available transferrin sites are used to transport iron.	Total iron-binding capacity (TIBC) is commonly used with iron level to evaluate iron status. Both tests are used to calculate transferrin saturation, which is a functional marker of iron status rather than just iron or TIBC alone.	Readily available in most laboratories.	More reliable than ferritin.
Hepcidin	Not standardised – see comments.	A hepatic derived plasma protein that regulates intestinal iron absorption. Released when adequate or high iron stores binding and down regulating intestinal ferroportin, reducing dietary absorption. When stores are low, release is suppressed leading to an increase of iron efflux from enterocytes into the blood.	Available only in a few laboratories and not yet widely used.	Easily detected in urine, hepcidin estimation seems a potentially accurate test that reflects the actual iron status.

IRON THERAPY

Oral preparations

Oral iron therapy is common treatment for IDA, despite having significant limitations relating to intake and absorption. The most common cause of oral iron therapy failure is non-compliance because of side effect-related patient intolerance. The side effects of oral iron therapy include gastrointestinal disturbances (colicky pain, nausea, vomiting, diarrhoea and constipation) and occur in up to 50 per cent of patients taking oral iron preparations[12,15].

The most widely prescribed oral iron is mainly composed of ferrous salts. Unfortunately, there are low and variable absorption rates, limited by ingestion of certain foods or by mucosal luminal damage and needing an acidic medium for optimum absorption[12,15]. Ferric compounds were introduced to avoid such obstacles, but the available compounds are generally less soluble and have poor bioavailability. A new oral ferric polymaltose compound (Vifor Pharma Inc., Zürich, Switzerland) appears to have less side effects and better absorption. These promising results warrant further clinical trials to confirm the effectiveness and utility of this new oral iron polymaltose in the treatment of IDA.

The usual recommended oral ferrous sulphate dose for the treatment of iron deficiency is at least 80mg daily of elemental iron, which is equivalent to 250mg of oral iron sulphate tablets (Abbott, Australasia Pty Ltd).

Intravenous preparations

Parenteral iron is seen as an attractive option in the treatment of IDA. It is likely to be more popular due to the introduction of new and relatively safe intravenous iron preparations that allow substantial doses of iron to be administered rapidly in a single convenient treatment[12,15].

First-generation intravenous iron preparations (dextran complexes) had serious side effects, including anaphylaxis, limiting their use in the treatment of IDA. Iron sucrose was released in the 1990s and is safer, but its maximum weekly dose of 600mg limits its use. More recent formulations, such as iron polymaltose and carboxymaltose complexes, are better tolerated and can be used for rapid repletion of iron stores[12,15]. Nevertheless, intravenous iron remains underutilised because of previous concerns with tolerability of the older intravenous iron preparations and in spite of increasing evidence of the safety of the newer preparations, both in pregnant and general populations[8,12,15].

Cost analysis

Most of the cost of intravenous iron therapy is that of the product itself, plus the cost of administration in a day procedure or outpatient setting. The cost of iron polymaltose and carboxymaltose are similar (despite the higher product cost of carboxymaltose), as less nursing time is required to administer the carboxymaltose. There are small costs for expendables, clerical work and disposal of waste (Figure 4). Intravenous iron therapy is much cheaper than transfusing even one unit of blood.

Figure 4. Costing for iron supplementation courses of comparable efficacy (AUD)

Product	Cost per unit	Administration time	Cost (approximate)
Ferrous sulphate	$0.3 per tablet	6-9 months	$54-89
Iron polymaltose	$100 (for 1g)	2.5 hours	$375
Iron carboxymaltose	$232 (for 1g)	15 minutes	$300

EVIDENCE

Iron therapy in obstetrics

A randomised controlled trial of oral versus intravenous iron for the treatment of mild-moderate IDA in pregnancy was conducted at LGH between 2007 and 2009 and published in 2010[12]. Both oral and intravenous iron therapy were effective in treating IDA in pregnancy and the intravenous iron group had a statistically lower rate of anaemia (16 per cent) at term compared to the oral iron group (29 per cent).

A protocol was introduced concurrently so that all women referred to the obstetric clinic received a full blood count and iron studies in their first trimester, allowing for timely identification and treatment of IDA of pregnancy. The hospital's current protocol is that pregnant women are routinely screened for iron deficiency; those with moderate to severe iron deficiency are given intravenous iron, while those with mild iron deficiency are treated with oral iron.

The frequency of blood transfusion in the obstetric population at the LGH has approximately halved since the completion of the project in 2009.

Preoperative iron therapy

Preoperative oral iron therapy has been shown to be effective in the treatment of IDA[19,20]. Most of the data to support this statement is derived from trials of orthopaedic patients, in which one month of oral iron therapy preoperatively improved preoperative haemoglobin, postoperative haemoglobin and decreased the need for blood transfusion.

The timeframe required for intravenous iron to be effective is unclear. There is some evidence from small orthopaedic trials to suggest that in neck-of-femur fracture fixation, joint replacement and spinal surgery, an iron infusion less than four days preoperatively decreased the need for blood transfusion and decreased rates of wound infection[21–23].

Preoperative erythropoiesis-stimulating agents (ESA)

Studies investigating the efficacy of ESAs for the treatment of preoperative anaemia commonly combine ESAs with iron therapy. Available evidence suggests that in non-cardiac surgical patients treatment of IDA with ESAs offers no advantage over treatment with iron therapy alone in relation to postoperative haemoglobin levels and blood transfusion[3].

Patients who have chronic kidney disease, or those who are anaemic and have had nutritional deficiencies ruled out or corrected, may benefit from preoperative ESA therapy[24]. This should be arranged in consultation with a haematologist and renal physician.

Postoperative iron therapy

Postoperatively, the erythropoietic response to blood loss is blunted by the systemic inflammatory response to surgery[25]. As alluded to earlier, the expression of hepcidin impairs absorption of oral iron such that postoperative oral iron therapy fails to increase haemoglobin concentration[26]. There is contradictory evidence for intravenous iron therapy for the treatment of postoperative anaemia with several small trials in the setting of cardiac and orthopaedic surgery demonstrating no benefit[27,28]; while one observational study showed a decrease in transfusion rate post-joint replacement[29].

Regional flavour – preoperative screening, diagnosis and treatment of IDA

Patients attending the LGH may come from distances of up to 250km and several hours by road. For many, this is a daunting and expensive journey not to be repeated without good reason. The current LGH practice is that often a surgical date is given, followed by an appointment in the preoperative assessment unit. Only those patients perceived to be at special risk are seen in the preoperative assessment unit by an anaesthetist. When there may only be a couple of weeks between preoperative assessment and booked surgery, the choice between a month of oral iron therapy or a same-day 15-minute intravenous infusion is simple. Many a patient has languished on the surgical waiting list for a year or more and to add further delay is distressing. Worse, the patient will have already made work and family arrangements for the original surgical date.

The clinical need to operate soon can be a pressing one, notably for malignancies. The safety benefit of correcting IDA before surgery is well documented and the use of intravenous iron polymaltose or carboxymaltose is expeditious, effective and low-risk. A short course of oral iron therapy is not necessarily tolerated or effective.

Treatment of IDA tends to improve post-surgical outcomes. However, if the underlying cause of IDA is not identified and treated the IDA is likely to recur postoperatively[8]. With this in mind, the patient's general practitioner should be informed of the need for IDA investigation and other management before and/or after surgery. Iron carboxymaltose is now available in general practice via the Pharmaceutical Benefits Scheme. It provides an alternative to a hospital day-procedure unit admission for administration of intravenous iron.

Point-of-care testing

In 2010, the LGH undertook an industry-funded trial of use of point-of-care testing to minimise the need for repeat visits or delayed return for patients requiring preoperative iron infusions. A Pronto 7 with Rainbow 4D Sensor probe (Masimo) was used to screen patients on arrival in the preoperative assessment unit. Patients found to have a low haemoglobin level were sent for urgent full blood count and iron studies before (instead of after) their appointment. If they were found to be anaemic and iron deficient, they would be referred to the day procedure unit for an intravenous iron infusion after anaesthetic assessment. Iron carboxymaltose (Ferrinject) was made available so the infusion took only 15 minutes instead of the several-hour protocol that occurs with iron polymaltose administration.

The study protocol enabled the rapid identification and treatment of IDA. Use of the Masimo probe required some finesse, was more sensitive in males than females and was a good overall screening tool to identify patients with IDA, allowing same-day iron replacement and reducing the number of hospital visits[30].

Taking stock

An audit of 100 consecutive major elective surgical cases at the LGH was undertaken in 2015 and compared with 100 comparable cases from 2010 (Figure 5). The rates of preoperative anaemia are similar between the two cohorts; the most commonly identified patients were those presenting for hip or knee arthroplasty and gastrointestinal cancer resection (44 per cent and 42 per cent respectively of all identified cases of preoperative anaemia). Fewer of the major orthopaedic patients were anaemic (23 per cent), compared to patients with gastrointestinal malignancies (40 per cent). In 2015, 76 per cent of patients presenting for major elective surgery had iron studies preoperatively – this can be improved upon as a relatively new practice.

Of all anaemic patients identified in 2015, 14 had co-existing iron deficiency; of these 14 patients, nine received a preoperative iron infusion. There were four cases of preoperative anaemia where ferritin levels exceeded 300μg/L.

It is of note that in 2015, a further 11 patients with preoperative haemoglobin in the "low end" of the normal range had iron studies suggestive of iron deficiency (ferritin 30-50μg/L with low transferrin saturation). None of these patients received preoperative iron therapy. It is unclear whether we should be targeting these patients with preoperative iron therapy due to their impending blood loss – this remains an area of research.

Blood transfusion occurred in six patients in 2015, compared with 13 in 2010. The decrease in transfusion rate may arguably be due to a decrease in transfusion threshold, iron therapy or both.

Figure 5. Audit of LGH anaemia rates, iron infusion and blood transfusion practice 2010 and 2015

	2010	2015
Preoperative anaemia prevalence	20%	18%
Preoperative iron studies requested	2%	76%
Blood transfusion rate	13%	6%
Iron infusion administered in setting of IDA	N/A	9/14

Where to from here?

Preoperative identification and treatment of IDA as part of a blood conservation strategy is a relatively new concept in anaesthetic practice. If done well, it is of benefit to patients undergoing major elective surgery. Even now, the widely applauded process of patient blood management instigated statewide in Western Australia seems a little difficult to replicate[1].

In their analysis of the Western Australian success, Farmer et al. acknowledged that changing medical practice in a sustainable manner is challenging. Cultural change takes time to implement and requires consistent practice and communication from those driving the change. They refer to a three-stage, eight-step model published originally by Kotter, and inform that over 50 per cent of organisations will fail in the earliest stage: "Defrosting a hardened status quo"[31]. For example despite the success of the Masimo probe as a screening tool it is not currently being used in the preoperative assessment unit at the LGH.

Streamlining for success – better operative planning

The LGH Department of Anaesthesia is planning the best way forward. Recently published guidelines have encouraged a sustained change with regard to PBM and haematinic optimisation. The role of transfusion nurse will be expanded to incorporate all perioperative PBM coordination. That will include the ongoing task of directing perioperative haematinic optimisation, and linking with various hospital departments; including haematology, anaesthesia, surgery, emergency medicine and intensive care. There will also be more emphasis on contact with general practitioners, such that patients listed for major elective surgery are screened (and where necessary, investigated and treated) for iron deficiency in the community in order to avoid surgical delays from late diagnosis.

The LGH Department of Anaesthesia is currently encouraging major elective surgical patients to be seen by an anaesthetist at least four weeks in before their surgical date, so that haematinic therapy can be timely, effective and convenient.

We plan to reintroduce point-of-care testing in the preoperative assessment unit using the Masimo. Patients from remote areas with low haemoglobin readings with this device will be prepared for a same-day iron carboxymaltose infusion, pending their formal haemoglobin and iron study results. In order to retain clinic efficiency, local patients will have a return visit coordinated after results of iron studies are known.

Checking of preoperative blood tests will become automated by the introduction of computer-based, pathology-server linked, anaesthetic assessment chart software. It will automatically populate preoperative results directly into patients' anaesthetic files and abnormal results will automatically be flagged for intervention.

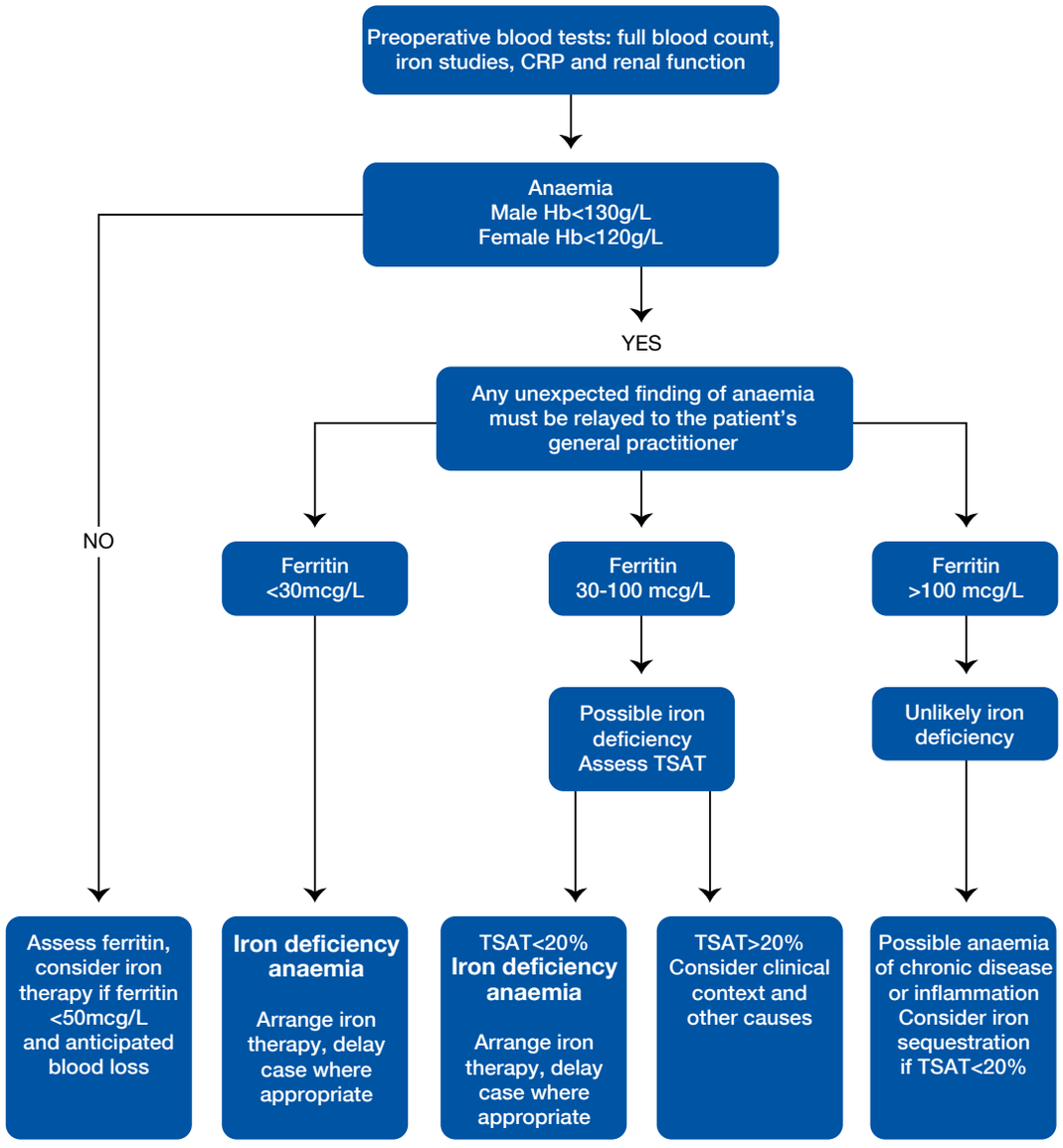
We have revised our clinical guideline for interpreting preoperative iron studies. Specifically, this guideline will incorporate transferrin saturation results to improve the diagnosis and treatment rate of iron deficiency (Figure 6).

Our plan for urgent cancer surgery patients includes mandatory full blood count and iron studies at the time the surgeon books the procedure. Results are directed to the anaesthetic clinic for timely subsequent management.

It has taken several years to implement, but since May 2015 the LGH stocks and administers intravenous iron carboxymaltose in the day procedure unit. Previously it was not stocked due to its expense. However, the LGH departments of Anaesthesia and Haematology convinced hospital management that, despite being a more expensive product, the 15-minute administration time is where the real cost saving is to be realised. It also allows identification and treatment of IDA on the day of clinic appointment, thus avoiding expensive repeat visits.

We must all acknowledge that criteria for surgical readiness have changed. IDA is common, easily identifiable and readily treatable. If IDA is left untreated, major elective surgical patients are exposed to unnecessary risk. Inadequately treated IDA subsequently represents a contraindication to major elective surgery.

Figure 6. Diagnostic flowchart for preoperative anaemia



CRP (C-reactive protein), TSAT (Transferrin saturation)

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Perioperative nutrition

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INTRODUCTION

Optimisation of nutrition during the perioperative period is increasingly recognised for its potential contribution to improving clinical outcomes. This review aims to collate evidence relating to perioperative nutrition in the hope it will guide implementation of evidence-based nutrition practices in this patient population.

PERIOPERATIVE METABOLISM

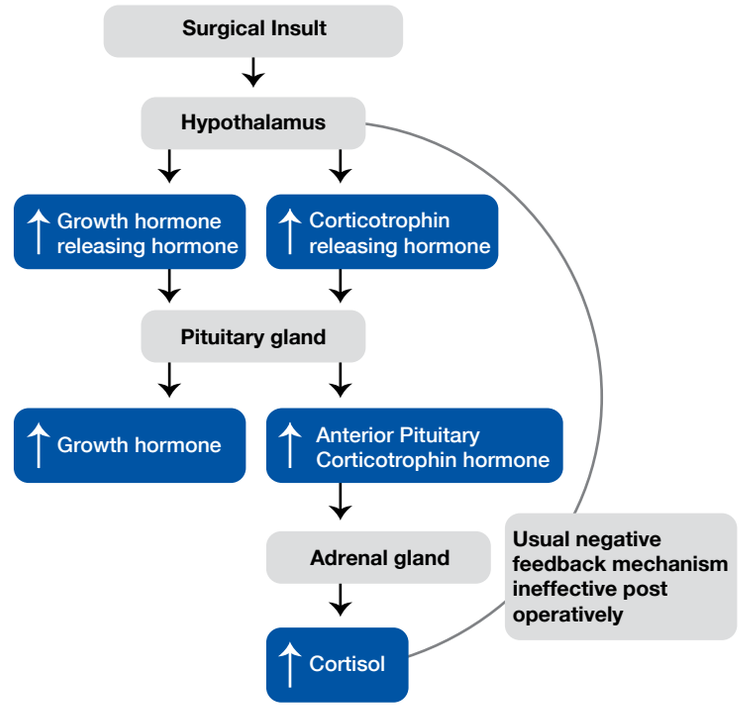
Surgical insult initiates a cascade of metabolic events affecting aspects of the endocrine, immunological and haematological systems[1]. The injured site triggers a response to the hypothalamus via the nervous system. In turn, the hypothalamus releases hormonal secretions such as growth hormone releasing hormone (GHRH) and corticotrophin releasing hormone (CRH) to exert an influence over the pituitary gland. GHRH and CRH stimulate the pituitary gland to produce increased amounts of growth hormone (GH) and anterior pituitary corticotrophins hormone (ACTH). ACTH specifically leads to the adrenal gland increasing its production of cortisol (Figure 1).

Figure 1. The post-operative metabolic response

1. Surgical insult initiates the postoperative metabolic response by sending signals to the hypothalamus via the nervous system.

2. The hypothalamus releases growth hormone-releasing hormone (GHRH) and corticotrophin-releasing hormone (CRH) to exert an influence over the pitutary gland.

3. The pitutary gland increases growth hormone (GH) and anterior pitutary corticotrophin hormones (ACTH) production.



Cortisol is a hormone that significantly impacts on a patient's metabolic processes by promoting gluconeogenesis, which subsequently leads to an increase in blood sugar levels. Growth hormone is responsible for the regulation of protein catabolism, influencing the rate of lipolysis and inhibiting the effects of insulin in order to stimulate protein synthesis. The inhibition of insulin in response to GH further contributes to raising blood sugar levels. Coupled together, the hyperglycaemic effect is notable and impacts on a patient's wound healing and recovery[2]. Furthermore, the usual negative feedback mechanism responsible for the regulation of cortisol is rendered relatively ineffective post-operatively, leading to ongoing production of this hormone and a marked increase in the stress response. While this provides an overall picture of the metabolic response to surgery, both hyperglycaemia and muscle catabolism have been shown to influence outcomes[3,4]. Thus, the metabolic processes should be explored in greater depth.

Insulin and glucagon are the key hormones responsible for regulation of glucose entering the bloodstream. Insulin is produced by the pancreas and released in response to an increase in blood glucose levels. It facilitates the movement of glucose into muscles and adipose tissue and promotes the conversion of excess amounts of glucose into glycogen and triglycerides[1]. Insulin also has a protective effect on muscle stores as it mitigates protein catabolism and lipolysis. During surgery, the anaesthesia administered to a patient has been noted to interfere with the secretion of insulin, an effect that may be related to the inhibition of β cell secretions[1]. Furthermore, cells seemingly become immune to the effects of insulin creating "insulin resistance" during the post-operative period. Glucagon, while promoting glycogenolysis, has been found to minimally contribute to hyperglycaemia post surgically[1]. Subsequently, post-operative hyperglycaemia is a common occurrence. Kiran and colleagues undertook a large study comprising of approximately 16,400 post-operative blood glucose readings in 2667 non-diabetic, colorectal patients[3]. It was found that approximately 67 per cent of patients experienced hyperglycaemia following surgery. Given the high percentage of patients likely to experience hyperglycaemia post-operatively, appropriate management is imperative. Poorly controlled hyperglycaemia can lead to delayed wound healing and adverse outcomes such as infection, sepsis and mortality.

Protein catabolism is the other significant metabolic process of concern. Catabolism of muscle stores is related to cortisol production, which becomes elevated perioperatively triggered by the stress response mentioned previously. The end products of muscle breakdown are amino acids, which are often metabolised into other energy substrates such as glucose, fatty acids and ketone bodies[1]. This process takes places in all patients undergoing major surgery, however, catabolism of muscle stores and subsequent muscle wasting occurs to a much greater extent in patients who are receiving suboptimal energy and protein[5]. Carbohydrate stored in the body as glycogen in the liver is rapidly depleted within the first 24 hours of starvation. It is for this reason that starvation beyond this 24-hour period leads to a shift in energy source, where muscle stores are broken down as part of our body's natural adaptive process to meet the energy demands of vital organs such as the brain and erythrocytes[6]. These metabolic processes are the triggering factors that necessitate due consideration be given to the nutrition a perioperative patient receives.

PREOPERATIVE EVALUATION

Current clinical practice for identifying "high-risk" patients preoperatively usually encompasses an anaesthetist assessing patients for possible cardiac and respiratory related issues, which increase the risk of surgery[7]. Neither the Australian and New Zealand College of Anaesthetists, the American Society of Anesthesiologists nor the American College of Surgeons mandate nutrition assessment as part of their preoperative risk assessments. As such, it is fitting to explore the need for nutrition to form part of the routine assessments. Two key nutrition-related risk factors predispose patients to adverse outcomes during the perioperative period – obesity and under nutrition. Patients who are malnourished have been shown to have an increased rate of nosocomial infections, an increased likelihood of ending up in the ICU, longer hospital stays, an increase in mortality in severe instances and, as a reflection of each of these problems, increased healthcare costs[8]. Malnutrition is often misunderstood to encompass under-nutrition alone, when malnutrition also includes those patients who are obese. Obesity is usually a consequence of poor diet and a lack of exercise, both contributing to a relative decrease in muscle mass and increased amounts of adipose tissue. As such, these two nutrition related states will be explored further.

UNDER-NUTRITION

The association between malnutrition and an increased risk of surgical complications is well established in the literature. In most cases this relates to the impact under-nutrition has on a patient's immune system thereby increasing the risk of infection[9]. Despite this knowledge, nutrition screening is often overlooked preoperatively. There is an abundance of screening tools but the Nutritional Risk Screening 2002 (NRS-2002) tool is the only validated one for surgical patients in terms of predicting clinical outcomes[10]. It was initially developed in 1999 and later validated against 128 retrospective randomised controlled trials by classifying patients based on nutritional state and severity of disease to determine whether or not nutritional support had any impact on clinical outcome[11]. Since then, there have been further studies supporting the reliability and pragmatic nature of the NRS-2002[12-14]. However, while the NRS-2002 is the only level I graded tool that predicts on outcomes[12], it is not as sensitive and specific in detecting malnutrition as the malnutrition-screening tool (MST)[15]. The MST is a simple tool validated in the acute setting, shown to have a high inter-rater reliability score and can be carried out in a short period of time (Table 1)[15,16].

Table 1. Malnutrition-screening tool (MST)

Have you lost weight recently without trying?	
No	0
Unsure	2
If yes, how much weight (kilograms) have you lost?	
1-5	1
6-10	2
11-15	3
>15	4
Unsure	2
Have you been eating poorly because of a decreased appetite?	
No	0
Yes	1
Total	

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Despite acknowledgement that malnutrition screening should form a part of standard preoperative assessments, it is rarely carried out. Multidisciplinary allied health teams, including dietitians, are often inadequately resourced to follow up on patients identified as nutritionally compromised or at risk. A deficit in appropriate staffing is often attributable to budgetary concerns and a lack of insight into the improvement in clinical outcomes and associated cost savings that can be achieved with appropriate nutrition intervention. Further work is needed to ensure hospitals implement routine screening so undernourished patients or those patients at risk of under-nutrition are identified early, and nutrition intervention can occur in a timely manner.

Nutrition intervention usually involves the implementation of a nutrition plan, tailored to a patient's clinical and nutritional status. Factors need to be considered such as current nutrition intake, expected surgical insult and subsequent metabolic demand. For instance, a severely undernourished patient presenting for major gynae-oncological procedure is likely to require intensive pre and post-operative nutrition support, whereas a relatively healthy patient having an appendectomy is unlikely to need any nutrition intervention at all. Depending on the clinical state, adequate optimisation of an under-nourished patient may not always be possible. Patients undergoing surgical procedures for malignancy need to be treated in the least time-intensive manner possible to prevent the disease advancing[17]. Studies show there is benefit in as little as five to seven days of nutrition support preoperatively for patients who require optimisation. It is important to accept that the intention behind preoperative nutrition support is not to reverse the months or years of malnutrition but instead prepare the patient to endure the surgical insult from a metabolic perspective[17]. For example, a patient with gastrointestinal malignancy who presents with large amounts of unexplained weight loss, poor intake and subsequent malnutrition would be categorised as high risk as a result of their premorbid malnourished state and the anticipated surgical insult of a large surgery. The benefits of preoperative nutrition optimisation in this patient group include a reduction in complications, mortality and length of hospital stay[18-20].

OBESITY

Obesity is associated with adverse surgical outcomes with an increase in both intraoperative and post-operative complications[21-23]. Visceral body fat complicates technical aspects of surgery thereby increasing length of surgery and associated complications[24]. With an increase in pressure on health services to cut costs, all avenues of cost savings are being explored. It is then no surprise that despite a lack of strong evidence the use of strict low-calorie diets to facilitate rapid preoperative weight loss has become commonplace. This approach to managing the obese surgical patient is extrapolated from the assumption that if obesity is related to adverse outcomes then weight loss to reduce this risk will have better outcomes. Studies evaluating the efficacy of preoperative weight loss and its impact on post-surgical outcomes have predominantly been undertaken in bariatric surgical patients[25-26].

There are limited, if any, data on the applicability of a very low calorie diet (VLCD) preoperatively for patients who require surgical intervention for malignancy. The primary concern of using a VLCD preoperatively in this patient population is the large and rapid weight reduction patients achieve, which can result in loss of lean muscle mass[27].

Obese patients at baseline, prior to a large weight loss, often have poor muscle stores, which may be related to poor quality nutrient intake and lack of physical activity. Inadequate muscle stores have been linked to suboptimal outcomes; therefore loss of this mass should be mitigated where possible. Muscle stores often form the primary fuel for wound healing and immune defence post-operatively. There is a gap in evidence, which warrants further investigation, as to whether the benefits of preoperative weight loss by means of a VLCD regime is greater than the risk of loss of soft tissue mass preoperatively. This risk needs to be assessed in terms of post-operative outcomes, focusing on high-risk groups such as those undergoing major gastrointestinal or gynae-oncological surgery.

PERIOPERATIVE NUTRITIONAL MANAGEMENT

A number of nutritional approaches have been studied or advocated in the perioperative context. Based on prominence in the published literature, elements that will be discussed further include parenteral nutrition (PN), immuno-nutrition, enhanced recovery after surgery (ERAS) and glycaemic control.

Parenteral nutrition in the perioperative patient

Perioperative nutrition is usually in the form of oral or enteral nutrition, however in some instances parenteral nutrition may be warranted. The American Society of Parenteral and Enteral Nutrition (ASPEN) recommend consideration of parenteral nutrition in malnourished patients undergoing gastrointestinal surgery. Specifically they recommend parental nutrition be commenced preoperatively for five to seven days continuing into the post-operative period should the patient be unable to tolerate adequate enteral nutrition[28,29]. However, there has been much debate surrounding parenteral nutrition and its role in the perioperative and/or critically ill patient. The strongest deterrent for most physicians is the perceived increased risk of infection. This concern is primarily based on data from older studies[30,31], where adequate glycaemic control was not a priority, strict aseptic techniques for preparation of parenteral nutrition was not the norm and the available lipid formulations were high in polyunsaturated fats, which have the potential to be pro-inflammatory[32]. Some more recent large randomised controlled trials reflect these same adverse outcomes, while others show no increase in infection rates, length of stay or mortality. While the studies are predominantly in the ICU setting, the results may be considered applicable to perioperative patients that require parenteral nutrition. To explain these differences in outcomes, the study design and patient cohort need to be considered.

Caesar and colleagues showed an increased risk of infection, increased proportion of patients requiring mechanical ventilation for greater than two days, an increased mean duration of renal replacement therapy and an increased cost to the healthcare in patients receiving early supplemental parental nutrition in the EPaNIC study[33].There are a few factors that could have potentially influenced this outcome. Firstly, patients randomised to the intervention arm may or may not have had a clinical indication for parenteral nutrition. A patient who has a functioning gut should ideally persist with enteral nutrition preferentially over parenteral nutrition[34] and, as such, this aspect of the study makes generalisation of the findings difficult to apply to patients who clinically require parenteral nutrition. Secondly, patients in the intervention arm received a large glucose load within the first 24-48 hours thereby contributing to a hyperglycaemic state. While there is no definitive evidence to suggest poor outcomes with the introduction of early glucose, evidence does exist that hyperglycaemia on admission and within the first 24 hours is associated with a higher mortality[35-37]. The third key issue in this study is that despite being in the intervention arm where nutrition was meant to be optimised, patients on supplemental parenteral nutrition never received >1g per kilogram of body weight of protein, and inadequate protein has been shown to impact on mortality outcomes[4,38]. Results from the EPaNIC trial are in direct conflict with those of the more recently published Early Parenteral Nutrition trial by Doig and colleagues[40]. This study took an approach more akin to normal clinical practice and recruited patients who had relative contraindications to receiving enteral nutrition. Patients were randomised to standard care versus early parenteral nutrition. Results showed no difference in rates of infection between groups, no difference in length of ICU or hospital stay, and no difference in mortality. With a large sample size (n=1372) this study was sufficiently powered to detect such differences if they were to exist. Interestingly, this study did find a significant result for one additional outcome, a reduction in duration of mechanical ventilation for patients in the intervention arm. The results of the study by Doig and colleagues are supported by the findings of the CALORIES trial, which also found no significant difference in rate of infection or mortality[39,40]. The CALORIES trial is a large, randomised controlled trial, which compared the enteral to the parenteral route in an effort to optimise nutrition delivered to patients admitted unexpectedly into the ICU. Its key findings included no difference in mortality or infectious complications between the enteral and parenteral group[39]. The comparison between these studies are summarised in Table 2.

Table 2. Summary of mentioned supplemental parenteral nutrition studies

	Design	Intervention	Outcomes	Limitations/ confounding factors	Key conclusions
Caesar et. al (2011)[33] – EPaNIC	Randomised controlled trial (n=4640). Patients recruited and consented if they scored >3 on the NRS tool.	Compared early initiation of parenteral nutrition with late initiation to supplement insufficient enteral nutrition.	The intervention arm (early PN) showed: ↑ Risk of infection. ↑ Number of patients requiring mechanical ventilation >2 days. ↑ Duration of renal replacement therapy. ↑ Cost to healthcare.	• Large glucose load within the first 24-48 hours in intervention arm. • Premixed PN – low dose protein to energy ratio.	• Caution when prescribing supplemental PN in instances when it is not clinically indicated (e.g. gut function intact). • Consider allowing seven days of EN/oral intake prior to commencing PN in patients who are otherwise well nourished.
Doig et.al (2013)[40] – Early PN	Randomised controlled trial (n=1372).	Recruited patients who had relative contraindications to receiving enteral nutrition. Patients were randomised to standard care versus early parenteral nutrition.	↑ In length of mechanical ventilation. No difference between groups for: • Mortality. • Infectious complications. • Length of stay.	• Applies to a much narrower subset of patients than the EPaNIC trial.	• Aligns with clinical practice. • No increase in infections between groups.
Harvey et.al (2014)[39] – CALORIES	Randomised controlled trial (n=2400).	Assigned patients who could be fed through either the parenteral or the enteral route to a delivery route initiated within 36 hours after admission and continued for up to five days.	No difference between groups for: • Mortality. • Infectious complications. Reduction in: • Episodes of hypoglycaemia. • Nausea or vomiting.	• The target delivery of 25 kcal/kg/d was not reached in a majority of patients in each study group.	• No increase in risk of infection between groups.

PN = parenteral nutrition.

In light of the fact that there appears to be no increased risk of infection in patients commenced on parenteral nutrition when clinically indicated, it should ultimately be left to the clinical judgement of the treating healthcare professional as to whether there will be any benefit in commencing parenteral nutrition. Potentially, early parenteral nutrition (within seven days) should be reserved for patients with a BMI <25 or >35kg/m^2 as it appears that patients in these groups tend to have lower muscle mass and subsequently benefit from early, aggressive nutrition[41].

Immuno-nutrition

Immuno-nutrition, also known as pharmaco-nutrition, is the enrichment of enteral nutrition with specialised nutrients such as arginine, ω-3 fatty acids, glutamine and other antioxidants. The benefits of glutamine and other antioxidants have been predominantly demonstrated in the critically ill patient and for this reason will not be examined in depth in this review.

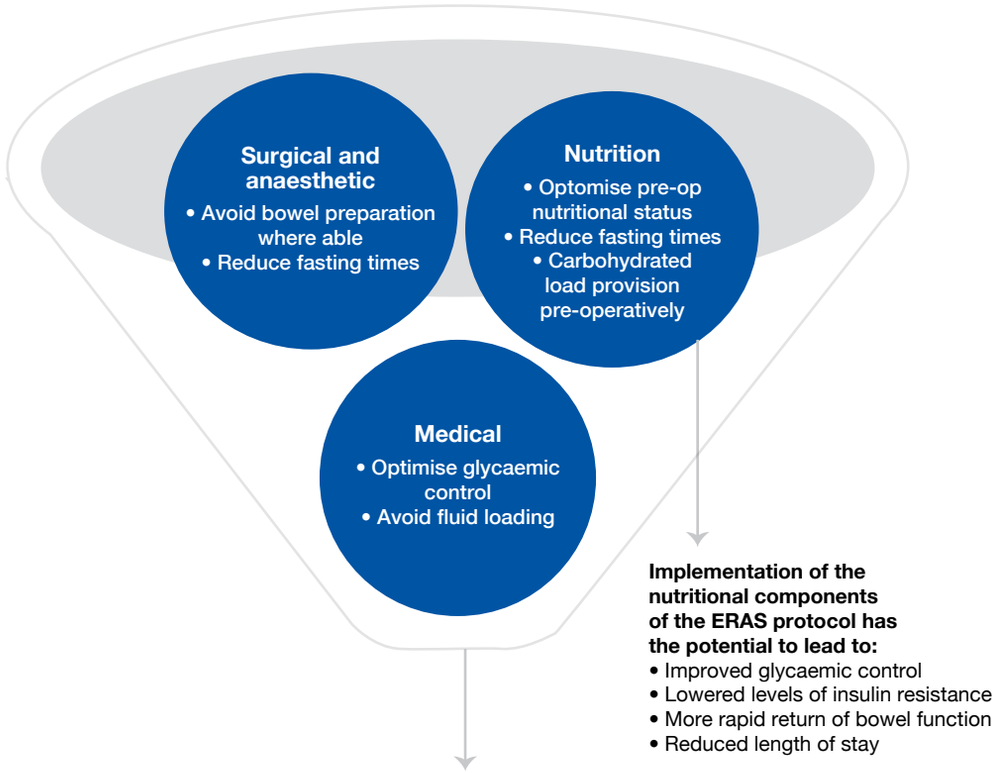
Most studies have investigated the synergistic effect of arginine and ω-3 fatty acids in gastrointestinal cancer patients undergoing resection. These nutrients have been shown to positively modulate immune response, influence gut function, and attenuate the inflammatory response post-operatively[42]. Meta-analyses and systematic reviews synthesising data from studies predominantly undertaken in gastrointestinal (GI) surgical patients have shown improvements in short-term clinical outcomes such as a reduction in post-operative infections and shorter lengths of hospital stay[43-45]. In fact, the largest nutritional governing body in Europe, the European Society of Parenteral and Enteral Nutrition (ESPEN), endorse the recommendation of immune-modulating formulae use in elective upper GI surgical patients[46]. While this may be the case, controversy regarding the efficacy of perioperative immuno-nutrition when compared to preoperative immuno-nutrition continues to exist. Studies have found that preoperative administration of immuno-nutrition provides a similar beneficial effect when compared to perioperative use of these products[47,48]. The use of preoperative supplements alone could potentially mean a cost saving and, as such, further research is required into the benefits and need for perioperative immuno-nutrition. Clinicians also should note that the Canadian Critical Care Clinical Practice Guidelines recommend against use of arginine-enriched formulations in critically ill patients as these have been associated with increased mortality based on the results of a few studies[49,50]. Since larger, more robust studies have not been carried out to definitively confirm these findings, it is best to err on the side of caution should patients become critically ill during the perioperative period thereby mitigating the risk posed to them.

Enhanced recovery after surgery (ERAS)

The ERAS study group, encompassing leaders in surgical care, was formed in 2001 with the aim of implementing best practice by means of multimodal surgical care. Their first publication was 10 years ago when a consensus document for protocols in patients undergoing colonic surgery was formulated. As the evidence grew, a society was formed in 2010. Since the initial guidelines, the ERAS Society has endeavoured to validate the ERAS protocol in various surgical patient populations. The ERAS Society, in conjunction with ESPEN, has published consensus guidelines for the management of patients undergoing gastrectomy, radical cystectomy, pancreatico-duodenectomy, elective colonic surgery and elective rectal/ pelvic surgery[51-55]. The ERAS protocol accounts for various aspects of care in the pre, intra and post-operative phases of surgery, including anaesthetics, nutrition, mobility and fluid control.

The ERAS protocol discourages use of mechanical bowel preparation, advocates for adequate glycaemic control (<12mmol/L at a ward level), a reduction in fasting duration to six hours for solids and two hours for clear fluids, carbohydrate loading two hours preoperatively with a 12.5 per cent carbohydrate solution comprised of predominantly maltodextrin and an early introduction of enteral nutrition including the use of oral nutrition supplements for at least the first four days post-operatively to assist patients in meeting a greater percentage of their requirements[51-55]. Prior to the release of these guidelines, the standard preoperative fasting period was usually between eight to 12 hours. Since glycogen stores are depleted within 24 hours of starvation, patients fasting for lengthy periods of time often mobilise lean tissue mass early in the post-operative phase[6]. Muscle wasting, if persistent, is associated with adverse outcomes such as an increased risk of acquired infections, muscle weakness and an increased length of stay[56,57]. Implementation of the nutritional components of the ERAS protocol has led to improved glycaemic control, lowered levels of insulin resistance, more rapid return of bowel function and a reduced length of stay (Figure 2)[10,58]. Certain patient groups form an exception to ERAS recommendations; these include diabetic patients and patients with delayed gastric emptying. Carbohydrate loading in diabetic patients is counterintuitive due to the expected hyperglycaemic effect it has and therefore should be avoided for this patient population. Patients with delayed gastric emptying are at an increased risk of aspiration on administration of anaesthesia. Studies have confirmed that gastric emptying of solids may be an issue, but to date have been unable to determine if the emptying of fluids is also of concern[51]. As such, the fasting duration preoperatively for solids should continue to be eight to 12 hours; however, whether the majority of patients are able to consume clear fluids up to two hours preoperatively remains unclear until further studies can be undertaken.

Figure 2. Summary of ERAS nutritional concepts



While certain aspects of the ERAS protocol are relatively low risk based on available evidence, other aspects of the protocol warrant clinical consideration on a case-by-case basis. Adequate glycaemic control and post-operative nutritional supplements are low risk and should routinely be implemented with minimal clinical concern. Preoperative carbohydrate loading in the majority of patients undergoing major abdominal surgery should be recommended with the exception of patients with diabetes and those who have delayed gastric emptying. Duration of fasting from solids preoperatively and the type of bowel preparation used is likely to continue to be determined on a case-to-case basis by the treating surgeon due to the associated risks.

Glycaemic control

Post-operative insulin resistance and hyperglycaemia is commonplace in surgical patients as the insult sustained during surgery initiates a cascade of metabolic events conducive to this state. Hyperglycaemia is well known for its association with adverse outcomes in post-operative patients such as delayed wound healing, increased rates of infection, sepsis and mortality[2-4,59]. While adequate preoperative glycaemic control potentially impacts on these outcomes; limited data is available and therefore no conclusive recommendations can be made. Van De Berghe and colleagues generated much discussion when data from her study conducted in a surgical ICU depicting the strong mortality benefit that intensive insulin therapy had was published[60]. Following this, further studies were undertaken and, in particular, one large randomised controlled trial found that intensive insulin therapy was associated with an increase in hypoglycaemic episodes and subsequently increased mortality[61]. Since then it has been widely agreed that a more conventional approach to glycaemic control would be taken with a target of <12mmol/L and, ideally, where possible, <10mmol/L. Implementation of appropriate insulin therapy, along with elements of the ERAS protocol that assist with blunting the post-surgical hyperglycaemic response, is likely to lead to improved patient outcomes.

POST-OPERATIVE ENTERAL INTAKE

Post-operative nutrition, especially following major elective surgery, may be delayed due to the surgical prejudice surrounding accepted feeding practices in the post-operative patient. More specifically, there is much controversy surrounding feeding patients after gastrointestinal surgery. Enteral feeding in this patient population was, and sometimes still is, considered to be high risk, with concerns specifically related to the breakdown of the anastomosis and subsequent leakage into the peritoneal cavity[62]. Historically, post-operative nutrition was delayed until a patient passed flatus or a bowel motion, thereby putting them at an increased risk of malnutrition and delayed post-operative recovery. There are at least three recent (2001 onwards) meta-analyses surrounding enteral feeding initiation within 48 hours of surgery, none of which reported an increased incidence of anastomotic leak[63-65]. In fact, the largest meta-analysis incorporated 15 studies (n= 1240) and spanned more than 30 years, focused on gastrointestinal resection surgery and showed that patients receiving nutrition proximal to their anastomoses had a statistically significant reduction in morbidity[65]. Furthermore, no adverse effects were noted. Despite this strong body of evidence, hospitals around the world have been slow to implement a change in practice and the delay in feeding patients remains relatively common. Potentially newer models of multidisciplinary team involvement in patient care will contribute to an increase in adoption of early enteral feeding post-operatively.

COLLABORATIVE APPROACH TO PERIOPERATIVE NUTRITION

It has been suggested by Martindale and colleagues that patients undergoing elective surgical procedures ideally receive a “prehabilitation” period, which includes early nutrition assessment preoperatively to identify at-risk patients, an exercise physiologist to establish adequate physical activity in order to attenuate any muscle wasting, assessment and optimisation of glycaemic control and a smoking cessation program 30 days prior to surgery[10]. From a nutrition perspective, identifying patients at risk will include patients who are either undernourished or obese. The undernourished patients will ideally receive five to seven days of nutrition optimisation pre surgically[18-20,66]. Immuno-enhanced formulas in this preoperative period of known benefit for patients undergoing GI surgery for malignancy and should be considered as part of routine clinical practice[42-45]. However, more studies measuring the benefits of perioperative immuno-nutrition need to be undertaken prior to implementing the post-operative immuno-nutrition component[43,67-69]. Additional studies also are needed to address the treatment of the obese patient pre-surgically. At present, data surrounding the adverse effects of obesity on post-surgical outcomes have been extrapolated to formulate management strategies preoperatively. Patients may benefit from intensive weight loss programs with a concurrent exercise program to minimise muscle wasting pre-surgically, but this benefit in patients undergoing surgery for malignancy is yet to be shown in any randomised controlled trials.

Patients requiring specialised nutrition support post-operatively, such as those undergoing gastrointestinal surgery, should be trialled on enteral nutrition where viable. Use of parenteral nutrition should be limited to patients who are unable to receive nourishment via the enteral route. Due to the associated risks of parenteral nutrition, it seems prudent that it should be held off for at least five to seven days in well-nourished patients[33], but may be provided sooner for malnourished patients with poor intake[70]. Early administration of parenteral nutrition may also be considered in the critically ill surgical patient to facilitate an earlier wean off invasive ventilation[40]. In light of the complicated nature of nutrition support in patients undergoing surgical procedures, a multidisciplinary approach, including dietetic referral, is recommended to optimise patient outcomes.

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Modern metal implant toxicity and anaesthesia

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INTRODUCTION

The use of metals in therapeutic procedures dates back several centuries. Corrosion and lack of tensile strength restricted the application and development of early implants. The introduction of stainless steel in the 1920s lead to an increasing number of implantable metallic devices for medical use. These devices are becoming more common for therapeutic and diagnostic purposes. Wear, corrosion and failure can lead to the release of metal ions, which may result in local and systemic effects. Although several metals, including iron, zinc, copper, manganese, iodine, chromium, selenium, molybdenum and cobalt, are essential to life, in higher concentrations these and many non-essential metals are toxic[1]. Metal toxicity from implantable devices can cause a range of clinical symptoms and organ impairment. The safety of metal-on-metal implants has been the subject of recent debate and media attention[2]. This review will provide a brief history of metals in medicine, outline the toxicity of metals used in modern prostheses and suggest an approach for pre-operative assessment of patients with new organ impairment and known metallic implant.

HISTORICAL USES OF METALS IN MEDICINE

Metals have been used in medicine for thousands of years. Metallic silver was known to the Chaldeans as early as 4000BC. Together with gold and copper, these metals were the antimicrobials of the ancient world. The Phoenicians, Greeks, Romans, Egyptians and others used silver to preserve food and water. Silver nitrate was used to treat surgical wounds, skin ulcers and compound fractures. Silver sutures were used to treat vesico-vaginal fistulas in the 1800s[3]. Te (tellurium) and Mg (magnesium) oxides as well as Cu (copper) and Hg (mercury) salts have been used to treat diseases such as leprosy, tuberculosis, gonorrhoea and syphilis. Hg(I) chloride was traditionally used in the 16th century as a diuretic and laxative throughout Europe[4]. The metalloid, arsenic, well known as a poison, was prescribed for a range of ailments, such as rheumatism, malaria, tuberculosis and diabetes. Although the toxicity of these medicines caused them to be largely abandoned for therapeutic use in Western society they may still be found in traditional Chinese, Tibetan and Ayurvedic medicines[5,6].

Some of the earliest uses of metal implants were by the Romans, Chinese and Aztecs, who used gold in dentistry more than 2000 years ago. Europeans fashioned replacement teeth out of iron from around 200 AD[7]. Ancient Incas used silver or gold plates to repair cranial defects[8]. In the early 1800s, experiments were undertaken to examine the suitability of implant materials testing silver, gold, lead and platinum in animals. In 1886, metal plates were used for the first time for internal fixation of a fracture. Early implants were often problematic because of corrosion, lack of tensile strength, surgical technique and infection. The discovery of stainless steel in 1924 allowed metals to be used in the body routinely, at a reasonable cost and with greatly increased reliability. A cobalt (Co) metal alloy was introduced in 1936 and became one of the most popular metal alloys in orthopaedic surgery for many years. Titanium (Ti), titanium alloys, stainless steel and cobalt-chromium (Cr) alloys form the majority of modern metallic implants in what is a multi-billion dollar industry with millions of procedures performed each year[9].

CORROSION OF METALS

Corrosion of metal implants is of great clinical concern. Structural failure or reduced implant integrity may result in increased local and systemic concentrations of metals leading to patient morbidity. These patients may present to the anaesthetic preadmission clinic for review. Corrosion is of particular concern in younger patients, who may be exposed to the systemic metal toxicity for longer periods of time. Any metallic implant within the body is subjected to electrochemical degradation. The combination of various ions in an aqueous environment, including sodium, chloride, calcium, magnesium, bicarbonate and plasma proteins, create a thermodynamic force for oxidation reduction reactions. A protective oxide layer, surface modification techniques and materials provide some protection reducing the rate of corrosive attack[10].

Dissolution of metal from implants leads to erosion and implant fracture, which may accelerate the release of metal ions resulting in the accumulation of metal in the soft tissue surrounding the implant, periprosthetic soft tissue destruction, osteolysis, pseudo tumours and infiltrates of lymphocytes and plasma cells[11]. Several forms of corrosion are recognised, including uniform, pitting, galvanic, fatigue and leaching. Titanium is a relatively inert metal with good biocompatibility. It has corrosion rates that are typically less than 0.02mm per year and well below the 0.13mm per year maximum corrosion rate commonly accepted for biomaterial design and application[12]. Different metals within alloys have different rates of corrosion in the same electrolyte solution. Selective leaching of one element may impair the structural integrity and performance of the implant[13].

METAL TOXICITY

The toxicity of metals has been known for thousands of years. The early Greeks and Romans documented both the toxic and therapeutic effects of metals. Industrialisation has increased exposure to metals through new applications in medicine, industry and agriculture as well as environmental contamination. The clinical consequences of metal toxicity depend on the type of exposure (ingestion, inhalation, dermal absorption), the form of metal (elemental, salt, particulate, vapour, amalgam), the dose and the duration or frequency of exposure. Mechanisms of metal toxicity are diverse including; inhibition of enzymes, disruption of structure and or function of cellular processes, free-radical production, interaction with DNA leading to mutagenesis and carcinogenesis, covalent modifications of proteins or displacement of critical metals in metal dependent processes or structures[14]. Generation of reactive oxygen species (ROS) in excess of the hosts detoxification mechanisms may result in tissue damage, leading to the development of chronic and degenerative diseases such as cancer, autoimmune disorders, ageing, cataracts, rheumatoid arthritis, cardiovascular and neurodegenerative diseases[15].

Exposure to certain metals in both environmental and occupational settings has been reported to be carcinogenic. Nickel, vanadium, arsenic, cadmium, cobalt, chromium and copper have been identified as carcinogenic in both animals and humans. Certain compounds including of cobalt, iron, lead, manganese, platinum, titanium and zinc have induced tumours in experimental animals, but the doses used and modes of administration differed from those of any known human exposure[16]. Metals can cause genotoxicity and carcinogenicity through multiple pathways or enhance a biological effect itself. Several mechanism, in addition to ROS, have been identified including metal induced regulation of transcription factors, effects on signal transduction pathways, metal induced apoptosis, mutagenesis through DNA repair inhibition or alterations in cell cycle control[17]. The carcinogenic capability of metals depends mainly on factors such as oxidation states and chemical structures. Trivalent chromium Cr(III) is an essential metal while hexavalent chromium Cr(VI) compounds have been shown to exert genotoxicity in vivo and in vitro[18].

NEUROTOXICITY OF METALS

Metals play an import role in the neurological structure and function. Metal dyshomeostasis has been implicated in the pathology of neurodegenerative diseases including Alzheimer's disease, amyotrophic lateral sclerosis, Huntington disease, Menkes, occipital horn syndrome, Parkinson's and Prion disease[19]. Metals including aluminium, copper, lead, manganese, mercury and thallium are known nervous system toxins. Oxidative stress may be a significant factor in the development or progression of neurodegenerative disorders[20]. Neurological symptoms, including cognitive decline, memory difficulties, tremor, inco-ordination, polyneuropathy, vertigo, hearing loss and visual changes have been reported from cobalt and chromium toxicity post hip replacement[21].

RESPIRATORY TOXICITY

Metal induced respiratory disease is largely caused by inhalation injury. Cobalt chloride can induce pulmonary hypertension through upregulation of HIF1α activator and increased muscularisation of the small pulmonary blood vessels[22,23]. Metallo-protein formation may result in immediate type (IgE-mediated) and cellular hypersensitivity induced asthma and chronic bronchitis. Several metals have been linked to granulomatous lung disease including titanium, aluminium and copper. Gold lung presents as hypersensitivity pneumonitis in rheumatoid arthritis patients treated with gold salts[24].

GASTROINTESTINAL TOXICITY

Gastrointestinal metal-associated toxicity usually arises from the ingestion of food, minerals supplements or hereditary storage diseases such as haemochromatosis and Wilson's disease. Elevated titanium, chromium and cobalt levels have been found in the liver and spleen of patients with failed hip or knee prostheses[25]. Titanium alloy particles can cause granulomatous hepatitis and hepatosplenomegaly[26].

RENAL TOXICITY

The kidneys are particularly sensitive to metal-induced toxicity. Accumulation of metals in the proximal tubule may induce a Fanconi syndrome characterised by a decreased glomerular filtration rate (GFR), increase in urinary flow rate, proteinuria, glycosuria, aminoaciduria and the loss of phosphate and bicarbonate ions[27]. Chronic exposure to lead, cadmium, mercury, antimony, chromium, gold and platinum may lead to chronic kidney disease or the development of end stage renal failure[28].

HAEMATOLOGICAL TOXICITY

Metal toxicity may have a variable effect on haematological parameters. Cobalt has an erythropoietic effect and has been used to treat anaemia and for blood doping in sport[29]. Chromium may compete with iron in binding to apo-transferrin causing anaemia[30].

IMMUNOLOGICAL TOXICITY

Nickel, cobalt, chromium and titanium are capable of producing immunological responses through altered B and T cell function, modified cytokine release, haptenisation or direct immunotoxicity. Numerous case reports have linked immunological responses to adverse performance of metallic cardiovascular, orthopaedic, plastic surgical and dental implants. In vivo metal sensitivity may play a role in the failure of implants containing these metals[31].

ENDOCRINE TOXICITY

Metals including cobalt, nickel, aluminium and vanadium are endocrine disruptors. Hypothyroidism results from inhibition of tyrosine iodinase by cobalt(II) ions[29]. Aluminium, cadmium, chromium, cobalt, copper, nickel, tin and vanadate also have been identified as metalloestrogens, compounds cable of binding to cellular oestrogen receptors and mimicking the actions of physical oestrogen. Their role in aberrant oestrogen signalling in the human breast requires further research[32].

CARDIAC TOXICITY

Epidemiological evidence suggests metal contaminants may play a role in the development of atherosclerosis and its complications[33]. Cobalt accumulation within the myocardium may result in a cardiomyopathy and echocardiographic changes that suggest altered left ventricular relaxation and early filling[34].

MUSCULOSKELETAL TOXICITY

Adverse local tissue reactions are locally destructive lesions resulting from inflammatory reactions, which may account for implant failure. Muscle atrophy, abductor tendon avulsion, pseudo tumour formation, peri-prosthetic collections and synovial thickening are reported soft-tissue abnormalities suspected to result from the inflammatory response to metal wear debris in patients with metal-on-metal hip implants[35].

CARCINOGENESIS AND DEVELOPMENTAL TOXICITY

There have been few studies of carcinogenicity of metal-on-metal hip resurfacing arthroplasty. There is no consistent evidence of an overall increase in cancer rates although non-statistically significant higher rates of haematopoietic malignancy, prostate cancer and melanoma have been noted. Transplacental passage of metal ions has been demonstrated without any observed teratogenic effect[36,37].

METALS, MODERN IMPLANTS AND ANAESTHESIA

Metals used in most modern surgical implants include stainless steel, titanium, titanium alloys and cobalt chromium alloys (Table 1). While there is no evidence that elevated serum levels of these metals directly influence either inhalation or intravenous anaesthesia, it is clear from hereditary metal disorders that the pharmacokinetics and pharmacodynamics of anaesthetic drugs can be significantly altered by end organ impairment[38]. Although classified as inert or biocompatible metals, there are increasing numbers of case reports of patients presenting for joint-revision surgery following either local or systemic toxicity from these implants. It is an emerging area of concern the anaesthetist should be aware of.

Table 1. Major metal alloys and their selected biomedical applications

Implant	Example	Type of metal
Neurological	Neuromodulation device	Ti; Ti6Al4V
	Recording electrodes	Pt; W; PtIr; 316L SS
	Cochlear implant	Pt
	Coils	Pt
Cardiovascular	Stents	316L SS; CoCr; CoCrPt;Ti; PtCr; Ti6Al4V; TiNi; PtW; PtIr
	Artificial valve	316L SS; Ti6Al4V; CoCrMo
	Pacemaker, ICD	Pt; PtIr; Ti
	Catheters	316L SS; Pt; Ti; TiNi; Ti6AL4V
Orthopaedic	Bone fixation (plate, screw pin)	316L SS; Ti;Ti6Al4V
	Artificial joints	CoCrMo; Ti6Al4V;Ti6AlNb
	Spinal rods	316L SS; CoCrMo; Ti; Ti6Al4V
Dentistry	Orthodontic wire	316LSS; CoCrMo;TiNi; TiMo
	Orthodontic brackets	316L SS; Ti
	Fillings	AgSn(Cu)Hg amalgam; Au
	Restorations	Au-Pt-Pd-Ag; Au-Pt-Cu-Zn
Craniofacial	Plate and screw	316L SS; CoCrMo; Ti; Ti6Al4V
	Cranial plates	316L SS, Ti; TiNi; Ti6Al4V
	Orbit reconstruction	CoCrMo; Ti; TiNi; Ti6Al4V
Otorhinology	Artificial ear drum	316L SS
Gynaecological	Intrauterine devices	Cu; CuAg (Nova T380)

(Ti) titanium, (Al) aluminium, (Pt) platinum, (W) tungsten, (SS) stainless steel, (Ir) iridium, (Co) cobalt, (Cr) chromium, (Mo) molybdenum, (Pt) platinum, (Ni) nickel, (Ag) silver, (Au) gold, (Cu) copper, (Sn) tin.

STAINLESS STEEL

Stainless steel was discovered in 1904 and use in surgical applications began in 1926. Stainless steel is an alloy of iron, carbon and other elements. A minimum of 12 per cent chromium is added to make the steel "stainless" and prevent corrosive attack by the formation of a stable and passive oxide film. Medical-grade stainless steel (316L) is an alloy containing 16 per cent chromium, 10 per cent nickel and 2 per cent molybdenum[39]. Stainless steel is still one of the most used alloys in implants ranging from cardiovascular to otorhinology. Iron, chromium and nickel release have been reported from stainless steel arch bars used for maxillomandibular fixation, however the released amounts were significantly below the average dietary intake[40]. There is little data available on metal release from prosthetic stainless steel implants. Nickel is a common contact allergen but, based on the low release rates of nickel, sensitisation caused by stainless steel is unlikely. Nickel-free implants have been developed. Serum and urine levels of chromium and nickel have been found to be elevated in patients with scoliosis who had undergone spinal instrumentation[41].

TITANIUM

Titanium is a high-strength, highly corrosion resistant, low allergic potential metal commonly used in stainless steels as a stabilising element. Pure titanium and the alloy titanium-aluminium-vanadium (Ti–6Al–4V) are among the most widely used for biomedical applications[42]. Although regarded as a relatively inert metal, accumulation of titanium particles and ions can induce osteolytic cytokines and inhibit osteoblast collagen expression in vitro. Raised serum levels of titanium have been found within synovial fluid, serum and urine of patients after total hip and knee arthroplasty and following instrumented spinal arthrodesis[43-45].

COBALT

Cobalt is used in the production of steel and alloys. Its purpose is to impart a higher melting point, strength and resistance to corrosion. Common surgical alloys include: Co-Cr, Co-Cr-Mo (molybdenum) but tungsten, nickel, iron and titanium are also used. It is an essential metal being required for cobalamin (Vit B12). Cobalt toxicity (cobaltism) can occur from beer additives, industrial exposure or ingestion and may result in neurological, cardiac and endocrine symptoms (Table 2). Arthroprosthetic cobaltism refers toxic manifestations in patients with joint replacements. Cobalt levels higher than 120 nmol/L may indicate joint deterioration but levels can be affected by changes in renal function, environmental or occupation exposure and consumption of Co-containing supplements[46,47].

Table 2. Systemic effects of metal toxicity

Metal	Biological effects
Aluminium	Dialysis encephalopathy and dementia, emotional lability, putative role in neurodegenerative diseases, inhibition of bone remodelling, inhibition of osteoblast and osteoclast activities, hypochromic microcytic anaemia, increased risk ischaemic heart disease.
Cobalt	Polycythemia, dermatitis, hypertriglyceridemia, hypocoagulability, cardiomyopathy, goiter, hypothyroidism, headache, anxiety, peripheral neuropathy, optic nerve atrophy, tinnitus, deafness, tremor, diminished co-ordination, slow cognition, seizure.
Chromium#	Skin ulceration, acute irritative dermatitis, allergic eczematous dermatitis, renal tubular lesions, hepatocellular necrosis, gastritis, enteritis, asthma, lung cancer, septal ulceration and perforation, fetal abnormalities in animal studies, teeth discolouration.
Nickel	Contact allergy, eczema, skin erythema, allergic asthma, carcinogenesis.
Platinum*	Conjunctivitis, urticaria, dermatitis, eczema.
Tantalum	Allergy.
Titanium	Yellow nail syndrome (YNS).
Vanadium	Greenish-black tongue discolouration, polyneuropathy, ototoxicity.

* Metallic platinum is relatively inert. Toxicity from complex platinum salts; (YNS): triad of nail changes, lymphoedema and respiratory tract involvement[67];

Chromium (III) low toxicity. Chromium(VI) readily crosses cell membranes to cause toxicity.

CHROMIUM

There is evidence to suggest that chromium was used by the ancient Egyptians and Qin dynasty in sword production. Chromium (III) appears to be essential for glucose metabolism. Hexavalent Cr(VI) is largely responsible for acute and chronic toxic effects. Chromium is added to alloys to impart corrosion resistance. Accelerated wear of metal-on-metal implants leads to higher levels of chromium in the blood. There is currently no accepted level of chromium in the blood associated with adverse health. The Therapeutic Goods Administration (TGA) recommends that patients with hip pain and metal-on-metal implants have chromium levels measured at least annually and approximately every three months thereafter where metal ions levels continue to increase. Levels higher than 135 nmol/L 18 months after implantation can indicate the implant is beginning to fail. Soft tissue damage around the joint may occur if the implant is not revised[48].

PLATINUM

Medical applications for platinum include anti-cancer drugs, the construction of dental equipment such as crowns, bridges, pins, fillings, and implanted biomedical devices, such as pacemakers and catheters. Its electrical conductivity and ability to fabricate extremely small and complex shapes has seen its use in neuromodulator devices, implantable cardioverter-defibrillators (ICDs), coils and catheters for the treatment of brain aneurysms[49]. The main health effect platinum compounds, excluding the neurotoxicity of the chemotherapeutic agents cisplatinum, carboplatin and oxaliplatin, is sensitisation. Soluble platinum salts induce allergic reactions in which both the respiratory tract and the skin are involved. There is limited human or experimental data on the toxicity or carcinogenicity of platinum compounds[50].

NICKEL

Nickel is a highly toxic metal and is known to cause systemic, immunologic, neurologic, reproductive, developmental and carcinogenic effects. The most common adverse reaction is allergic skin reactions[51]. Nickel concentration has been observed to be elevated from two to six weeks post hip arthroplasty with cobalt-chromium-nickel prosthesis[52].

ALUMINIUM

Aluminium is a suspected neurotoxin and also has been implicated in the pathogenesis of dialysis encephalopathy, osteodystrophy, anaemia and inhibition of bone remodelling. Animal studies also have reported altered cognitive function. Aluminium is added to titanium alloys to improve strength and ductility[53]. Aluminium levels have been found to be elevated in a failed knee arthroplasty from metal-on-metal contact of a Ti–6Al–4V alloy prosthesis and in patients following scoliosis repair[54,55].

VANADIUM

Vanadium (V) is present in almost all-living organisms but its necessity in cellular functions is yet to be established. Hip replacements were initially made from stainless steel but are now mostly contain titanium alloy, the most commonly available being Ti–6Al–4V. Vanadium may be cytotoxic in vivo and produces gastrointestinal distress, fatigue, cardiac palpitation, renal injury and metabolic alterations in experimental animals. Vanadium-free titanium alloys have been developed including Ti-15Mo-5Zr-3Al for cemented and Ti-6Al-2Nb-1Ta-0.8Mo for non-cemented hips[56]. Raised vanadium levels have been found in blood, serum and urine of patients implanted with the titanium alloy Ti–6Al–4V[57]. Vanadium metallosis caused polyneuropathy, ototoxicity, and tongue discolouration in a patient with a ceramic on ceramic hip arthroprosthesis containing a femoral titanium alloy component[58].

NEWER ALLOYS

Concern over biocompatibility and corrosion resistance has lead to the development of new titanium alloys incorporating zirconium (Zr), niobium (Nb), tantalum (Ta), palladium (Pd) and indium (In)[59]. Elevated niobium levels have been detected from Ti-Al-Nb alloys used for scoliosis repair in paediatric patients[60]. Tantalum metallosis has been reported following a failed hip arthroplasty. There is little data on the long-term toxic effects of niobium or tantalum[61].

DIAGNOSIS AND TREATMENT OF METALLOSIS INDUCED METAL TOXICITY

Metallosis has been defined as aseptic fibrosis, local necrosis or loosening of the prosthesis secondary to metallic corrosion and release of wear debris. It has been reported with a wide range of metallic implants including stainless steel, titanium and cobalt-chromium alloys but may also occur with metal on polyethylene joint replacements[62,63]. Diagnosis depends upon clinical history, examination and investigations. Symptoms and signs of metallosis may include pain, grey discolouration of the tissues surrounding the joint, increasing noise from the replacement, a sense of joint instability and effusion although implant loosening, peri-prosthetic fracture, osteonecrosis, infection, tendinitis, impingement and referred pain may cause similar symptoms.

Investigations including serum metal levels, hip aspiration and imaging may be useful. Rising serum cobalt and chromium levels may be an early indicator of implant failure. Cobalt levels in hair, blood, urine and placenta are often elevated in patients with metal-on-metal hip replacements. The diagnosis may be confirmed by the aspiration of dark grey or black synovial fluid[64]. Radiological findings may include misalignment and loss of joint space, suggesting wear or fracture of the prosthesis liner, amorphous densities in the peri-prosthetic tissues and hyperdense rounded images with a higher contour (metal deposits)[65]. Effective treatment involves joint revision surgery to remove metal debris and bone graft areas of osteolysis. Elevated blood levels of cobalt and chromium can persist for at least a year following revision, especially in patients with high levels of exposure[66].

SUMMARY

Metals have a long history of use in medicine. The discovery of new alloys and improvement in metallurgy has expanded both the therapeutic and diagnostic indications for metal-containing implants. Concerns regarding systemic and local metal ion toxicity, most notably metal-on-metal hip replacements containing cobalt and chromium, have resulted in regulatory bodies including the US Food and Drug Administration (FDA), UK Medicines and Health Care Products and Regulatory Authority (MHRA) and Therapeutic Goods Administration (TGA) publishing clinical algorithms to detect potential implant failure and metal toxicity. There is currently no consensus statement outlining the relationship between symptoms, peak metal ion levels or the length of exposure. For other metal implants and newer alloys, little toxicity data exists.

Important pre-operative consideration for the anaesthetist when assessing a patient for surgery who has new neurological, cardiac, thyroid, renal or haematological impairment should include a thorough history, particularly noting the presence of metal implants. If clinical history and examination are insufficient to explain the patient's symptoms and they have a metal prosthesis, then an attempt should be made to identify the type, components and duration of implant insertion. For patients with older implants, known to contain cobalt or chromium, or have clinical features of metallosis, then consideration should be given to a toxicological evaluation to exclude metal toxicity as an underlying cause of the organ impairment.

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Anaphylactic shock under anaesthesia: A reappraisal of the pathophysiology and management

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INTRODUCTION

Almost every day in Australia and New Zealand there will be a case of anaphylaxis during surgery that challenges the attending anaesthetist. By following current management guidelines (http://www.anzaag.com/Mgmt%20Resources.aspx) most will respond to treatment and surgery will be completed. However, there are others that require an escalation in treatment, including CPR, large doses of adrenaline, abandonment of surgery and continuing care in an intensive care environment. Sadly, some of these patients do not survive. It is the treatment of these very sick patients that perhaps raises the most controversy. It is not clear why the cardiovascular depression in some patients is unresponsive to large doses of adrenaline, but various authors express enthusiasm for other alpha agonists or vasopressin, as well as novel agents such as sugammadex in rocuronium allergy. All the information about the proposed benefit of these treatments is based on a few case reports that, in general, are subject to criticism because they lack scientific rigour.

This is an opinion piece that hopefully challenges some of our understanding of the pathophysiology, haemodynamic changes and management of severe anaphylaxis.

PATHOPHYSIOLOGY OF ANAPHYLAXIS

Cross-linking of the high affinity receptor

The syndrome of anaphylaxis can be triggered by a number of different mechanisms. During anaesthesia, the most common – and that which causes the most severe reaction – is mediated by the antibody immunoglobulin E (IgE). Mast cells and basophils are responsible for the release of the chemical mediators, such as histamine, that are responsible for the physiological changes seen during anaphylaxis. Mast cells reside in the tissues and basophils in the circulation. They both express high affinity receptors (FcεRI) on their surfaces. Because of easier isolation, basophils have been studied more intensively. The number of FcεRI varies between 29,000-680,000 per cell in different individuals[1]. A correspondingly variable amount of IgE is bound with a very high affinity ($Kd = 10^{-9} – 10^{-10}$ M)[2] to the FcεRI. The production of receptors by the cell and the stability of the complex are enhanced by an increased concentration of IgE in the circulation. Pholcodine-containing cough suppressants have been shown to dramatically increase the serum IgE levels when experimentally imbibed by patients who have been selected because of previous anaphylactic reactions to neuromuscular blocking agents[3]. This increase in antibodies is most notable for those that recognise substituted ammonia groups present in pholcodine, morphine and suxamethonium, but also to unrelated items such as inhaled aero-allergens. With increasing IgE levels, there is a corresponding increase in FcεRI numbers on mast cells with their complementary bound antibody. Binding of an allergen to adjacent FcεRI/antibody complexes, “cross-linking”, will lead to a sequence of signalling events starting with clustering of the FcεRI/allergen complexes into lipid rafts in the cell membrane, resulting in mediator release from the mast cell or basophil. The mediator release or degranulation is not all or none and even maximal stimulation will only release 10-20 per cent of stored mediators.

A minimum number of cross-linking events, between 100 and 1000, are required for any degree of release, and the lifetime of the cluster is also important[4]. Studies have shown a 30-fold range of sensitivity (number of IgE molecules for 50 per cent of the maximum IgE mediated response) between basophils from different individuals. The optimal release of any mediator in granular form, such as histamine, from an individual cell by a specific allergen is dependent on the amount of specific antibody bound to the FcεRI, the concentration of antigen and the degree of affinity of the IgE for the antigen. This variability in mediator release is evidenced by the severity of the clinical presentation expressed as the grade of anaphylaxis and measured by the mast cell tryptase released into the circulation.

There are a number of unusual characteristics of anaphylaxis caused by neuromuscular-blocking drugs (NMBDs). It is uncommon for small molecular-weight drugs, less than 10,000 daltons, to be allergenic unless bound to a protein, the process of hapten formation. This is not the case with NMBDs, which are relatively small (rocuronium has a molecular weight of 610 daltons) and in which the substituted ammonia groups have been shown to be the complementary allergenic sites[5]. Most anaphylactic events precipitated by a NMBD occur on first exposure, suggesting environmental exposure and sensitisation to substituted ammonia groups in commonly used chemicals such as pholcodine[6], or those used by hairdressers[7].

The requirement for a drug to have a blocking effect at the neuromuscular junction requires a chemical structure with two substituted ammonia groups separated at a distance from 1 to 1.45nm[8]. It is this bivalent structure that makes the molecule ideally structured to bind adjacent FcεRI/antibody complexes on the mast cell.

Because the antibodies in the sensitised individual have not been specifically raised to a single NMBD, but merely recognise the substituted ammonia groups, one would expect all muscle relaxants to behave similarly; however, there is a spectrum of affinity within the members of the group. We therefore see a spectrum of cross-sensitivity that is quite unpredictable. One cannot conclude that a benzylisoquinoline is safe in a patient who has had a reaction caused by a steroidal muscle relaxant and vice versa. In a setting of a supramaximal dose of the intravenously administered antigen, the clinical response is dictated by a genetically determined "cellular sensitivity"[9] that may represent multiple other types of receptors that can influence the response, and the affinity of the NMBD for the antibody that determines the effectiveness of cross-linking and clustering.

MEDIATOR RELEASE AND TERMINATION OF RESPONSE

With so many variables influencing the amount and type of mediator release, it is not surprising that the clinical response is so variable. After full activation of the FcεRI and maintenance of the receptor complex for as little as 100 seconds, there is transduction of intracellular signals that lead to the release of pre-synthesised mediators such as histamine, serotonin, various proteases (for example, tryptases and carboxypeptidases) and other enzymes contained in granular stores[10]. These, particularly histamine, are responsible for the immediate cardiovascular, respiratory and skin changes that occur at the onset of anaphylaxis. Phospholipid metabolites are the second group of mediators, generated as a consequence of the release of phospholipases A2 – such as platelet-activating factor (PAF) and the eicosanoids – PGD2, LTC4, and LTB4 that can each have physiological consequences, such as bronchospasm and local or generalised angioedema. Enhanced gene expression leads to the production of the third group of mediators, the cytokines and chemokines, which are responsible for cell signalling and chemotaxis[11]. The physiological responses from the complex interaction of these multiple mediators with their individual receptors may vary in duration, intensity and clinical features. Under anaesthesia, even severe anaphylaxis associated with profound hypotension usually resolves by 20 minutes of onset (article in preparation).

FcεRI engagement also generates negative intracellular signals that limit the duration and intensity of the release process. Endocytosis of the activated antigen-antibody- FcεRI complex occurs, removing them from the cell surface and preventing further cellular interactions. This results in acute desensitisation of the mast cell to the antigen. After internalisation of the activated complex, some of the FcεRI are bound to regulatory proteins called ubiquitins, a necessary step before degradation by liposomal pathways. Not all FcεRI are degraded and some are returned to the cell surface after removal of antigen/antibody complex by "sorting" and "recycling" endosomes[12].

Although there is in-vitro evidence that disengagement of an antigen from the FcεRI can terminate downstream intracellular signalling, there is no evidence that mediator release or the time course of the physiological derangement of anaphylaxis can be attenuated by the discontinuation of the causative allergen, although this is a common recommendation. In the case of disengagement of rocuronium by sugammadex, for any possibility of prevention of downstream signalling events, it would have to occur before the endocytic process has occurred with disappearance of the complex from the surface. This process is complete in minutes and thus, in most clinical circumstances, sugammadex is being administered after the mast cell has already rendered itself unresponsive to rocuronium. The validity of this concept of acute desensitisation of the mast cell is supported by the fact that this is not the only situation in which it occurs and is commonly used with clinical benefit.

It is possible to acutely desensitise individuals who are allergic to antibiotics and other drugs without triggering anaphylaxis by administering rapidly escalating doses of the required drug over three to four hours – "rapid drug desensitisation". Mast cells are rendered hypo-responsive by this process and specific skin test reactivity is abolished, enabling a full course of the drug to be administered without allergic manifestations. The desensitised state remains indefinitely, as long as the course is maintained. Any interval significantly longer than the half-life of the drug will lead to the return of the sensitised state. A number of mechanisms have been proposed to explain this phenomenon such as hapten inhibition, consumption of IgE, mediator depletion, internalisation of FcεRI and depletion of activating signal transduction components, but the cause remains undetermined[13]. In the case of acute anaphylaxis caused by rocuronium, it is likely that the mast cell has been rendered inactive to further degranulation without the presence of sugammadex, and even further doses of rocuronium would be unlikely to induce further mediator release. The desensitisation process is specific to the original drug to which the cell is exposed; therefore, challenge with another antigen to which the cell is sensitised will lead to further mediator release. Thus, in the patient having an anaphylactic episode caused by rocuronium, it is theoretically less risky to readminister rocuronium to maintain muscle relaxation than it is to administer a different NMBD, although we would strongly recommend that this hypothesis is not tested. In reality, if rocuronium is thought to be the cause of the anaphylaxis, it is recommended no further muscle relaxant be administered until the patient has been skin-tested four weeks after the event. In some circumstances this is impossible and our data suggests the muscle relaxant least likely to cross react is *cis*-atracurium.

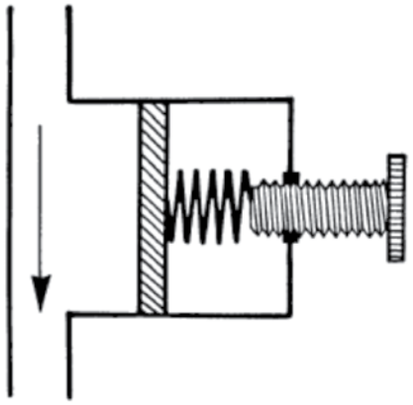
THE HAEMODYNAMIC RESPONSE

In a setting of patient heterogeneity and complex mediator release mechanisms, it is not surprising that the physiological response is unpredictable, in both the individual organ and in overall severity. It has been pointed out by Brown that extrapolation of findings in one form of anaphylaxis, such as insect sting envenomation, to other forms should be done with caution[14]. With food allergy in the asthmatic subject, allergen ingestion may lead to severe bronchospasm as the sole feature, which may be prolonged, but with no accompanying hypotension. This is not common under anaesthesia, and we should be cautious of basing management protocols on anything other than the experience in the operating theatre. Fisher[15] from clinical observations of anaphylaxis under anaesthesia in 227 patients was able to draw a number of conclusions. The most common manifestation, occurring in 205 patients, was cardiovascular depression characterised by profound hypotension, sinus tachycardia, loss into the interstitial space of up to 35 per cent of blood volume and low cardiac filling pressures. It should be added that mild increases in airway pressure are common, but severe bronchospasm is rare and usually only seen in patients with a history of increased airway responsiveness such as in asthma, smoking and other conditions associated with chronic airflow limitation. There are rare reports of bronchospasm being the only presenting feature. Arrhythmias and cardiac failure were not a problem in patients without pre-existing cardiac disease. These features are in keeping with our own experience. It is important to understand the pathophysiological processes responsible for the cardiovascular depression. Moss *et al*, in a seminal case report[16], showed that the hypotension, tachycardia and fall in systemic vascular resistance in a patient experiencing an anaphylactic reaction under anaesthesia caused by suxamethonium paralleled the blood level of histamine. Natural catecholamine levels rose dramatically and resolution occurred without adrenaline administration, but with volume replacement alone in 20 minutes – the time required for the histamine levels to return to normal. Although simplistic, it is not unreasonable to regard histamine as the principle mediator released that is responsible for the initial cardiovascular effects. There is a large body of knowledge about histamine, its receptors and the physiological response it engenders in multiple animal models that are not particularly useful in interpreting the anaphylactic response in humans because of marked species differences. Histamine in dogs causes generalised arteriolar vasodilatation and sequestration of blood in the limbs, but most importantly constriction of the hepatic venous bed leading to massive splanchnic pooling of blood – the principle cause of death in anaphylaxis in these animals[17]. In rats, histamine causes a dose-dependent dilatation of arterioles, pre-capillary sphincters and muscular venules[18]. In man, resting plasma histamine levels in one study were 0.62 ± 0.52 ng/ml and after infusion of histamine to achieve blood levels around 2.5 ng/ml, there was a significant flush and headache, and a 30 per cent increase in heart rate and pulse pressure[19]. Lorenz investigated the histamine-releasing properties of Propanidid in the 1970s using 140 healthy volunteers[20]. From a mean baseline of 1ng/ml, a consistent rise to a mean of 3.5ng/ml was found associated with an immediate tachycardia that preceded the histamine rise and moderate hypotension and increase in stomach acid secretion that paralleled the histamine rise. Four subjects developed anaphylaxis that ranged in severity from circulatory arrest to mild hypotension, tachycardia and erythema. The increase in plasma histamine was in accordance with the severity and duration of the reaction; in the worst case, plasma levels were greater than 90ng/ml. It is feasible that cessation of the circulation in severe reactions could lead to a delay in the normally rapid breakdown of histamine, thus prolonging its effect. In three patients, resolution of the tachycardia occurred in less than 30 minutes, but took over 90 minutes in the most severe reaction.

More recently, Clarke et al. shed some light on the circulatory changes in man in reporting a case of anaphylaxis triggered by a succinylated gelatin during cardiopulmonary bypass[21]. A marked fall in systemic vascular resistance and blood pressure was associated with almost complete failure of venous return to the venous reservoir which, to prevent critical depletion, required the addition of 3680ml to maintain an adequate output from the cardiopulmonary bypass pump. This case demonstrates that hypotension occurs not only as a result of a fall in systemic vascular resistance, but also because of failure of venous return due to both interstitial loss and sequestration of blood in the peripheral venous systems. It also demonstrates that vasopressors, essential to increase systemic vascular resistance, will be ineffectual on their own unless cardiac output is maintained by volume repletion. Having studied details of 214 deaths associated with anaphylaxis, Pumphrey in 2003 reported a striking pattern of sudden death after a change to an upright posture in 10 of 38 anaphylactic shock deaths that occurred outside hospital[22]. He described a mechanism based on lack of venous return to explain this phenomenon. He went on to express the importance of the recumbent position, with legs raised, in first aid of shocked patients and explained why adrenaline can be ineffective in these patients. The benefit of posture has also been echoed by Brown[23] in the emergency medicine setting, as has the benefit of the pneumatic anti-shock garment, or MAST suit[24]. The importance of venous capacitance has largely been forgotten or ignored in discussions of the circulatory changes during anaphylactic shock, although the relationship between venous capacitance and cardiac output are well described[25]. The veins are not merely conduits to carry blood back to the heart, but by their compliant nature can contain variable volumes of blood. Sympathetic stimulus will lead to a reduction of venous compliance, an increase in mean circulatory pressure and mobilisation of blood with an increase in venous return, right ventricular end diastolic pressure and volume; in effect, when the veins constrict, the heart expands and vice versa.

Figure 1. A mechanical analogue of the variable-capacitance function of the veins.

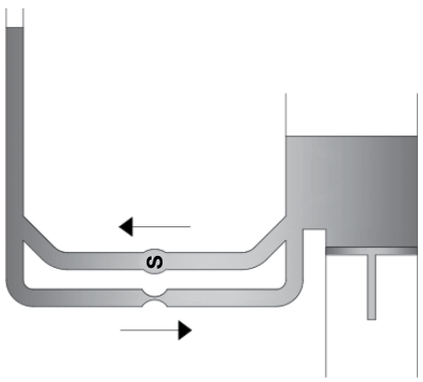
The position of the piston determines venous capacitance. Outward movement of the screw represents the condition during anaphylaxis, in which a large increase in capacitance occurs with a consequent reduction in venous return to the heart (Modified from Gow[26] with permission of the American Physiological Society).



The relationship between capacitance and right atrial pressure is elegantly and simply demonstrated by Gow's mechanical screw analogue shown in Figure 1[26]. In anaphylactic shock a massive increase in capacitance leads to failure of venous return. Figure 2A shows a hydraulic model of the normal circulation with the capacitance of the venous system alterable by a piston. In times of increase demand such as the onset of exercise sympathetic stimulation leads to a decrease in compliance and maintenance of venous return and cardiac filling. During severe anaphylaxis, as in Figure 2B, dilatation of the venous system occurs, demonstrated as a marked fall in the piston, leading to pooling in the peripheral circulation and failure of venous return. This effect is enhanced by the loss of volume from the intravascular to the interstitial compartment.

Figure 2A. A hydraulic model of the normal circulation modified from Tyberg, JV25.

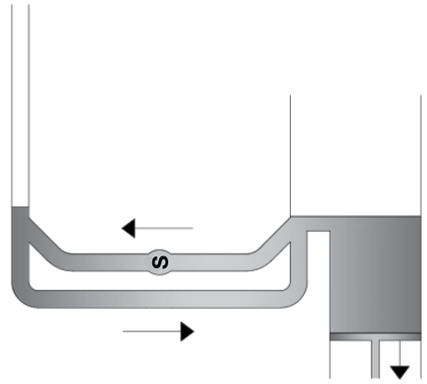
The heart is represented by a pump that moves blood from a low-pressure, high-compliance venous reservoir to a high-pressure, low-compliance arterial reservoir. Blood flows back to the heart from the high pressure arterial system through a resistance (systemic vascular resistance) to the venous reservoir. The variable capacitance of the venous reservoir represented by movement of the piston is the principal variable on the venous side of the circulation, determining the volume of blood available for cardiac filling.



Normal condition

Figure 2B. Representation of a severe allergic reaction. Systemic arteries and veins dilate.

The downward movement of the piston represents the dramatic increase in capacitance of the highly compliant venous system. Blood is sequestered in portal and systemic veins, critically reducing cardiac filling. Volume is also lost from the circulation into the interstitial space. Systemic arteriolar dilatation causes a fall in systemic vascular resistance which, combined with the severely compromised cardiac output, leads to severe hypotension.



Anaphylaxis

THE TREATMENT OF ANAPHYLAXIS

The management of anaphylaxis is represented pictorially in Figure 2C. Endogenous catecholamine release at the onset of anaphylaxis is massive[16]. The use of echocardiography during anaphylaxis characteristically shows a hyperdynamic but empty heart[21,27]. This would suggest that, in most cases, there is not a primary pump problem, although in rare circumstances acute coronary syndromes have been described that include stress cardiomyopathy (Takotsubo and reverse Takotsubo syndrome), which may more commonly be caused by the adrenaline used for treatment rather than endogenous catecholamines, or allergic myocardial infarction (Kounis syndrome). The inotropic and chronotropic effects of adrenaline – endogenous and exogenous – on the heart will have little beneficial effect on cardiac output, and thus blood pressure, if the heart is empty and until venous return is restored.

Adrenaline is a potent alpha-agonist in large doses, possibly offset by a beta2 agonist effect of vasodilatation in skeletal muscle. What overall effect this has on resistance and blood volume in skeletal muscle affected by neuromuscular blocking drugs and the mediators of anaphylaxis is unknown. The use of alpha agonists such as metaraminol, methoxamine[28] or vasopressin[29] has been recommended in anaphylactic shock that is unresponsive to adrenaline and fluid replacement. Although the mechanism of the beneficial effect is unclear, it is proposed that the principle effect is on the peripheral arterial circulation, increasing systemic vascular resistance and diastolic pressure. An attractive alternative explanation is a reduction in venous capacitance with a resultant increase in cardiac filling, but there is little evidence that vasopressin or alpha-agonists have a significant effect on venous smooth muscle.

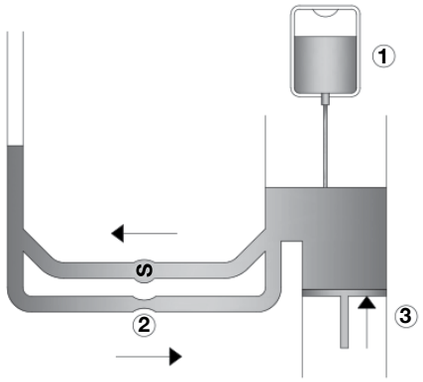
Although fluid replacement is recognised as essential, and often successful without other intervention, it is not always immediately possible because of inadequate venous access. Often small-bore central venous lines are inserted in preference to large-bore peripheral cannulae, and the focus of treatment is usually adrenaline. In a rat model, adrenaline alone was shown to be less effective than with concurrent volume replacement, and colloid was more effective than normal or hypertonic saline[30]. Although the use of the Trendelenberg position has not found favour in other forms of shock, in the distributive shock seen in anaphylaxis it would aid in venous return, as would the simple measure of elevating the lower limbs. The early use of transoesophageal echocardiography, if available, is useful in determining the contractility and filling of the heart.

Sugammadex will reverse muscle relaxation and increase muscle tone, which will compress intramuscular and intra-abdominal vessels, increasing venous return and translocating blood into the heart. The recommendation to minimise all anaesthetic drugs during shock may lead to patient arousal and movement exaggerating this effect. This is analogous to the onset of exercise, when muscle activity and a concomitant sympathetically mediated decrease in venous compliance increase venous return by as much as 500ml[31]. It has been suggested that early administration of sugammadex in large doses is more likely to be beneficial by minimising the immunological cascade[32]. In a skin model of anaphylaxis in individuals sensitised to rocuronium, an equivalent to 240mg.kg^{-1} was ineffective in modifying the flare and wheal response to rocuronium[33]. Administering a large dose of sugammadex presumes that the diagnosis of anaphylaxis is correct and that rocuronium is the trigger, which is not always the case. There are cases in which sugammadex has been reported to be of benefit when the anaphylaxis has subsequently been proven to have been caused by an antibiotic.

If this improvement can be substantiated, it would rule out an immunological mechanism. With conventional treatment, anaphylaxis is often rapidly curtailed and the surgical procedure completed. Administration of sugammadex may preclude this option. If the sugammadex is ineffectual and the haemodynamic disturbance unresponsive to treatment, a dilemma can arise if further muscle relaxation is required.

Figure 2C. Adrenaline and volume replacement are the mainstays of treatment of hypotension.

Systemic vascular resistance and both cardiac contractility and rate are increased. This will have no beneficial effect unless volume replacement and decreased venous capacitance, represented by upward movement of the piston, have improved venous return and cardiac filling.



Treatment of anaphylaxis

CONCLUSION

The importance of venous capacitance and its regulatory role on circulatory haemodynamics are important concepts to understand in the management of severe anaphylaxis. Increased focus on this aspect of treatment may improve the outcome in the most severe cases that are unresponsive to adrenaline. If there is one area for improvement in the management of anaphylaxis in the operating theatre, it would be the more aggressive use of volume, which would be simplified by immediate insertion of large-bore peripheral or central cannulae in preference to a conventional central line.

We also propose that in the unlikely event that there is any beneficial effect of sugammadex on the circulation in intraoperative anaphylaxis, it is not an immunological but a circulatory response secondary to improved cardiac filling.

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Pulmonary hypertension: An overview for the "non-cardiac" anaesthetist

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INTRODUCTION

For many anaesthetists, providing safe anaesthesia for patients with known pulmonary hypertension (PH) is a daunting prospect. Mortality is very high with observational reviews quoting 10-15 per cent[1-4]. Perioperative morbidity approaches 40 per cent; this includes arrhythmias, respiratory and right ventricular (RV) failure[3].

This review is aimed at the generalist anaesthetist who may see these patients infrequently and those preparing for the final examination. The aims are to improve the understanding of the aetiology, classification and pathophysiology of pulmonary hypertension, the therapies available, and the principals of providing safe anaesthesia.

PULMONARY HYPERTENSION

Pulmonary hypertension (PH) is defined according to mean pulmonary artery pressure (mPAP) at rest as assessed by right heart catheterisation (RHC)[5]. The resistance to flow though the pulmonary vascular bed is most simply defined using Ohm's law. The pressure drop across the system divided by flow equals the resistance. This is an oversimplification but is adequate for most clinical scenarios.

RHC is the gold standard for assessment but is an invasive procedure. It provides information on right heart and pulmonary artery pressures, cardiac output and index, and pulmonary artery occlusion pressure (as a surrogate for left ventricular end diastolic pressure).

It must be noted, just as in left heart failure, that a failing right heart may be unable to generate high pressures. Hence, presence of a low pulmonary artery pressure does not guarantee a normal right heart and pulmonary vasculature, it may be a sign of severely declining function and the function of the right heart must be taken into consideration with the pressures.

Table 1. Normal and abnormal values

	Normal	Mild PH	Moderate PH	Severe PH
RAP	2-5			
mPAP	12-15	25-40	40-55	>55
PAPs/d	25/7			>2/3 systemic systolic
LAP	6-10			
CI	>2.2			
PVR	<250			

PH pulmonary hypertension, RAP right atrial pressure, mPAP mean pulmonary artery pressure, PAPs/d pulmonary artery pressure systolic/diastolic, LAP left atrial pressure, CI cardiac index L/min/m^2, PVR pulmonary vascular resistance dynes/sec/cm^5. All pressures mmHg.

Transthoracic echocardiographic criteria

Transthoracic echocardiography (TTE) criteria provide a non-invasive assessment of right and left heart function, valve function and morphology. From Doppler interrogation of the velocity of any tricuspid regurgitation jet, a modified Bernoulli equation can be used to estimate right ventricular systolic pressure (RVSP) (not mean pressure, systolic). RVSP = right atrial pressure + (tricuspid regurgitation jet $velocity^2$) x 4.

Table 2. Echocardiographic features suggestive of pulmonary hypertension

Pulmonary hypertension
Unlikely – TR jet velocity ≤ 2.8m/s, PA systolic ≤ 36mmHg and no echo features suggestive of PH
Possible – TR jet velocity ≤ 2.8m/s, PA systolic ≤ 36mmHg but presence of echo features suggestive of PH OR TR jet velocity 2.9-3.4m/s, PA systolic pressure 37-50mmHg, with or without echo features suggestive of PH
Likely – TR jet velocity > 3.4m/s, PA systolic pressure >50mmHg with or without echo features suggestive of PH

PA pulmonary artery, PH pulmonary hypertension, TR tricuspid regurgitation. Adapted from Galie et al. Eur Heart J. 2009 30: 2493-537[5].

Classification of pulmonary hypertension

PH was considered either primary or secondary; however, the World Health Organization (WHO) has reclassified it[5]. Clinical conditions with PH are separated into five groups according to pathophysiological and therapeutic characteristics. Despite comparable elevations of pulmonary artery pressure (PAP) and pulmonary vascular resistance (PVR) in the different clinical groups, it is important to know the underlying cause of PH in order to optimise perioperatively. For instance, pulmonary arterial hypertension may require sildenafil, a patient with mitral stenosis may require a balloon valvuloplasty or mitral valve replacement, and a patient with obstructive sleep apnoea may require continuous positive airway pressure therapy. Furthermore, different WHO groups have different degrees of risk.

Table 3. WHO classification of pulmonary hypertension

1. Pulmonary arterial hypertension
   - 1.1 Idiopathic PAH
   - 1.2 Heritable PAH
   - 1.3 Drug and toxin induced
   - 1.4 Associated with:
     - 1.4.1 Connective tissue disease
     - 1.4.2 HIV infection
     - 1.4.3 Portal hypertension
     - 1.4.4 Congenital heart diseases
     - 1.4.5 Schistosomiasis, pulmonary veno-occlusive disease and/or pulmonary capillary haemangiomatosis, persistent pulmonary hypertension of the newborn
2. Pulmonary hypertension due to left heart disease
3. Pulmonary hypertension due to lung diseases and/or hypoxia
4. Chronic thromboembolic pulmonary hypertension (CTEPH)
5. Pulmonary hypertension with unclear multifactorial mechanisms

Adapted from Galie et al. Eur Heart J. 2009 30: 2493-537[5].

Pulmonary vascular resistance (PVR)

The right ventricular output (approximately equal to left heart output) flows through the pulmonary vascular bed. This has a surface area of 50 to 100m^2. Despite flowing though a single organ, the pressures are approximately one sixth that of the same output flowing through the entire systemic vasculature. Left heart output can rise fivefold to 25L/min during exercise and pulmonary vasculature flow increases in parallel. Despite this massive increase in flow, pulmonary pressures do not rise as resistance remains constant. This is for a number of reasons that will be discussed. Beyond anaerobic threshold, there is an increase in resistance thought due to intense sympathetic vasoconstriction, acidosis and a falling mixed venous oxygen concentration.

Multiple factors influence PVR; they can be broadly classified as mechanical or neurohumoral6. The pulmonary vasculature receives dense innervation from the sympathetic nervous system. This contains alpha1 receptors causing noradrenaline (NA)-mediated vasoconstriction and beta2 receptors causing adrenaline-mediated vasodilation. There is also a cholinergic system carried through the vagus nerves, muscarinic receptors increase nitric oxide (NO) causing vasodilatation.

Humoral factors including prostaglandins, prostacyclins, endothelin, amines (histamine, serotonin) can also influence PVR. Hypoxic pulmonary vasoconstriction (HPVC) is a reflex locally mediated within the pulmonary vasculature. It takes flow away from poorly ventilated areas and improves flow to well-ventilated areas. Within five minutes of a lobes obstruction, HPVC can decrease the blood flow by 50 per cent. The exact mechanism is unclear, it likely involves NO inhibition, possibly cycloxygenase inhibition and increased endothelin. Chronic hypoxia leads to arteriolar muscular hyperplasia and chronically elevated pulmonary arterial resistance and pressure. Hypercarbia causes pulmonary vasoconstriction, hypocarbia and alkalosis leads to dilation and abolition of the HPVC response.

The pulmonary vasculature being intimately related to the bronchial tree and alveolar network is directly affected by lung expansion (mechanical effects). PVR is at its lowest at functional residual capacity (FRC). PVR rises with full inspiration (capillary stretch) and with full expiration (collapse of extra alveolar vessels). Plotting lung volume against PVR shows a parabolic function, the lowest point of PVR being FRC.

Hydrostatic forces also affect pulmonary flow. As cardiac output rises, PA pressure may rise, however it causes recruitment of closed capillary beds, hence the total cross-sectional area available rises and PVR remains the same or falls. Distension plays a lesser role in increasing pulmonary blood flow. Should pulmonary flow remain excessively elevated for a prolonged period, such as systemic to pulmonary shunting (for example, patent ductus, atrial or ventricular septal defect – ASD or VSD), arteriolar smooth muscle becomes hyperplastic. This will eventually lead to a fixed rise in PVR that is poorly responsive to pulmonary vasodilator therapy. Once PVR exceeds systemic vascular resistance (SVR), flow across the shunt reverses. In the case of an ASD, flow will no longer be from the left to right atrium but right to left, allowing venous blood to perfuse the systemic circulation. This shunt reversal and systemic desaturation is known as Eisenmenger's syndrome. By the time this happens, pulmonary pressures have typically exceeded systemic.

Right ventricular function

The interventricular septum (IVS) lies between right and left ventricles. Normally it forms a crescent shape concave to the left side moving to the centre of the LV donut during systole.

The normal wall thickness of the RV free wall in end diastole is 5mm, thin and easily distensible to allow easy filling from the low-pressure venous circulation. LV thickness is twice this or more.

In contrast to the LV, the RV is a low pressure, low resistance pump; it is not suited to sudden rises in pulmonary vascular resistance[7]. Acute rises in PVR result in rapid RV failure with dilation and bradycardia. Patients with chronic elevations of PVR may develop RV hypertrophy, which allows them to generate supra systemic pulmonary pressures. RV hypertrophy leads to RV stiffness (diastolic dysfunction), this results in elevated filling pressures (reflected in an elevated CVP) and atrial systole becomes more important in ventricular filling.

Intermittent positive pressure ventilation (IPPV) may have profound effects on RV performance and cardiac output. IPPV impedes venous return and right atrial filling causing an immediate fall in RV output. This may happen despite only small intra-thoracic pressure changes. In the presence of moderate to severe RV impairment this effect is amplified. IPPV may increase PVR by direct small vessel compression and a reduction in FRC will also contribute to their collapse.

The concept of ventricular interdependence describes the synergistic relationship between the RV and LV. Despite considering each of the pumps separately from performance aspects, they are intimately related and reliant upon each other. Two factors are key in this relationship, the pericardial space in which the heart lies and the shared fibres of the IVS.

The heart is constrained in a non-compliant sack, the pericardium. Should the right heart acutely dilate, the left heart must shrink.

With progression of PH, the IVS becomes concave to the right in systole rather than to the left. This septal dyskinesis (moving to the right during systole rather than the left) causes worsening LV function as a direct mechanical effect with a fall in cardiac output[7]. The septal dyskineses also affects the tricuspid valves' septal leaflet due to attachment of the subvalvular apparatus. Also, with progressive pressure overload of the RV, the tricuspid annulus begins to dilate. Both of these factors contribute to progressive TR. The TR volume will affect venous flow and create flow reversal in vena cavae, contributing to hepatic congestion and reduced renal perfusion pressure. Slow heart rates prolong diastole, increasing the regurgitant volume. Mild tachycardia can reduce the time for regurgitation (and improve forward flow) and reduces distension by shortening filling time. This may be advantageous for reducing tricuspid annular dilation (and TR) and wall stress.

Coronary blood flow

As pulmonary hypertension progresses, RV muscle mass increases threefold or more due to hypertrophy[8]. Right ventricular wall strain becomes similar to that of the left and may exceed it. In this situation, right coronary flow takes on a left-sided flow dynamic, that is, flow in diastole only[8].

This may be inadequate oxygen for the RV with an increased workload and muscle mass. In severe pulmonary hypertension it is imperative to maintain SVR to ensure the right coronary flow is maintained by adequate aortic root pressure. If the patient develops systemic hypotension, right coronary flow will stop, the RV becomes ischaemic, function falls affecting both LV mechanics (because of septal shift) and also LV filling so LV output and hence root pressure fall even further, a downward spiral. The intra aortic balloon pump (IABP) has demonstrated significant improvements in survival in acute right heart failure post cardiac surgery, probably due to improving right coronary flow oxygen delivery to the myocardium[9].

PRE-OPERATIVE EVALUATION

In idiopathic or familial PH, presentation may be non-specific. Symptomatic patients may complain of dyspnoea on exertion and chest pain, due to right heart ischaemia. Syncope may occur but is often a late sign heralding a severe situation. Rarely, patients may have hoarseness from left main pulmonary artery enlargement and left recurrent laryngeal nerve stretch[10]. In types two to five, other symptoms may be apparent from the primary condition causing the PH. Haemoptysis is uncommon.

The patient should be examined from a multi-system approach looking at primary and secondary effects. They may be hypotensive, partly from low cardiac output, but also as a consequence of medical therapy. Pulse oximetry may show hypoxia, this may worsen with exercise due to low output, V/Q mismatching or intracardiac shunts. The jugular venous pulse may be elevated and rise abnormally with inspiration. As the RV dilates, TR may cause a prominent V wave. The praecordium may demonstrate an RV heave and a loud second heart sound with increased splitting. Signs of congenital heart disease should be sought, cyanosis, clubbing and previous cardiothoracic surgery. Hepatomegaly, ascites and peripheral oedema are signs of hepatic congestion. Some patients may have had a pacemaker or automated implanted cardiac defibrillator (AICD). They may have long-term central venous catheters for prostacyclin delivery.

Echocardiography is a highly sensitive tool for the diagnosis of PH. It provides information on causes (such as CHD and left-sided heart disease) and on the heart's response to elevated pulmonary pressures. An RV that is compensating for increased afterload may generate a mean PAP of 60mmHg, however with failure this falls and should not be mistaken as a less severe situation, the pressure should be interpreted in the context of RV function and trends. Imaging of RV function will help in this distinction. The complex mechanics of the RV make echo assessment less robust than LV assessment. Tricuspid annular plane systolic excursion (TAPSE) measures the distance the tricuspid annulus moves during systole, >15mm is considered normal; TAPSE decreases as RV function declines, <18mm being associated with worsening outcomes in the context of PH[11]. Pressure overload will cause flattening of the IVS throughout the cardiac cycle, becoming concave to the left when severe.

The tricuspid regurgitation jet velocity is indicative of pulmonary pressures. TTE will also describe the size, dilation and function of the RV.

Cardiac MRI is excellent for RV assessment; it has the ability to calculate accurate volumes and ejection/regurgitant fractions. It remains a highly specialised study and requires skill in interpretation. It will not be discussed further here. Presence of an AICD contraindicates MRI scanning.

Pulmonary function tests may demonstrate underlying intrinsic lung disease, restrictive or obstructive patterns may be seen.

The six-minute walk test is a useful non-invasive test that correlates well with maximal oxygen uptake (VO_2max). A distance walked less than 600 metres correlates with a VO_2max of 15ml/kg/min and less than 300 metres is associated with increased morbidity and mortality.

Blood sampling may demonstrate polycythaemia in those with hypoxaemia, hypercapnoea and compensatory changes. Hypoxaemia may be present due to intrinsic lung disease and left-sided heart disease (for example, mitral regurgitation) causing pulmonary venous pressure elevation and increased alveolar water. The low cardiac output due to RV impairment causes reduced oxygen delivery to the body. This causes a decrease in the mixed venous oxygen saturation, which contributes to systemic desaturation and hypoxaemia. Should the patient have an intra-cardiac right to left shunt such as an ASD, this will also cause desaturation. Sampling before sedation can be a useful indicator of where the chronically ill patient "lives" and what targets are reasonable intra and post-operatively.

A number of factors have been associated with worse outcomes in pulmonary hypertension. These are summarised in Table 4.

Table 4. Prognostic variables in pulmonary hypertension

Determinants of Risk	Lower risk/good prognosis	Higher risk/worse prognosis
Clinical signs RV failure	No	Yes
Progression of symptoms	Slow	Fast
Syncope	No	Yes
WHO PH functional class	I or II	IV
6MWT distance	>500m	<300m
VO_2max	>15ml/kg/min	<12ml/kg/min
Echo assessment	Minimal RV dysfunction, TAPSE >20mm	Pericardial effusion, RV dilation/dysfunction, RA enlargement, TAPSE <15mm
RHC	RAP<8mmHg, CI>2.5 L/min/m^2	RAP>15mmHg, CI<2.0 L/min/m^2
BNP	Minimal change	Significant elevation

RV right ventricle, 6MWT six-minute walk test, VO_2max derived from cardiopulmonary exercise testing, RA right atrium, RAP right atrial pressure, TAPSE tricuspid annular plane systolic excursion, BNP brain natriuretic peptide. WHO PH functional class – class I asymptomatic, class II dyspnoea chest pain or near syncope with ordinary physical activity, class III marked limitation in activity with chest pain, dyspnoea or near syncope but comfortable at rest, class IV all symptoms present at rest and worsen with any activity. Adapted from Galie et al. Eur Heart J. 2009 30: 2493-537[5].

Pharmacotherapeutic considerations

Patients may be receiving treatment for the cause of PH, such as anti-retrovirals, steroids and immunosupressives. They may be anticoagulated due to a thrombophilic state, atrial fibrillation, presence of a caval filter or low cardiac output. Emergency surgery may require use of prothrombin complex concentrates, which can rapidly reverse warfarin without the large volumes required of fresh frozen plasma that may overload the RV.

Diuretics are used to reduce renal and hepatic congestion, but excessive use may reduce RV and LV preload. Patients may be on continuous home-oxygen therapy.

Once patients are established functional class II or worse, depending on their WHO PH classification, they are managed with advanced agents aimed at reducing PVR.

These drugs can be classed as endothelin receptor antagonists (ERAs), phosphodiesterase type 5 inhibitors (PDE5i), prostacyclin analogues and soluble guanylate cyclase stimulants (sGCs). None should be interrupted in the perioperative period.

Prostacyclin is continuously delivered by PICC due to a very short half life. Brief interruption can lead to profound rises in PVR and death.

ANAESTHETIC AND PROCEDURAL MANAGEMENT

A basic premise that fits many cardio pulmonary diseases requiring anaesthesia is "keep them where they live", meaning that safe haemodynamic and metabolic targets are those present in the awake, non-sedated patient.

Whatever technique is chosen, two golden rules should be followed: maintain RV coronary perfusion (use arterial line and pressor) and avoid/prevent rises in PVR.

Spinal anaesthesia

This may cause rapid and sometimes unpredictable changes in SVR and preload and cause dangerously unstable haemodynamics so is not recommended.

Epidural anaesthesia

Slowly titrated block level in those with intact coagulation remains a very useful and safe tool, but invasive pressure monitoring is suggested.

Limb and plexus blocks

Barring the contraindications of anticoagulation and anti platelet use, limb or plexus blocks may prove excellent techniques where appropriate. The effects of diaphragmatic paralysis though should be considered, as it may be tolerated very poorly in those with a low cardio respiratory reserve.

Procedural sedation

Monitored sedation may pose higher risk than general anaesthesia. Sedative agents can cause reduced minute ventilation and airway obstruction leading to hypercapnoea, hypoxia and respiratory acidosis. Cardiovascular effects of dexmedetomidine and remifentanil include bradycardia and hypotension, both undesirable. Agitation, disorientation and restlessness can be hard to control. Unplanned conversion to general anaesthesia may increase instability and reduce the control over the patient's physiology.

General anaesthesia

Where general anaesthesia is necessary, key points include:

- Avoid sympathetic surges – adequate sympathetic nervous system blunting for laryngoscopy/intubation/extubation but maintain SVR and coronary perfusion pressure.
- Preventing shivering. Judicious use of forced air warmers from the pre-op bay to recovery, warm the operating room prior to patient entry.
- Avoid hypoxia.
- Avoid hypercapnoea, adequate bag mask ventilation and minute ventilation.
- When beginning positive pressure ventilation, the impairment to venous return may cause severe hypotension.
- Adequate pain relief in the post-operative period to avoid inadequate respiration and splinting.
- Venous thromboembolism prophylaxis.

Monitoring should always include invasive arterial pressure monitoring. If long procedures or fluid shifts are anticipated, or major body-cavity surgery is planned, a central venous catheter (CVC) is useful. This may be necessary pre-induction to allow inotropes or pressor to be infused during the high-risk period of induction. Anxiety should also be managed, it may raise sympathetic tone. AICD deactivation and application of external defibrillator pads may be required.

In some cases, continuous trans-oesophageal echocardiography may be beneficial. Pulmonary artery catheters (PAC) are less commonly used since several studies failed to validate their utility and demonstrated increased complications[12]. However, in this patient group they provide valuable information to those familiar with their use and insertion. The incidence of arrhythmias with PAC usage is higher in the PH population and the arrhythmias will be poorly tolerated. The presence of severe TR will make cardiac output measurement inaccurate[13].

Induction agents should be carefully considered. Propofol is very effective in preventing a pressor response to laryngoscopy, but may produce systemic hypotension leading to a downward spiral due to failed right coronary perfusion.

Where available, etomidate potentially offers a favourable haemodynamic profile. However, it may be preferable to avoid its impact upon the adrenal access in the critically ill[14].

Ketamine provides excellent haemodynamic stability at induction doses of 2-3mg/kg without impairing SVR or changing PVR though conflicting studies have caused confusion regarding the effects of ketamine on pulmonary pressures[15]. The classic cardiac induction, heavy on fentanyl and midazolam, gives good haemodynamic stability with little effect on PVR, SVR or cardiac contractility. It significantly reduces sympathetic nervous system tone, which the patient may be relying upon, and is not suited to rapid emergence requiring prolonged ventilation.

The circulation time of drugs will be slow, when titrating drugs to a response, small doses with time to achieve effect is the key.

Adequate muscle relaxation prevents coughing or straining with intubation, otherwise large fluctuations in venous return result that are poorly tolerated. Using agents that do not cause histamine release (and the resulting bronchospasm and vasodilation) is suggested. Full reversal prior to extubation is also important, to prevent hypoxia, hypercarbia and anxiety.

Nitrous oxide should be avoided as it directly raises PVR[16].

Analgesic techniques should consider the risks of post-operative respiratory depression and hypercapnoea.

Vasoactive agents can be considered as pressors, positive inotropes and those with pulmonary vasodilatory effects, most are mixed. Specific pressors are phenylepherine, metaraminol, noradrenaline and vasopressin, ideally they should only raise SVR and not PVR. Vasopressin is thought to offer more systemic than pulmonary bias[17].

Milrinone has effective inodilator properties and should preferably be infused with vasopressin (over noradrenaline) to maintain SVR[17]. Levosimendan has a long half-life and may contribute to hypotension so is not suited to intraoperative use.

Nitric oxide (iNO) is an inhaled gas delivered via the breathing circuit in compatible anaesthetic machines, via an intensive care ventilator or by a tightly fitting face mask. Its extremely short half-life means it must not be interrupted (for example, bagging or transfer), interruption may cause rebound PH severe hypoxaemia and death.

Surgical approach

It is important that surgery for PH patients is well planned, involving a multidisciplinary approach where pulmonary physicians, anaesthesiologists, intensive care physicians and surgeons collectively form a plan. Ideally the case should be done during normal working hours early in the week when full clinical resources are available.

In the case of abdominal procedures, laparoscopic approaches are often favourable due to better post-operative recovery. The surgery should be performed proficiently with low insufflation pressures (for example, 10-12cmH_2O). Pneumoperitoneum immediately raises intra-thoracic pressures, raises PVR and impairs venous return. Carbon dioxide is absorbed through the peritoneum raising $PaCO_2$ and requiring a compensatory rise in minute ventilation. This may exacerbate raised intra-thoracic pressures and impaired venous return. Also, laparoscopic surgery may require reverse or Trendelenburg positioning for surgical access, both of which may worsen respiratory mechanics and haemodynamics.

Obstetric patients

Should a patient with severe PH present for delivery, a multidisciplinary approach in a tertiary-level care unit is required and should be planned early. Maternal mortality risk remains around 30 per cent and is most common in the month post delivery[18]. Published case series describe both vaginal delivery and Caesarean section in the context of maternal pulmonary hypertension. The overall trend appears to favour vaginal delivery. This may be related to less bleeding, less coagulation disturbance and lower infection risk. Epidural anaesthesia has a lower maternal mortality than general anaesthesia likely due to greater haemodynamic stability. Invasive arterial and central venous pressure monitoring are required. Commonly active third-stage management includes agents such as oxytocin. Slow, low-volume infusion rather than bolus and large-volume (1000ml) infusion is safest. Carboprost (PGF2α) causes intense pulmonary vasoconstriction so is absolutely contraindicated. After delivery, auto-transfusion from uterine contraction can cause RV failure due to rapid rise in preload. Most maternal deaths in the PH group occur between two and 30 days post partum, vigilance must continue with ICU level care for a recommended 72 hours. Early reintroduction of thromboembolic prophylaxis should be done when safe. Non interruption of PH medical therapy is mandatory.

POST-OPERATIVE PLACEMENT

Despite perfect pre and intra-operative care, these patients can die unpredictably in the post-operative period. They require high level post-operative monitoring for 48-72 hours. They should have invasive arterial pressure monitoring and continuous pulse oximetry. If patient-controlled analgesia is used, extra vigilance is needed to detect any respiratory depression. Patients should have intensive care unit (ICU) or high dependency beds booked preoperatively. Close monitoring is ideal during epidural discontinuation and transition to enteral or IV analgesia.

THE ACUTE PULMONARY HYPERTENSIVE CRISIS

This may occur at any time during the patient’s course of care. Failure to recognise and treat may result in death. Presentation may include distress, dyspnoea and progressive signs of a low cardiac output, including hypotension and end organ hypoperfusion. Signs include raised CVP/JVP, systemic hypotension and features of low cardiac output, such as a falling urine output. The patient may rapidly develop a metabolic acidosis with elevated lactate, but have limited ability to increase respiratory compensation causing rapid progression. Management should aim to lower PVR, maintain SVR and restore cardiac output and remove triggers. Triggers may include hypercapnoea from excess opiates, or intense sympathetic vasoconstriction from poorly managed pain. Sometimes no trigger will be identified. Opiates such as morphine and anxiolytics may help break the cycle. However, inotropes, ventilation and pulmonary vasodilators may be required including milrinone and iNO. In cases of severe crisis, unresponsive to maximal medical therapy in patients considered retrievable with a reversible cause, peripheral veno-arterial extra corporeal membranous oxygenation should be considered.

CONCLUSION

Patients with severe PH are rare, but may present for elective or emergency surgery. They remain an extremely high-risk group of patients to anaesthetise with increased mortality and morbidity. Transfer to a cardiac unit should be considered depending on local expertise and urgency. An understanding of the patient’s physiology is mandated to provide optimal anaesthesia. The period of risk doesn’t end with placement of the surgical dressing. A crisis may happen unpredictably in the two to three days post-operatively despite perfect intra-operative care. Multidisciplinary teams should plan and co-ordinate care and post-operative intensive care is strongly advised.

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Goal-directed transthoracic echocardiography – a translational education program

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INTRODUCTION

Transthoracic echocardiography is used in many areas of medicine as a clinical, diagnostic and research device. It is non-invasive, safe and acceptable to patients. The ability of transthoracic echocardiography to provide volumetric and flow data – as well as to visually show the two and three-dimensional graphics of the heart – means that it is a powerful tool[1]. Not only is it a useful device in the clinical setting, it also has a role in education, enabling teaching of cardiac physiology and pathophysiology and the modernisation of the curriculum for all those learning the function and structure of the human body.

Many groups have recognised these advantages, including emergency physicians and intensive care clinicians[1-6]. Cardiac anaesthetists have a long-established structured educational and quality assurance program for transoesophageal echocardiography that has been incorporated into most hospitals providing cardiac anaesthesia. The use of transthoracic echocardiography, as opposed to transoesophageal echocardiography, by anaesthetists is increasing; however, there are few departments in Australia or internationally that have established a sustainable educational program that incorporates quality assurance and outcome measurements for transthoracic echocardiography teaching and training into their everyday practice. The purpose of this article is to outline an educational program that may fulfil the requirements for a sustainable program in transthoracic echocardiography, enabling integration of this important diagnostic tool into everyday clinical practice – a translational education program.

TRANSTHORACIC ECHOCARDIOGRAPHY

Transthoracic echocardiography has undergone significant advances in the past decade, with machine size reducing and portability increasing[1]. Coupled with this is the absence, in some health services, of 24-hour echocardiography services to attend clinical emergencies. This has meant that anaesthetists have started to upskill in the area of echocardiography to assist with the management of critically ill patients. There have also been steady improvements in image quality and reproduction, meaning that instantly available scanning and point-of-patient-care devices are being increasing used[7]. This enables clinicians to answer clinical questions at the point of care and measure the responses to interventions. Importantly, regarding accuracy of the data supplied by echocardiography, in skilled hands it has been shown to be accurate for estimating pulmonary artery pressure, left atrial pressure and left ventricular pressure. In addition, echocardiography has been compared with thermodilution, electromagnetic and roller pump methods of determining cardiac output and found to be accurate.

Regarding the clinical applicability of echocardiography, many international groups have published recommendations[8-12] and there are published guidelines on how to perform measurements and calculations, so that uniformity, precision and accuracy are maintained[13,14]. In addition, there are also guidelines on how to maintain device safety, the issues of bioeffects and cleaning and infection control.

TRANSTHORACIC ECHOCARDIOGRAPHY AND ANAESTHESIA AND CRITICAL ILLNESS

Many of our patients undergoing anaesthesia are healthy with no pre-existing medical problems and are having elective low-risk surgery of short duration. This group of patients is unlikely to benefit from the routine application of transthoracic echocardiography, including a pre-operative transthoracic echocardiography examination. However, the situation is vastly different if we consider a high-risk patient population, such as those with pre-existing cardiovascular disease, the elderly, the pregnant or extremely obese, or the high-risk surgery population – perhaps those undergoing cardiac, neurological, obstetric, cancer, or emergency surgery – or the high-risk anaesthetic population. Often, baseline cardiac function is unknown prior to surgery and we rely on our knowledge of the predicable physiological responses to our pharmacological interventions. In the area of acute emergencies and unpredictable responses to treatment interventions, transthoracic echocardiography may be of use. In these situations, diagnostic dilemmas may arise and we may be unsure of the patient's volume status, their estimated left ventricular end-diastolic pressure, or their ejection fraction. Reducing diagnostic uncertainty is important and there is the need for improvements in clinical care and accurate diagnoses[15].

Transthoracic echocardiography can be used to correctly answer clinically relevant questions and enable correct interventions in a timely manner (Table 1). It could be predicted that if the correct diagnosis (versus the wrong diagnosis) was made, thereby enabling the correct interventions to be commenced (versus incorrect treatments), then over time on a population level there would be positive impacts on patient outcomes. This is particularly

important in the area of the evaluation of hypotension, shock or haemodynamic instability of uncertain or suspected cardiac aetiology, as this meets the highest level of appropriateness or Class 1 recommendation according to American, British and European guidelines[8,16]. A pre-operative evaluation involving transthoracic echocardiography to establish baseline cardiac function and structure, and then serial intra-operative and postoperative scanning, may be of assistance in guiding resuscitation, fluid therapy, use of vasopressors and inotropes and in decisions related to location of postoperative care.

The following is a typical example of a diagnostic dilemma that may occur during fluid resuscitation in a patient who has bled, but remains hypotensive.

A 32 year-old woman is experiencing a postpartum haemorrhage (blood loss 750 mL) and the informal bedside haemoglobin value is 9 g/dL after 2000 mL of intravenous crystalloid. Vital signs: heart rate 120, sinus rhythm, blood pressure 86/42 mmHg, respiratory rate 30 breaths per minute, oxygen saturation 94 per cent on room air, temperature 38.1⁰ Celsius. The formal haemoglobin measurement and bedside arterial blood gases are sent but pending.

Table 1. Clinical scenarios and clinical questions in critical illness.

Clinical scenarios	
Critical illness and acute emergencies	Major haemorrhage Myocardial Ischaemia Cardiac failure Sepsis Embolism – pulmonary (blood clot), amniotic fluid, air Critical hypertension Coagulopathy Aortic dissection Respiratory emergencies (asthma) Endocrine emergencies Extreme obesity Trauma Cardiac arrest
Clinical symptoms and signs	Bleeding; Unexplained tachycardia; Hypotension; Chest pain; Shortness of breath; Severe hypertension; Fever; Reduced conscious state; Collapse
Clinical questions addressed with the use of echocardiography	What is the intravenous volume status? ↓,↑, normal Are there regional wall motion abnormalities? What is the left ventricular contractility? ↓,↑, normal Is there right ventricular outflow tract obstruction? What is the right ventricular size and contractility? ↓,↑, normal Is there pericardial tamponade? Is there pulseless electrical activity?

↓ = decreased, ↑ = increased. Adapted from reference 1.

WHAT TREATMENT DO YOU COMMENCE?

In this case, the cause of the haemodynamic instability is unclear and a diagnostic dilemma exists. It could be hypovolaemia, or alternatively it could be reduced ejection fraction heart failure. One is faced with the options of administering more fluid (for relative or absolute hypovolaemia) or administering an inotropic agent (because of poor contractility, reduced ejection fraction).[17] Incorrect therapy in this situation has the complications of acute pulmonary oedema and ongoing poor organ perfusion and end organ damage. This dilemma is one that most anaesthetists undertaking high-risk surgery, high-risk patients and high-risk anaesthesia have or will experience. Transthoracic echocardiography will immediately answer the question of whether there is heart failure or hypovolaemia, the two most likely diagnoses: 1) reduced left ventricular end-diastolic diameter will indicate hypovolaemia; and 2) reduced ejection fraction will indicate heart failure.

Despite there being enthusiasm for the more widespread application of transthoracic echocardiography in anaesthesia, implementation is hindered by the requirement for significant upskilling and training and equipment costs, as well as limited outcome data demonstrating patient benefit with the use of the technology. In addition, the relative rarity of the critical clinical events means that educational opportunities on patients with critical illness

are limited. In this setting, the use of simulation as a teaching, training and maintenance-of-standards tool would be beneficial. It is therefore fortuitous that, concurrent with the increasing portability and image quality of transthoracic echocardiography, there have also been significant developments in the fidelity and quality of transthoracic echocardiography simulators for teaching and training in echocardiography.

There are many benefits of integrating simulation into education[18] and the benefits of simulation in the specific area of echocardiography are emerging[19-22]. Simulation has significant advantages, as it enhances clinical education, creates opportunities for deliberate practice of new skills and allows the student to be exposed to clinical scenarios that are rare or uncommon[18]. In the area of anaesthesia where practising transthoracic echocardiography may be time consuming, the use of a simulator to obtain and maintain skills could be highly advantageous.

EDUCATION IN TRANSTHORACIC ECHOCARDIOGRAPHY

Formalised education in transthoracic echocardiography exists for cardiology and ultrasonography and some areas of critical-care medicine; however, training for other groups is less defined[23]. There is a wide range of brief courses and training workshops that occur predominantly outside the hospital environment. These courses are excellent in giving the novice operator (or someone with no experience at all) exposure to transthoracic echocardiography and the ability to experience transthoracic echocardiography first-hand. They are, however, limited by the fact that ongoing training, experience and quality assurance may be limited if the people being trained do not integrate with a hospital-based program for ongoing training, supervision and credentialing.

This leads on to the recognition of two groups of training levels – the novice and the advanced or expert operator, and two groups of transthoracic echocardiography examination scans – the goal-directed transthoracic echocardiography scan and the comprehensive transthoracic echocardiography scan. The novice or basic-level operator can perform an emergency transthoracic echocardiography scan and recognise life-threatening clinical conditions such as hypotension caused by hypovolaemia, reduced ejection fraction, right ventricular failure or cardiac tamponade. However, the novice operator must appreciate the limitations of their skills and in doing so minimises a risk of transthoracic echocardiography – incorrect diagnosis from lack of training. The advanced or expert operator has the ability, after training in a stepwise fashion from basic to advanced skills and knowledge, to perform a full cardiac assessment.

Regarding transthoracic echocardiography examination scans, goal-directed transthoracic echocardiography is ideally suited to anaesthesia and critical care. Goal-directed transthoracic echocardiography is defined as an abbreviated or shortened transthoracic echocardiography examination, performed at the point of patient care, designed to rule out the presence of major abnormalities as the cause of the acute physiological disturbance. It involves the acquisition, recording and storage of a reproducible, easy to obtain, clinically relevant minimum data set[1], by a trained operator, that can be used to make a clinical diagnosis and assist with treatment interventions.

Principles of goal-directed scans are:

Acceptable and applicable
Bedside test
Comfortable and concise examination – limited views
Diagnosis and response to therapy – contractility status and volume status
Embolism (air, blood, amniotic fluid) – right heart function/relative size
Foetal heart rate assessment (in the case of a pregnant woman)

In 2014 the Australian and New Zealand College of Anaesthetists (ANZCA) developed PS46, the guidelines for the training and practice of perioperative cardiac ultrasound in adults[24]. For goal-directed echocardiography, the PS46 document recommends that at least 20 supervised transthoracic echocardiography studies, at least 20 additional unsupervised transthoracic echocardiography studies with full review by a supervisor, and at least 50 additional goal-directed transthoracic echocardiography studies (with review by supervisor as necessary), be performed. After basic training is achieved, maintenance of standards is achieved by participating in audit and peer review of cardiac ultrasound cases and the performance of at least 50 transthoracic echocardiography studies annually.

Included in PS46, transthoracic echocardiography education must have quality assurance. PS46 does not include the need to record outcome data; however, with the implementation of any new device or educational program, this too is essential. Regarding outcome assessment for educational programs, Kirkpatrick's framework[18,25] provides four levels of assessment for evaluating their impact:

Level 1 – Reaction – participant's reaction to the intervention.
Level 2 – Learning – the degree to which the learning occurs as a result of the intervention.
Level 3 – Behavioural change – the transfer of learning to behaviour at work.
Level 4 – Organisational performance – the impact of learning on patient outcomes.

Ideally, educational programs satisfying these four areas of evaluation would result in a positive reaction by participants to the education program (Kirkpatrick level 1), improved learning by the participant (level 2), the transfer of skills and knowledge to the clinical environment by the participant (level 3) and an improvement in patient outcomes (level 4).

Therefore it is within the framework of:

1. The new guidelines from ANZCA regarding the training and practice of perioperative cardiac ultrasound
2. The applicability of goal directed transthoracic echocardiography in anaesthesia and critical illness and
3. The role of simulation in enhancing education

that this example of an educational program is presented (Figure 1).

A GOAL-DIRECTED TRANSTHORACIC ECHOCARDIOGRAPHY EDUCATIONAL PROGRAM

An example of an educational program is shown in Figure 1. The program aims to educate a small number of senior anaesthesia trainees or fellows (five) and a larger number of anaesthetic consultants (15) in goal-directed echocardiography. The staff who participate in the educational program should work at least four sessions per week at the hospital and should be planning to continue working at that hospital for the time required for education in goal-directed transthoracic echocardiography (one year). Specifically, the program incorporates the recognition and management of acute emergencies including hypotensive heart failure, acute hypertensive heart failure and acute hypovolaemia. It does this by teaching the participants the knowledge and skills to determine ejection fraction, contractility, left ventricular end-diastolic pressures and left and right ventricular end-diastolic volumes using both simulator cases of normal and abnormal cardiac function and structure, and human cases of normal and abnormal cardiac function and structure.

Evaluation of the program

Evaluation is performed by applying Kirkpatrick's framework, with evaluation occurring at four distinct time points:

Assessment 1 – prior to commencing the education program.
Assessment 2 – after the initial four-month training period.
Assessment 3 – after the subsequent four-month probationary training period.
Assessment 4 – after the final four-month independent training period.

Organisational performance and the impact of learning on patient outcomes

Level 4 outcomes are assessed for individual patients by review of logbook data as recorded by the participant. A standardised case-reporting form is used and all cases are stored on a database. Answers to the following questions are recorded:

- Did echocardiography result in the diagnosis of reduced ejection fraction?
- Did echocardiography result in a beneficial change of therapy?
- Was an incorrect therapy commenced as the result of incorrect echocardiography findings?
- Did echocardiography contribute to patient satisfaction at the time of its use?

Outcomes are also aggregated from the group of participants and used to record group patient outcomes. These include:

1. The number of patients in which goal-directed echocardiography resulted in the diagnosis of reduced ejection fraction.
2. The number of patients in which goal-directed echocardiography resulted in a beneficial change of therapy.
3. The number of patients who experienced complications of echocardiography, including incorrect therapy, as a result of incorrect echocardiography findings.
4. Patient's satisfaction level (five-point Likert scale) – either with their involvement in the education program, or as a patient with the use of echocardiography.

Hospital and department

For a program to be successful, the anaesthetic department has to be interested in and committed to its implementation. As with the introduction of any new program, there needs to be a philosophy of discovery and learning, and teaching activities need to be encouraged and supported within the organisation. As internet learning is part of the curriculum, widespread modern internet connections, 24-hour library access and quiet workspaces to enable both virtual and real-life learning are necessary.

Personnel

The educational leader and curriculum developer for the educational program need to be decided upon for each department and be advanced or expert-level operators. The leader needs to have assistance to run hospital-based workshops and initial teaching – at least two additional trained people. Ideally, there should also be a person who can recruit patients for the human workshops and coordinate the review of participants' echocardiography studies during the initial and probationary training period.

Figure 1. Educational program outline for a 12-month continuing program in echocardiography

Assessment 1
Pre-education
Pre-existing knowledge and skills questionnaire and scenario-based clinical management questionnaire†

↓

Initial training
Four months
Internet and textbook learning – Anaesthesia and Critical Illness Curriculum (tailored to department's AOI)*
Workshops – four-hour duration – one machine: five trainees – 1 trainer: five trainees
Simulation studies – 25 cases (20 fully supervised); Human studies – five cases (five fully supervised)

↓

Assessment 2
Post initial education
Participant's reaction to the initial training – questionnaire (Kirkpatrick Level 1 evaluation)
Degree to which learning occurs due to the initial training – questionnaire (Kirkpatrick Level 2 evaluation)
Acquired knowledge and skills test and scenario based clinical management test
Skills station assessment – setting up, performing and reporting a normal goal-directed TTE scan

↓

Probationary training
Four months
Case studies (simulation and human) – 2 cases/week – 32 cases (20 fully reviewed) Logbook recording#

↓

Assessment 3
Post-probationary training
The participant's transfer of learning to behaviour at work (Kirkpatrick Level 3) – assessment of logbook (i.e., number of times TTE independently used), self-assessment questionnaire, feedback from staff
Acquired knowledge and skills test and scenario based clinical management test
Skills station assessment – setting up, performing and reporting an abnormal goal-directed TTE scan

↓

Independent training
Four months
Case studies (simulation and human) – 2 cases/week – 32 cases (reviewed as required)
Logbook recording#
Attend departmental TTE clinical case quality assurance review meeting every two weeks

↓

Assessment 4
Post-independent training
Impact of learning on patient outcomes (Kirkpatrick Level 4)
Acquired knowledge and skills test and scenario based clinical management test
Teaching station assessment – demonstrating the set-up, performance and reporting of a goal-directed TTE scan to a novice trainee

↓

Completion of training and commencement of Maintenance of skills and knowledge
Attendance at yearly update and refresher course
Yearly review of logbook# – one case/week (50 per year) (simulation or human)
Attendance at departmental TTE clinical case quality assurance review meeting (six per year)
Self-nominated interested participants who have demonstrated aptitude and excellence on tests will be offered opportunity to teach in subsequent programs

TTE = transthoracic echocardiography
AOI = area of interest
†similar to that presented in this article
*i.e. general and subspecialty anaesthesia.
#standardised case reporting form and all cases stored on departmental database

Equipment
At least one portable transthoracic echocardiography machine with data storage and review capability is necessary. Access to an echocardiography simulator would be advantageous to readily enable practice scanning and maintenance of skills.

Clinical review and quality assurance meetings
Clinical review meetings are necessary – similar to what occurs in departments with a transoesophageal echocardiography service – with presentation of all scans performed during the previous selected time period (two weeks), with opportunities for review, discussion and highlighting of key issues.

Time and access to in-real-life learning
The person implementing the educational program needs dedicated teaching time (one session per week) to run workshops, and supervise transthoracic echocardiography scanning as well as conduct and coordinate the departmental transthoracic echocardiography clinical case, quality assurance review meetings. In order to enable the smooth integration of transthoracic echocardiography into clinical practice, the department should allocate least one elective theatre list as a transthoracic echocardiography scanning list where, after obtaining consent, all patients on that list undergo transthoracic echocardiography scanning prior to their surgery.

SUMMARY

Transthoracic echocardiography has significant advantages and does have a place in anaesthesia and critical illness. Workshops and short training programs external to hospitals offer people a chance to learn what transthoracic echocardiography is all about and obtain basic views and initial training. Unfortunately, few, if any hospital-based anaesthesia departments, offer a sustainable program of transthoracic echocardiography education with which these people can build upon their knowledge and skills. This means that these skills are not maintained and there is little quality assurance or maintenance of standards.

The time has come to develop formal hospital-based educational programs, such as the one outlined here, that incorporates quality assurance and outcome measurements, so that the skills and knowledge acquired by learning transthoracic echocardiography can be translated into clinical practice and improved in patient outcomes. We, as anaesthetists, have an opportunity to be leaders in this translational education. It is only through the hard work and commitment of anaesthetic departments and financial support to obtain equipment and staff, that the dream of widespread implementation of transthoracic echocardiography in medicine will become a reality.

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Pain management for trauma: Time to embrace regional anaesthesia?

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INTRODUCTION

Debate persists regarding best-practice pain management for patients sustaining traumatic injuries. In the developed world, trauma (meaning "wound") is the leading cause of death in the first four decades of life, and the fourth-leading cause of death in all age groups. In recent decades, introduction of standardised protocols for early trauma management has dramatically improved survival rates. Of the survivors, a large proportion progress to chronic pain and functional disability. This represents a global healthcare problem that may, in part, be addressed by improving pain management.

Regional anaesthesia is established as an integral component of high-quality, evidence-based perioperative anaesthetic care. Safety, efficacy and versatility are greater than ever before. Enhanced recovery pathways for elective surgery use regional techniques extensively[1]. This has spread into "high risk" specialties, such as thoracic and vascular surgery, and emergency care[2-3]. Principal aims include avoidance of iatrogenic problems (for example, opioid-related side effects), minimising the stress response, and facilitation of early return to normal function. Using regional anaesthesia to achieve these objectives would appear to be highly desirable, irrespective of whether one was on a true enhanced recovery pathway or not. However, acceptance for the use of regional anaesthesia in treating trauma has been hindered by numerous barriers.

Pain as a symptom is almost ubiquitous following injury, and remains poorly treated. Isolated historical reports, representing low-level evidence and subject to reporting and publication bias, have fuelled an aversion to regional techniques in this population. Systemic opioids form the main analgesic strategy, exposing patients to suboptimal analgesia and a range of undesirable side effects.

The logic driving traditional resistance to the use of regional anaesthesia in trauma is under scrutiny. The weight of evidence is shifting, with favourable data attesting to the feasibility, efficacy and safety of regional interventions in managing victims of battlefield and natural disasters. Performed under extreme and challenging conditions, such demonstrable improvements represent an opportunity to refine pain management for civilian trauma.

In this review we will discuss the challenge of effective pain control following traumatic injury, mechanisms of transition from acute to chronic pain, controversies surrounding analgesic management in trauma, the advancing role of regional anaesthesia for trauma, and safety considerations for the use of regional anaesthesia following injury.

THE "STRESS" OF TRAUMA

"Stress response" is a term denoting the complex physiological response to tissue injury, involving activation of the neural, metabolic, endocrine, haematological and immunological systems. The magnitude of this catabolic state is commensurate with the extent of tissue damage. In evolutionary terms, adaptive changes such as hypercoagulability, immunosuppression, vasoconstriction and fluid retention may have conferred a survival advantage. In the context of modern medicine, it is unclear whether these changes actually benefit the individual, and attenuation of the stress response has become a meaningful treatment objective. Plausible advantages of avoiding "stress" include improvement of the myocardial oxygen supply/demand ratio, maintenance of gut and immune function, and reduced thromboembolism risk. A sympathetic blockade may improve regional blood flow and support survival of an injured extremity.

BACKGROUND

Conjecture in the surgical literature has apportioned blame to regional interventions in trauma patients for contributing to undesirable outcomes. Scepticism concerning the safety profile of regional anaesthesia and fear of litigation has led to an aversion to its performance. Specific issues include coagulopathy, potential secondary nerve injury and perceived delayed diagnosis of acute compartment syndrome (ACS). For decades, management has defaulted to general anaesthesia and systemic analgesia alone, despite multiple recognised drawbacks.

FOR CHANGE

More recent data suggest risks concerning regional anaesthesia are probably overstated and may be negotiated with appropriate training and infrastructure. Through improvements in resuscitation and damage-control surgical techniques, injuries that previously were considered fatal are increasingly survived[4].

The expanding contribution of regional anaesthesia in trauma pain management may be explained through:

- Improved reliability and safety, through developments in training and technology (for example, needle design and ultrasound).
- Low quality of evidence against the use of regional interventions.
- Publication of data disputing historical concerns over true attributable risk of regional interventions.
- Greater awareness of the importance of pain, with inadequate control associated with poor functional and psychological outcome.
- Limited efficacy of systemic analgesics, coupled with a predictable multisystem morbidity profile.
- Professional guidelines addressing balance of risk issues.
- Favourable data from military sources detailing benefits of regional anaesthesia for complex trauma.

ADVANTAGES/LIMITATIONS OF REGIONAL ANAESTHESIA FOR TRAUMA

In the setting of trauma, there are numerous reasons to consider regional anaesthesia. However, there are several caveats and these are listed in Table 1.

Table 1. Advantages and limitations of regional anaesthesia for trauma

Advantages

- Superior pain control
- Chronic pain protection
- Avoidance of airway management (for example, difficult/failed intubation, bleeding, oedema, dental damage, cervical spine movement)
- Stable haemodynamics
- Satisfaction
- Ease of transport
- Facilitation of physiotherapy
- Reduced nursing requirement
- Attenuation of stress response
- Reduced opioid dosage

Limitations

- Competition with resuscitation objectives
- Acute compartment syndrome
- Secondary nerve injury
- Coagulopathy
- Training, infrastructure, education, attitudes
- Polytrauma
- Positioning
- Local Anaesthetic Systemic Toxicity (LAST) risk
- Management mandating general anaesthesia (for example, sternotomy, craniotomy)

THE CHALLENGE OF PAIN

The International Association for the Study of Pain (IASP) defines pain as “an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in such terms”[5]. This is a dynamic process, involving a myriad of initiating and maintaining factors within the central and peripheral nervous systems. Pain is now recognised as a disease entity in its own right, rather than a symptom.

Regional anaesthesia for elective surgery is established, affording superior analgesia with opioid sparing. Anticipatory “primary prevention” strategies reduce or eliminate the acute pain stimulus. Pre-emptive analgesia includes targeted pre-operative regional and systemic drug administration[6], in addition to behavioural and cognitive therapy. These interventions serve to protect against chronic pain, denoted as pain experienced beyond the expected duration of tissue healing, usually considered as three months. Despite this, a proportion of patients develop persistent pain. Debilitating symptoms following relatively minor surgery, such as inguinal hernia repair, are well documented.

The unpredictable nature of trauma precludes primary preventative interventions. Following injury, “secondary prevention” relies on prompt pain control to prevent transition from “normal” acute pain to maladaptive neural sensitisation that serves no useful function. Initiation of suitable therapy is problematic. Early management of trauma follows ATLS® resuscitation protocols, with stabilisation through simultaneous assessment and management of injuries. Immediate focus is on preserving life. Analgesia is given lower priority status than resuscitation treatment objectives. Caregiver concern may also limit analgesia provision, for fear of compounding physiological derangement through side effects including respiratory depression, hypotension and clouding of consciousness. Consequently, the true incidence and significance of pain is notoriously under-recognised and undertreated in trauma victims.

Unrelieved acute pain is an independent risk factor for progression to chronic pain. Where nerve injury occurs, through trauma or definitive surgical repair, neuropathic sequelae are more likely. Not surprisingly, operations associated with significant nociceptive input and neural injury, such as thoracotomy and amputation, exhibit high incidences of chronic pain (6-65 per cent and 50-85 per cent respectively)[7].

Often described separately, post-surgical and post-traumatic pain share similar underlying aetiologies and pathophysiological responses to tissue injury[8]. Both account for a large proportion of patients attending chronic pain clinics. A survey of pain clinics in the United Kingdom identified trauma as the primary cause in 18.7 per cent of patients, and post-surgical pain in 22.5 per cent[9]. Traumatic injury frequently mandates definitive surgical management; thus, precise boundaries can be indistinct between post-surgical and post-traumatic pain.

The World Health Organization (WHO) defines health as “a state of complete physical, social and mental well-being and not merely the absence of disease or infirmity”[10]. Traditional opioid-based strategies for treating acute traumatic pain often fail to satisfactorily alleviate pain and restore a significant proportion of patients to a state of healthy functioning[11]. Countries including the United States and Australia now face endemic social problems resulting from opioid dependence and misuse. The global socioeconomic health burden from trauma can be measured in terms of short-term healthcare costs, or indirectly through lost productivity, unemployment or further medical expenditure. The global financial cost in the United States has been estimated to be between $US560-635 billion annually[12]. A strong association exists between chronic pain, financial dependence, psychiatric disease and substance abuse. Additionally, pain is a risk factor for other conditions such as thrombosis and respiratory tract infection. Breaking this pattern is a major healthcare priority.

TRANSITION FROM ACUTE TO CHRONIC PAIN

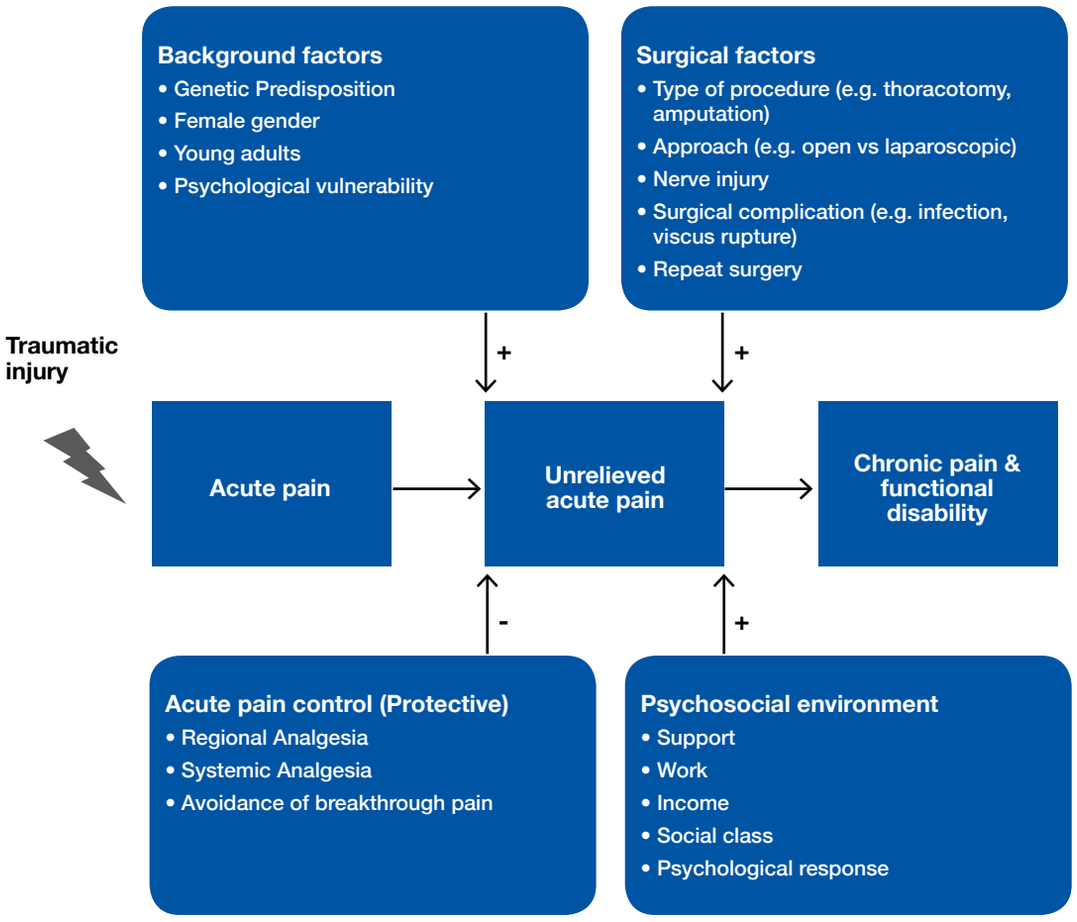
Pain signalling has a complex neurophysiological basis involving neurotransmitters, receptors, secondary messengers and selective gene expression, coupled with significant psychological overlay. Following injury, pathophysiological changes occur at all levels between the site of injury, the peripheral nerves, spinal cord and brain.

Peripherally, the spontaneous discharge rate of primary afferent nociceptors increases. Hyperexcitability is maintained by pro-inflammatory mediators that increase sensitivity to further stimuli (primary hyperalgesia) in damaged tissue. This may progress to secondary hyperalgesia, in which pain sensitivity occurs in surrounding undamaged tissues. Regeneration of damaged nerve endings may lead to neuroma formation, with an increase in ectopic activity. Central pain pathway changes occur at the level of the spinal cord, brainstem and cerebral cortex, including increased dorsal horn excitability, increased central microglial signalling and suppression of inhibitory synaptic transmission. Where these changes are maintained, the end result is persistent pain with diminished function.

Pain is a major treatment target and an important quality-of-life indicator. Effective analgesia influences the physiological and psychological response of trauma victims. Control of acute pain to prevent chronic pain development is an important, yet elusive, treatment objective.

Factors contributing to progression from acute to chronic pain are summarised in Figure 1.

Figure 1. Transitional factors — acute to chronic pain



WHY REGIONAL FOR TRAUMA?

Urgent, effective pain control is a key clinical and humanitarian goal. Regional anaesthesia affords many features of an ideal analgesic agent, including superior analgesia, avoidance of general anaesthesia, ease of transport, reduced polypharmacy, satisfaction and improved functional outcome.

An opioid-sparing strategy reduces predictable multisystem side effects, including respiratory depression, sedation, delirium, pruritus, immunosuppression, ileus, nausea, urinary retention, tolerance and dependence. Minimising opioid dosage permits certain recovery goals to be met, including participation in physiotherapy and an earlier return to oral diet.

Regional anaesthesia is highly desirable for a range of traumatic injuries. Essentially opioid-free pathways support continuous catheter infusions for neck of femur fractures[13]. Paravertebral and thoracic epidural blocks reduce respiratory morbidity and possibly mortality for multiple rib fractures[14,15]. These are considered the gold standard for pain relief following thoracotomy. Abdominal wall blocks, such as rectus sheath and transversus abdominis plane, provide somatic analgesia to the anterior abdominal wall and may be used where neuraxial techniques are unsuitable[16]. Brachial plexus interventions, such as interscalene blocks for shoulder reductions[17], and axillary blocks for distal radius fractures[18], yield efficiencies and cost savings for both emergency departments and theatres. Beneficial end points have included reduced nursing requirement, recovery-room bypass and earlier hospital discharge.

Despite some success, there are injuries – such as tibial shaft fractures – where resistance to regional techniques remains high. Default to general anaesthesia and systemic analgesia is frequent. There remains a need to properly appraise the true, rather than perceived, risk of regional anaesthesia in such patients.

In recent years, military medical sources have published extensively on the feasibility, appeal and safety of regional interventions following traumatic injury.

MILITARY EXPERIENCE

Experience from conflict zones has long driven medical innovation. Damage control resuscitation, transfusion medicine and human factors training represent advances that have transitioned well into, and become best practice in, civilian trauma care. Impressive advances in pain management are also described.

Opioid-based analgesia for trauma dates to the American Civil War following the invention of the hypodermic needle. The term ‘Soldier’s Disease’ was subsequently coined, denoting the propensity for opioid dependence among war-wounded soldiers. It is perhaps surprising that a greater connection between inadequate pain control, opioid dependence and death was not made until the end of World War II.

The Vietnam War first demonstrated the feasibility of regional interventions for managing combat casualties[19]. Recent conflicts have renewed interest in trauma pain management. Complex battlefield injury patterns trigger sudden massive nociceptive input, often coupled with evidence of neuropathic symptoms. High-energy blast injuries from suicide bombers and improvised explosive devices (IEDs), alongside technological developments in body armour, have resulted in extremity amputations becoming a distinguishing injury pattern. Despite the increasing lethality of weapons used, a survival rate of about 90 per cent is high, comparative to previous conflicts. The ability to survive injuries that hitherto were almost uniformly fatal is also attributable to medical advances including improved surgical and critical-care techniques, blood transfusion strategies and human factors training.

Military campaigns in Afghanistan and Iraq have tasked clinicians working in difficult environments to accomplish optimal pain relief, transport and functional recovery for complex trauma. Anaesthetists have been accountable for safely accomplishing long-distance chains of aeronautical medical evacuation. Following major injury, the wounded are evacuated from base hospitals by military aircraft to hospitals in Europe and North America. Multiple surgical episodes are undertaken at points along the chain, involving initial damage-control surgery and later, restorative procedures. Victims face life-altering physical and psychological changes. Effective and sustained pain relief is essential to optimise outcome.

A striking development has been the emergence of regional techniques as the standard of care for a range of injuries[20-24]. The greatest benefit appears to be conferred through peri-neural catheter techniques using protocols agreed between anaesthetists, surgeons and emergency physicians. An encouraging and growing body of evidence identifies regional interventions as making a key contribution in the management of combat victims. Additionally, traditional objections to regional anaesthesia in trauma can be negotiated with appropriate training, infrastructure and interdisciplinary dialogue. This novel approach has challenged conventional attitudes and redefined best-practice analgesic management. In contrast, opioid-based therapy alone confers suboptimal analgesia, a multitude of adverse side effects and can require repeated provision of general anaesthesia to achieve these objectives.

Where systemic analgesics are administered for acute severe pain, the British military has used a “reverse pain ladder”. This inverts the classic WHO analgesic ladder. Strong analgesics initially form the mainstay of treatment, stepping down in strength and dose over time as recovery progresses. An additional modification is “step 4” for uncontrolled severe pain, involving intravenous ketamine, clonidine and/or lignocaine[25]. Anti-neuropathic medication such as gabapentinoids and tricyclic antidepressants are started early where evolving neuropathic phenomena are suspected.

Anaesthetists can influence pain relief at all stages in the recovery pathway, from the point of injury through to rehabilitation. Demonstrable success on the battlefield suggests a potential for greater use of regional interventions in civilian environments. It is noteworthy that regional anaesthesia is conspicuous among medical advances in trauma, since this has yet to transition successfully to any great extent.

CAVEATS TO REGIONAL ANAESTHESIA

Major trauma

The use of general anaesthesia is widely applicable for emergency treatment following major trauma. Comparatively, regional anaesthesia use may be limited in a number of circumstances:

- Competition with life-saving treatment.
- Standard contraindications (for example, untreated coagulopathy or refusal).
- Injuries mandating general anaesthesia (for example, cranial) for surgical management.
- Inability to obtain reliable consent.
- Polytrauma.
- Safety issues from combative patients.
- Inability to position patient for procedure (for example, spinal cord injury).
- Lack of appropriate training, equipment and support.

Where feasible, combining general with regional anaesthesia may expedite recovery[26]. Potential benefits in critical-care patients include reduced opioid side effects, easier patient evaluation during sedation breaks, faster respiratory weaning, early tracheal extubation and greater participation in physiotherapy. Improvements in oxygenation and ventilation following thoracic epidural, paravertebral or intercostal nerve blockade is well described[27-29]. This may avert the need for invasive ventilation following pulmonary contusion. Paravertebral blockade is also described as providing unilateral segmental analgesia for multiple fractured ribs, while preserving neurological assessment in patients with concomitant lumbar spinal trauma[30].

However, the intensive-care environment poses numerous practical challenges, including positioning, staff familiarity, wrong route administration, distorted anatomy and lack of appropriate space. Multisystem dysfunction

poses additional considerations such as coagulopathy, immune-compromise and safety concerns over regional interventions in sedated patients. Where feasible, peripheral techniques are subject to fewer limitations and are preferred to neuraxial approaches. Despite advantageous features, only limited and low-level evidence addresses regional interventions in the critical-care setting. Detailed individual risk-benefit appraisal is warranted.

Acute compartment syndrome

ACS is a limb-threatening condition. This is an uncommon yet feared consequence of traumatic injury. Annual incidence is estimated as 7.3 per 100,000 for males and 0.7 per 100,000 for females[31]. A critical pressure increase in a confined myofascial space leads to microvascular ischaemia of nerves and vessels traversing the affected compartments. Definitive treatment is emergency fasciotomy decompression. Delays in treatment are a source of morbidity, mortality and litigation. Poor functional outcome and successful litigation are particularly likely if time from onset to compartmental release exceeds 12 hours, though irreversible damage can occur within four to six hours. Clinical assessment is challenging, and should include objective compartmental pressure monitoring for at-risk patients.

Pain disproportionate to the clinical situation is a cardinal feature of ACS. Nerve blockade in this context is controversial, since it may delay diagnosis by eliminating pain as the herald symptom. The evidence opposing regional techniques as analgesic modalities following trauma is neither compelling nor consistent. Isolated case reports provide limited evidence against regional anaesthesia where ACS is a concern. Such reports detail co-existent contributory factors to delayed treatment, including misattribution of blame to the wrong nerve distribution, inadequate monitoring and delayed decision-making, despite obvious clinical signs[32-35]. The true contribution of regional blockade to delayed diagnosis in these reports, if any, is debatable.

In orthopaedic literature, pain is an unreliable symptom, yielding poor sensitivity (19 per cent) and positive predictive value (14 per cent) for ACS[36]. Following injury, any analgesic modality may conceivably mask evolving ACS. Patient-controlled opioids[37], peripheral nerve and central neuraxial blockade have all been implicated in case reports as contributing to delayed diagnosis. A systematic literature review by Mar et al. indicates there is no association between regional interventions and delayed detection of ACS[38]. Rather, diagnosis may be assisted where breakthrough pain is reported in the presence of previously satisfactory perineural blockade. More recent reports support this, detailing breakthrough pain in a patient with an effective brachial plexus catheter as an indicator of developing ACS, facilitating prompt diagnosis and fasciotomy[39-40]. A prospective national paediatric epidural audit also found no association with regional interventions and delayed ACS diagnosis. Of 10,663 epidurals, there were four incidents of ACS. None were masked by the epidural[41].

On logical, practical and humanitarian grounds, ACS risk does not preclude regional blockade. Prior discussion should occur with the responsible surgeon concerning the suitability of neural blockade. Strategies for safe practice in patients with ACS risk are described in Table 2.

Table 2. Evidence-based factors influencing regional anaesthesia safety in patients with ACS risk

Institutional factors

- Vigilance
- Interdisciplinary communication
- Staff training
- Patient information
- Local protocols
- High-quality documentation
- Frequent clinical evaluation (including compartmental pressures)
- “Sign in” and “Time out” procedures before proceeding with surgery
- Attention to contributory causes of ACS (for example, circumferential casts, inadequate resuscitation, poor positioning)
- Audit

Pharmacological factors

- Avoid dense, long-acting regional blocks
- Peripheral nerve approaches where possible
- Boluses of short-acting local anaesthetic for operative ‘top-up’
- Benefit of adjuvant drugs is not established
- For continuous perineural catheters:
  - Use minimal effective concentration of long-acting local anaesthetic agent.
  - Patient-controlled function can increase reporting of breakthrough pain.
  - Avoid motor block.

Nerve injury

Neuropathy is a recognised complication of traumatic injury. Mechanisms for nerve injury include laceration, axial stretch, compression and vascular compromise. Neurological deficit may also be acquired or aggravated by iatrogenic causes, such as surgical fixation, poor positioning and regional anaesthesia interventions.

The “double crush” phenomenon, proposed by Upton and McComas in 1973, describes an association between cervical radiculopathy and carpal tunnel syndrome[42]. A unifying explanation is that individual lesions in a nerve increase the risk of injury at a second location along the same nerve. Decades later, significance of the association between two apparently unrelated pathologies remains uncertain. However, concern over potential secondary nerve injury has led to a continued reluctance of practitioners to undertake regional interventions in patients with potential or confirmed neuropathy.

Individual risk assessment is crucial. Though additional risk may be conferred at the time of the block through needle trauma, a resulting sympathetic block and superior analgesia may contribute to improved function. Comprehensive neurological evaluation, with documentation of findings, is essential prior to block performance. Where perineural catheters are used, postoperative surgical assessment of function may be done before bolus administration of local anaesthetic. Recommended modifications to practice where potential nerve injury exists include using less potent local anaesthetic agents, reducing dose and avoiding vasoconstrictors[43]. Contributory causes to neurological dysfunction should also be remedied, such as arterial hypotension, tight casts and poor positioning.

Coagulopathy

Coagulation disturbance is common following injury. Acute coagulopathy of trauma is a complex process initiated by tissue trauma, hypoperfusion, hypothermia and acidaemia. This is often compounded by large-volume autologous blood transfusion. Following definitive haemorrhage control, the balance of risk shifts towards thrombosis, and thromboprophylaxis administration is standard practice.

Professional guidelines exist for regional anaesthesia practice in patients with abnormalities of coagulation[44-45], yet there is little available to guide management of such interventions, specifically in trauma patients. Point-of-care testing such as thromboelastometry provides prompt, objective data on coagulation status. This is used in addition to standard laboratory tests of haemostatic function. Though safe reference points for point-of-care tests are not covered by current published guidelines, they have become used extensively to guide the suitability of interventions. The likely sequelae of coagulation status following injury must be considered to facilitate individualised provision of regional interventions. Where a complex risk-benefit balance exists, two consultants should agree the risk is justified.

The Camp Bastion Protocol is an approach to regional anaesthesia in subjects with suspected or confirmed coagulopathy of trauma[46]. Implemented in May 2010 for combat victims in Afghanistan, significant bleeding-related complications have not been reported.

FUTURE DIRECTION

High-quality data from clinical trials in military or civilian trauma victims is hard to acquire. Most studies rely on observational data. Though challenging, acquisition of prospective data on regional interventions and functional outcome in trauma is a worthy research initiative. At an institutional level, a collaborative approach must complement appropriate training and infrastructure to ensure safe practice of regional anaesthesia in trauma patients.

SUMMARY

A strong association exists between traumatic injury, persistent pain and poor functional state. Pain control following trauma has historically been poor, and its significance under-recognised. Innovation from military campaigns has provided a growing evidence base supportive of regional interventions in patients whom historically such practice would have been considered irresponsible or contraindicated. Such experience of complex trauma has arguably redefined best-practice pain medicine. Effective multimodal analgesia strategies using an integrated, multidisciplinary approach has exemplified the value of effective, sustained pain control. Challenges remain in translating observed benefits into civilian care.

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The role of regional anaesthesia in clavicle fracture surgery

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INTRODUCTION

The clavicle is a commonly injured bone in the human body accounting for 2.6 per cent to 4 per cent of all adult fractures with an annual incidence of 29 to 64 per 100,000 population per year[1]. Fractures of the shaft account for between 69 to 82 per cent of all clavicle fractures while lateral end injuries are less common (21 per cent to 28 per cent) and medial end injuries are comparatively uncommon (2 per cent to 3 per cent)[1].

The typical patient is a young adult male involved in a sporting injury where force has been applied to the point of the shoulder, though there is a second smaller peak of incidence in elderly patients sustained during falls, which are more likely to be lateral or medial end fractures[1]. Owing to the mechanism of injury, patients with clavicle fractures often have other injuries such as rib fractures or pneumothorax, which have anaesthetic implications.

TREATMENT OPTIONS

Treatment options of clavicular fractures can broadly be categorised as non-operative and operative treatments. Traditionally, acute mid-clavicular fractures have been treated conservatively with a sling or figure-of-eight bandage. However, owing to reports of improved functional outcomes and lower non-union rates with operative treatment, particularly for displaced clavicle fractures, the rate of surgical fixation for this injury is increasing[2-6].

The operative treatment options of clavicular fracture, which include plate or intramedullary fixation, achieve similar success rates in range of shoulder movement and bone union[7,8]. Plate insertion requires extensive soft tissue dissection, which risks injury to the supraclavicular nerves and the plate may produce a prominence that the patient finds irritating. Conversely, intramedullary fixation is less invasive, requiring two small incisions, but is more technically challenging and has a higher rate of implant failure, particularly in rotationally or axially unstable fractures[7].

A recent Cochrane review of intramedullary fixation versus plate fixation for clavicle fracture surgery[8] incorporated an analysis of pain between the two techniques. Four small studies compared intramedullary fixation with plate fixation in 160 people with acute collarbone fractures. The studies found little difference between intramedullary fixation and plate fixation with respect to pain. One study reported lower post-operative pain scores on days four and five post-operatively, but not on days one to three when a Knowles pin was used compared to plating for treating middle third clavicle fractures[9]. Overall the authors concluded the available evidence is very limited and that further studies are justified.

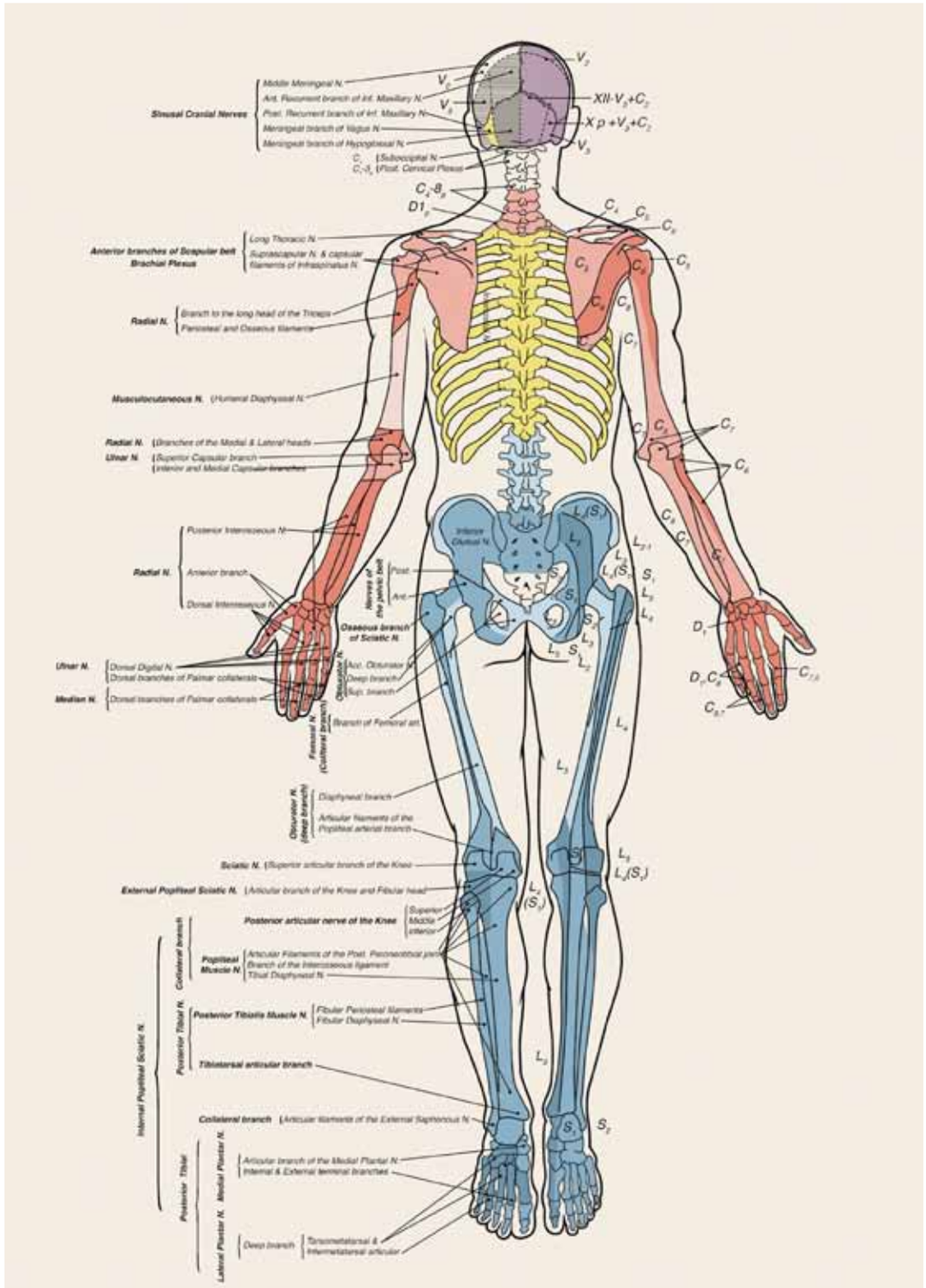
INNERVATION OF THE CLAVICLE

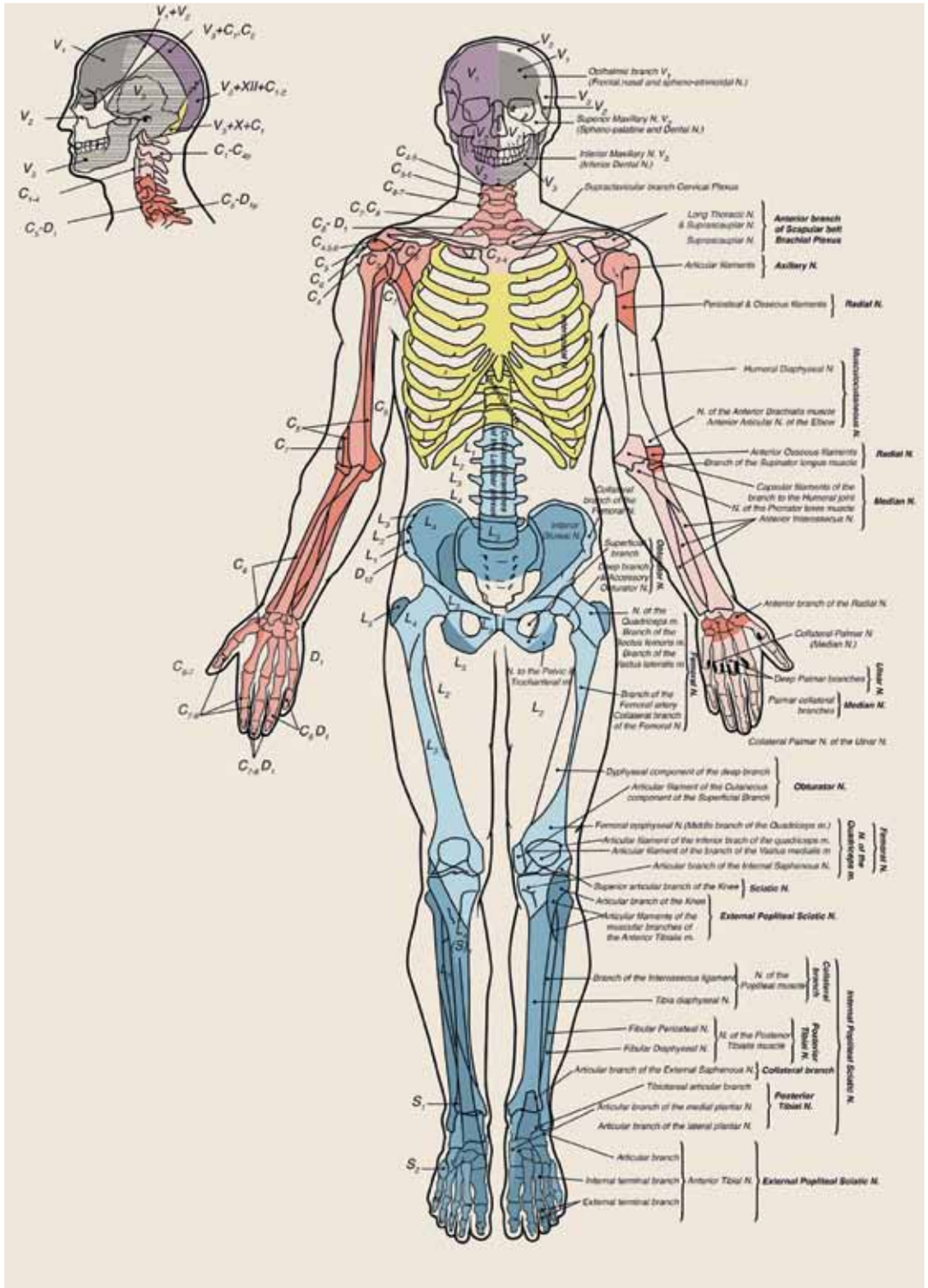
The clavicle is unusual in the field of regional anaesthesia in that its innervation is poorly defined. It is widely accepted that supraclavicular nerve, a branch of the superficial cervical plexus, innervates the skin overlying the clavicle and shoulder, however the precise sensory innervation of the clavicle bone remains elusive. Among anatomy and regional anaesthesia textbooks, some attribute the innervation of the clavicle to the supraclavicular nerve originating from the superficial cervical plexus, while others state that the innervation arises from the brachial plexus via the following nerves alone or in combination: subclavian nerve, suprascapular nerve, long thoracic nerve[10].

From first principles, the innervation of the clavicle can be predicted by using Hilton's law, which, as originally written in 1863 is: "The same trunks of nerves whose branches supply the groups of muscles moving a joint furnish also a distribution of nerves to the skin over the insertions of the same muscles; and – what at this moment more especially merits our attention – the interior of the joint receives its nerves from the same source."[11]

Hilton's law was found to be reliable and applicable to all cranial and peripheral nerves when critically analysed in 2014[11]. It can be paraphrased to "a joint is innervated by the same nerves that supply the muscles acting on the joint, which also supply the skin overlying the articular insertions of those muscles". Thus it would be expected that the nerves to subclavius (subclavian nerve), pectoralis major, clavicular head (lateral pectoral nerve) and deltoid (axillary nerve) also contribute to clavicular articular innervation. These nerves arise from the upper brachial plexus (C5,6,7).

Figure 1: Translated reproduction of Dejerine's Illustration (reproduced with permission Tran de QH, Tiyaprasertkul W and Gonzalez AP. Analgesia for clavicular fracture and surgery: a call for evidence. Regional Anesthesia & Pain Medicine. 2013. 38(6): 539-43).





Motor nerves to muscles derived from the pharyngeal arches are special visceral efferent fibres, which are not accompanied by sensory fibres. Muscles relevant to the clavicle are sternocleidomastoid and trapezius, which arise from the fifth pharyngeal arch and receive motor innervation from the accessory nerve. Local sensory nerves exist, which arise from the same spinal levels as the motor fibres (C2,3 for sternocleidomastoid and C3,4 for trapezius)[12] via the transverse cervical and supraclavicular nerves and most likely provide sensory innervation to the clavicle.

The clavicular part of pectoralis major is supplied by lateral pectoral nerve (C5-7), which arises behind the clavicle and runs under subclavius along the deltopectoral triangle giving several branches that enter the clavicular part of pectoralis major between the coracoid process and the site of insertion of pectoralis major to the clavicle[13]. The clavicular part of pectoralis major can be considered a separate anatomic entity to the rest of pectoralis major and is used as a myocutaneous flap to cover acromioclavicular defects, repair injuries caused by cervical tumours or recover motility in cases of facial paralysis. When the clavicular part is detached and reversed for flap surgery, branches of lateral pectoral nerve are seen penetrating the posterior surface[13], which may continue to the clavicle. This would be consistent with senior author Professor Boddu's experience of successful clavicle fracture surgery under PEC blocks (infiltration of local anaesthetic between pectoralis major and minor).

A French neurologist named Joseph Dejerine first published that the clavicle may receive innervation from both the brachial and superficial cervical plexuses[14]. He attributed the sensory innervation of the medial clavicle to the superficial cervical plexus via the supraclavicular nerve with contributions C3 and C4. He attributed innervation of the lateral clavicle to the brachial plexus, however he makes no mention of the subclavian nerve (although other authors have quoted him as attributing the innervation of the clavicle to the subclavian nerve). Instead, he suggests the suprascapular and long thoracic nerves supply the lateral clavicle with their fibres originating from C5. It is unknown how Dejerine reached his conclusions and he doesn't reference others to substantiate his claims. Dejerine produced a useful diagram of sclerotomes (regions of bone innervated by a single pair of nerve roots) and the peripheral nerve supply of each bone (see Figure 2. Cutaneous innervation of the supraclavicular nerve.). The fact that brachial plexus injuries following clavicle surgery most commonly involve the suprascapular nerve suggests the suprascapular nerve may provide sensory innervation to the clavicle[15].

Adding further complexity is the fact that the ventral axial line of the upper limb (where the sensory innervation of the anterior chest wall jumps from C5 to T1) runs in close proximity to the clavicle region and could conceivably be crossed by an incision made to facilitate clavicle surgery.

There is very little in the literature to provide evidence for the innervation of the clavicle and the use of regional techniques for clavicle fracture surgery (primarily case reports and case series) but what is available is summarised here.

Good regional analgesia for clavicle fracture has been described with the following techniques:

- Interscalene brachial plexus block using of high dose (200mg) bupivacaine in 22 patients with midshaft clavicle fractures[16].
- Superficial cervical plexus block in one patient with a midshaft clavicle fracture[17].
- Combined superficial cervical plexus block and C5 nerve root block in a total of three patients, one with a lateral clavicle fracture and two where the location of the fracture was not specified[18,19].

Other authors report inadequate analgesia/anaesthesia for clavicle fracture surgery using a single regional technique:

- King reported a patient with a lateral clavicle fracture who had excellent pre-operative analgesia after a superficial cervical plexus block, but after surgery the patient woke with severe pain in the lateral clavicle, which was effectively treated with an interscalene brachial plexus block[20].
- Santos reports a patient who had an interscalene brachial plexus block performed preoperatively. The block was deemed sufficient to attempt surgery under a purely regional technique but, when retractors were placed in the medial clavicle region, the patient experienced discomfort and required opioid analgesia/sedation to complete surgery[21].

Four authors have reported successful use of a pure regional technique for clavicle fracture surgery when both the superficial cervical and brachial (interscalene) plexuses were blocked:

- Anirban, one patient with a midshaft fracture[22].
- Avvaru, 30 patients, location of fracture not stated[23].
- Dillane, one patient, location of fracture not stated[24].
- Vandepitte, one patient with a midshaft fracture[25].

One or more foramina are usually present (96.1 per cent in one study) in the middle one third of the clavicle along its superior border, which transmit a nutrient artery and occasionally a medial fascicle of the supraclavicular nerve en route to the anterior chest. It is possible that the variable occurrence of these transiting fibres could account for variability in pain experienced from clavicle fractures (with injury to these transiting fibres resulting in increased pain)[26].

It would appear that a single regional technique cannot reliably be used to achieve surgical anaesthesia or perioperative analgesia for clavicle fracture surgery. Superficial cervical plexus block or isolated supraclavicular nerve block in addition to a C5 nerve root block, either alone or as part of an interscalene block, may permit a regional-only technique for clavicle fracture surgery, with the medial clavicle likely innervated by the superficial cervical plexus and the lateral clavicle likely innervated by the brachial plexus. Some scepticism is warranted owing to the paucity of available evidence and inter-individual variability.

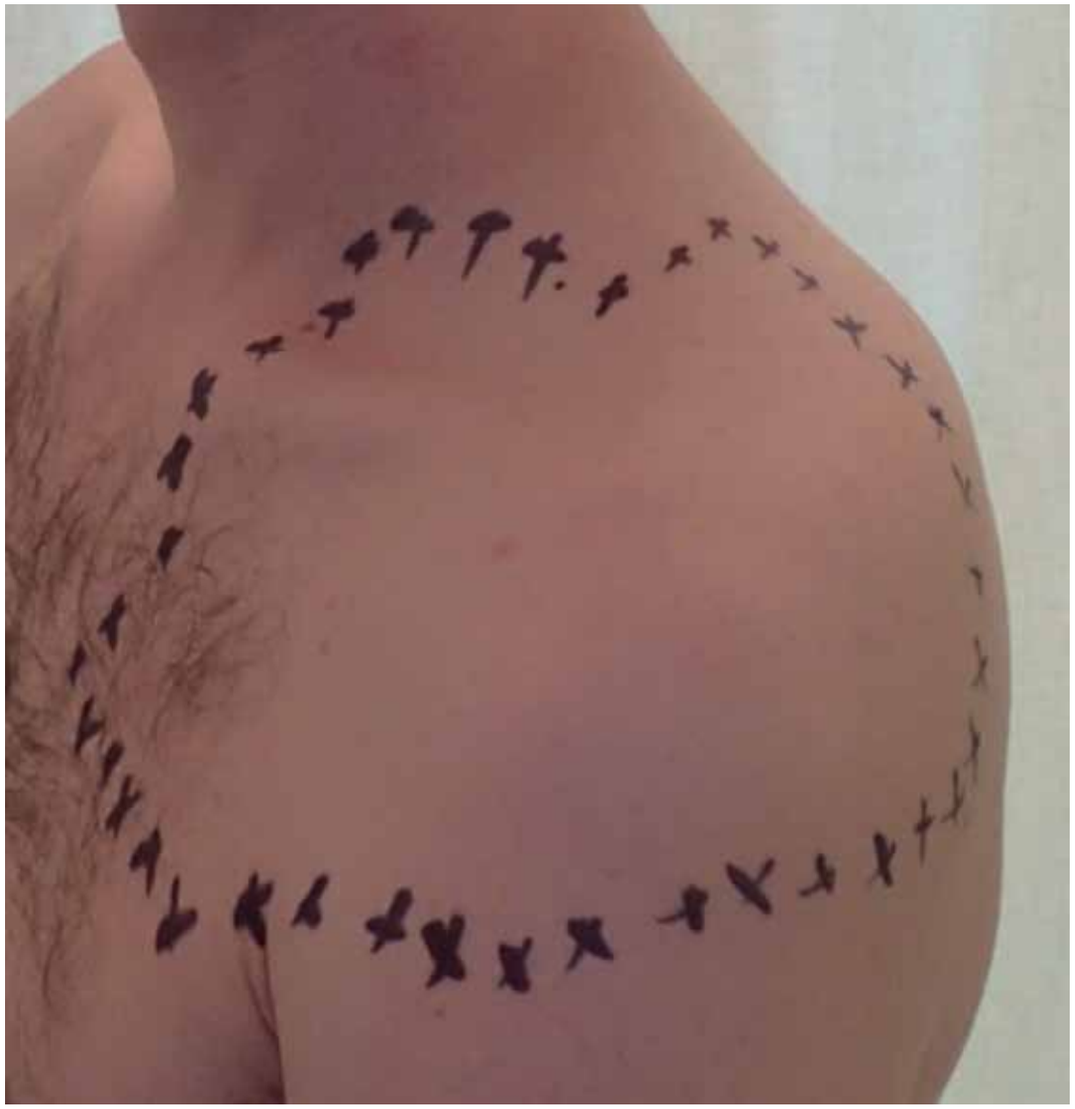
RELEVANT ANATOMY

The superficial cervical plexus originates from nerve roots C1 to C4 and is located at level of the thyroid cartilage (C4), beneath the posterior border of sternocleidomastoid.

The plexus has four terminal branches:

1. Greater auricular nerve – ascends to innervate the external ear.
2. Lesser occipital nerve – also ascends to innervate posterior neck and scalp.
3. Transverse cervical nerve – travels towards the mandible supplying the skin of the anterior neck.
4. Supraclavicular nerve – originates from the C3 and C4 nerve roots and is the only branch of the superficial cervical plexus that travels caudally. It descends over the posterior triangle of the neck to innervate the skin of the anteromedial shoulder and proximal chest wall inferior to the clavicle (see Figure 2)[27]. The supraclavicular nerve commonly divides into a medial and lateral branch and in some cases there may be an additional intermediate branch. The medial branch appears to cross at the medial third of the clavicle, while the lateral branch tends to cross at the lateral third of the clavicle. The intermediate branch, if present, tends to shows a more variable branching pattern[28].

Figure 2. Cutaneous innervation of the supraclavicular nerve.



The brachial plexus is composed of the peripheral nerves of the upper extremity from the root level to the terminal branches. It is classically described as forming from the C5 through T1 nerve roots. The interscalene groove is the potential space between the anterior and middle scalene muscles. In the supraclavicular region, the brachial plexus emerges from the interscalene groove and travels laterally and inferiorly beneath the clavicle[29]. Of relevance to further discussion, the subclavian and suprascapular nerves arise from the superior trunk of the brachial plexus with C5 innervation, and the long thoracic nerve arises from the roots of C5, C6 and C7.

POSSIBLE REGIONAL TECHNIQUES

Superficial cervical plexus block using a high volume of local anaesthetic. A cadaveric study has shown 30ml methylene blue injected around the superficial cervical plexus actually permeates through the superficial cervical fascia and reaches deeper structures, such as the deep cervical plexus and the brachial plexus[30].

- Interscalene brachial plexus block using a high volume of local anaesthetic aiming for spread to reach the supraclavicular nerve or superficial cervical plexus, accepting the likelihood of phrenic nerve blockade and the possibility of Horner's syndrome, recurrent laryngeal nerve blockade as well as sensory and motor blockade of the upper limb.
- Interscalene block plus superficial cervical plexus block has been used successfully for surgical anaesthesia, but still risks phrenic nerve block.
- Interscalene block plus supraclavicular nerve block.
- C5 nerve root block plus superficial cervical plexus block, which would make phrenic nerve blockade unlikely.
- C5 nerve root block plus supraclavicular nerve block, the most targeted and precise option permitting very low doses of local anaesthetic.

C5 nerve root block is a risky procedure (risks include injection into the vertebral artery and intrathecal injection through a dural sleeve), but it may have a role in patients with significant respiratory problems, who may benefit from avoiding an interscalene block and general anaesthesia.

Only one study comparing anaesthetic technique for clavicle fracture surgery could be located. This was a retrospective cohort study of 30 patients having clavicle fracture surgery. One group received an interscalene block plus a superficial cervical plexus block followed by general anaesthesia (eight patients). The other group received a general anaesthetic and local anaesthetic infiltration by the surgeon (22 patients). Outcomes analysed were opioid use and length of stay, both in recovery and in hospital. The only statistically significant difference was a modest reduction in recovery morphine use in the group that received regional anaesthesia[31].

DESCRIPTION OF REGIONAL TECHNIQUES

A technique for C5 nerve root block is included primarily for interest. Of key importance is identifying the C5 level. A reliable method of doing this is to use the C7 vertebra as a reference point. C7 is distinct from the other cervical vertebrae in that the transverse processes of the other cervical vertebrae have prominent anterior and posterior tubercles, while the C7 vertebra has a prominent posterior tubercle but a rudimentary, almost non-existent anterior tubercle (see Figure 3). The tubercles can be visualised on ultrasound with the probe in a transverse orientation across lateral neck and the patient in the lateral position. Once the C7 vertebra is identified, one can move the probe cephalad past the C6 vertebra with its sharp anterior tubercle (Chassaignac's tubercle) to the C5 vertebra, where the anterior and posterior tubercles of transverse process form a characteristic two-humped camel sign with the nerve root nestled between the two humps (see Figure 4). To perform the block, one would enter the skin posterior to the ultrasound probe, needle in plane, angling anteriorly and advancing needle tip close to the nerve root between the two tubercles[32].

A superficial cervical plexus block is usually performed at the level of C4 (level of thyroid cartilage) with the needle advanced below the posterolateral edge of sternocleidomastoid, which is often underneath the external jugular vein[33].

Blockade of the supraclavicular nerve and interscalene brachial plexus can readily be achieved with a single needle insertion site. The supraclavicular nerve descends from the superficial cervical plexus over the belly of the middle scalene muscle, but deep to posterior border of sternocleidomastoid where it divides into two or three branches between the deep and superficial cervical fascia. A standard interscalene view of the brachial plexus is slightly more caudal than the superficial cervical plexus and a good place to pick up the supraclavicular nerve travelling between the deep and superficial cervical fascia because the other branches of the superficial cervical plexus have already diverged. With modest movements of the probe up and down the neck it is possible to appreciate the branches of supraclavicular nerve as small hypoechoic structures that can be targeted. If a nerve stimulator is used, paraesthesia may be elicited over the shoulder region. Only small volumes of local anaesthetic are required to block these nerves (1-2ml)[27].

Figure 3. C7 vertebra with prominent posterior tubercle (root) illustration 89 from Gray's Anatomy (licensed under public domain via Wikimedia Commons).

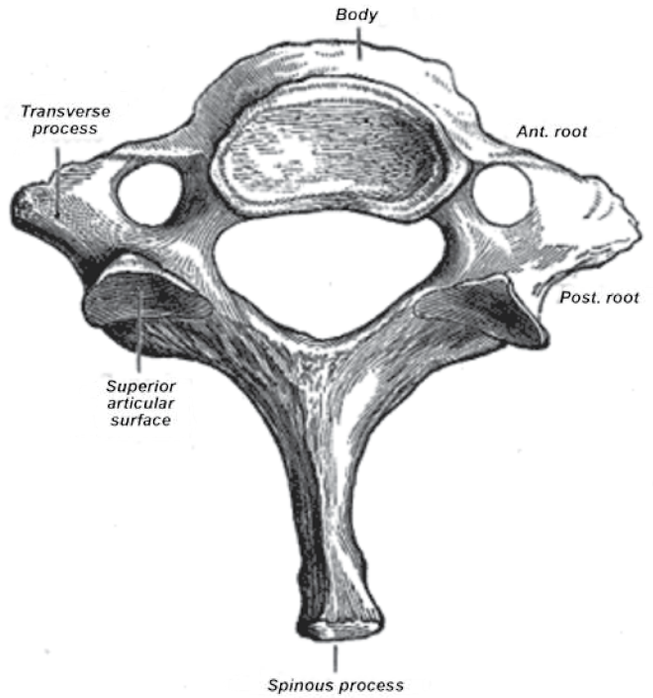
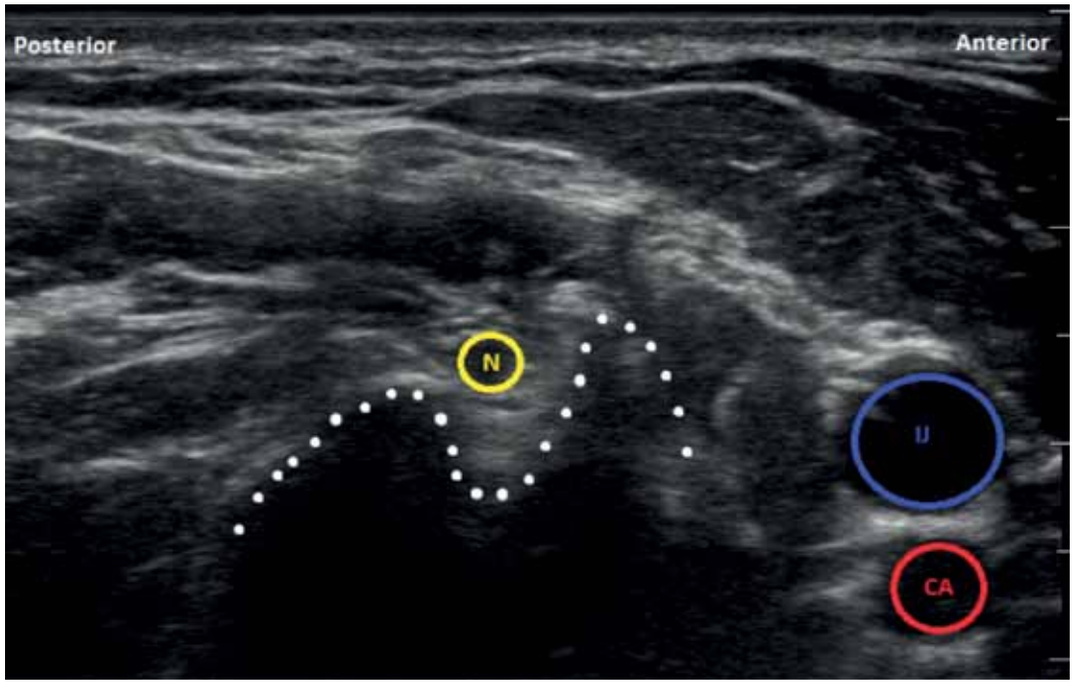


Figure 4. Axial transverse ultrasound image showing the anterior tubercle and posterior tubercle of the C5 transverse process as the "two-humped camel" sign. N indicates nerve root; CA carotid artery, IJ internal jugular.



RISK OF NERVE INJURY FROM SURGERY

Injury to the supraclavicular nerve as a consequence of surgery is high, and performing a superficial cervical plexus block or a supraclavicular nerve block may implicate the anaesthetist as a potential cause of post-operative altered sensation in the distribution of the supraclavicular nerve. Significantly, this can affect the breast and nipple area. In two small retrospective studies looking at the rate of post-operative numbness in the supraclavicular nerve distribution following clavicle plating, the rate of numbness was found to be 55.3 per cent in one study[34] and 45.7 per cent in the other[35]. In the second study there was a significant difference in the rate of numbness depending on whether the surgeon used a horizontal or vertical incision (with a vertical incision being less likely to injure the supraclavicular nerves). Thirteen of 21 patients (62 per cent) with a horizontal incision reported the presence of numbness. In comparison, only three of 14 patients (21 per cent) with a vertical incision reported numbness ($p = 0.019$)[35]. In the first study, two of 38 patients (5.2 per cent) reported being significantly bothered by their numbness and, in the second, five of 35 (14.2 per cent) reported being very or extremely bothered by their numbness at follow-up beyond 12 months.

There is a well-recognised association between fracture of the clavicle and injury to the brachial plexus, which usually occurs following supraclavicular high-energy traction injuries[36]. Direct injury to the brachial plexus from clavicular bone fragments occurs less frequently, in the order of 1 per cent[37].

The incidence of brachial plexus injury (transient or otherwise) after clavicle surgery is estimated at between 0 and 1.5 per cent[15]. Cases of reported brachial plexus injury in this setting have a characteristic presentation of unremitting radicular pain, profound weakness and sensory loss in the immediate post-operative period[15]. Such a complication would be particularly devastating for the young active patients that typically undergo surgical management of clavicle fractures.

A retrospective cohort study of all patients referred to the Peripheral Nerve Injury Unit at the Royal National Orthopaedic Hospital in the UK suggests delayed fixation is a risk factor for post-operative brachial plexus injury occurring. The study reviewed all patients referred with brachial plexus injury following fixation of clavicle between September 2000 and September 2011. Patients with symptoms of brachial plexus injury prior to clavicle fixation were excluded. The cohort comprised 21 patients and all of them had a significant delay between the time of injury and the time of surgery with a mean of 19 days. It is thought the brachial plexus becomes tethered to the underside of the clavicle at the fracture site by the inflammatory process associated with callus formation and subsequent mobilisation of fracture fragments results in a traction injury to the plexus[38].

RISK OF NERVE INJURY FROM REGIONAL ANAESTHESIA

The risk of serious adverse events following superficial cervical plexus block seems low. A meta-analysis looking at complications following superficial or deep cervical plexus blockade for carotid endarterectomy found that out of 2533 superficial cervical plexus blocks there were no serious complications related to the block[39].

There is a case report of superficial cervical plexus neuropathy and chronic pain under the mandible after superficial cervical plexus block, which arguably could have been avoided if only the supraclavicular nerve was blocked[40].

Furthermore, a study of 273 patients undergoing elective shoulder/upper arm surgery with a single shot interscalene nerve block performed with nerve stimulation using a large volume of bupivacaine (40-50ml depending on weight) looked at sensory deficits of the superficial cervical plexus at 24 hours and 31 days[41]. All symptomatic patients were again followed up at six months. Not surprisingly, a proportion 21 of 273 (7.7 per cent, 95 per cent confidence interval 4-11 per cent) had superficial cervical plexus neuropathy (numbness) at 24 hours. At 31 days, five of 273 (1.8 per cent, 95 per cent confidence interval 0.4-3 per cent) had superficial cervical plexus neuropathy and, at six months, all neuropathies had resolved. The transverse cervical and supraclavicular nerves were the most commonly affected. It seems logical that if the superficial cervical plexus can be injured when attempting to perform an interscalene block, it is likely that the risk of superficial cervical plexus injury is higher when attempting to block the superficial cervical plexus itself.

The first brachial plexus block was reported in 1885 when William Halsted applied cocaine directly to a surgically exposed brachial plexus[42]. Needless to say, the morbidity associated with open exposure of the brachial plexus limited its widespread use. Despite refinements in technique, interscalene block is regarded as carrying the highest risk of transient neurological dysfunction of all peripheral nerve blocks. A meta-analysis analysing 6017 interscalene brachial plexus blocks performed in seven studies between 1999 and 2005 found an overall rate of neurological symptoms following interscalene block of 2.84 per 100 blocks (95 per cent confidence interval 1.33-5.98 per cent) with no permanent injuries[43]. Of note, only a minority of these studies used ultrasound to perform the blocks and the rate of neurological symptoms may be altered with ultrasound use.

CONCLUSION

It seems likely that the clavicle receives dual innervation from both the superficial cervical plexus (medial clavicle) and the brachial plexus (lateral clavicle) but the exact contribution of each plexus is yet to be defined. Multiple block combinations have shown the ability to provide surgical anaesthesia or perioperative analgesia for clavicle fracture surgery, but two blocks are probably required. A superficial cervical plexus block or supraclavicular nerve block in addition to an interscalene block is likely to be adequate for a regional-only technique, if so desired. However, for the patient where avoiding the potential hazards of an interscalene block is important, other techniques, such as a C5 nerve root injection, may have role. The utility of pectoral nerve block for control of clavicular fracture pain warrants further evaluation. Further investigation to obtain a better understanding of the differences in analgesia requirements between the two operative techniques for clavicle fracture surgery (plate and intramedullary fixation) is warranted.

In summary, best practice for anaesthetic management of clavicle fracture surgery is yet to be defined. It will likely require a randomised-control trial with patients randomised to receive superficial cervical plexus block, interscalene block, or both, using low volumes of local anaesthetic, ultrasound guidance and performing the superficial cervical plexus block at the C4 level to avoid cross contamination of local anaesthetic between the two plexuses[10].

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Strategies to reduce emergence agitation in children

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INCIDENCE AND DEFINITIONS

Emergence agitation (EA) is a very common issue after anaesthesia in children. The incidence of EA varies widely in individual randomised-controlled trials (RCTs) and depends on the definition used and the clinical setting studied. As an overall estimate of the extent of the problem, approximately one third of children will experience EA after sevoflurane anaesthesia. This figure is based on the 37 per cent incidence of EA in the 6281 children in the sevoflurane control arms of a recent Cochrane systematic review[1].

The term "emergence delirium" (ED) is also commonly used, often interchangeably with EA. The term EA is preferred for this article as recent research suggests that a relatively low proportion of agitated children are genuinely delirious[2,3]. It is possible that ED is a subset of EA. Others have introduced the term "early post-operative negative behaviour" (e-PONB) encompassing EA, ED and pain, with separate definitions for EA and ED[4].

There is no universal agreement on a definition of EA. At least 16 different scales have been used to assess EA[5] but the most widely accepted scale at the present time is the Pediatric Anesthesia Emergence Delirium (PAED) scale. The PAED scale was first described[6] in 2004 and is frequently referred to as the only "validated" scale. The PAED scale (Figure 1) consists of five items, each of which is scored zero to four, giving a maximum score of 20. The first three items, which are said to be more delirium specific, are reverse scored. The last two items are forward scored. The designers of the scale did not define a threshold PAED score for EA. Some EA studies simply compare PAED scores but most set an arbitrary threshold PAED score for presence or absence of EA. At least five thresholds have been used (≥10, >10, ≥12, >12, ≥16) with research supporting a threshold PAED score >12[3]. Modifications of the PAED scale have also been described[7]. Due to the complexity of the PAED scale, researchers may also use a simple scale such as the Watcha scale (Figure 2)[8]. In the case of the Watcha scale, consolability is the difference between being classified as having EA (score ≥3) or not.

Figure 1. PAED scale

	Not at all	Just a little	Quite a bit	Very much	Extremely
The child makes eye contact with the caregiver	4	3	2	1	0
The child's actions are purposeful	4	3	2	1	0
The child is aware of his/her surroundings	4	3	2	1	0
The child is restless	0	1	2	3	4
The child is inconsolable	0	1	2	3	4

Figure 2. Watcha scale

	Score
Calm, quiet	1
Crying, but can be consoled	2
Crying, cannot be consoled	3
Agitated and thrashing around	4

AETIOLOGY AND RISK FACTORS

There is no known unifying mechanism for EA, however risk factors have been well described. These include preschool aged group, pre-operative anxiety, certain temperaments (for example, poorly adaptable), ophthalmological and ear, nose and throat (ENT) procedures, sevoflurane or desflurane anaesthesia, and inadequate analgesia at the time of emergence. EA can certainly still occur in the absence of pain. This has been demonstrated in studies in the settings of MRI scans or surgical procedures with "effective" regional blocks (for example, caudal block with no haemodynamic response to surgical stimulation).

A wide variety of pharmacological agents that delay the emergence from sevoflurane anaesthesia also have been observed to reduce EA. This suggests that "sevoflurane washout" may be a possible unifying mechanism for their effectiveness. That is, by delaying emergence after cessation of sevoflurane, a child might emerge with a sevoflurane brain concentration of say 0.03-0.05 per cent rather than the more usual 0.1-0.2 per cent, but this is purely speculative. Additional analgesia may help explain the benefits demonstrated in some studies, particularly in the settings of

painful procedures where an analgesic intervention has been studied but inadequate analgesia has been given to control group patients[1,9].

CONSEQUENCES OF EA

EA is usually self-limiting with resolution within 15-30 minutes of emergence. However, the two main issues with EA are self-injury and dissatisfaction. The agitated child may thrash around resulting in injury, including dislodgement of intravenous cannulae or other indwelling devices. EA can certainly result in unsatisfied and distressed parents, recovery-room staff and anaesthetists. One study has suggested an association between emergence agitation and new onset post-operative maladaptive behaviour after returning home from hospital[10]. However, these findings are questionable as the measure used for this research is not well validated and the study counted the children with negative behaviour, but did not consider those whose behaviour improved post-operatively. Nevertheless, the issues of self-injury and dissatisfaction are reason enough to consider strategies to reduce EA, especially in the high-risk pre-school population.

INTERVENTIONS TO REDUCE EA

Recent systematic reviews with meta-analyses provide an overview of effective interventions either compared to sevoflurane anaesthesia or as adjuncts to sevoflurane anaesthesia[1,11,12,13]. The largest of these is a Cochrane systematic review, which included 158 RCTs involving 14,045 children[1]. Although there are limitations with these reviews, in particular heterogeneity in the clinical settings studied and the definitions of EA, they do provide a useful overview to guide clinical practice. Effective and ineffective interventions are summarised in Table 1. The greatest body of evidence exists for propofol, fentanyl, α_2-agonists (particularly dexmedetomidine) and halothane. Selected interventions are discussed in greater detail below.

Table 1. Summary of effective and ineffective interventions for sevoflurane EA

Effective	Ineffective
Propofol	Desflurane
Fentanyl	Isoflurane
Dexmedetomidine	Midazolam premedication
Clonidine	Parental presence at emergence
Halothane	Gradual sevoflurane cessation
Ketamine	Lower sevoflurane concentration during maintenance
IV Midazolam at end	
Analgesia	
Various sedatives	
N2O washout	

PROPOFOL

Propofol has been studied in many ways to reduce EA and can be effective as either total intravenous anaesthesia (TIVA), as infusion throughout maintenance, as transition at the end (3mg/kg over three minutes), or as a bolus at the end (1mg/kg). Given our knowledge of the duration of action of propofol, it's not surprising that studies of propofol used only in the early stages of anaesthesia (for induction only, or as a 1mg/kg bolus shortly after induction) did not find a reduction in EA (Cochrane). Unfortunately the different propofol interventions have not been compared directly against each other in the same RCT.

Meta-analysis of 14 studies found that propofol TIVA reduced the incidence of EA to about one third when compared with sevoflurane induction and maintenance[1]. Switching to propofol maintenance after sevoflurane induction may be more convenient if a gaseous induction is preferred, and is also effective in reducing EA[1]. Propofol administered as a 1mg/kg bolus at the end of sevoflurane anaesthesia has been successful in reducing EA in some RCTs but not in others, with meta-analyses showing a benefit, but not of the same magnitude as TIVA[1,14]. One of the 1mg/kg studies that found a benefit for propofol used an unusually high PAED score threshold of ≥16 for EA[15].

In view of the mixed results with propofol 1mg/kg, our group of researchers investigated a simple late transition to propofol (3mg/kg over three minutes) manually administered from a syringe at the end of sevoflurane anaesthesia[16]. EA was reduced to one quarter of the incidence in children undergoing MRI scans where pain was not a confounding factor (7 per cent versus 29 per cent with EA defined as PAED score >12)[16]. Emergence times were prolonged by eight minutes with this approach[16], whereas propofol 1mg/kg prolongs emergence by four minutes (weighted mean difference from meta-analysis[14]). Outside of the MRI suite, where there is easy access to both the IV cannula and the anaesthetic machine, it is possible to make the transition to propofol prior to the end of the procedure to minimise emergence time in PACU. Others have also described and advocated their personal techniques of transition to propofol in the latter stages of sevoflurane anaesthesia to reduce EA[17,18].

FENTANYL

Recent meta-analysis shows that fentanyl is an effective adjunct to sevoflurane anaesthesia for reducing EA by a variety of routes, in particular by either intravenous (IV) or intranasal routes[1]. In contrast, an earlier systematic review with far fewer included studies reported that intranasal fentanyl was effective but not IV fentanyl when subgroup analyses were performed[11].

The nasal route has been successfully used in children undergoing insertion of grommets to prevent EA with these studies suggesting an optimal dose of 2mcg/kg[19–21]. As well as being a viable option for prevention of EA in a child with no IV access, intranasal fentanyl is also an option for treating established EA in a child in with no IV access, including the scenario where a child has dislodged their IV cannula as a consequence of EA.

Fentanyl can be an effective adjunct even in the absence of pain. This has been demonstrated in the MRI setting where 1mcg/kg IV at the end of sevoflurane anaesthesia reduced EA without increasing side effects[22]. Fentanyl has recently been directly compared against other EA adjuncts (propofol bolus[23], clonidine[4]) in two RCTs in the potentially pain-free settings of surgery with "effective" regional blocks. A comparison of IV fentanyl 1mcg/kg versus propofol 1mg/kg versus placebo administered at the end of sevoflurane anaesthesia in children undergoing inguinal hernia surgery with caudal blocks found that fentanyl and propofol were equally effective in reducing EA, but there was more post-operative nausea and vomiting (PONV) with fentanyl[23]. Unfortunately there was no "fentanyl plus propofol" group to assess any additive or synergistic effects of these interventions. This is consistent with an identified deficit of RCTs assessing multimodal approaches to EA prevention[1]. A comparison of IV fentanyl 2mcg/kg versus IV clonidine 2mcg/kg versus placebo administered at the start of sub-umbilical surgery in children with "effective blocks" found that only fentanyl reduced EA (but there was more PONV with fentanyl)[4]. In terms of the ability to generalise these results, it is important to note that in these two studies, no prophylactic anti-emetics were administered, which is likely to be contrast to the actual clinical practice of many anaesthetists.

CLONIDINE

In individual RCTs, clonidine can be effective in reducing EA via several routes (oral, IV, caudal) and at a range of doses[1]. However, when looked at systematically, RCT evidence for effectiveness of clonidine appears limited to the setting of surgery with regional blocks (seven of the nine studies in Cochrane review meta-analysis) rather than ENT surgery[1]. In terms of IV clonidine, the majority of studies have used a dose of 2mcg/kg. Few studies have looked at lower doses, with mixed results. Clonidine 1.5mcg/kg IV was ineffective in reducing EA in children undergoing adenoidectomy[24]. The pilot study for this trial used 2mcg/kg but this dose resulted in sedation that delayed discharge[24]. An RCT comparing 1mcg/kg versus 2mcg/kg versus placebo in children undergoing cataract surgery with sub-tenon blocks found both doses effective, but discharge was delayed with 2mcg/kg[25]. The RCT that studied clonidine 3mcg/kg reported sedation that delayed discharge and a significant reduction in blood pressure[26]. A recent prospective audit of clonidine use for adenotonsillectomy has been reported[27]. This audit did not standardise analgesia, EA adjuncts or clonidine dose (that is, everything was at the discretion of the treating anaesthetist). It found that clonidine did not reduce EA, and resulted in dose-dependent prolongation of emergence. There was an emergence half-time of 25 minutes with 2mcg/kg clonidine compared with 10.8 minutes without clonidine. However, this audit had a very low rate of EA in the "no clonidine" patients (around 11 per cent) almost certainly due to effective use of propofol, fentanyl and other analgesics, which is often lacking in the control arms of RCTs[27].

DEXMEDETOMIDINE

Dexmedetomidine has been extensively studied as an adjunct to prevent EA and the results are far more impressive than those observed with clonidine. The magnitude and consistency in effect across trials is evident when comparing the forest plots for dexmedetomidine against those for clonidine in either the Cochrane systematic review[1] or in another recent systematic review looking specifically at intraoperative α_2-agonists on post-operative behaviour in children[13]. Other reported benefits of intraoperative dexmedetomidine include reduction in EA with or without regional blocks, reduction in EA with adenotonsillectomy, reduction in rescue analgesia, reduction in PONV and a minimal increase in emergence time (statistically significant, but not necessarily clinically significant)[28–32].

However, financial cost remains a significant hurdle to clinical use, limiting or preventing access in most workplaces. A significant increase in dexmedetomidine use is expected if and when it becomes more affordable, either administered IV intraoperatively or as intranasal premedication. In terms of IV dosing, numerous regimens have been studied, including IV doses of 0.15, 0.3, 0.5, 1mcg/kg given either in the early or late stages of anaesthesia, and IV infusions throughout anaesthesia with or without loading doses[1]. In clinical practice, the optimal IV dosing regimen will be context-specific and depend on whether the effects of dexmedetomidine (for example, reduced heart rate and blood pressure, MAC-sparing, analgesia) are desired intraoperatively, or only for emergence. Dosage and timing of administration may influence emergence time and haemodynamics. A predictable drop in heart and blood pressure is reported in RCTs and is typically described as being not clinically significant (despite statistical significance), but this obviously depends on an individual patient's comorbidities and the clinical scenario. Bolus administration of IV dexmedetomidine is recommended as a loading dose infused over 10 minutes, although one group of researchers has recently investigated the hemodynamic effects of various doses of IV dexmedetomidine given as a rapid five-second bolus to healthy children[33]. One group has attempted to determine the optimal IV dose of dexmedetomidine for the prevention of EA after desflurane anaesthesia for tonsillectomy or adenoidectomy in children and concluded that the 95 per cent effective dose was 0.38mcg/kg[34].

There are numerous studies now looking at dexmedetomidine (nasal or oral) for premedication with recent systematic reviews summarising the dexmedetomidine versus. midazolam trials[35,36]. Some of these premedication trials also investigated EA as an outcome measure. The systematic reviews conclude that dexmedetomidine performed either better than or equal to midazolam for induction outcomes (parental separation, mask acceptance, etc) and reduced the incidence of EA35,36. The intranasal route is more commonly studied than the oral route for dexmedetomidine. In terms of guiding intranasal dosage, a very recent RCT compared intranasal dexmedetomidine 1mcg/kg versus 2mcg/kg versus placebo given 45 minutes prior to induction and found a dose-dependent reduction in EA, dose-dependent reduction in MAC_{LMA}, emergence time prolonged six and eight minutes respectively but no difference in time in PACU[37]. At our institution we recently introduced intranasal dexmedetomidine premedication in very selected cases (due to cost constraints) with the most commonly used dosage being 1.5mcg/kg given 45 minutes pre-induction. We are currently auditing our results.

OTHER VOLATILE AGENTS VERSUS SEVOFLURANE

Halothane has been extensively compared with sevoflurane in more than 30 RCTS and meta-analysis shows a halving of the rate of EA[1,12]. There is clearly no benefit for desflurane maintenance compared to sevoflurane in reducing EA with six studies meta-analysed[1] plus one further RCT[7] published after the search cut-off date in the Cochrane review. Meta-analysis of six RCTs comparing isoflurane and sevoflurane found no difference in EA[1] with just one of the six individual isoflurane RCTs finding a benefit[38].

OTHER ADJUNCTS

Ketamine either as a bolus of 0.25mg/kg at the end anaesthesia or as premedication may reduce EA[1].

Meta-analysis of seven RCTs shows no difference in EA with midazolam premedication; however IV midazolam at the end (but not the beginning) of anaesthesia may reduce EA[1].

A variety of analgesics including various opioids, tramadol, ketorolac and regional blocks have reduced EA, but the adequacy of control group analgesia needs to be considered when interpreting these studies[1].

Various agents with sedative properties including an antihistamine (hydroxyzine) may reduce EA[1]. There are mixed results with magnesium use[1,39].

One extremely small but interesting study found EA was reduced by using nitrous oxide to washout sevoflurane (that is, in the intervention group nitrous oxide was left on while sevoflurane was washed out until the BIS had risen to 80)[40].

Two RCTs investigating parental presence at emergence found no difference in EA[1].

CONCLUSION – A GENERAL APPROACH FOR A CALM EMERGENCE

There are many pharmacological interventions that can reduce EA and improve the likelihood of the desirable calm emergence. Anaesthetists on a quest for a simple, universally effective, one-size fits-all magic bullet to prevent EA with no adverse effects and no prolongation of emergence are likely to be disappointed. However, a context-specific, multimodal approach to EA prevention can result in reduced EA and greater satisfaction. This approach is analogous to PONV prophylaxis or intraoperative analgesia loading to minimise pain upon emergence: that is, stratify the risk factors (patient and procedure) and decide on the number and nature of prophylactic EA interventions.

1. Ensure adequate analgesia for painful procedures at the time of emergence, including IV fentanyl (intranasal fentanyl if no IV access).
2. Emerge on propofol rather than a volatile agent if there is IV access – choose one of the following: TIVA, switch to propofol maintenance after gas induction, transition from volatile maintenance to propofol late in the procedure, or a propofol bolus at the end. Emergence on propofol may have additional benefits of reduced airway reactivity[41] and reduced PONV.
3. Consider an α_2-agonist, particularly dexmedetomidine if it is available to you (either IV intraoperatively or as premedication in the anxious child).

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Intraoperative awareness and general anaesthesia for caesarean delivery: A fresh look at an ongoing problem

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INTRODUCTION

The evolution of general anaesthesia for caesarean delivery has created a certain mystique among anaesthetists, obstetricians, midwives and mothers. Our past and current colleagues have strived by means of research, reviews, confidential enquiries and guidelines to facilitate performing this surgery in the safest way for the mother and baby.

To define safety is not as easy as it may seem. While one endeavours to employ good evidence in every medical decision, personal opinion is necessarily employed to weigh the importance of certain outcomes against competing ones. Frequently, little evidence is available, and experience and extrapolation from other settings are vital.

Sometimes by historical accident, or perhaps due to common cognitive biases, some evidence and opinion is given more weight than others and gains a momentum that is difficult to slow.

In this article, concentrating on awareness and pharmacology, we question some of the opinions and guidelines about providing general anaesthesia for a caesarean delivery, and present arguments and evidence for weighing the risks and benefits differently.

ACCIDENTAL AWARENESS DURING GENERAL ANAESTHESIA (AAGA) FOR CAESAREAN DELIVERY

Obstetric general anaesthesia has an unfortunate history with respect to accidental intra-operative awareness. In 1959, Hamer Hodges et al. described a technique for obstetric general anaesthesia involving thiopentone and suxamethonium followed by maintenance with nitrous oxide in oxygen[1]. Ten years later, a series of patients anaesthetised with this technique were interviewed, 17 per cent of whom described unpleasant recall, and 6.7 per cent recounted recall with pain[2].

In the modern era, the situation is still less than perfect. The anaesthetic environment in obstetrics creates a perfect storm of risk factors for awareness: rapid sequence induction, higher incidence of airway difficulty, pharmacokinetic changes of pregnancy, and often urgency. An estimated rate of self-reported AAGA during caesarean delivery in the United Kingdom (UK) is one in 670, more than 10 times the average risk across all anaesthesia sub-specialties[3]. This is comparable to an Australia-New Zealand prospective study estimating a risk of one in 382[4].

AAGA reported by the UK National Audit Project 5 (NAP5) refers to explicit recall of operative events during general anaesthesia. This is only one of many definitions of awareness. “Consciousness and memory are dissociable cognitive processes”[5] and it is clear from isolated forearm technique (IFT) studies that response to even complex commands under relaxant anaesthesia occurs much more frequently than explicit recall of intraoperative events[5,6]. Tunstall first described the IFT in 1977 on obstetric patients. He documented four out of 12 mothers who moved their fingers in a “precise and direct response” to taped verbal instructions during surgery[6]. No patient reported postoperative recall. This state of responsiveness without explicit recall is common during caesarean delivery, even with modern anaesthetic techniques[7], and the term “dysanaesthesia” has emerged to describe it[8].

Aside from the increased probability of recall, this carries ethical and philosophical implications. Does providing amnesia without unconsciousness satisfy our responsibility to patients?

Determining the true rate of AAGA in the obstetric population is challenging and depends on the research methodology used. Prospective studies using the modified Brice interview detect a greater incidence of AAGA than other methods[5]. Accidental awareness carries a significant risk of psychiatric morbidity including post-traumatic stress disorder (PTSD)[9]. Furthermore, lack of pain perception during awareness does not necessarily seem to be protective against PTSD[9]. Avoidance behaviour features prominently in PTSD – the impact of this on reporting rates is not clear. In a 2007 series, 85 per cent of patients reported their AAGA to friends or relatives, but only 50 per cent reported it to hospital staff[10]. In at least one well-chronicled account of definite awareness, the patient later recoiled from questioning and began denying any recall of intraoperative events to the investigators[11]. The spontaneous self-reporting of AAGA to NAP5 may represent the tip of the iceberg.

INDUCTION AGENTS: HAS THIOPENTONE HAD ITS DAY?

Recent high-profile publications have called into question the ongoing place of thiopentone in obstetric anaesthesia[12–15]. It can be argued that propofol is the preferred induction agent for caesarean delivery when maternal haemodynamics are robust.

There does not appear to be a clear advantage to either drug in terms of maternal or neonatal outcomes[16]. A Cochrane meta-analysis is underway to shed further light on this assumption. Proponents of thiopentone highlight its longer history of post-marketing surveillance. There is, however, a growing list of human and institutional factors that are probably pushing the balance towards the use of propofol[13].

Organisational factors

Anaesthesia as a specialty arguably leads the medical profession in its exploration of human factors and risk management in reducing patient harm. The modern anaesthetic environment demands a close examination of thiopentone within this framework.

Advantages of propofol include: Greater familiarity for most modern anaesthetic trainees, less potential for drug errors and syringe swaps, reliable supply, no need for reconstitution and lower relative cost[13].

Syringe swaps are a recurring theme in accidental awareness, implicated in 14 per cent of cases of obstetric AAGA in NAP5. These events typically involve sterile water, antibiotic or local anaesthetic being given at induction instead of thiopentone[14].

Drug licensing remains a concern for many anaesthetists. In the UK, thiopentone is only licensed for use in pregnancy in doses up to 250mg;[13] however, this restriction does not appear on the Australian therapeutic goods administration prescriber information. The dose recommended by the authors of NAP5 is at least 5mg/kg[14]. Propofol remains off-label in pregnancy. Many drugs used in obstetrics are unlicensed, but concerns about licensing alone should not preclude their use[17].

In a 2011 survey of UK anaesthetists, 93 per cent of respondents used thiopentone as the induction agent of choice for caesarean delivery. The most frequently cited impetuses were “for historical reasons” in 37 per cent and “to reduce awareness” in 31 per cent[17]. The results of NAP5 have shown the latter notion to be, in practice, spurious.

Pharmacological factors

Desirable features of an induction agent include rapid predictable loss of consciousness, haemodynamic stability and minimal adverse impact on the foetus. Thiopentone may marginally outperform propofol in this regard. Extrapolating these observations to meaningful patient outcomes is not without its challenges.

The haemodynamic effects of induction agents in common use have been well characterised. At typical induction doses, propofol dulls the response to laryngoscopy and the catecholamine surge more effectively than thiopentone, resulting in lower blood pressure and a greater incidence of hypotension[16]. Induction of anaesthesia in the septic or hypovolaemic patient creates specific challenges. Ketamine is associated with an improved haemodynamic profile[18], reliable amnesia and acceptable indices of early neonatal wellbeing[19]. It is a reasonable choice in this setting. Excessive doses of thiopentone administered to haemodynamically compromised women were discussed in the most recent MBRRACE-UK report on maternal mortality. This contrasts somewhat with NAP5, which criticised the inadequate dosing of thiopentone. The authors of both publications questioned “whether thiopental should continue as the drug of choice for obstetric anaesthesia”[15] and “whether thiopental should continue to have a place”[14], although seemingly for different reasons. This serves to illustrate the particularly narrow therapeutic index for this drug.

Predictability is a highly desirable drug characteristic. It has been said that thiopentone is less variable than propofol, although we have not found convincing published support for this contention. Moore documented similar variance in induction dose required for either agent when titrating to loss of lash reflex[16]. The propofol plasma concentration to prevent movement to skin incision in 50 per cent of people (cp50) has a normalised standard deviation of around 15 per cent[20], greater than the 10 per cent observed for the minimum alveolar concentration (MAC) of volatiles. The intravenous route (when compared to the inhalational route) exposes inter-individual pharmacokinetic differences that will further compound this variability.

Traditional rapid-sequence induction demands a rapid onset of anaesthesia. In non-pregnant patients, 4mg/kg thiopentone and 2mg/kg propofol have comparable onset times, averaging 43 and 46 seconds respectively[21]. Return to consciousness is significantly longer for propofol, at 529 versus 330 seconds. Some patients receiving thiopentone are able to provide a positive IFT response at only 114 seconds post-induction[21]. One explanation for these observations may be that thiopentone has intrinsically faster onset, so it is given in a relatively lower dose.

Determining dose equivalence is not without its challenges. Equisedative plasma concentrations are about four times higher for thiopentone, compared to propofol. However, equiamnesic concentrations are about seven times higher for thiopentone, implying more profound amnesia for a given degree of sedation when propofol is used[22]. Importantly, this also suggests that propofol will be superior in ensuring greater amnesia following induction.

Neonatal and maternal outcomes

Key outcome measures, including neonatal wellbeing and maternal blood loss, are comparable when thiopentone or propofol are used for induction of general anaesthesia for caesarean delivery[16]. Thiopentone has been observed to produce higher Apgar and neurobehavioural scores[23] although this was in the setting of relatively low doses of thiopentone and has been challenged in more recent studies[24].

At typical induction doses, neither thiopentone nor propofol demonstrate a sufficient plasma level to reliably prevent awareness by the time of skin incision and delivery during elective caesarean delivery[7,16,21].

Induction agents and the pharmacological changes in pregnancy

Consideration of the pharmacokinetic changes of term pregnancy is prudent. The pregnant patient has a blood volume expansion of about 45 per cent. In physiological modelling of drug behaviour, this would represent a much larger initial volume of distribution. The increased cardiac output occurring in pregnancy can be expected to accelerate the redistribution and early clearance of intravenous induction agents, the predicted net effect being a reduced peak plasma concentration and a more rapid offset of effect. After a 2mg/kg bolus dose of propofol, plasma concentrations have been observed to be, on average, lower in pregnant compared to non-pregnant patients[25].

Target-controlled infusions (TCI) of propofol have been used in obstetric anaesthesia without modifications for pregnancy. However, it is not clear whether target bias exists in the algorithm accuracy for the obstetric population. The mean absolute prediction error of Marsh TCI is about 35 per cent in both pregnant and non-pregnant patients[26]. It is worth considering the potential for the algorithm to underestimate the central compartment volume and central compartment clearance.

The MAC sparing effect of pregnancy for volatile anaesthetics may not be directly applicable to intravenous hypnotic agents. The weight-based dose of thiopentone to produce unconsciousness in early pregnancy appears to be 17 per cent lower than for non-pregnant women[27]. The mean plasma concentration of propofol required to produce unconsciousness during pregnancy seems to be relatively unchanged[26,28].

VOLATILE ANAESTHETIC AGENTS

After rapid-sequence induction of anaesthesia, the redistribution of the induction drug in the pregnant patient is rapid. When induction to delivery time is more than five minutes, the plasma concentrations of both propofol and thiopentone are significantly below those required for a high probability of unconsciousness[16,21]. To ensure anaesthesia is maintained, one should not rely on the lasting effects of an induction dose of intravenous agent. A sufficient effect-site concentration of volatile anaesthetic must be achieved.

Alveolar partial pressure and effect site concentration

As anaesthetists, we have no direct measure of drug-induced inhibition of memory formation and we use indirect measures to estimate the probability of amnesia. It is fortuitous that the amnesic effects of volatile agents occur at subanaesthetic concentrations[29]. MAC awake is thus a useful surrogate for the probability of amnesia. Studies of MAC awake occur in the absence of noxious stimuli[29]. The effect of intense surgical stimulus on arousal and potentially on recall cannot be dismissed. Clearly there is a distinction between the concentration of anaesthetic agent required for a high probability of amnesia in unstimulated patients compared to patients undergoing surgery[29,30]. Can we extrapolate loss of recall for words, pictures or emotionally charged events to the loss of recall for a Pfannenstiel incision[31]?

Measures of MAC assume sufficient time for the effect-site concentration or biophase to equilibrate with the alveolar concentration. Physiologically based pharmacodynamic modelling assumes this process to occur in an exponential manner and is described by the rate constant for equilibration $t_{1/2}$ keo. Estimates of this half time for biophase equilibration are 4.3 minutes for sevoflurane and isoflurane and 2.3 minutes for desflurane[32]. The time for biophase equilibration with nitrous oxide is not well studied; however, we assume it to be rapid. This time delay is clearly of importance in achieving a desired effect-site concentration of volatile prior to skin incision. This premise seems to be neglected in published recommendations for obstetric general anaesthesia. Many modern guidelines still advocate minimal-inspired concentrations of volatile agent[33,34], which is a practice we wish to challenge. The rate of rise of alveolar to inspired ratio (FA/FI) has been well characterised for inhalational anaesthetic agents in current use[35]. The increased cardiac output of pregnancy can be expected to delay the rise in alveolar partial pressure[4]. Delivering an inspired concentration higher than one hopes to achieve in the alveoli (overpressuring) can attenuate the clinical effects of this change. In the presence of significant ventilation perfusion inequality (as may occur with airway closure in pregnancy), the alveolar partial pressure may be greater than the arterial partial pressure during wash in[36]. These changes, if not appreciated, can be expected to further delay the achievement of a sufficient brain partial-pressure of anaesthetic agent.

Isolated forearm studies repeatedly demonstrate unsettlingly high rates of positive responses when sub-MAC (and near-MAC) end-tidal concentrations of volatile agents are used during caesarean delivery[7,37,38]. In one study of obstetric patients, 97 per cent of patients responded with finger flexion to command during skin incision while anaesthetised with 0.5 per cent halothane and 50 per cent nitrous oxide[38].

We find the above considerations compelling reasons to overpressure the volatile agent immediately after induction and prior to foetal delivery.

MAC reduction in pregnancy

Pregnancy decreases the MAC of volatile anaesthetic agents, although the magnitude of this reduction in humans is not well established. The estimated MAC sparing effect for isoflurane in early human pregnancy is 28 per cent and, importantly, the narrow inter-individual variability appears preserved[39]. Reduction in MAC is presumed to apply to desflurane and sevoflurane, but to our knowledge this has only been demonstrated in animals.

Given that MAC-sparing drugs typically reduce MAC by a greater proportion than MAC awake[20], can it be assumed that the MAC sparing effect of pregnancy will reflect a similar magnitude of reduction in MAC awake or amnesia?

Anaesthetic agents and uterine atony

Potent volatile anaesthetic agents are known to impair myometrial contraction and confer risk for uterine atony. An impaired response to oxytocin becomes apparent around 0.75 MAC in vitro[40]. A Cochrane meta-analysis noted a greater fall in haematocrit and a greater estimated blood loss (by 127mL) at caesarean delivery when general anaesthesia was used compared to regional anaesthesia[41]. This did not translate into a greater need for blood transfusion in the study populations.

Nitrous oxide appears to preserve the ability of the uterus to contract, although this looks to be implied from work done in 1969 on non-pregnant *in vitro* specimens of human myometrium[42].

Impact on the foetus

Foetal exposure to anaesthetic agents prior to delivery is an unwanted but unavoidable consequence of general anaesthesia. Appropriate staff and facilities for support of the newborn must be at hand. In the truly compromised foetus the underlying pathology, and not the anaesthetic agents, is the greater concern. The modulating effects of anaesthetic agents on intrauterine resuscitation are unclear; however, maintenance of uterine perfusion pressure and oxygen delivery and avoidance of caval compression are priorities.

A 2012 Cochrane review comparing general to regional anaesthesia for elective caesarean delivery reported no statistically significant difference in Apgar scores, cord blood gases, neurological adaptive scores or need for oxygen resuscitation[41]. This supports the contention that "the effect on the foetus of anaesthetic agents … is innocuous and reversible"[43] and should not preclude the provision of adequate anaesthesia to the mother.

NITROUS OXIDE

Nitrous oxide has been advocated for its disproportionately rapid wash-in (the concentration effect), its properties as a carrier gas (the second gas effect) and as a means of sparing the dose of potent volatile agents.

Its low potency imposes some restrictions on the use of higher fractions of inspired oxygen (FiO2). High FiO2 administered to the mother increases foetal oxygen content and partial pressure of oxygen[44]. Serum markers of free radical mediated oxidative stress are also increased in both the mother and neonate[45]. It is unlikely that hyperoxia is of benefit in the elective setting – and may cause harm. Any potential benefits of maternal oxygen therapy to a compromised foetus are speculative[46].

To our knowledge, the impact of pregnancy on the MAC of nitrous oxide in humans has not been studied. To assume that pregnancy is MAC sparing for nitrous oxide deserves thought, because of the distinctly different pharmacodynamic effects of this drug compared to the halogenated volatile agents.

The ENIGMA trial brought into question the routine use of nitrous oxide and changed the anaesthetic landscape for a generation of training anaesthetists. No difference was observed between groups in the primary endpoint (duration of hospital stay), however, the secondary endpoints of wound infection, pneumonia, atelectasis and severe nausea and vomiting (PONV) were increased in the nitrous oxide group compared to the 80 per cent oxygen group[47]. There may be some movement back toward the use of nitrous oxide since the publication of ENIGMA-II in 2014. This larger trial supported the observation of an increased incidence of PONV (15 per cent in the nitrous oxide group versus 11 per cent in the no nitrous oxide group), but demonstrated no increase in other adverse outcomes, including cardiorespiratory morbidity[48].

A follow-up study of 640 ENIGMA patients observed a significant reduction in chronic post-surgical pain in the nitrous oxide group suggesting a possible preventative analgesic effect of the drug[49]. In an as-yet unpublished study exploring this, with chronic pain as the primary outcome, nitrous oxide had no effect[50]. Chronic post-surgical pain is known to occur after caesarean delivery, albeit usually with minimal impact on quality of life[51]. Encouraging early observations regarding a protective role of nitrous oxide may not be actualised.

The high MAC awake to MAC ratio of 0.64 for nitrous oxide is relevant when predicting the probability of awareness in any given patient. Anaesthetic agents with a higher ratio of MAC awake/MAC are poorer providers of amnesia[52]. Delivery of one MAC may range from three multiples of MAC awake (nitrous free) to two multiples of MAC awake (volatile plus 70 per cent nitrous oxide) with potential implications for the probability of amnesia. Given that immobility (MAC) is mediated by drug effect in the spinal cord[53] and response to command (MAC awake) is more likely mediated by the brain, describing anaesthetic concentrations relative to multiples of MAC awake rather than MAC seems more logical.

Keeping these considerations in mind, nitrous oxide is a useful agent to rapidly achieve and maintain a desired depth of anaesthesia.

OPIOIDS

The MAC sparing effect of opioids is well documented, but how this translates to amnesia is not as clear. The reduction in MAC by co-administration of fentanyl is far greater than the reduction in MAC awake[54]. Fentanyl also appears to have minimal effect on the cp50 (response to command) for propofol, but a profound reduction on cp50 for movement[20]. Administration of opioids, while MAC sparing, may not confer a proportionate advantage in maintaining amnesia as their MAC reduction may suggest.

Opioids are a useful alternative to muscle relaxants to maintain controlled ventilation and satisfactory surgical conditions after foetal delivery. Paralysis is a major focus of psychological distress in victims of awareness, even in the absence of pain[14]. Neuromuscular blocking drugs increase the risk of awareness[14] and generate a focus for psychological trauma. Opioids have a robust role in obviating the need for muscle relaxants in the post-delivery period, but should not be expected to contribute significantly to the provision of amnesia, nor should their analgesic effect be expected to lessen the psychological impact on the patient if awareness occurs.

Opioid administration may be indicated at induction for maternal reasons. In the setting of pre-eclampsia, vigilance should be applied to ablating the hypertensive response to intubation, as this has been identified as a cause of direct maternal mortality[55]. Alfentanil and remifentanil are both efficacious in this regard, but both increase transient early neonatal respiratory depression[56,57]. If an opioid is indicated for maternal reasons, it should be given and the person responsible for neonatal care at birth made aware[55]. For reasons stated previously, we caution against an overzealous reduction in the dose of hypnotic anaesthetic, when opioid co-induction is used.

DEPTH OF ANAESTHESIA MONITORING USING THE BISPECTRAL INDEX (BIS)

The interpretation and utility of BIS is not without controversy. It is known that paralysis alone in brave volunteers can produce substantial reductions in BIS values, presumably due to the significant influence of electro-ocular and electromyographic signal processing[58]. The correlation of BIS value and depth of anaesthesia is drug sensitive, with nitrous oxide and ketamine having paradoxical effects. BIS has been shown to reduce the incidence of AAGA when compared to clinical signs; however, it is probably not superior to an approach incorporating end-tidal volatile monitoring with alarms set at <0.7 age-adjusted MAC[59]. When comparing BIS to isolated forearm technique (IFT) in general anaesthesia for caesarean delivery; 41, 46, and 23 per cent of patients demonstrated a positive IFT response at laryngoscopy, intubation and skin incision respectively. BIS was unable to reliably predict responders and non-responders at these three points. None of the 61 patients reported explicit recall[7].

BIS is designed to provide a prediction of the probability of recall. It is neither designed for, nor accurate at, predicting the likelihood of intraoperative responsiveness (as measured using the IFT) or patient movement. "Depth of anaesthesia" is arguably a misnomer[60].

It is clear that use of BIS does not prevent all cases of AAGA. Of course, no monitor alone can make any difference without an associated intervention, so there may be training and practice issues. The NAP 5 activity survey estimated that BIS was used in 2.8 per cent of anaesthetics in the UK during the audit period and in 4.3 per cent of cases of AAGA, the use of BIS was recorded[14]. Its use was thus over-represented. This may represent selective use of BIS in high-risk cases, and general lack of familiarity with its use, but highlights the potential for awareness despite the use of BIS.

BIS has been used successfully to achieve rapid wake-up, shorter recovery times and a lower total anaesthetic drug usage[59]. This approach as an anaesthetic sparing device has gained traction, with observational evidence correlating cumulative deep hypnotic time (BIS <40) with increased mortality and morbidity[61]. The "Balanced" trial currently recruiting may shed some light on the clinical utility of this MAC sparing approach in sick elderly patients.

It can be argued that using BIS as a tool to minimise anaesthetic usage and hasten wake-up is a goal dichotomous to its use in preventing awareness. Application of BIS has been advocated in general anaesthesia for caesarean delivery[4]; however, appropriate interpretation in this high-risk group may be challenging.

CONCLUSIONS

The rate of accidental awareness during general anaesthesia for caesarean delivery is known to be high. Nevertheless, this high incidence may well be an underestimate. The frequency and severity of the consequences may also be understated, with lack of pain not necessarily being protective. Awareness not only causes individual patient harm, but fractures the trust and relationship between anaesthetists and the community. Accidental awareness during general anaesthesia is not only a result of drug substitution errors or obvious inadvertent underdosing.

Propofol is a suitable alternative to thiopentone for induction of anaesthesia because of its greater amnesic properties and less potential for drug error. However, the lasting effects of the induction agents cannot be relied on to provide a high probability of unconsciousness as surgery begins and progresses. Inhaled agents need to be overpressured, aiming for a sufficient effect-site concentration to provide anaesthesia and amnesia. In practice, this probably means starting with an end tidal concentration many multiples above MAC awake, given the delay in end tidal to brain equilibration. Concentrations can be reduced if uterine atony becomes a problem.

After delivery of the foetus, nitrous oxide and opioids have a valuable role in obviating the need for muscle relaxants, thereby reducing the risk of awareness. Caution needs to be exercised, however, given nitrous oxide's high MAC awake to MAC ratio and the small contribution of opioids to reducing MAC awake.

The neonatal effects of anaesthetic agents appear to be transient and reversible and should not preclude the provision of adequate anaesthesia to the mother. Likewise, minimising anaesthetic delivery is not a suitable substitute for adequate resuscitation in the hypovolaemic patient.

In this discussion we have questioned traditional published recommendations for general anaesthesia in operative obstetrics, which, even lately, advocate heavy paralysis and light anaesthesia. We favour an approach designed to minimise the risk of accidental awareness, which may be significantly underdiagnosed and carries serious consequences.

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Remifentanil patient-controlled analgesia (PCA) on the delivery suite – past, present and future

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INTRODUCTION

Patient-controlled analgesia (PCA) is an established and efficacious delivery medium for post-operative pain relief, but its role in the management of pain in labour remains uncertain. Remifentanil is the most recent of numerous opioids to be trialled during labour using patient-controlled delivery and has been in use for over 15 years. Some centres report its use in more than 100 women per month without problems[1] and numerous studies attest to high levels of maternal satisfaction with its use. Recently, however, case reports of serious morbidity associated with its use have led to questions over its suitability for use on the labour ward[2-4]. This review explores the background to the use of remifentanil PCA on the delivery suite, the available evidence on whether it is an appropriate option to offer women in labour and future directions for its use.

HISTORICAL USE OF PCA IN LABOUR

The labour ward has had a prominent role in the development of patient-controlled analgesia as we know it today. In 1970, Scott published the first description of a PCA device in a paper, in which he presented findings on 56 women in labour who had received pethidine via a spring-loaded clamp that they would squeeze when in need of pain relief[5]. Administration of a dilute solution of the pethidine would pass down the giving set as long as the clamp was held open. The women were instructed to release the clamp when pain relief was adequate. Eighty-nine per cent of women regarded the method as "good" or "very good", and Scott believed "an enormous benefit was obtained merely *if the mother had personal control of analgesic administration*" (his italics)[5].

In 1976, Evans presented a study of women in labour using a digitally controlled syringe pump containing pethidine, with which the prescriber could determine the bolus dose, rate of delivery and the lockout time[6]. Interestingly, the patient was required to pass a test of simple reaction time in order to receive a bolus, with the intention that only those sufficiently alert would receive further analgesia – the test being that the patient was required to press the button twice within one second when making a demand. This apparatus evolved into the first commercially available PCA device, the "Cardiff Palliator". However improvements in epidural technology and management during the 1970s and 1980s – primarily the advent of infusions and more compact epidural pumps – together with its high quality pain relief and lack of sedation, led to rapid increases in its popularity and the relative paucity of labour PCA development[7]. Occasional reports of opioid PCA in labour – including fentanyl and tramadol PCA – appeared, although it was consistently noted in these studies that analgesia was better and side effects were fewer (both maternal and neonatal) with epidural analgesia[8-10].

THE EMERGENCE OF REMIFENTANIL

This was the state of play when remifentanil PCA was first postulated as having a potential role in the delivery suite. Remifentanil was developed in the early 1990s and initially known as GI87084B[11]. Its unique ester structure allowed it to be metabolised by blood and non-specific tissue esterases, resulting in an extremely rapid clearance of three litres per minute. In contrast to other opioids, its termination of effect was primarily due to metabolism rather than redistribution, resulting in an extremely short offset of effect, even for prolonged infusions[12]. As noted in an early commentary, "remifentanil appears to be a very titratable opioid that will make it suitable for administration for either very brief periods, in which analgesia is required, or over prolonged periods, without the concern for prolonged recovery"[13].

The first reported use of remifentanil as a labour analgesic was by Brada in 1998, who used a remifentanil infusion to facilitate the siting of an epidural[14]. The following year, Jones first described it in a PCA delivery system in a series of three patients, all with platelet counts too low to allow safe epidural analgesia[15]. All three had a two-minute lockout and respective bolus doses of 75mcg, 35mcg and 40mcg, which provided effective analgesia with acceptable side effects. Apgars of the neonates appeared unaffected by the PCA, despite a cumulative time of 20 hours of use by the three patients. This latter finding was consistent with an earlier study by Kan, who had studied the neonatal effects of remifentanil infusion at caesarean section and found that placental transfer occurred readily, but was accompanied by rapid metabolism and/or redistribution by the foetus, resulting in an absence of adverse effects at the time of delivery[16]. Other promising series were soon published[17] but it was not long before concerns arose. Olufolabi conducted a study of anaesthetist-assisted remifentanil bolus analgesia in four parturients using a 0.25-0.5mg/kg bolus, but all subjects were eventually withdrawn from the study because of inadequate analgesia and significant opioid-related side effects[18]. These early reports reflect the course of the literature thereafter, with promising studies and supportive commentaries interspersed with tempering case reports and editorial caution.

HOW GOOD IS REMIFENTANIL PCA?

When using maternal satisfaction as a measure of efficacy, remifentanil PCA ranks highly. For example, in studies where verbal descriptors were used to assess satisfaction, 94 per cent of users rated it good, very good or excellent[19] and 93 per cent were satisfied or very satisfied[20]. When directly compared to intramuscular pethidine[21] and pethidine PCA[22,23], remifentanil PCA resulted in significantly higher maternal satisfaction. Satisfaction was found to be similar when compared to fentanyl PCA[23] and in numerous studies comparing remifentanil PCA with epidural analgesia[24-29]. The most recent and largest study comparing remifentanil PCA to epidurals found that satisfaction was significantly higher in women receiving epidural analgesia[30]. In this multicentre study, in which maternal satisfaction was the primary outcome, 1414 women were randomised antenatally to receive epidural or remifentanil PCA analgesia if they wished for pain relief during labour. Ultimately, 447 women received a remifentanil PCA and 296 women an epidural. Although the study found that satisfaction was significantly higher in the epidural group, it should be noted that there was a large amount of missing data (29% in the remifentanil group and 43% in the epidural group).

Despite high levels of maternal satisfaction, pain scores showed only modest reductions during remifentanil PCA use. Typically there were falls in the pain scores following initiation of the PCA, which drifted back toward the baseline with ongoing use. This return to baseline has also been demonstrated with fentanyl and pethidine PCAs during labour[23]. In a study where women in labour were asked for their acceptable pain score prior to PCA use, and were then able to titrate a remifentanil PCA bolus at regular intervals, it was found that even though their pain scores later became higher than their "acceptable" pain score, women stated that they did not want an increase in the PCA dose[31.] The author attributed this to an increase in pain tolerance, postulating that as with other opioids, a combination of sedation, euphoria and a rewarding effect made the pain more manageable.

The ownership of the PCA button may also have a role in the relatively high maternal satisfaction in the context of modestly reduced pain scores. It has been demonstrated in acute post-operative pain and chronic pain that success and/or satisfaction is more likely when the patient is actively involved in their pain-management plan[32-35] and pushing the PCA button enables this. Interestingly, in the study by Olufolabi, which was prematurely stopped partially on account of poor analgesia, the remifentanil boluses were administered by an anaesthetist and not the parturient[18]. Other factors, such as ease of setting up, simplicity of use and flexibility of duration of use may also contribute to high satisfaction.

When comparing pain scores between analgesic modalities in labour, those from remifentanil PCA have been shown to be significantly lower than those from nitrous oxide and pethidine[36-39]. However, meta-analyses show that pain scores from epidural analgesia are significantly lower than those of remifentanil[40,41].

An alternative measure of analgesic efficacy is the incidence of failure of the analgesic technique. Conversion rates from remifentanil PCA to epidural analgesia, while reasonably low at 2-14 per cent (looking at studies with greater than 40 patients)[20,23,30,42], are considerably greater than the conversion rates from epidural to remifentanil PCA, which in Freeman's multicentre study was 1 per cent[30].

Hence, although giving only modest reductions in pain scores, the great majority of women are satisfied with remifentanil PCA. Pain relief is better and satisfaction higher when compared to pethidine and, when compared to epidural analgesia, pain relief is poorer but satisfaction similar.

IS IT SAFE?

Although an analgesic medication may be efficacious and acceptable to the recipient, it must also be safe for them. Historically, opioids have often been criticised on the grounds that they result in heavy sedation and incomplete pain relief for the mother, in addition to having adverse effects on the newborn[43]. Studies of remifentanil PCA are only partially reassuring in this regard, the two most concerning side effects being sedation and respiratory depression.

Some degree of sedation is experienced by the majority of women using a remifentanil PCA and, during three studies, excessive sedation has been reported to occur in subjects. In one study, the high sedation scores of three of the 41 parturients required the PCA pump to be temporarily stopped[20]. In another study a patient was unresponsive when her name was called loudly, but did respond to mild prodding or shaking[44]. In the third study, in which an observer sedation score of 1-5 was used (1 = alert, 2 = slightly drowsy, 3 = drowsy, 4 = very drowsy, 5 = unrousable), a recording of 4 was made[27]. Of note, PCA boluses from the first and third studies were up to 1.05 mcg/kg, considerably higher than in the majority of other studies, and in the second study a background infusion was used in addition to a bolus.

Reported results of respiratory depression appear reassuring, although it becomes less clear when one looks closer. The majority of remifentanil PCA studies have had an observer in the room to monitor and record respiratory events. These studies have almost uniformly reported reassuring findings of maternal oxygenation. Only four studies have recorded maternal oxygen saturations using stored pulse oximetry data that was later downloaded for analysis. In two of these studies, significant desaturation trends emerged: Blair found that while using remifentanil PCA, seven out of 19 women spent more than 5 per cent of time with an oxygen saturation of less than 90 per cent[22], and Stocki found that women occasionally desaturated to below 75 per cent, even when receiving supplementary oxygen[29]. Also of note is that, of the 24 clinical studies included for this review, seven reported oxygen saturations only as mean and standard deviation or median and interquartile range[24,25,27,36,38,45,46].

While this gives the reader an accurate picture of the central tendency and spread around the central value, it gives no information about the outliers at the lower range, which is what is of interest for identifying safety concerns. In some studies, the number of episodes of desaturation – for example, the number of times the oxygen saturation fell below 94 per cent – have been reported, but without additional details such as the depth or duration of the

desaturation events[24,27,31,47]. In two other studies, no maternal oxygenation data was presented at all[28,37]. In studies where the range of oxygen saturations have been included, values as low as 50 per cent have been reported[30]. One study used capnography to monitor respiratory function during remifentanil PCA use[29]. Using an oral-nasal cannula to continuously sample carbon dioxide, it was found that nine of 19 women experienced a total of 27 apnoea events (defined as a respiratory rate of zero for at least 20 seconds), with 14 of these events occurring during the first two hours of use. Maternal oxygen saturations fell to as low as 74 per cent during the apnoeic events despite firstly, supplementary oxygen being given and secondly, women being prompted with verbal and light physical stimuli when the oxygen saturation fell below 90 per cent.

Although the above suggests that respiratory depression with remifentanil PCA may be occurring more frequently than some of the studies suggest, it is unclear whether this results in a dangerous level of oxygen saturation for women in labour. Significant maternal desaturation has been demonstrated during normal labour[49,50] and in women who have received traditional opioid and nitrous oxide analgesia. Early pulse oximetry studies reported oxygen saturations as low as 60 per cent after intramuscular pethidine[51] and as low as 75 per cent during nitrous oxide inhalation[52], without apparent undue effects on the mother. Perhaps women receiving nitrous oxide and intramuscular opioids in today's delivery suites are still experiencing significant desaturations, similar to those found in the remifentanil studies of Blair and Stocki, but they are not being monitored to detect these events[22,29].

Epidural analgesia, in contrast, has been shown to have a beneficial effect on respiratory parameters during labour[50]. Effective analgesia with only mild sedation (or no sedation at all if opioids are not used in the epidural solution) facilitates a relaxed breathing pattern and avoids the maternal hyper-hypoventilation cycle that can lead to desaturation. Epidurals have consistently been shown to improve maternal oxygen saturations and sedation scores when compared to remifentanil PCA[24,26,29,30].

No woman has received naloxone, required airway support or ventilatory assistance during remifentanil PCA use in any of the published studies. In terms of mode of delivery, labour outcomes appear to be unaffected by remifentanil use. Neonatal data is reassuring. Although remifentanil readily crosses the placenta (mean umbilical vein:maternal artery ratio = 0.88), it is rapidly metabolised, redistributed or both by the foetus (mean umbilical artery:umbilical vein ratio = 0.29)[16]. Konefał found no significant differences in heart rate, oxygen saturation and blood pressure in newborns during the first 24 hours after delivery by mothers who had used remifentanil PCA during labour[53]. Other studies have also reported an absence of neonatal effects at birth[20,21,24,26,38,42,44,45,47,54,55]. When comparing remifentanil PCA to fentanyl PCA during labour, Marwah found a significant reduction in the number of neonates requiring resuscitation in the remifentanil group[55], although Douma found no difference[23].

SERIOUS MORBIDITY

There have been three case reports of respiratory and/or cardiac arrest associated with remifentanil PCA[2-4]. One case was confirmed to be related to a drug error when a syringe containing 10 times the prescribed concentration of remifentanil was used[2]. The patient became apnoeic, briefly lost cardiac output and foetal cardiac activity was undetectable after she received an initial bolus of 400mcg. An emergent bedside caesarean section was performed and the neonate had Apgars of one and eight at one and five minutes respectively. The newborn was assisted with positive pressure ventilation, but no naloxone was given. The mother was anaesthetised prior to delivery and tracheal extubation occurred uneventfully after a formal wound closure in theatre. Both mother and baby made complete neurological recoveries. Pharmaceutical analysis of the syringe contents confirmed the drug error.

The two other case reports involved women labouring with foetal deaths *in utero*. In both cases the attending midwife was out of the patient's room when the incident occurred, the emergency bell being rung by relatives. In one case[3], the patient was found unresponsive and cyanosed; cardiopulmonary resuscitation was initiated and a return of cardiac output was detected as an emergent caesarean section began in the delivery suite. No adrenaline was administered. The mother was anaesthetised after delivery of the foetus and tracheal extubation occurred uneventfully in intensive care 12 hours later. In the second case[4] the patient was also found unresponsive and blue, albeit with a palpable carotid pulse. The patient resumed spontaneous ventilation after a brief period of bag-and-mask ventilation. She quickly recovered full consciousness and continued on to a vaginal delivery. These two women also made full recoveries.

In all three cases naloxone was not administered. An accompanying editorial issued caution and recommended the continuous presence of a midwife during PCA use, continuous oxygen saturation monitoring, continuous cardiotocography (CTG) monitoring, a minimum three minute lockout for the PCA protocol and a rigorous internal audit process in order to make remifentanil a safer option for women in labour[56].

DOSING AND DELIVERY

Fixed boluses, flexible boluses, with or without background infusions, and lockout times varying between one and five minutes have all been reported in making up remifentani PCA delivery protocols. Numerous dosing studies have been made. Volmanen found that there was a fourfold variation in the individual dose required for effective analgesia[31] and Blair found that adding a background infusion increased side effects but not efficacy[47]. The majority of studies have used a bolus of between 20-50mcg, a lockout of between one and two minutes and no background infusion. Respiratory depression and sedation are more frequent at higher doses[20].

NOVEL IDEAS

It was remifentanil's rapid onset time of 30 to 60 seconds and lack of accumulation with long-term use (context-sensitive half-life of three to four minutes)[57] that made it attractive to trial as a labour analgesic. It was thought that analgesia might be provided for each contraction without accumulation. However, given that the average duration of a contraction is 70 seconds and the peak effect of remifentanil is at two and a half minutes[59] it would appear that in many patients, maximum levels of effect would occur between contractions. This mismatch, resulting in significant remifentanil concentrations after the painful stimulus of the contraction had subsided, would result in the high sedation scores and respiratory depression as reported in some of the previously mentioned studies.

Several attempts have been made to improve the correlation of maximal contraction pain and peak remifentanil effect. Volmanen, by observing the intervals between contractions, programmed a remifentanil PCA to deliver a bolus 140 seconds before the next expected contraction[46]. However, when compared to a control group in which there was conventional pressing of the PCA button at the start of the contraction, there was no improvement in pain relief and maternal oxygen saturations were similar. In another study, the timing, duration, spacing and intensity of contraction pains were recorded and there was an attempt to mathematically model remifentanil delivery to co-ordinate peak remifentanil concentration with peak contraction strength[60]. However, because of the large variability of inter-contraction intervals, it was not possible to reduce the calculated mean remifentanil effect-site concentration in between contractions.

In a different approach, Jost asked women to press the PCA button continually until the peak of the contraction, with remifentanil being given at a reducing rate while the button was being pressed[54]. There was no difference in satisfaction or maternal safety parameters when compared to a conventional delivery system. Perhaps the idea with the most promise is a vital signs-controlled, patient assisted intravenous analgesia delivery system proposed by Sia[61]. In a closed-loop interactive system the remifentanil bolus is titrated according to the number of demands made in 15 minutely periods. If the oxygen saturation fell below 95% for greater than 15 seconds or maternal heart rate fell below 60 beats per minute for greater than 15 seconds, the pump automatically paused for five minutes then restarted with a smaller demand dose. If the desaturation continued for longer than five minutes the pump stopped and alarmed. The study presented a case where during a seven-hour period of use, the pump paused for transient oxygen desaturations on 17 occasions and the lowset recorded oxygen saturation was 90%.

CONCLUSION

Since the initial description of remifentanil PCA as a labour analgesic, numerous studies have attempted to clarify its efficacy, optimal delivery, safety and role. Many studies have been relatively small. From what information we have available, it is apparent that women like remifentanil as a form of pain relief during labour. It is relatively non-invasive, simple to initiate and affords the woman some degree of control over her contraction pains. It is a useful alternative for women in whom epidural analgesia is contraindicated or not possible, and attractive to women who are concerned about the nature and possible complications of epidurals. The analgesia offered is better and gives higher maternal satisfaction when compared to intramuscular pethidine. Data on the effects on newborns is reassuring. However, the analgesic effect of remifentanil PCA is inferior to that of an epidural and between one in seven and one in 10 will find it inadequate to the point where they will elect to receive an epidural instead.

The primary concern arising with its use is the significant degree of sedation and respiratory depression that occurs in a minority of women. Many delivery suites do not have anaesthetic personnel on the floor and as such, monitoring and care of the patient is entrusted to the midwives. It is clear that where remifentanil PCA is to be used, adequate resources must be available to ensure its safe delivery. These would include, but are not exclusive to, education of midwifery staff on the signs of increasing sedation and respiratory depression, clear and simple guidelines for management of increasing sedation and respiratory depression, continual presence of a midwife with the patient, regular audit of PCA charts (and ideally of pulse oximeters used where the oxygen saturation data is stored on the oximeter) and follow-up of patients to ascertain satisfaction and concerns. Hence the decision as to whether to offer remifentanil should be taken bearing the above in mind. Novel techniques of administration may improve safety while maintaining efficacy in the future.

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The combined oral contraceptive pill and perioperative venous thomboembolism risk

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BACKGROUND

The combined oral contraceptive pill (COCP) or "the pill" was introduced to Australia on January 1, 1961. In the same year a 40-year-old British nurse was the first patient to be diagnosed with a pulmonary embolus (PE) believed to be secondary to its use. The risk of venous thromboembolism (VTE) has been the subject of research and controversy over the subsequent decades as further generations of COCP have been developed.

The background rate of VTE in women of reproductive age is around four per 10,000 per year and it is accepted that this risk is two to three times higher in those taking the COCP1. VTE risks from COCP use are further increased within four months of commencing and returns to baseline within three months of cessation. VTE risk is even higher during the peri-partum period[2] as illustrated in Table 1[1].

Table 1. VTE risk in the peri-partum period compared with COCP use

	Annual risk per 10,000 women
VTE – no hormonal contraception and not pregnant	3 – 5
VTE – low dose COCP containing levonorgestrel or norethisterone (2nd generation)	5 – 8
VTE – low dose COCP containing newer progesterones (3rd generation)	9 – 12
VTE – antenatal	29
VTE – immediate postpartum	300 – 400
Death from VTE secondary to COCP	0.09

The sequelae of DVT may include significant leg pain with the potential to progress to a persistent pain condition and pulmonary embolus, which in rare cases may be fatal.

The increased risk of acute myocardial infarction and stroke reported are of a much smaller magnitude and will not be discussed further in this article. Post-menopausal hormone replacement therapy (HRT) involves an older age group and different hormonal doses and will not be discussed in this article.

ANAESTHESIA RELEVANCE

The use of the COCP is a modifiable risk factor for perioperative VTE. Like many patient risks managed by anaesthetists, this adverse event is low probability but with potentially serious outcomes, including death. It is well known that surgery increases VTE risk and the high-risk post-operative period for VTE events may be considered to extend to 12 weeks post-operatively[3].

Given that more than one in five women in Australia aged 16-59 years old takes the COCP[4], its perioperative management has relevance to many anaesthetists.

PATHOPHYSIOLOGY

VTE risk can be considered in terms of the interplay of haemodynamic changes, hypercoaguability and endothelial dysfunction; the so-called "Virchow's triad". This triad is relevant to perioperative COCP use and post-operative VTE risk with all of these factors being relevant to some degree.

The COCP contains oestrogen and progesterone. These hormones cause the suppression of follicle stimulating hormone (FSH) and luteinising hormone (LH) making tubal, cervical and endometrial conditions unfavourable for conception. Following COCP introduction, an increased rate of adverse VTE and cardiovascular events were noted. Oestrogen and progesterone doses have subsequently been modified in second and third-generation COCP formulations. For the purposes of this paper, the authors will use the generic term COCP.

The pathophysiology of this increased VTE risk is due to the effects of both oestrogen and progesterone having a procoagulant effect. Oestrogen increases the levels of clotting factors (VII, VIII, X, fibrinogen) and plasminogen, lowering antithrombin III and protein S levels, and altering activated protein C (APC) resistance. APC induces decreased factor V activity. With increased APC resistance, this inhibition is not in effect and the coagulation cascade proceeds. The net effect of combination pills is a procoagulant effect. Allied to this is the procoagulant effect of surgery with venous stasis (especially associated with the use of a tourniquet), increased acute phase proteins associated with stress response to surgery and endothelial changes either associated with the site of surgery or the use of a tourniquet.

The use of progesterone only pills (POPs) or the "mini-pill" does not appear to be associated with an increased risk of venous thromboembolism[5] and will not be discussed further in this review.

CONSENT

While an extensive discussion of consent is beyond the scope of this paper the authors wish to highlight several considerations relevant to COCP use, VTE risk management and patient consent. Gebhard, a US lawyer, coined the term "informed consent" in 1957 built on three primary considerations. The patient should be:

1. Informed.
2. Competent (ability to: understand and retain information; assess rationally; to repeat and decide based on own values; communicate decision).
3. Not acting under undue influence.

It is accepted that COCP use increases the perioperative risk of VTE but to quantify this risk is difficult and depends on other patient and surgical factors. Felcher et al showed that for patients undergoing foot and ankle surgery the rate of post-procedure VTE in patients taking COCP approximately doubled from the background rate of 3/1,000[6]. It would seem that other anaesthesia risks, which are less likely and have less potential for morbidity, may still be communicated to patients, such as dental damage 2/10,000[7].

In prescribing the COCP, GPs typically justify the increased VTE risk of the COCP above baseline on the basis that the VTE risk is still very low and the risk in pregnancy is higher than that of the COCP. The authors contend it may not be appropriate to automatically extend this argument to perioperative COCP use. Patients taking the COCP may prefer to manage their contraception by alternative means for the perioperative period to decrease the increased VTE risk, including a switch the lower risk progesterone-only pill. This option should be offered to patients awaiting elective surgery.

There have been several pill scares regarding risk of VTE with some brands, which resulted in an increased number of pregnancies and therapeutic abortions after COCP use declined. Advice given to women on perioperative COCP use must also include these possible consequences of stopping the pill.

The extent to which patients are informed of risk and offered the opportunity to modify this risk in the perioperative period is further explored in the survey.

VTE RISK MANAGEMENT

The broad approach to VTE risk management in hospitals is as per the National Health and Medical Research Council (NHMRC) clinical practice guideline for the Prevention of VTE in Patients Admitted to Australian Hospitals[8]. For surgical patients, this involves risk stratification based on individual patient VTE risk, bleeding risk factors and surgical factors.

Patient risk factors include previous VTE, increasing age, cardiac or respiratory failure, prolonged immobility, cancer, malignancy, varicose veins, obesity, smoking and inherited or acquired haematological abnormalities. Higher risk surgical procedures include abdominal, pelvic, thoracic or orthopaedic surgery. Major joint surgery and curative cancer surgery are identified as particularly high risk.

Treatment options include early mobilisation, non-pharmacological treatment, including compression stockings and pneumatic calf compression, and pharmacological treatments typically heparin or enoxaparin. In this NHMRC guideline, COCP is only mentioned as an individual patient risk factor to be considered.

MIMS Australia, a widely used medicines information publication, states that the COCP should be ceased four weeks prior to major elective surgery with an increased risk of VTE and should not be restarted until two weeks after full ambulation. The product information for COCPs states similar advice. Australian family planning associations generally advise that women contact their GP at least four weeks preoperatively and that they should expect their GP will advise they use alternative means of contraception for the perioperative period. In the authors' institution, a local policy exists with a similar approach to COCP cessation four weeks preoperatively and to resume after two weeks of full ambulation but, anecdotally, compliance with this policy is inconsistent.

Contraindications to COCP use include VTE, stoke, coronary artery disease, structural heart disease, diabetes with complications, peripheral vascular disease, hypertension (blood pressure >160/100 mmHg), breast cancer, liver disease, headaches with focal neurological symptoms, major surgery or prolonged immobilisation, age greater than 35 years old or smoker greater than 20 per day and within the first 21 days post-partum.

SURVEY OF PRACTICE

Methodology

The South Metropolitan Health Service of Western Australia Human Research and Ethics Committee considered that ethics approval was not necessary due to the nature of the project so approval for the survey was sought and granted by the Fremantle Hospital clinical governance office.

A pilot survey was distributed to 12 consultant anaesthetists at Fremantle Hospital and Royal Perth Hospital with a response rate of eight (67 per cent). Minor changes to the survey format were made based on feedback from respondents.

The survey was distributed by the ANZCA Trials Group to 500 randomly selected Fellows of the College using Survey Monkey electronic survey distribution. The survey was voluntary, anonymous, confidential and IP addresses were not collected. Survey results were analysed using descriptive statistics.

Results

One hundred and twenty two (122) surveys were completed, yielding a response rate of approximately 24 per cent. The demographics of the survey respondents were predominantly (57 per cent) senior anaesthetist (>10 years of practice) mostly in full-time public practice. The results of the survey are presented in Appendix A.

Discussion

The low response rate of 24 per cent is consistent with response rates for previous surveys distributed by the ANZCA Trials Group[9]. Given the data is from a survey and with a low response rate, rigorous conclusions about practice will not be made but simply used as a basis for discussion. To further investigate the practice of anaesthetists in terms of actual consent and perioperative practice would be a highly resource intensive project.

Given that 68 per cent of anaesthetists only "sometimes", "rarely" or "never" routinely specifically ask about COCP use, it seems a recognised VTE risk is not being routinely assessed as part of the patient history. In some preadmission settings, where a pharmacist reviews a patient prior to medical review, this information may be better elucidated.

Having identified COCP use (a risk factor for VTE) only 22 per cent of respondents would inquire into a family history of thromboembolic disease. Other VTE risk factors such as smoking, obesity and patient history of clotting disorders were regularly identified. However, in the opinion of the authors, these factors are an important part of any anaesthesia preoperative assessment regardless of COCP use.

The majority (89 per cent) of respondents would use some form of non-pharmacological prophylaxis in an otherwise healthy woman taking the COCP having a laparoscopic cholecystectomy and 61 per cent would use pharmacological prophylaxis. Other techniques included maintaining hydration by minimising fasting times and through use of intraoperative intravenous fluid, although convincing evidence of the effectiveness of this is not found in the literature. Several respondents stated management of VTE prophylaxis was either specified by their institution or exclusively the responsibility of the surgeon.

Despite the presence of additional risk factors, including obesity, smoking, patient history or family history of VTE, a significant majority (87 per cent) of respondents would not cancel the patient to enable perioperative cessation of the COCP.

Only 25 per cent of respondents were aware of best practice or hospital guidelines on the perioperative management of the COCP. Where known, these guidelines were typically followed. It would suggest that a best practice approach to managing perioperative COCP would be followed if anaesthetists were aware of such an approach. This represents an opportunity to improve patient care.

The increased risk of VTE from COCP use is communicated "usually" or "always" to the patient by only 21 per cent of respondents. Unfortunately it seems that patients are given suboptimal information about this potentially modifiable risk factor. Further, 88 per cent of respondents said they would "rarely" or "never" give a patient an opportunity to postpone surgery to cease the COCP perioperatively. The authors feel this does not provide sufficient autonomy to women to manage their contraception by other means during the perioperative period.

There was extensive agreement (89 per cent) of respondents that VTE prophylaxis is a shared responsibility of surgeons and anaesthetists, although the remaining 11 per cent felt it was exclusively the surgeon's responsibility. The authors consider this illustrates the importance of having surgical colleges involved in the development and implementation of a national approach on perioperative COCP management.

There are many clinical settings, such as private practice, where the anaesthetist may not be involved in the patient's perioperative management before the four-week preoperative date for which temporary COCP cessation could be considered. It is important for surgeons at the time of offering surgery and for GPs to have input in perioperative COCP management.

RECOMMENDATIONS

The authors recommend that a consistent risk avoidance approach to perioperative VTE risk management from COCP use should be adopted. This would include routinely taking a direct history of COCP use in women of reproductive age, VTE risk, including smoking status, obesity and family/personal history of VTE risk, together with the risk category of the planned surgery. Based on this information an agreed plan between patient, surgeon and anaesthetist should be made, informed by a guideline. This plan would include pharmacological and non-pharmacological treatment options and include the possibility of deferring surgery. The patient should be central to the whole process and be appropriately consented in the perioperative management process.

The COCP is a modifiable and easily identifiable perioperative risk factor for VTE. It is identified as such and recommendations exist for its cessation perioperative period based on patient and surgical risk factors. Our audit showed a lack of consensus among anaesthetists about perioperative management of COCP. As a specialty group, we should be playing our part in reducing perioperative COCP-associated VTE.

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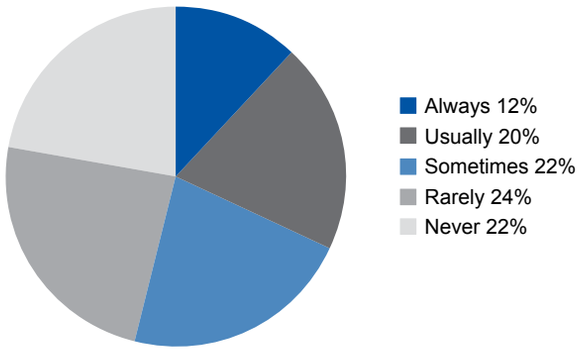
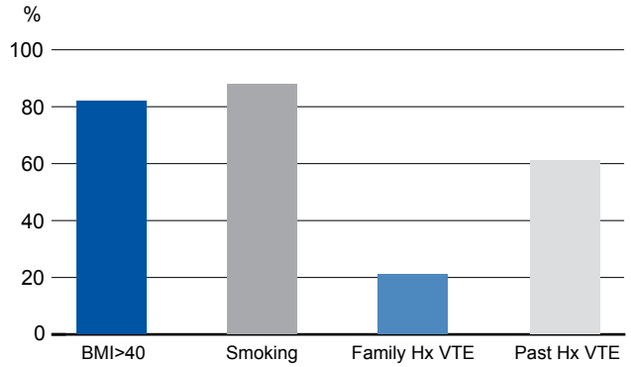
APPENDIX A: SURVEY RESULTS

Q1: Do you directly ask 14 to 50-year-old female patients whether they are taking the COCP?



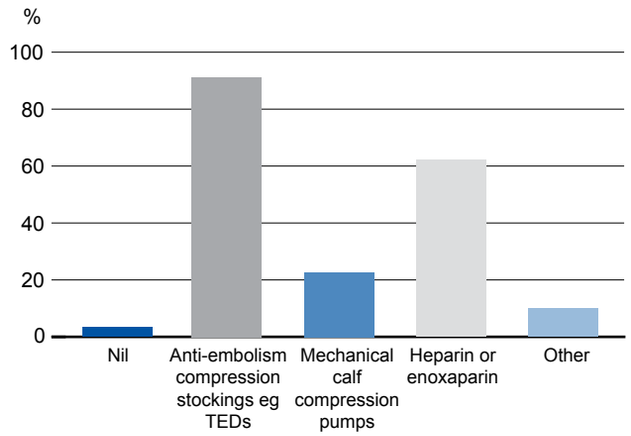
Q2: If you encounter a patient on your list for laparoscopic cholecystectomy who is taking the COCP, which of the following risk factors for DVT/PE do you routinely inquire about? (You may select more than one of the options below.)



Q3: You meet a healthy, slim 38-year-old female non-smoker with no significant personal medical history or family history presenting for elective laparoscopic cholecystectomy. The only medication she takes is the COCP.

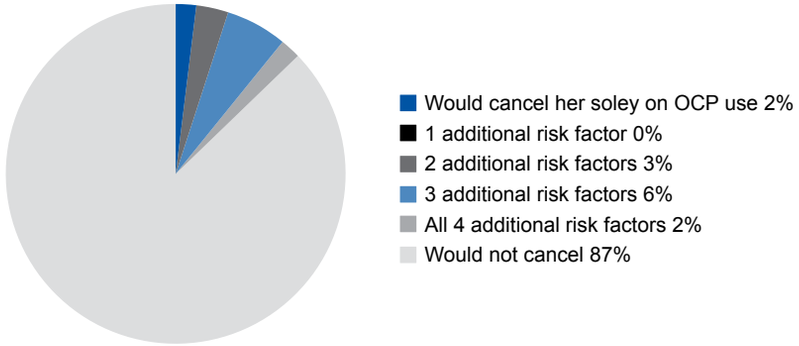
You are due to operate/anaesthetise her on your list today.

On such a patient with regard to DVT/PE prophylaxis would you routinely use any of the following (please select as many options that you feel appropriate):

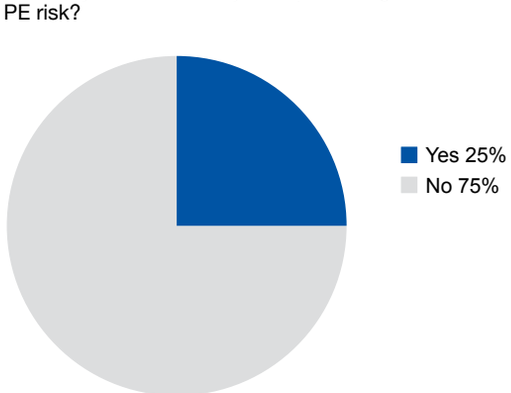


Q4: If the above patient was to have some combination of the following additional risk factors for DVT/PE listed below:
- Smoker.
- Body mass index (BMI) >40.
- Family history of DVT/PE/thrombophilia.
- Personal history of DVT/PE/thrombophilia.

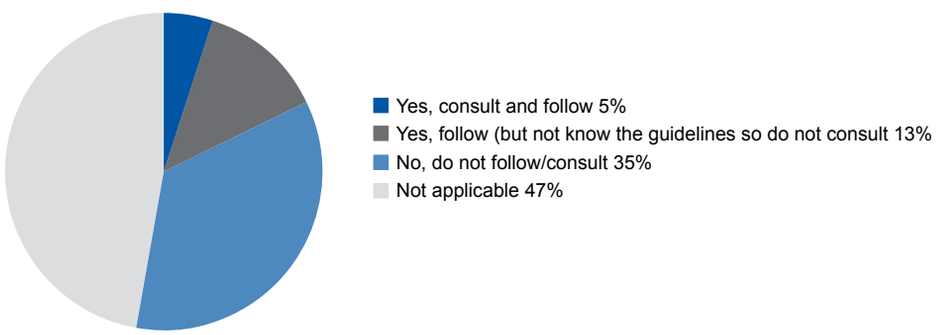
Would the presence of some combination of these additional risk factors cause you to cancel surgery in order for her to cease the COCP perioperatively?



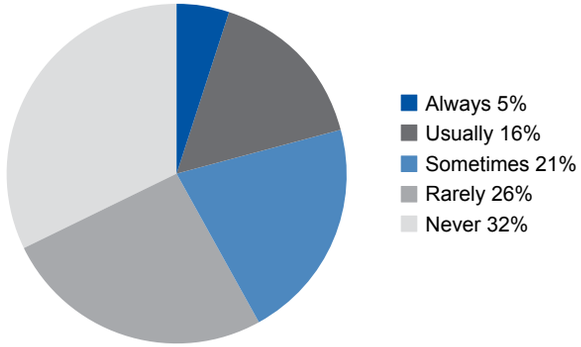
Q5: Are you aware of any best practice guidelines or hospital policy regarding COCP use and perioperative DVT/PE risk?



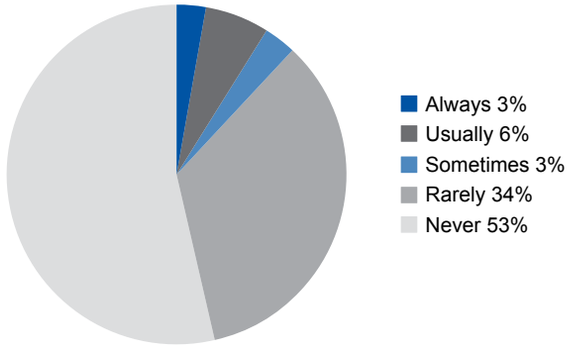
Q6: Do you consult and follow these guidelines when seeing a patient preoperatively on the COCP?



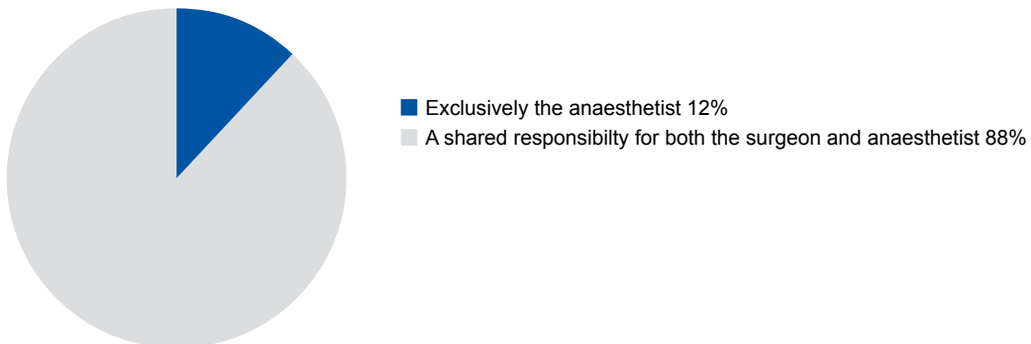
Q7: Do you warn patients taking the COCP regarding an increased risk of perioperative DVT/PE associated with COCP use?



Q8: Do you give patients the opportunity to postpone surgery should they wish to cease the OCP perioperatively?



Q9: VTE prophylaxis is the responsibility of:



Will my patient get stuck in ICU?

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INTRODUCTION

It is generally acknowledged that intensive care medicine was born as an improvised response to the poliomyelitis epidemic of 1952[1]. As part of a desperate attempt to save the life of a 12-year-old girl, Dr Björn Ibsen, a Danish anaesthesiologist, was invited out of the operating room to apply his skills. Since then, intensive care units have become a mainstream component of modern hospital systems, with an emphasis on improving survival of high-risk medical and surgical patients.

Despite an emphasis on reversible illness, the modern era of intensive care is confronted with the conundrum of patients that may survive surgery or critical illness but then require prolonged or indefinite organ support. Such patients might be considered “stuck” in ICU. This problem has become known as chronic critical illness. The term was coined by Girard and Raffin in 1985 with an article titled “The chronically critically ill: to save or let die?”[2]. Patients who were previously considered ineligible for surgery are now candidates, but this is apparently contributing to a large and growing population of chronically critically ill patients[3]. The ability to predict the development of postoperative chronic critical illness could guide discussion and decision making. High-risk patients, their families, friends and/or carers, as well as their clinicians, might shy away from operative management if it could be reliably known that lingering dependence on organ support would ensue. Also prediction of chronic critical illness could guide ICU resource management, as these patients generally spend significant time in ICU, require significant resources and are typically very slow to show improvements. The aim of this review is to assimilate research that has been published regarding chronic critical illness in order to characterise the prevailing issues, with a focus on the prospect of predicting high risk peri-operative patients.

DEFINITION OF CHRONIC CRITICAL ILLNESS

A binding definition of chronic critical illness remains elusive. The question of what exactly defines the condition has been a subject of debate internationally, with no real consistency in the literature to date. Although many papers have declared the need for a consensus definition, especially for data comparison and standardised research, the literature remains littered with different criteria.

A potential contributor to inconsistent definition is that investigators and clinicians are likely to approach the problem from a number of different viewpoints[4]. Clinicians are inclined to recognise chronic critical illness from a pragmatic stance: the patient has survived acute critical illness or injury but has not yet recovered to the point of liberation from life sustaining therapies. Although this might translate adequately on the morning ward round, it is challenging to build into research, audit or health economic analysis.

From a research and audit perspective the definition for an illness or syndrome should[4]:

- Have good sensitivity and specificity for the condition.
- Be easy to apply using data that is routinely present in the medical record.
- Be widely accepted by investigators, clinicians and administrators.

In attempting to apply a broadly relevant definition, it is important to appreciate that the transition from acute to chronic critical illness is gradual and there is no clear point of demarcation. Clinical thresholds that appear to hold most potential are the requirement for prolonged mechanical ventilation (PMV),[5] or the insertion of a tracheostomy[5]. Clearly, there is considerable overlap, but each threshold has arguments in favour or against (Table 1).

Table 1. Comparison of tracheostomy insertion and prolonged mechanical ventilation as defining criteria for chronic critical illness. Adapted from content published by Carson et al. Respir Care 2012[4].

	Tracheostomy insertion	Mechanical ventilation duration
Pro	• Anticipation of prolonged mechanical ventilation = start of protracted course. • Likely to survive for a reasonable amount of time. • Family has consented (want ongoing invasive support). • Procedure is clearly recognized from the clinical record.	• Prolonged mechanical ventilation is one of the hallmarks of chronic critical illness. • Mechanical ventilation requires ICU care in most acute hospitals. • High nurse to patient ratio. • Economic impact. • High resource utilisation and equipment costs. • Simple, uniform definition. • Days of mechanical ventilation can be ascertained from clinical record.
Con	• Timing of tracheostomy not standardized: – Differs between institutions. – Differs between practitioners. – Influenced by patient diagnosis and condition.	• Most administrative databases do not record duration of mechanical ventilation. • Investigators apply different thresholds for "prolonged". • Studies range from 2 days to 29 days. • NAMDRC Consensus Statement 2005: – PMV defined as mechanical ventilation for ≥ 6 hours/day for ≥ 21 consecutive days.

Prolonged mechanical ventilation

A hallmark of chronic critical illness is the requirement for PMV. In 2005 a consensus statement was published in the American Chest Journal, recommending the definition of PMV as greater than or equal to 21 days of mechanical ventilation, with at least six hours of mechanical ventilation per day[5].

The ideal definition of chronic critical illness should identify the time point that, once reached, signals a higher incidence of associated morbidities, excess mortality or increased resource utilisation. North American authors have favoured the definition of the chronic critical illness "syndrome" as being characterised as >21 days of mechanical ventilation (based on the definition of PMV)[5], or tracheostomy insertion. However, considerable variation persists; for instance, very recent studies have used 14 days of mechanical ventilation as their definition[6,7].

Other studies propose a time period combined with a clinical judgement such as mechanical ventilation for 7 days with a physician not expecting death or liberation from mechanical ventilation within 72 hours[8]. It should be noted that ENT surgical patients and patients with neuromuscular disease states such as muscular dystrophy are a specific subset of the population and are typically excluded. Clinician prediction of PMV has been shown to be poorly correlative to actual duration of ventilatory support, especially if greater than 14 days[9]. Thus it is difficult to argue for a definition that includes a clinical judgement that has shown to be poorly performed.

Tracheostomy

Tracheostomy is an appealing threshold for defining chronic critical illness. It is a discrete time point that should be easily recorded or identified from the clinical record. It also indicates an acceptance by clinicians, and the individual providing consent, that prolonged ventilatory support is likely to be required and is indicated; the patient remains critically ill but end-of-life care is not planned or imminent. On the other hand, tracheostomy insertion times are variable with significant variance in times of insertion depending on individual clinician and institutional practices. Additional arguments include the possibility that timing of tracheostomy might influence outcome, and that patients that progress to chronic critical illness (according to other criteria) tend to be scheduled for tracheostomy after a longer period of mechanical ventilation.

Conflicting data has emerged regarding potential benefits of early versus late tracheostomy insertion. There are data that tracheostomy insertion, compared to ongoing mechanical ventilation via conventional oral endotracheal tube, reduces mortality, decreases ICU length of stay and increases patient comfort[10,11]. One randomised controlled trial (N=600) reported no statistical benefit in ventilator-associated pneumonia[12]. This trial scheduled early tracheostomy insertion at 6-8 days of mechanical ventilation and only measured pneumonia as an endpoint. Subsequently, another prospective randomised trial (N=119) reported the early tracheostomy group (three days) to have significantly less complications such as decreased ventilator associated pneumonia and more ventilator free days than patients with late or no tracheostomy insertions[13]. Despite inconsistent results, the potential influence of timing on outcome might weaken the argument for tracheostomy as the defining time point for chronic critical illness.

In the 1990s, tracheostomy was usually inserted at approximately 10-12 days[10], with the trend being towards earlier insertion. However, recent trials demonstrate a tendency toward later insertion in patients with chronic critical illness. Average insertion times of 16-17 days have been reported[7,14]. It is conceivable that this reflects clinical selection biases. For example, tracheostomy might be considered earlier in young, previously healthy patient with rib fractures following trauma, versus an elderly post-operative patient with a slow ventilatory wean due to chronic obstructive pulmonary disease (COPD) and heart failure. The outcomes of these patients would be expected to be very different due to comorbidities and functional reserve.

THE CHRONIC CRITICAL ILLNESS SYNDROME

Beyond the persistence of respiratory failure requiring prolonged support, and regardless of definition, chronic critical illness appears to be characterised by a number of metabolic and pathologic associations[8,15].

A plethora of endocrine changes are associated with chronic critical illness. These range from thyroid disturbance to adrenal insufficiency. Insulin resistance is common. Changes in growth hormone and vitamin D metabolism are also reported.

Gastrointestinal dysfunction is also common. Muscle wasting, metabolic derangement and malnutrition are common features of chronic critical illness.

Infection can be recurrent. Impaired immune function is not unusual. Skin breakdown is also common. Development of pressure ulcers and issues with wound healing are often experienced.

Cognitive dysfunction (ICU delirium) and neuromuscular disorders (including critical care weakness), are frequently encountered in the chronically critically ill.

Conventional ICU management acknowledges many of these associations with prolonged management and endeavours to anticipate and avoid iatrogenesis[16].

EPIDEMIOLOGY

It is reported that 5-15% of ICU patients progress to develop chronic critical illness[4].Typically these patients are characterized by advanced age, but despite multiple comorbidities, they have lived at home with good functional status before acute illness. Of patients fulfilling criteria for chronic critical illness, surgical patients (approximately 40%) are less common than survivors of medical illness requiring ongoing mechanical ventilation.

Certain surgical cohorts appear more likely to progress to chronic critical illness[15]. Based on analysis ventilator dependent post-operative patients in long term care facilities (N=1419; from 23 weaning centres across the USA)[17], cardiac surgery (CABG 30%; heart valve 13.7%) had the highest representation. Other associations included gastro-intestinal surgery (non-neoplastic 15.9%; neoplastic 4.5%), neurosurgery (craniotomy 6.6%) and orthopaedic surgery (6.1%). Males and females were equally represented, and the median age was 71.8 years (range 18-97.7). Overlapping co-morbidities included: COPD (43%), cardiovascular disease (54%), prior stroke (12%), diabetes mellitus (25%) and prior tobacco use (59%).

Regardless of the definition applied, the prevalence of chronic critical illness appears to be increasing problem worldwide. It is possible to speculate a number of contributors that could reflect knock-on effects of improvements in peri-operative care. Increased public expectations may be coupled with a lowering threshold to consider surgical treatment in patients with a higher degree of frailty. Also with increased specialisation and abilities of intensive care units, patients who would not have been selected for ICU are now being accepted and are surviving their initial illnesses.

The published data mostly reports American studies showing a very significant burden of chronic critical illness with rates approaching 15%. High dependency respiratory units (weaning facilities) in which patients can be stepped down from ICU and undergo ventilator weaning protocols with a lower nurse staffing ratio environment. Due to differences in clinical practice, as well as healthcare funding models, it is likely that Australasian epidemiologic data will be different. To date, this has not been reported in the literature.

It must be acknowledged the studies report significantly different incidence rates from each other and that these are influenced by the definitions applied with each study (Table 2).

Having already identified an over-representation of cardiac surgical patients, the literature suggests the possibility that this cohort behaves differently to conventional chronic critical illness. Post-operative cardiac patients are typically delivered to ICU intubated and sedated for maintenance of haemodynamic and respiratory stability. Analysis of this cohort suggested that mechanical ventilation beyond 24 hours identified outliers at risk of PMV, but that these patients generally had better outcomes than other patients with PMV[18,19].

Table 2. Comparison of a range of studies reporting chronic critical illness (CCI) and prolonged mechanical ventilation (PMV). Heterogeneity in definition, representation and significance are demonstrated.

	Combes et al. 2003[19].	Loss et al. 2013[7].	Clark et al. 2013[6].	Zampieri et al. 2014[20].
Study type	Prospective observational cohort study. Four years.	Prospective observational cohort study.	Retrospective analysis of patients requiring MV in ICU.	Retrospective analysis over 18 months
ICU type	17 Beds. Public. Medical and surgical.	Private. 32 beds. Medical and surgical.	Medical ICU only.	Mixed medical and surgical. 34 beds.
Definition of PMV	Greater than or equal to 14 days	Greater than 20 days of ICU stay.	>14 days	>14 days
Number enrolled	347	453 Adults	130 consecutive patients requiring MV support.	2908
PMV %	–	CCI = 11% 84% of this was due to PMV.	31%	6.6%
Rate of tracheostomy	–	76% @ average of 16.8 days after admission.	15% @ average of 11.5 days.	–
Mortality	44% in hospital mortality. 25% one year post-ICU discharge.	58% in hospital mortality.		48.8% hospital mortality
Morbidity	Assessed via questionnaire. Significantly higher morbidity post ICU in PMV patients.			
Notes	Significantly higher rates of patients post cardiac surgery compared to other admissions. 33% ICU mortality in patients ventilated <14 days. Long-term survival higher in post cardiac patients.	Pressure ulcers seen mostly after day 10.		Showed similar morbidity and mortality post discharge in CCI and non-CCI patients. Low PMV rate 15% PMV admission from OT PMV patients consumed 42 % of ICU days.

HEALTH ECONOMICS

In the US, the issue of chronic critical illness is becoming a significant concern in health care expenditure (the following dollar amounts are reported in USD). The average hospital cost for a patient with >21 days of mechanical ventilation is approximately $423,596[11]. The health economic implications persist even when different definitions of chronic critical illness are applied. Sources have showed that chronic critical illness patients (>14 days PMV) comprised 11% of patients and absorbed 40.6% of ICU resources with an average daily cost of $2121 compared to non- chronic critical illness of $1347[7]. Other studies using PMV as > 96 hours stated and average length of stay per patient cost between $158,000 and $198,000[10]. Costs are starting to be appreciated in other cultures, with a Taiwanese study reporting that the increasing costs of chronic critical illness are not sustainable and alternative approaches need to be considered[21].

American predictions with population analysis suggesting an increase in PMV patients > 200% by 2020; yet this could be an exaggeration of the real problem as it defines PMV as > 96 hours[22]. However, based on Australian data, it is hypothesised that the rates of PMV in ICU patients are significantly lower than described elsewhere.

OUTCOMES

Regardless of definition, cohort studies of acute care hospitals document one year survival between 30 to 50% for chronic critical illness patients[4,8]. In the modern era, this is worse than most cancers.

With regard to one year mortality, outcomes are similar between medical and surgical ICU. The exception is trauma patients, who typically demonstrate much better survival. Long-term survival has not improved over the past 20 years[4].

If patients survive their hospital admission, morbidity and mortality remains high with a significantly increased rate of readmission to ICU in the future and high risk of another prolonged ICU stay[19,23]. Survivors of critical illness are often left with physical and cognitive deficits. Chronic critical illness patients tend to be even more severely affected. Only 10% of patients with chronic critical illness are alive at home and functionally independent at one year. The overall impact upon quality of life is inconsistently reported[4]. Some studies claim relatively good quality of life post discharge, while others report excess morbidity[24-26].

PREDICTION OF AT RISK PATIENTS

The ability to predict patients at highest risk of requiring prolonged ICU management post-operatively is a laudable goal. Potential benefits could be realised by patients, clinicians and hospital administrators. However, reliable prediction remains impossible.

Previous studies have found using the critical illness severity scores such as the SOFA, SAPS3, ODIN, APACHE and IPS scores to determine for correlation with prediction of PMV on admission have shown no significant correlation to date[14,19,20,27].

One predictive scoring system has been created called the ProVent© score which assesses the one year mortality of patients with PMV according to age >50, Vasopressor use, thrombocytopenia and haemodialysis[14]. This scoring system has been externally validated in a subsequent trials[28], but would not be suitable for pre-emptive surgical decision making.

At least three notable retrospective studies have been performed in this area in recent years[6,7,20]. Unfortunately, consistency of definition is still lacking with two studies using mechanical ventilation > 14 days[6,20] and the other ICU length of stay >20 days[7]. These studies range in size from N=130 to N=2908. They are difficult to compare and found minimal collaborative data for predicting chronic critical illness.

DISCUSSION

Chronic critical illness is an emerging issue with huge consequences for patients, family, caregivers and funding organisations. This issue has been receiving increasing interest internationally over the past decade, but scant data exists in the Australasian context. The lack of a consistently applied definition of chronic critical illness remains a significant barrier to research interpretation. External validity is also challenged by differences in case mix. The ICU's involved are often single centre units, a mix of public or private units and varying combinations of surgical or medical units with relatively small recruitment numbers. It has been hypothesised that these rates of chronic critical illness are not as high in Australia compared to other countries but published data is lagging.

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Pain, older people and opioids

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CLINICAL SCENARIO

An inpatient consultation request to the pain management service: To provide a pain management review for a female, 92 years old, admitted with severe abdominal pain and agitation, unresponsive to oxycodone.

Her background: A nursing home resident with moderate dementia and widespread musculoskeletal pain on transdermal fentanyl patches 100mg and 50mg every third day. Further prescription history revealed she had been prescribed Panadeine Forte six tablets per day for two years and changed to fentanyl patch 25mg some six months earlier. An initial benefit had been noted, but dose escalation occurred after two months and then at monthlyintervals.

Medical and surgical reviews had found no new or acute pathology in her abdomen. A presumed diagnosis of opioid-induced agitation/pain was confirmed when she settled with rapid reduction and cessation of fentanyl and conversion to transdermal buprenorphine patch 10mg weekly. Her nursing home prescriber was surprised when informed the daily oral morphine equivalence of her prescribed fentanyl patch was almost 500mg and was the cause of the severe pain.

This clinical situation perfectly illustrates the subject matter of a recent editorial in *Pain Medicine*, "Optimal pharmacological pain management in the older adult – an ongoing quagmire"[1].

So, how did we get ourselves into this quagmire?

THE ROOT OF THE PROBLEM

Many clinicians working in pain medicine some 20 years ago in the period when opioids were becoming more commonly prescribed in chronic non-cancer pain (CNCP) had high expectations of their benefit. In retrospect, their expectations may have been unrealistic. The arrival of systematic reviews and meta-analyses on opioid efficacy led to a calculation of an NNT (number needed to treat) around 2.4 for short-term use. This implies that three out of five patients will not benefit from opioid analgesia in the context of chronic non-cancer pain. If a responder, the analgesic benefit was recognised to be unlikely to be greater than 50 per cent at best and only as a component of a multimodal approach. Also, the widely accepted term "strong painkiller" for opioids may have encouraged similarly unrealistic expectations from patients. In brief, the evidence of benefit was less than expected and the evidence of harm has been greater than expected. In the clinical scenario described previously, benefit from strong opioid was limited and the development of tolerance encouraged dose escalation, leading to serious adverse events.

In looking at the bigger picture behind the clinical scenario outlined, it is recognised that the elderly have a higher prevalence of pain than other age groups in the community and this is more likely to be undertreated. This is reflected in a rapid escalation of opioid use in the elderly over the past 10 years compared with opioid use in other age groups. Predictably, this age group is more at risk of adverse events due to their less robust general health and frequent poly-pharmacy. In the clinical situation highlighted, the patient's long-term codeine intake prior to the initiation of fentanyl may have been a significant contributor to inducing opioid tolerance and possibly opioid-induced pain sensitivity. This is exacerbated by the fact that some clinicians appear to be unaware of current thinking in regard to opioid ceiling dose and prescription duration recommendations for chronic non-cancer pain. This manifests as failure to recognise when prescribing is heading toward the "high dose, high-risk range" and expectations of medium-term use only, rather than lifelong dosing and efficacy.

Of more concern, basic understanding of the relative opioid equivalence of different opioids (morphine-equivalent daily dose or MEDD) by some prescribers may be lacking. The rapid increase in the range of different strong opioids available for community prescribers, combined with multiple-dose formulations of each product without the benefit of MEDD labelling, has added to the potential for inadvertent misadventure. The relatively higher potency of the newer agents (oxycodone, fentanyl, hydromorphone) in comparison with morphine may be encouraging unrecognised over-dosing rather than under-dosing.

AILMENTS AND AGEING

The general community burden of disease from low back pain, neck pain and other musculoskeletal disorders is becoming clearer. The Global Burden of Disease study 2010[2] provides the rankings for years lived with disability from medical conditions. Not surprisingly to those who work in the area, low back pain was ranked first with neck pain and other musculoskeletal disorders both within the top six.

The wide ranging BEACH program of primary healthcare research recently surveyed chronic pain in Australian general practice patients[3] with 192 general practitioners surveying 5800 patients. In this survey, 20 per cent of patients reported chronic pain – osteoarthritis and back pain provided close to 80 per cent of diagnoses. Almost two thirds of the disease burden was in patients over the age of 65. Medication alone was used in 56 per cent of the population, which may reflect unrealistic expectations of benefit of "painkillers", along with difficulties in accessing non-pharmacological therapies. Of the opioid-based medications used, codeine 30mg combinations were prescribed

in 11 per cent, with tramadol in 8.9 per cent and oxycodone in 7.7 per cent. The most common non-pharmacological treatment was physiotherapy, used in 13 per cent. Advice/education and exercise was provided to less than 4 per cent. With referral to specialist care for only 3.7 per cent, it would appear that more than 96 per cent of individuals with chronic pain in the community are managed by their general practitioner alone. The apparent reliance upon analgesics as the sole modality of care in chronic non-cancer pain appears misguided at best.

Recent work from the US4 highlighted that in the decade from 1999, opioid prescribing for older adults has doubled. The authors highlighted that the difficulties of distinguishing between "quality prescribing" or not, noting the unmet pain management needs in this age group. In Australia, Gadzhanova et al[5] explored which analgesics older people use prior to initiating oxycodone for non-cancer pain in 11,000 DVA clients in 2010. They were concerned that the initiation of a strong opioid (oxycodone) occurred in over one-third of community-living DVA clients without prior use of simple analgesics or weaker opioids. Roxburgh et al[6] reviewed prescriptions for morphine and oxycodone dispensed via the Pharmaceutical Benefits Scheme from 2002 to 2008 and again noted that in the 80-years-plus age group, morphine prescribing had diminished and oxycodone use had escalated almost fourfold. Further work[7] by the same author in regard to fentanyl patch prescriptions between 2002 and 2010 noted an almost sevenfold escalation in fentanyl patch use in the 80-years-plus population – they too were unable to determine whether this reflected quality prescribing or not.

Some indications of the appropriateness or otherwise of opioid prescribing have been explored by Rogers et al[8] by Pharmaceutical Benefits Scheme prescription review (2006 to 2009) of the 100,000 Australians being followed in "45 and up" cohort. They note that 5 per cent of their study population was taking long-term opioids, 5 per cent was on intermittent opioids and 50 per cent of prescriptions were for those over 70 years of age. They were concerned by the possible adverse selection highlighted in the multidimensional profile of individuals receiving opioids; in particular, opioid dispensing was associated with smoking, obesity and lower levels of physical activity. These individuals also had lower income, reduced private health-insurance rates, were often living outside a major city, and displayed higher markers of psychological distress. Of interest, however, rates of opioid dispensing were highest in the youngest age group studied (45 to 49 years). It will be of great interest to follow the progress of this cohort if opioid prescribing is maintained as they age, observing the long-term sequelae of opioid prescribing in this population to ascertain if this causes an additional set of health burdens. Prospective work by the NDARC team[9], who followed 1500 individuals who were dispensed opioids, has reinforced the strong association between opioid dispensing and psychological distress as well as poor health and lower income, with social and psychological factors playing a more significant role in younger patients.

Both studies imply that opioid prescribing is more likely in those with complex and difficult lives (as well as medical conditions) and lower capacity to access non-pharmacological therapies – apparent adverse selection from a risk/benefit viewpoint.

Home medicine reviews (pharmacist-conducted comprehensive medication review) provide an opportunity in Australia to evaluate medications and the increased risk of medication-related adverse events. Almost 20,000 medication reviews between 2010 and 2012 were analysed by Veal et al[10] with over 22 per cent of the study group taking opioids regularly (89 per cent of these being over 60 years of age). They highlighted the suboptimal use of multimodal analgesia, particularly the low use of non-opioid analgesics. Of more concern from a risk component, 45 per cent were taking concurrent anxiolytic/hypnotics. Almost 12 per cent of patients were taking a MEDD of greater than 120mg (the recommended ceiling dose). The reporting of a mean daily dose of 36mg in the group of patients taking less than 120mg per day is somewhat reassuring, but the mean dose of 245mg daily in the higher dose group is of concern. The higher dose group more commonly used anxiolytics and hypnotics as well as other analgesic adjuncts.

The use of higher doses of opioids in the elderly has been flagged recently as a significant contributor to fractures. While delineating MEDD of 100-120mg as the usual ceiling has been derived primarily from consensus, recent work from Saunders et al[11] highlights that the annual fracture risk doubles in older chronic pain patients if MEDD is greater than 50mg. From an anaesthesia viewpoint, increased opioid prescribing in the elderly may bring an increased burden of orthogeriatric patients requiring surgery for fragility fractures, who present with the added complexity of opioid tolerance to complicate analgesia management.

Adding to the concerns about significant side effects with opioids, authors such as Sullivan[12] are reconsidering the longstanding belief that slow-release long-acting opioids are preferable to intermittent short-acting opioids for chronic pain. While this has been the premise leading the use of opioids for some decades in chronic non-cancer pain, failure to show improvement in safety, efficacy, quality of life, pain stability and sleep with long-acting opioids has encouraged a rethinking of this approach.

Other entrenched analgesic prescribing practices are coming under the spotlight with new research. With codeine being available in over-the-counter preparations and in 30mg compound preparations, the work by Johnson et al[13] exploring glial activation and codeine-induced hyperalgesia and allodynia is illuminating. They note that glial activation initiates tolerance and hyperalgesia via a non-mu receptor process, and that codeine activated glia mg per mg as much as morphine. This raises the implication that the regular use of codeine for milder pain conditions may lead to as much tolerance and increased pain sensitivity as larger doses of strong opioids, and potentially contributes to poor outcomes if disease progression warrants more potent analgesia.

SOLUTIONS?

One approach to reducing the harm from opioids in the elderly is to ensure that non-pharmacological options are used to their greatest extent as the preferred approach to chronic non-cancer pain in older adults. A clinician-guided internet-delivered cognitive behaviour therapy program is being trialled in Australia and early results are promising for a cost-effective, accessible option, with no apparent adverse effects[14]. Whether this is applicable to the elderly is yet unclear. Pain-coping skills training by nurses in a primary-care setting can lead to significant improvement in pain intensity, physical functioning, fatigue and analgesic requirements, among other improvements, again with no adverse events[15].

Providing greater accessibly to a range of non-pharmacological treatments will decrease the need for primary-care providers to rely upon opioid medications to the current extent. This will require a change to the current approach of primary-care health funding models, which provide subsidised support for pharmaceuticals via the Pharmaceutical Benefits Scheme, but limited support for non-pharmacological pain management approaches.

With the vast bulk of opioid prescription for chronic non-cancer pain performed by general practitioners, improving the knowledge base in regard to opioids is critical. A systems-based approach will be helpful, with electronic prescribing software flagging MEDD whenever opioids are prescribed. Ideally, trends toward high-dose prescribing also would be flagged to alert practitioners to consider other means of analgesic management. Clear labelling of opioids with MEDD also would be helpful, allowing both prescribers and patients to keep track of opioid dosing.

Ultimately the importance of education for prescribers and patients cannot be over-emphasised. In an ideal world, both patients and doctors would be aware of the breadth of pain-management strategies, both pharmacological and non-pharmacological, the logical outcome being a balanced analgesic management approach, maximising the benefits of carefully titrated doses of opioids to facilitate non-pharmacological therapies and exercise.

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EDITOR'S NOTE

The following article is not typical of those normally published in *Australasian Anaesthesia*. However, I believe the personal insights into drug addiction provided by Dr Charles Slack are something all clinicians should read. I invited Dr Slack, a former Harvard professor of psychology now living in Perth, to speak at the annual dinner of the Department of Anaesthesia, Royal Perth Hospital, in 1999. I soon discovered his many and varied experiences in life; his encounters with Albert Einstein, his research with Timothy Leary into psychoactive substances, personal addiction and then recovery. Finally, that he has devoted his professional life to assisting others with histories of substance abuse.

His remarkable story is too fascinating to remain untold.

Dr Richard Riley,
Editor, *Australasian Anaesthesia*

A cautionary tale with a promising finish

CHARLES WILLIAM SLACK, PHD.

PhD in experimental psychology in 1954; Assistant Professor Clinical Psychology, Harvard 1955-60. Migrated to Australia in 1976 and employed by the Victorian Department of Social Welfare. In 1990 was employed by Department of Corrective Services (now Department of Justice) of Western Australia as clinical psychologist/program officer.

MY PROBLEM

In 1961, strictly by reason of being a research scientist, I took 500 micrograms of lysergic acid diethylamide (LSD) in a "house-party" setting. LSD was legal at that time and was labelled *psychotomimetic*. Psychologists at the Harvard Psychological Clinic, including Timothy Leary and I, were eager to correct that misclassification. We *experimental* psychologists (in contrast to *clinical* psychiatrists of the day) were convinced that *mental set* and *environmental setting* were major determinants of drug effects. If LSD was to be administered in a social setting with a festival atmosphere, instead of a medical (notably a mental-hospital) environment, outcomes would be salubrious.

As a strictly professional participant-observer at a house-party in a mansion on the banks of the Hudson River I saw God in a light-bulb, merged with the carpet, landed on a tiny moon crater which felt like a toilet seat, and was overall overcome by the overwhelming conviction that my altered state of mind was exceptionally beneficial[1]. Those lacking this transcendental experience might insinuate similarities to psychosis but not I. Being certain that I had never been more sane or more privileged, I firmly believed three conclusive truths had been revealed to me:

- LSD was absolutely *not* habit forming and should be administered frequently to heighten awareness of remarkable mental phenomena.
- The inner workings of my brain had been unveiled in such a way as to completely invalidate any form of naive realism[2] as a world view.
- Psychedelic substances had enabled me to possess other indescribable absolute truths.

My purpose in telling you my story is 1) to confess that, despite my professional career and perhaps partly because of it, I became an intransigent, poly-drug addict and 2) to show how I recovered through complete abstinence[3]. When I arrived in Australia in October 1976 I'd been drug and alcohol free for eight months. At this writing, 39 years have passed since I've ingested or injected any mind- or mood-altering substance.

Being a social scientist with the best of intentions did NOT prevent me from becoming addicted. Crazy behaviour, the madness of the 1960s, was a consequence, not a cause, of my problem. Being a colleague of such hippy luminaries as Timothy Leary and Baba Ram Dass (nee Dick Alpert) and taking LSD with them is an interesting part of my story. However, a more important part is that, whereas most of my celebrated companions from the Sixties are dead (or brain dead), I remained drug-free by pulling my head in and associating with humble, even anonymous, persons who also maintained continuing abstinence.

The fact that lysergic acid diethylamide did not seem habit-forming, and was unrelated to amphetamines and opioids, only meant that I believed I could take it as often as necessary to continue to experience all its effects. The fact my friends and I were high-status professionals doing important research with legal drugs was of no consequence to the regions of our nervous systems that encoded motor programs and repeat behaviour. Later, when, with the very best of intentions, we "researched" first-hand the effects of certain opioids, our *accumbens nuclei* also reacted without reference to our professional status.

Let me state clearly what I believe to be the reason I became addicted. It was *my actions, not my motives.* Upon ingesting or injecting the substance, the immediate neurological consequences greatly increased the probability that the behaviour would be repeated. The reason *why* I took the drug was less important than the fact that I took it. The behaviour was reinforced no matter what my motive was for the behaviour. Any time I took a drug for any reason, the probability I would take it again – for any or no reason – increased. It took me 15 years to go from being an Assistant Professor of Clinical Psychology at Harvard to being unemployed in Birmingham, Alabama.

MY RECOVERY

How and why I took drugs is less important than why and how I quit. I attended a meeting of the American Correctional Association to look for work in a jail or institution (my career had slumped to the point where a "clink-shrink" job was my only hope). At that meeting, the novel concept of my attending a 12-step program was effectively planted in my mind by a renowned criminologist and former colleague. Identifying me as an alcoholic who needed help, Dr Alex Bassin[4] refrained from giving advice, instead asked me to lecture to his morning criminology class! Years had passed since I'd received such a request. I agreed without reservation and was careful not to drink on the day and to arrive on time. Alex introduced me to the class but then made a strange proposition. He said, "Today we do something different. Dr Slack will speak for 10 minutes and then I will speak for 10 minutes and so on – alternating throughout the hour." I had to agree – it was his class.

I think it is relevant that today I cannot remember what I said in any of my three 10-minute talks. However, I shall never forget what he said: Relating each of my talks to Alcoholics Anonymous. Criminology was crying out for someone like me to provide a professional assessment of why AA appears to be so successful. What kind of social relationship was at work in AA? What theory underlay that program of recovery? He thought my theoretical position remarkably similar to AA's. A cultural/anthropological informant was clearly required to attend, work the program and report findings. Heading north from Florida, I resumed drinking again in Mobile, Alabama. It was Mardi Gras; citizens drank on street corners and so did I until I lost consciousness. I came to on March 3 in a strange bed in a strange house where a stranger was informing me of my untoward behaviour. Among other transgressions I had apparently encountered a Supreme Court Justice of the State of Alabama and had informed him of precisely what was wrong with the justice system of that state.

Driving back from Mobile to where I lived near Birmingham, and having come to the end of my rope, I stopped the car and began to cry. I had reached what AA calls "rock bottom". Not long thereafter I attended the first of well over 5000 12-step meetings to date. My recovery requires complete abstinence on a daily basis; sustained by my associating regularly with others practicing a similar program. I have found that being easily influenced is no great handicap, providing I associate with those who are doing what I need to do. It's not what I do but the way that I do it. And it's not what I don't do but *with whom* I don't do it. Since March 3, 1976 I have remained completely abstinent from all mind- and mood-altering drugs including alcohol and nicotine[5]. I like to say there is nothing in my blood but blood.

I migrated to Australia in October 1976 to get work. In 1980 I became a Christian. I attend church regularly now and view the bible as a text-book on how to avoid being addicted (enslaved) to sinful things like drugs by becoming addicted (*devoted*) to Godly things like helping fellow addicts in recovery. Being fascinated by rehabilitation, personality change, reformation, character development, indeed anything related to the kind of identity transformation that accompanies what the bible calls "repentance", I still attend recovery meetings. I find it thrilling to observe improvement in others and to have others observe it in me.

Nearly 30 years ago, my oldest daughter phoned from California to say she had been attending 12-step meetings for two years. I asked her why she hadn't told me sooner and she said that she'd wanted to but, because I was such a "blab-mouth" I would have told everybody in the US. She said I could tell all my friends in Australia but that she didn't want everyone in America to know her whole story. I asked her why she'd chosen a 12-step program. She said she knew it worked. I asked how she knew. She said she could tell by my voice over the phone!

I was in Victoria and then Western Australia and she was in California. Unemployed, she was living what I used to call the hippy-lifestyle of the Haight-Ashbury district of San Francisco. Although I never consciously tried to influence her, the change in her father was obvious enough to spark a change in his daughter. With sobriety, her life took a remarkable turn. She got a good job, saved her money, earned a MA in Psychology, and is now director of a community-based mental-health centre in Oakland[6]. Other gratifying, remarkable things have happened to me since I became abstinent and began to make conscious contact with a loving deity.

CONCLUSION

Finally I must admit I cannot claim to have led a successful life. Nevertheless I do have the benefits – happy marriage, successful retirement, respect of colleagues, love of friends and family, and an opportunity to help others – as though I had been successful! To paraphrase televangelist, Joyce Meyer: "I must give the glory to God and the credit to my spouse and superiors, while I just take the privilege."

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3. I have been administered anaesthetics and pain killers in hospital on at least three occasions. Always careful to inform medical personnel of my history and to be accountable after release, I have not relapsed into self-used upon discharge.
4. Dr Alex Bassin, Professor of Criminology, Florida State University, formerly Chief Psychologist, New York State Supreme Court County of Kings.
5. Caffeine is an exception: I still drink coffee.
6. L'chaim Community Mental Health Center, Oakland, California (http://www.lacheim.org). For more information, contact Frances Slack Raeside, Clinic Director at frances@lacheim.org

Anaesthesia teaching for medical students

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INTRODUCTION

"The proposition that it is desirable to include in the curriculum prescribed by the General Medical Council the study of anaesthetics may appear too obvious for formal consideration."

Dudley Buxton. On the advisability of the inclusion of the study of anaesthetics as a compulsory subject in the medical curriculum. BMJ, 1901[1].

In Australia alone, medical schools graduated more than 3,300 new doctors in 2013 – double the number of graduands from a decade ago[1]. Anaesthesia, critical care, perioperative and pain medicine are taught in most Australian and New Zealand medical school curricula to some degree. However, no uniform curriculum exists between universities, and no standardisation occurs for the relevant knowledge and competencies of graduating doctors.

In this article we provide answers to a number of questions that may be asked about anaesthesia curricula for medical student teaching.

THE QUESTIONS

What is the rationale for teaching anaesthesia and perioperative medicine in the undergraduate curriculum?

Anaesthetists possess a wide range of knowledge and skills and are well suited to teach a variety of topics that benefit all medical undergraduates. As well as clinical anaesthesia, they can provide training in areas such as cardio-pulmonary resuscitation, care of the critically ill, preoperative assessment, perioperative medicine, important procedural skills, acute and chronic pain management, and applied physiology and pharmacology. Anaesthetists are also well positioned to explore other themes including aspects of teamwork, multidisciplinary work, patient safety, ethics and professionalism[2].

Previous studies have demonstrated deficiencies in knowledge and skills in many of these areas at an undergraduate and early postgraduate level[3]. Anaesthesia is the third largest hospital-based specialty in Australia and New Zealand but forms a very small proportion of the curriculum in most medical schools[4,5].

What is the state of current teaching of anaesthesia and perioperative medicine in medical schools?

This is highly variable throughout Australia and New Zealand. In a recent survey to which anaesthesia representatives from 57 per cent of medical schools in the two countries responded, half of the medical schools had a formal anaesthesia curriculum in place[6]. Anaesthesia teaching occurs primarily in the senior clinical years of the course, with durations ranging from optional lectures to three to four weeks of formal teaching and clinical placement. Two schools offered additional elective teaching on top of their pre-existing curricula. Where no formal curriculum exists, some anaesthesia topics are taught in either critical care blocks, as student electives, or in conjunction with surgical terms and basic science lectures.

The current content focuses on knowledge and skills, mainly relating to airway management, pharmacology, life support, and intravenous fluids and cannulation. Most schools use multiple methods of teaching, with almost all using clinical placements in theatre and two thirds or more additionally using simulation, lectures, and clinical skills tutorials. Most assess students at either the end of the placement or in a major examination.

What level of knowledge of anaesthesia and perioperative medicine do students possess?
There are no recent studies assessing student knowledge of anaesthesia and perioperative medicine, and none relating to Australian and New Zealand students. Studies from North America, Europe and the UK demonstrated deficiencies in knowledge and skills at an undergraduate and early postgraduate level. These areas included basic airway management; acute and chronic pain management; basic life support and simple procedures such as intravenous cannulation[7,8,9,10]. Some studies have measured frequency of teaching and confidence, rather than competence[11]. One study demonstrated that in medical students after an anaesthesia attachment, neither the number of times a skill was performed nor the level of confidence of the medical student correlated with competency using simulator-based assessment scenarios[12].

Are there barriers to teaching anaesthesia at an undergraduate level?
There are a number of barriers to overcome to increase the exposure of medical students to an anaesthesia curriculum.

- Importance of topic. Anecdotally, many medical schools still consider anaesthesia as a topic is not a high priority in their student curriculum. Some have not yet have realised that anaesthetists are ideally placed, and willing, to teach many important knowledge and skills topics under the broader umbrella of perioperative medicine.
- Timing. Immersive teaching in perioperative medicine is probably best placed in the later years of the student curriculum. Access to students at this time may be difficult as they stream into other clinical areas as well as elective sessions.
- Availability. Students are often scheduled for regular weekly activities either on campus or in various healthcare settings, which can pull them away from a block of time devoted to a hospital-based specialty, such as anaesthesia. Overcoming this issue if a block of training time is preferred may require extensive negotiations with the medical school.
- Faculty. Anaesthetists have varying degrees of training and interest in teaching medical students, as well as varying degrees of knowledge about and interest in the medical school curriculum.
- Organisation. Anaesthetists are often accompanied in theatre by junior staff such as junior anaesthesia trainees, emergency medicine trainees, intensive care unit trainees, and others seeking airway experience. The “burden” of another student can result in less enthusiastic teaching. It may be necessary to have both a trainee and a medical student rostered to a theatre, necessitating division of time and attention between the two. In larger anaesthesia departments it is difficult to ensure that teaching is consistent between teachers. Smaller clinical school departments have fewer theatres running on a daily basis and asking students to attend as a large group is unrealistic. The number of students that can be accommodated for in-theatre teaching is limited by the size and enthusiasm of the department.
- Co-existence with surgery. Many students will be more interested in the procedure than the anaesthesia, especially as surgery occupies more prominence in their curricula. Students’ perceptions of the learning experience can vary with how “exciting” they think the procedure is. This natural reaction on the part of the student misses the point of the in-theatre teaching of perioperative medicine, pain and anaesthesia, which can occur regardless of the case being undertaken. It is often easier for the teacher to engage with the student when the surgical case and accompanying anaesthesia are of lower acuity.

Should we be teaching airway and other procedural skills to medical students?
There is now a published consensus that our medical students do *not* need to learn the skill of endotracheal intubation[6]. Other more basic airway skills are, however, considered essential. Assessment of the airway, bag-and-mask ventilation, simple airway manoeuvres, and insertion of a nasopharyngeal airway and Laryngeal Mask Airway (LMA) are skills reported as being standard expectations of junior doctors. Anaesthesia teaching may be the best or even at times the only place that all could be routinely taught.

A survey of graduates from the University of Auckland found that year one doctors did not perform tracheal intubations, but they did perform bag mask ventilation and insert LMAs, both supervised and unsupervised. Further, 70 to 80 per cent had participated actively in a cardiac arrest/medical emergency team in this first year of practice[13].

The number of learners competing for operating theatre airway practice is an increasing problem. Local data suggests that even anaesthesia trainees may struggle to achieve sufficient airway experience, with reports of a total of between 150 to 200 intubations per year, and an average of 40 airway management experiences of all types per month[14,15]. Several weeks in anaesthesia will see a relatively small number of opportunities for medical students to practice airway management and other techniques, such as low-fidelity simulation training, may be usefully employed.

Intravenous cannulation is also considered a core skill for anaesthesia teaching. Opportunities to learn and practice this skill occur during an anaesthesia attachment but may be limited by protocol or logistical issues. Each location can assess its capacity to provide adequate cannulation teaching for students and use alternate methods, such as simulation or learning from a cannulation clinical nurse specialist, if required. Basic life support (BLS) and advanced life support (ALS) also are core components of an anaesthesia or critical care teaching curriculum.

What traits does the ideal teacher in anaesthesia possess?
The ideal teacher is motivated, interested, and understands the needs of the students. He or she would be familiar with the curriculum and understand that the aim of in-theatre teaching goes beyond the details of clinical anaesthesia. The theatre environment can be daunting and unfamiliar for students. The ideal teacher will recognise this and will familiarise the student with their new setting and ensure they feel welcome.

It is often helpful to designate one consultant with overall responsibility for co-ordinating medical students and ensuring both the students and other anaesthetists are familiar with the curriculum.

Is there a place for high-fidelity simulation in undergraduate anaesthesia education?
High-fidelity simulation allows for deliberate practice of routine, unusual and human factor knowledge and skills in a patient-safe environment. The use of high-fidelity simulation can allow medical students to experience the operating theatre environment prior to or during their clinical placement, which enables learning on multiple aspects of clinical anaesthesia, resuscitation, applied physiology, applied pharmacology, monitoring, human factors, and medication safety in a reproducible and efficient manner. There is no evidence that high-fidelity simulation is inferior to other methods of instruction when teaching medical students, with some studies showing it to be superior for teaching certain topics, such as management of various medical emergencies and induction of anaesthesia[16,17,18]. While there is interest and growing evidence supporting the use of high-fidelity simulation as a teaching tool in undergraduate medical education, it is not yet established as an assessment instrument.

What are the best teaching methods?
One-on-one bedside teaching during a clinical placement in theatre is probably the gold standard as a teaching method. This is, however, labour intensive and highly variable, depending on enthusiastic and informed teachers following set curriculum goals. Other useful methods include didactic teaching such as lectures, problem-based learning tutorials, clinical skills tutorials, simulation sessions, e-learning modules, and using logbooks or ward rounds to provide foci for discussion.

A longitudinal approach incorporating continuity in either patient care or consultant supervision also is possible. In the former case, students follow a patient from the preoperative assessment clinic into the operating theatre and for their post-operative care. This approach is more patient-centered than the traditional approach and can be tailored to cover specific knowledge or competency areas. Alternately, students can be paired with anaesthetists periodically over a longer period of time. This allows a more efficient coverage of objectives and formation of a greater bond between the two[2]. An Australian study has previously found that of students who intended to pursue a career in anaesthesia, 94 per cent identified a positive role model[19].

Where should teaching occur?
Anaesthesia teaching can occur either as an independent topic or as a component of a critical-care block. The operating theatre and the pain round are considered core environments. Other locations, such as the intensive care unit, the pre-operative assessment clinic, recovery units, lectures, and simulation workshops are also possible depending on local resources and collaborations.

Should a student anaesthesia curriculum be assessed?
Eighty per cent of the Australia and New Zealand survey respondents felt an anaesthesia curriculum should be assessed. A range of techniques can be employed. These include demonstration of practical skills, such as CPR or IV cannulation, a record of attendance, a logbook of cases seen, formal case presentations, case-based essays, completion of a workbook with set topics in a simulation environment or by formal techniques such as multiple-choice questions, short-answer questions, or in an Objective Structured Clinical Examination. Assessment is probably most appropriate at the end of the anaesthesia course or placement. This also could occur in end-of-year or final examinations, but agreement with the medical school needs to be negotiated. The outcomes of assessment also need to be considered; will there be a summative element to the assessment and what will be the consequences of an unsuccessful assessment? Students should be provided with formative feedback as well as have an opportunity to provide feedback on the course.

What would the “best practice” curriculum for student teaching of anaesthesia and perioperative medicine look like?
Recent Australian and New Zealand consensus guidelines noted that the operating theatre and pain rounds are ideal environments for undergraduate anaesthesia and perioperative medicine teaching[6]. Anaesthesia curricula should be taught in the more senior years, be of three to four weeks’ duration, and occur with collaboration from others as appropriate, for example, intensivists and pain nurses. The content should encompass general perioperative and critical care knowledge with relevant clinical, procedural, ethical, and professional skills as listed in Table 1. All respondents felt that the aim of anaesthesia curricula should be to aid in the production of safe junior doctors, and none felt that teaching students the details of clinical anaesthesia was the important goal.

In 1901, Dr Dudley Buxton, the vice-president of the Society of Anaesthetists in the UK, called for the introduction of a standardised study of anaesthesia knowledge and practical skills as a compulsory subject in the medical curriculum[20]. The reasons for this may have changed slightly over time, but many of the issues he discussed in implementing such a curriculum have not. More than 100 years later, we repeat this call, see Table 2.

Table 1. Content of an ideal anaesthesia student curriculum (reference 6)

Perioperative medicine	Preoperative assessment and preparation Assessment of comorbid conditions Exercise tolerance Management of medications preoperatively
Critical care	Basic and advanced life support Recognition and management of the deteriorating patient Care of the unconscious patient Management of shock, hypovolaemia, hypoxia
Applied basic sciences	Interpretation of standard blood test results Analgesic pharmacology ECG interpretation
Patient monitoring	Oxygen administration and monitoring
Airway management	Triple manoeuvre Bag-mask ventilation Nasopharyngeal airway insertion LMA insertion
Pain management	Acute pain Multimodal analgesia Postoperative pain
Intravenous fluid management	Principles of fluid therapy Assessing fluid balance Prescribing fluids Blood transfusion – indications, precautions, side effects
Procedural skills to learn (not covered above)	Intravenous cannulation Aseptic technique
Professional skills	Recognition of need to ask for help Human factors and communication in an emergency setting Decision-making and teamwork principles
Ethical skills	Consent principles Patient confidentiality End of life management Assessment and communication of risk

Table 2. Lessons learnt/Tips for success

• One overall co-ordinator is essential for success of a medical student rotation to anaesthesia, especially in busy departments with large numbers of anaesthetists.
• Making students feel welcome is very important as the theatre environment is pretty daunting at first. We name the students on our weekly roster in individual theatres and provide an introductory morning and physical orientation to the theatre complex.
• Provide a list of learning objectives as a prompt to help guide teaching. For example, one of our in-theatre teaching sessions focuses on fluid management and transfusion medicine. A list of learning objectives for the student to initiate questions might include: a) What are the major differences in composition of the different crystalloids? b) What is the consequence of giving many litres of normal saline? c) At what haemoglobin level is transfusion considered?
• Students need to have block time that is free from other distractions.
• Both students and anaesthetists need reminding that teaching should not focus on the specifics of anaesthesia. This needs reiterating at frequent intervals.

Source: Austin Health, Victoria

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Integrating CONSORT into journal clubs

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INTRODUCTION

Journal clubs are often activities that people think are good to establish but are limited by poor organisation, poor preparation and an unstructured process, which makes it unlikely for participants to leave the journal club with any sense of conclusion or ambition to change their practice. This article will present a fresh approach to conducting journal clubs with a discussion of a structured approach to reporting (and reviewing) trials and practical suggestions to improve participant satisfaction.

WHAT IS CONSORT?

CONSORT is an abbreviation for the Consolidated Standards of Reporting Trials, which is a checklist of items that should be included in the reporting of randomised-controlled trials to minimise bias or to allow better evaluation of trials.

In 1993, two groups in Canada and the US independently began developing lists of recommended items for inclusion within the reporting of randomised-controlled trials. In 1996, Drummond Rennie, a deputy editor at JAMA: *The Journal of the American Medical Association*, brought together representatives from each group to merge the best of these proposals into a single set of recommendations, initially published in 1996.

Further meetings have resulted in revisions in 2001 and 2010, with broadening of requirements to include “highly desirable” items, as well as “essential” items.

WHY IS CONSORT USEFUL?

The most recent CONSORT iteration includes 25 main items, with 12 divided into two sub-items. The items are grouped into headings of title and abstract, introduction, methods, results, discussion and other information. Each has been selected as a necessary inclusion to evaluate the trial or to reduce bias. Table 1 lists all of these. The rationale for inclusion has been detailed in an explanatory document first developed in 2001, and updated as part of each major review.

EXTENSIONS TO CONSORT

After the initial successful uptake as a reporting standard for randomised-controlled trials, the CONSORT group also has developed guidelines for cluster trials, non-inferiority and equivalence trials, pragmatic trials, herbal medicine interventions, non-pharmacological treatment interventions and acupuncture interventions. The group also has suggested improvements to the reporting of patient-reported outcomes, harms and abstracts.

Table 1. Consort 2010: Checklist of information to include when reporting a randomised trial

Section/topic	Item no	Checklist item
Title and abstract		
	1a	Identification as a randomised trial in the title
	1b	Structured summary of trial design, methods, results and conclusions
Introduction		
Background	2a	Scientific background and rationale
Objectives	2b	Specific objectives or hypotheses
Methods		
Trial design	3a	Description of trial design, including allocation ratio
	3b	Important changes to methods after trial commencement, with reasons
Participants	4a	Eligibility criteria for participants
	4b	Settings and locations where the data were collected
Interventions	5	The interventions for each group with sufficient details to allow replication, including how and when they were actually administered

Section/topic	Item no	Checklist item
Methods		
Outcomes	6a	Completely defined pre-specified primary and secondary outcome measures, including how and when they were assessed
	6b	Any changes to trial outcomes after the trial commenced, with reasons
Sample size	7a	How sample size was determined
	7b	When applicable, explanation of any interim analyses and stopping guidelines
Randomisation:		
Sequence	8a	Method used to generate the random allocation sequence
Generation	8b	Type of randomisation; details of any restriction
Allocation concealment	9	Mechanism used to implement the random allocation sequence, describing any steps taken to conceal the sequence until interventions were assigned
Implementation	10	Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions
Blinding	11a	If done, who was blinded after assignment to interventions and how
	11b	If relevant, description of the similarity of interventions
Statistical methods	12a	Statistical methods used to compare groups for primary and secondary outcomes
	12b	Methods for additional analyses, such as subgroup analyses and adjusted analyses
Results		
Participant flow	13a	For each group, the numbers of participants who were randomly assigned, received intended treatment
	13b	For each group, losses and exclusions after randomisation, together with reasons
Recruitment	14a	Dates defining the periods of recruitment and follow up
	14b	Why the trial was ended or stopped
Baseline data	15	A table showing baseline demographic and clinical characteristics for each group
Numbers analysed	16	For each group, number of participants included in each analysis and whether the analysis was by original assigned groups
Outcomes	17a	For each primary and secondary outcome, results for each group, and the estimated effect size and its precision
	17b	For binary outcomes, presentation of both absolute and relative effect sizes is recommended
Ancillary analyses	18	Results of other analyses performed, including subgroup analyses and adjusted analyses, distinguishing pre-specified from exploratory
Harms	19	All important harms or unintended effects in each group
Discussion		
Limitations	20	Trial limitations, addressing sources of potential bias, imprecision, and if relevant, multiplicity of analyses
Generalisability	21	Generalisability of the trial findings
Interpretation	22	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence

Section/topic	Item no	Checklist item
Other information		
Registration	23	Registration number and name of trial registry
Protocol	24	Where the full trial protocol can be accessed, if available
Funding	25	Sources of funding and other support, role of funders

Adapted from www.consort-statement.org/checklists/view/32-consort/66-title, accessed July 10, 2015

JOURNAL CLUBS

A journal club is a group of individuals who meet regularly to critically discuss the clinical applicability of articles in current medical journals. William Osler is widely acknowledged as having started the first journal club with the intention of sharing scant resources and translating best information of the day into clinical practice. In a review of the role of the journal club in medical education, Linzer notes that, over time, the teaching of critical appraisal skills has been added to the objectives. Critical appraisal is the process of carefully and systematically examining a research report to judge its trustworthiness, make sense of the results and assess the relevance of the findings in a particular context. Although value is placed on journal clubs by organisations, educators and learners and, given their ubiquitousness in learning environments, little research has been done on how these can best be conducted or what can be achieved within them.

LITERATURE ABOUT JOURNAL CLUBS

Ebbert and colleagues (2001), from the Mayo Clinic conducted a systematic review of journal clubs and found seven papers worthy of inclusion. They defined benefit as effective for improving patient care, teaching critical appraisal skills, improving reading habits, increasing knowledge of clinical epidemiology and biostatistics, and increasing the use of medical literature in clinical practice. He found conflicting evidence of benefit. In his discussion, he lamented the lack of rigour in the evaluation of potential benefit. He also discussed the potential usefulness of a critical appraisal checklist in running the journal club.

In a later systematic review of medical journal clubs, Deenadayalan and colleagues (2008) found 12 papers of sufficient quality for inclusion, with five of the seven papers from Ebbert. Effectiveness was defined by improving knowledge and critical appraisal skills. Much of the outcome data is favourable but relies on self-reporting of perceived improvements in related skills. From this review, Deenadayalan made a number of recommendations to improve the quality of journal clubs. These are summarised in Table 2.

Table 2. Summary of recommendations from Deenadayalan

- Members should be the same discipline or have similar interests.
- Establish an overarching goal, which should be reviewed regularly.
- Establish the purpose of each meeting, link this to paper or skill acquisition.
- Attendance should be an expectation and be recorded.
- Conduct meetings at regular, predictable intervals, probably monthly.
- Conduct at appropriate time of day.
- Consider including food.
- Leaders increase effectiveness.
- Leaders should choose articles, with input from members.
- Train the leader in relevant research design and/or statistical knowledge.
- The leader can change from meeting to meeting, tension between authority and expertise/knowledge.
- Provide access to statistician for support for leader.
- Choose relevant case-based or clinical articles.
- Provide all participants with pre-reading at a suitable time period.
- Use internet as medium for distribution, maintaining resources.
- Use established critical appraisal approaches, and structured worksheets.
- Formally conclude each journal club by putting the article in context of clinical practice.

STRUCTURING AN APPROACH

With both reviews highlighting the need for a checklist to guide inquiry and evaluation, the question is which checklist to use? Although various checklists exist, none have the broad base of support that CONSORT does. However, using a list of 37 items is cumbersome and makes grasping the overall worth of the article much more difficult.

Using summary questions to guide the evaluation makes the process seem manageable and achievable. There are four principal aspects to a study:

1. Why was it done?
Justification needs to be provided in the introduction section that the study is original, is based on scientific evidence and is a significant issue worthy of the effort of investigation.

2. How was it done?
Evaluation of the methodology includes understanding the design, and that steps have been taken to reduce bias and the planned statistical analysis.

3. What did it show?
The number of participants that were eligible, approached, recruited, randomised, treated and evaluated should be seen.

An understanding of the primary and secondary outcomes is necessary, and the principles of the analysis.

4. What relevance is it?
What this study shows in the context of the broader literature.

By adding a question on relevant aspect of statistics or trial design, the aim to foster improved understanding of this area is addressed.

WHY THESE QUESTIONS?

These questions align with the major domains of the CONSORT criteria and provide a framework to guide initial inquiry and discussion. They are brief enough to remember and still address the major aspects of the article. The detailed CONSORT criteria within each area can be used to amplify answers to these questions. The explanation and elaboration document that accompanies CONSORT provide a wealth of information about trial design and reporting. All of these are recommended to the reader to consider incorporating into journal clubs.

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Getting serious about research: measuring outcomes that matter

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INTRODUCTION

Anaesthesia and perioperative medicine research trial design has evolved; large, well-designed randomised controlled trials (RCTs) are now commonplace. For these trials to make a meaningful contribution to our practice, they must ask important clinical questions, and measure outcomes that are meaningful to clinicians and patients alike. As outcomes such as mortality and stroke are rare, investigators often use surrogate or composite outcome measures to reduce the sample size needed to adequately power a trial. The results of such trials can be difficult to interpret and apply to the clinical setting. The trials of the future should use patient-centred outcome measures, such as disability-free survival, to provide meaningful outcome data in appropriately sized clinical trials.

THE EVOLUTION OF ANAESTHETIC RESEARCH

Early anaesthesia research concerned the efficacy of novel anaesthetic agents such as nitrous oxide, ether and chloroform. These observational experiments were conducted on patients, colleagues or the investigator themselves. In 1844, dentist Horace Wells submitted himself to having his own wisdom tooth extracted by Dr John M. Riggs while nitrous oxide was administered by Gardner Quincy Colton. Impressed, Wells used nitrous oxide to provide painless dentistry for his patients until his failed demonstration of the anaesthetic properties of nitrous oxide in Boston the following year[1]. Notwithstanding this initial setback, there was near-universal adoption of nitrous oxide into anaesthetic practice, but it would be 163 years before large, well-designed randomised controlled trials would investigate the drug's safety[2,3].

In 1920, Guedel documented the eye signs of ether anaesthesia in *The American Journal of Surgery*[4]. This was the first of many small observational studies into the physiological and pharmacological effects of anaesthesia that dominated the literature for many years. Most of these studies were performed on a small non-random sample of volunteers and have never been repeated on a larger scale. Despite this, these seminal papers continue to be referenced in common texts and have formed accepted anaesthetic dogma. For example, our understanding of the alterations of respiratory mechanics due to surgical positioning is based on one study involving 10 patients[5].

A notable example of accepted dogma failing to translate to clinical outcome can be found in the area of blood transfusion. Until relatively recently, anaesthetists (and other clinicians) believed that blood transfusion was inherently good for patients. We transfused blood in a liberal manner to improve oxygen delivery to tissues. It wasn't until 1999, when the TRICC (Transfusion Requirements in Critical Care) trial demonstrated no difference in survival with restrictive (haemoglobin goal of 7-9 g/dL) versus liberal (haemoglobin goal of 10-12 g/dL) transfusion in critically ill patients that our practices changed.[6] Another recent example is the ABLE trial, which examined the common belief that older blood is associated with poorer outcomes. In fact, no outcome differences were discovered[7].

Anaesthetists, like other clinicians, were prone to adopting new technologies, drugs, or practices after early studies showed promise and the basic science seemed to make sense. Often these studies were industry sponsored and therefore biased towards favourable results[8]. Other small clinical studies showed surprisingly large treatment effects and guided clinical practice until subsequent large trials showed conflicting results. An example of this was the recommendation by perioperative guideline committees of beta-blockers for high-risk cardiac patients undergoing non-cardiac surgery[9].

The quality of anaesthesia trials has improved over the past three decades[10,11], with the recognition of the importance of large multi-centre randomised controlled trials (RCTs) in anaesthesia and perioperative medicine[12,13]. These trials are considered to provide the highest level of evidence for a single trial. The first anaesthetic trial of this type in Australia was the MASTER trial, which evaluated epidural analgesia versus intravenous opioids for major abdominal surgery. Contrary to popular belief, this trial demonstrated no reduction in mortality or major complications in patients that received an epidural and significantly changed anaesthetic practice around the world[14].

With the growth of anaesthetic research, large groups such as the Australian and New Zealand College of Anaesthetists Clinical Trials Network have been established to answer important clinical questions through collaboration between researchers and large multi-centre studies. As research funding and resources are finite, it has become increasingly important to justify the quality and value of our trials. It is therefore essential that future research conducted by these groups is designed to answer important clinical questions and measures outcomes that provide clear and meaningful answers.

QUESTIONS WORTH ASKING

With the expanding role of the anaesthetist as a perioperative physician, there has been a change in focus to the preoperative and intraoperative management strategies that affect short-and long-term postoperative outcomes[15]. Within this framework, trials have been designed to answer an important clinical question where genuine equipoise exists. These questions must be important to both clinicians and patients and focus on long-term outcomes[16]. Ideally, they should also be appealing to healthcare systems and be easily understood by funding bodies. In order to address this issue, the Research Council of the National Institute of Academic Anaesthesia in the United Kingdom published a document that endeavoured to determine research priorities in anaesthesia[17]. The suggestions were organised by a panel of representative and varied clinicians, as well as research experts, into a list of 14 key questions in anaesthesia (Table 1).

Table 1. Research priorities for anaesthesia and perioperative medicine*

What interventions can prevent perioperative cardiac complications?
Does a brief period of preoperative exercise training improve outcomes after major surgery?
What perioperative management strategies improve outcome in head injury?
What interventions prevent the development of chronic pain after surgery?
Does an enhanced perioperative care package improve outcome?
Under what circumstances should aspirin be discontinued in the perioperative period?
Would actively targeting preoperative blood pressure in the intraoperative period reduce the incidence of postoperative complications?
Does conventional (as opposed to tight) glycaemic control improve perioperative outcome?
What is the place of “anti-neuropathic” pain medications in the treatment of postoperative pain?
What are the best arrangements for the preoperative assessment of elective surgical patients?
Would higher nurse-to-patient ratios during the first 48 h after operation reduce the complication rate after major abdominal surgery?
What is the impact of same-day surgery on primary care?
How should patients for day surgery and 23 h surgery be selected?
Does the use of local or regional anaesthesia prevent cancer recurrence?

*Reproduced from Howell et al[17].

These questions are framed around clinical questions rather than basic science. That is not to discount the importance of understanding the genetic, cellular, physiological and pathological processes that contribute to disease. But rather, as Devereaux *et al*. argue, basic science research is “not designed to guide patient care, preventive strategies, or health policy decisions”[18]. They cite the example of milrinone, an inodilator previously used by cardiologists to treat heart failure. Evidence from a small (n=12) physiological study showed that milrinone increased exercise capacity by 22 per cent in patients with cardiac failure[19]. However, a subsequent RCT (n=1,088) demonstrated that milrinone increased mortality by 28 per cent relative to placebo[20]. This example also demonstrates the importance of using the right outcome measure. In the first small trial the assumption was made that patients with increased exercise capacity must have improved cardiac function and were therefore more likely to survive. The second, larger study was powered to detect a difference in survival, the real outcome of interest in this case.

OUTCOMES WORTH MEASURING

With more than 230 million major surgical procedures being performed annually, adverse patient outcomes following major surgery are considered a global public health issue[21]. When designing a perioperative clinical trial, choosing the ideal outcome measure can be challenging. Funding and other practical limitations may preclude measurement of the outcome that seems most important. Despite this, researchers must ensure that the primary outcome measure of a study answers the real clinical question, rather than being a surrogate that is easier to measure.

Fisher described the phenomenon of surrogate outcome measures in research involving post-operative nausea and vomiting[22-24]. He listed prolonged recovery-room stays, increased unplanned hospital admission and decreased patient satisfaction as “true” outcomes, with meaning for the hospital system in terms of cost and obvious import to the patient. However, most studies examine surrogate outcomes such as the number of episodes of vomiting or number of patients with no episodes of vomiting. Although objective, these outcomes do not necessarily have any bearing on patient satisfaction[22].

Mortality, in many ways, is an ideal outcome to measure. It is important, clearly understood and has meaning for clinicians, medical systems, and patients. As a result, mortality is commonly utilised in anaesthetic studies as a primary end point. The difficulty with this approach is that, fortunately for clinical practice, perioperative mortality is a rare event. Consequently, trials powered to show a statistically significant change in mortality (or other rare outcomes) require a very large sample size, generally greater than 10,000 patients.

One way of overcoming the problem of needing a large sample size to investigate rare events is to group a number of rare events together as a composite outcome measure. A commonly used example is MACE or Major Adverse Cardiac Events[25,26], in which a trial participant will be classified as having the primary outcome event if they have any one the MACE outcomes. This approach enables researchers to design trials that achieve statistically significant outcomes with apparently conclusive results. However, the approach has a number of pitfalls. Composite end points that are described the same way do not always represent the same spectrum of individual components. For example, with MACE, myocardial infarction (MI) and death are typically included, but revascularisation, troponin rise, cardiac arrest, heart failure, or bleeding are all variously included in different trials. This renders the term meaningless, prone to misinterpretation and includes end points that are likely to be dissimilar in import to patients[27].

An inherent assumption with composite end points is that each component has a similar weight, or burden, on health. In practice, this may not be the case. Postoperative complications, ranging in severity from surgical site infection to pulmonary embolus or stroke, may be combined with mortality as a composite primary outcome[28]. This can make direct comparison of the primary outcome between groups difficult to interpret and requires analysis of secondary outcomes, for which the trial was not powered, to add meaning to the results.

The Perioperative Ischemic Evaluation Study (POISE) trial investigated the use of metoprolol for patients at high risk of cardiovascular disease having non-cardiac surgery[29]. The primary end point was a composite of cardiovascular death, non-fatal MI and non-fatal cardiac arrest. Fewer patients in the metoprolol group reached the primary end point as a result of a decreased rate of non-fatal MI. However, there were significantly higher rates of stroke and death in patients taking metoprolol. How do we weigh these conflicting results? It is likely that few patients would accept a lower risk of MI at the cost of a higher risk of death or stroke, but to answer this question one must view the outcomes from the patient’s perspective. It is essential to know the degree of long-term disability that patients experience as a result of the MI or stroke. To measure this, a patient-centred outcome measure must be used.

PATIENT-CENTRED OUTCOME MEASURES

Patient-centred outcome measures are commonly used to monitor disease progression and response to treatment from patients with chronic medical conditions. This practice was born from the realisation that conventional physiological measures did not always correlate with the patient’s perception of their health. For example, patients with chronic obstructive pulmonary disease were historically monitored with objective pulmonary function measures, but quality-of-life outcomes are not well predicted from these measures[30].

The REASON study, carried out in Australia and New Zealand, identified that 5 per cent of older patients (>70 years) had died and 20 per cent had suffered a complication in the 30 days following surgery[31]. While these data are invaluable, questions remain. Of those patients with a complication, what proportion had a poor recovery or diminished quality of life as a result? What proportion of patients improved in the long-term and what proportion developed a new long-term disability as a consequence of surgery?

The classic medical joke, in which the surgeon proclaims “the surgery was a great success, but it’s a shame about the patient…” illustrates our failure to see surgical outcomes from the patient’s point of view. Goals that patients value after surgery include a return to or maintenance of health, functional capacity, and emotional wellbeing[32-34]. In recognition of these goals, perioperative research has begun to use metrics such as quality of life[34-36], quality of recovery[33,37,38], and disability-free survival[39] as outcome measures.

Prior to use in a clinical trial, patient-centred outcome measures need to undergo rigorous evaluation in the intended population and for the intended clinical situation (Table 2)[40]. In a systematic review, the only instrument designed to measure quality of recovery that fulfilled all eight criteria was the 40-item Quality of Recovery score (QoR-40)[41]. The QoR-40 is a measure of global recovery that assesses five domains of wellbeing: emotional state, physical comfort, psychological support, physical independence and pain[42]. It has been modified for use in different cultures and languages since its original publication[43,44]. Recently, a shorter version of the QoR-40 was validated – the QoR-15, utilising only 15 of the 40 questions previously asked. This version was completed in an average of 2.4 minutes, compared with about five minutes for the QoR-40, making it more efficient and clinically acceptable, while retaining its excellent reliability and responsiveness[45].

Table 2: Eight questions that need to be addressed in relation to a patient-centred outcome measure being considered for a clinical trial*

1) Is the content of the instrument appropriate to the questions that the clinical trial is intended to address? (Appropriateness)
2) Does the instrument produce results that are reproducible and internally consistent? (Reliability)
3) Does the instrument accurately measure what it claims to measure? (Validity)
4) Does the instrument measure changes over time that matter to patients? (Responsiveness)
5) How precise are the scores of the instrument? (Precision)
6) How interpretable are the scores of the instrument? (Interpretability)
7) Is the instrument non-invasive and acceptable to patients? (Acceptability)
8) Is the instrument easy to administer and process? (Feasibility)

*Adapted from Fitzpatrick et al[40].

The QoR-40 and QoR-15 are designed to evaluate short-term recovery from surgery. While a good recovery after cardiac surgery, as measured by the QoR-40, is associated with increased quality of life over three years postoperatively[46], the QoR-40 was never designed to measure medium to long-term outcomes after surgery.

In the past, quality-of-life measures such as the SF-36 have been used to assess global patient health following surgery and to measure longitudinal changes in overall patient wellbeing in the months following surgery[34]. Quality-of-life instruments measure health on a spectrum with no discrete cut-off point for "good" quality of life versus "poor" quality of life and no ability to define an adverse outcome or disability. As a result, they cannot be dichotomised for use as an end point in a clinical trial.

Disability is a concept that has meaning to patients and clinicians alike and is defined by the World Health Organization (WHO) International Classification of Functioning, Disability and Health as "difficulties in any area of functioning as they relate to environmental and personal factors"[47]. A tool that examines postoperative disability should not simply measure the presence or severity of symptoms, but should also seek to evaluate the impact of these symptoms on the patient's daily functioning, in terms of both emotional wellbeing and ability to participate in the usual activities of life[48]. Until recently, no instrument had been used to measure disability in perioperative studies.

The WHO Disability Assessment Schedule 2.0 (WHODAS) was designed to measure disability in the community and in medical patients with chronic health conditions. It has been tested and used extensively around the world, existing in over 30 languages4[9,50]. It asks about limitations over the past 30 days in six major life domains:

- Cognition.
- Mobility.
- Self-care.
- Interpersonal relationships.
- Work and household roles.
- Participation in society.

A multicentre, multinational study of over 500 patients recently evaluated a 12-item version of WHODAS as a measure of post-operative disability in a diverse surgical population up to 12 months after surgery[39]. WHODAS was shown to be clinically acceptable, valid, reliable and responsive in this population and was proposed as an ideal end point for future perioperative studies.

Disability, as measured by WHODAS, is an ideal end point for several reasons. It measures a real clinical outcome, rather than a surrogate, from the patient's perspective. WHODAS is easy to use and score, and is available on the public domain in self-report, proxy, and interviewer versions that can be administered in around five minutes[50]. Using WHODAS, the degree or severity of disability can be scaled according to the WHODAS and WHO International Classification of Functioning, Disability and Health: none (0-4 per cent); mild (5-24 per cent); moderate (25-49 per cent); severe (50-95 per cent); and complete (96-100 per cent) disability.[50] Alternatively Shulman *et al*. defined clinically significant "disability" as a WHODAS score of ≥25 per cent and "new disability" as a change in WHODAS score of ≥8 per cent from the preoperative state, thus providing two dichotomous outcomes. Further, they defined disability-free survival as the percentage of participants who were both alive and had a WHODAS score of <25 per cent at a given time point after surgery.

Disability is also an ideal outcome in perioperative research because it is common. In the above study, 27 per cent of participants had WHODAS-defined disability preoperatively, with disability persisting in 22 per cent of participants at three months and 18 per cent at six months. New disability, which persisted to 12 months after surgery, was present in 13 per cent of participants. The relative frequency with which clinically significant disability

occurred suggests that future studies could be designed to achieve adequate statistical power with modest sample sizes.

Measurement of disability-free survival is an attractive concept. Unlike health-related quality-of-life measures, which exclude non-survivors from analysis, this binary outcome measure includes all trial participants. In this way, it can be used as a single primary end point, or participants can be followed in the medium to long-term for survival analysis. Disability-free survival may be a particularly useful end point in trials in which participant groups have a similar baseline rate of disability and one wants to determine the effect of an intervention on patient recovery. Alternatively, for observational studies with a heterogeneous group of patients, it may be more practical to measure the rate of new or significantly increased disability.

Going forward, it is important that the understanding and definition of disability should be consistent across future studies in perioperative medicine. Shared language around patient-centred outcomes allows us to clearly share information and learn from others' experiences. In this way, the measurement of postoperative disability is an ideal method for clinical audit and quality assurance, an area of research that is often dominated by process measures. Perioperative medicine is a growing field in which anaesthetists are seeking to find a leading role[15]. With limited research resources and competitive grant review processes, we must produce quality research that addresses health outcomes that matter to patients, as well as clinicians and healthcare services. This research should guide our practice and help stratify patient risk and the allocation of resources to patients in need. Research outcomes that are easy to understand will also facilitate conversations between the perioperative team and patients regarding available treatment options. It is time we used patient-centred outcome measures to measure outcomes that matter to clinicians and patients alike.

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Combining clinical judgment and formalised risk assessment techniques in anaesthesiology: Lessons from bushfire emergency management

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INTRODUCTION

The underlying thinking in bushfire management has much to offer anaesthetists. Although it is imperative to develop improved methods of predicting the risk of perioperative patient morbidity and mortality, we must avoid them being used in a way that can undermine both individual clinical judgment on a case-by-case basis and the effectiveness of the methods themselves. This requires all concerned to be aware of the reliability and validity of the algorithms used to provide such predictions as well as the quality of the data upon which they are based. Like fire behaviour analysts, anaesthetists should still be free to trust their knowledge, expertise and experience. When experienced fire fighters sense a conflict between what the evidence on the ground is telling them and what a predictive fire map is saying, they use their understanding of limitations of the fire analysts' predictions to inform their own professional judgment.

IS THERE A TENSION BETWEEN PROFESSIONAL JUDGMENT AND FORMALISED RISK ASSESSMENT?

Anaesthesia is a necessary feature of most surgical procedures and poses various risks to the patient[1]. Most perioperative complications directly attributable to the administration of anaesthesia are relatively minor (for example, oral injury) but it can contribute to critical incidents that quickly become life-threatening[2,3]. Of these, more critical incidents, cardio-respiratory complications such as myocardial infarction, are the most common cause of perioperative mortality for patients undergoing non-cardiac elective surgery[4]. This is not to discount that a complex mix of factors also can contribute to perioperative patient morbidity[3]. This complexity makes it difficult for anaesthetists to make precise and accurate patient risk assessments prior to surgery and it is usually left for them to exercise their clinical judgment on this matter. This requires the anaesthesiologist to draw on their prior knowledge and general cognitive abilities, as well as their understanding of the immediate clinical situation, to develop a risk assessment for individual patients[5]. This is frequently an intuitive and ad hoc decision-making scenario and, as such, researchers have begun to focus on human decision-making theory and the behavioural sciences to understand the way in which errors and cognitive biases affect individual anaesthesiologists' clinical judgments[3,6]. In parallel with this focus on "end-of-the-bed" judgment, important advances are being made in developing a systematic understanding of anaesthesia risk factors that can be translated into formal risk-assessment techniques and decision-making rules that go well beyond the ASA's basic patient physical status classification system. Anaesthetists can then selectively apply such techniques and rules – for example, P-POSSUM – as part of the surgical team's overall preoperative risk assessment activities[6,7]. This increasingly common hybrid risk-assessment scenario in anaesthesiology – a combination of individual professional judgment (with all its potential biases and cognitive errors) and formalised techniques – has long been a common feature of emergency management and we draw on our research in this area to map out lessons for anaesthetists concerned with improving long-term patient outcomes following surgery.

The opposition between *subjective* professional judgment and *objective* formalised techniques is at the heart of conventional approaches to risk, whether in medical practice or emergency management. Since the notion of risk is posed in terms of consequence and likelihood, the logic with which one is to think and deal with risk is usually treated as being probabilistic in nature. On probabilistic grounds, the tension between subjective judgment and objective analysis plays out in the selection of either Bayesian or frequentist approaches. The former is based on a person's perception of a situation and is measured in terms of degrees of belief. The latter is based on objective causal relations that lead to events that occur at relative frequencies. However, what we have found in our research of bushfire emergency managers is that they face a practical situation where the opposition between subjective and objective assessments of risk are much more ambiguous. Thus, what we want to draw attention to is not

primarily the approach used in the calculation of probabilities with regards to the spread of bushfires (although this is of great technical importance to specialist risk analysts), but rather how the mere presence of such predictions are used as a sign pointing to the need for action. For example, if one were to say that risk was a numerical ratio or statement of degree (high, low), perhaps the most obvious question would be how accurate is this as a representation of changing conditions on the ground? Our intention is to ask the more fundamental question: what does the act of rendering of risk as percentage, ratio, or degree *do* more generally? In other words, what effect has creating apparently objective assessments of risk have on people on the frontline of emergency management who have to exercise their professional judgment in real time and in the face of real dangers? In short, we are interested in the practical implications of placing unjustified confidence in a number that is, at best, a rough estimate and, at worst, potentially a misleading distraction.

In bushfire emergency management, individual experts from diverse technical backgrounds (for example, fire fighters, climatologist, geographers and other land-use experts) have to make dynamic risk assessments under rapidly changing conditions that are then used on the ground by emergency response teams as they fight fires, evacuate the population and protect private and public assets. Since these risk assessments are done dynamically, any time to calculate probabilities is curtailed dramatically. Below we set out how the general approach to risk assessment and subsequent action has changed in emergency management following the catastrophic Victorian bushfires of February 2009. In particular, we look at how a new class of experts – fire behaviour analysts – are developing formalised techniques to predict fire spread and convey this to emergency response teams on the ground using visual-mapping techniques. We then consider how emergency responders act when these ostensibly precise predictions are taken up in deciding on response and recovery operations. On the basis of this discussion, we conclude by exploring how anaesthetists could respond to the effects generated by new formalised risk assessments and how these assessments potentially bring about a new medical logic.

CONTRASTING MEDICAL RISK AND ENVIRONMENTAL RISK

In order to draw a relevant link and explore the resonances between risk assessment in such apparently divergent disciplines as anaesthesiology and environmental management, we adopt a symptomatological approach. Although such an approach is familiar in clinical practice, its application in environmental management risk assessment is novel. By virtue of being preoccupied with the study of signs in general, and not necessarily medical ones, symptomatology presents an interesting point of convergence and divergence between medicine and emergency management. In clinical practice, the activity of symptomatology is traditionally followed by aetiology (establishing causes), prognosis (predicting the unfolding of an illness) and therapy (treating the illness). While most attention is directed to aetiology and the activities that follow, we forget that all these steps are subordinated to symptomatology in the first instance. Fire behaviour analysts dealing with bushfires also commence their practices with a symptomatology; they consider symptoms, such as changes in wind direction or humidity. It is after the symptomatology that they split from clinical practitioners. Whereas a meteorologist, for example, would be interested in the cause of wind change, the fire behaviour analyst tasked with predicting the spread of a fire front is not directly concerned with causes. The analyst wants to move straight to prognosis (that is, to predict how fires are likely to unfold and lead to potential emergency situations) and therapy (that is, how to intervene to suppress fires and mitigate these emergency situations). As we shall see below, the way in which fire behaviour analysts do symptomatology leads them to skip the aetiological stage and go straight from symptoms to prognosis. This move engenders new problems down the line for fire fighters and other emergency responders. These activities have been the focus of our study of fire behaviour analysis as they have developed formalised risk assessment techniques and we use this to draw lessons for risk management in anaesthesiology and, potentially, other areas of clinical practice.

WHY DEVELOP FORMALISED RISK ASSESSMENT TECHNIQUES IN ANAESTHESIOLOGY?

From a risk management perspective, we would consider the rationale for developing formalised risk assessment techniques in anaesthesiology as follows. In clinical symptomatology, the clinician considers an array of indicators or signs of disease. It is only by making a holistic assessment of these signs, a diagnosis, that the clinician is able to name, label and classify a disease. Sometimes a patient presents with symptoms that do not definitively point to one disease or another, opening up uncertainty with regards to the next step. This indeterminacy can lead to the naming of a new syndrome as it becomes evident that characteristic combinations of symptoms do not fit existing definitions of existing conditions. As a result, syndromes become known for the individual who isolates characteristic symptoms rather than the underlying pathology, for example Parkinson's disease versus motor neurone disease.

This raises general clinical challenges when moving from diagnosis to therapy without a definitive aetiology: clinicians may be able to agree on the symptoms (that is, they can name the syndrome) but disagree on the causes of disease and, therefore, how to treat it effectively. Thus, in situations where aetiology is uncertain, greater emphasis is placed on a careful description of symptoms as the driver of prognosis and therapy. By remaining at the level of symptomatology, one privileges the interpretation of signs (that is, symptoms) over establishing underlying cause. For example, when anaesthesiologists are called up to make an assessment of a patient's risk of suffering adverse effects from the administration of a particular anaesthetic, they may have to take into account primary symptoms, such as poor liver function or low mobility, without fully knowing the underlying causes of the patient's frailty. The motivation for the development of more formalised risk assessment techniques may actually stem from a tendency in medical practice to proceed with prognosis and therapy on the basis of a symptomatological diagnosis without an aetiology. How would the practice of anaesthesiology change if a step so apparently integral to clinical practice, namely aetiology, was sidestepped?

WHY EMERGENCY MANAGERS ARE DEVELOPING FORMALISED RISK ASSESSMENT TECHNIQUES

Emergency management, such as that involving the mitigation of bushfires, involves a consideration of uncertainty that is, in some important respects, the same as the clinical scenario set out above. In effect, the management of fire can be thought of as a practice of naming a new syndrome: each fire is "labelled" after a set of symptoms have converged, each fire is the unique association of symptoms; for example, the 1983 Ash Wednesday or the 2009 Black Saturday fires. Anticipating and responding to fire emergencies involves a consideration of these antecedent symptoms, for example, topography, fuel load and climatic conditions, such as humidity or wind strength/direction, as risk factors. Predictions of where a bushfire might start, how and where it will travel, and the intensity of the burn are the result of a particular arrangement and association of the symptoms. On the basis of this prediction, warnings are issued, important resource allocation decisions are made and, in the event that a fire does break out, emergency measures are enacted. Applying the symptomatological model, when fire behaviour analysts receive data from the Bureau of Meteorology, they receive signs. Their primary interest is for these signs to be "accurate" or "precise". In the language of signs, one could say they want "truthful" signs. During an emergency when there is no time and analysts are forced to produce predictions, they are not interested in the causes of wind changes or topographical shifts; what they really care about is that the wind or topography changes. Not why something happens but *that* it happens. Changing wind speed or humidity on their own are symptoms, yet when they are associated with an ignition point, they are qualified as risk factors. In other words, without knowing in detail and in advance the exact way in which the symptoms of a particular fire will interact, there will always be a good deal of uncertainty surrounding how to respond in an emergency situation. This uncertainty is perhaps best summed up by the fire fighters' adage: "You never fight the same fire twice". By this they mean there is always something indeterminate about bushfires for, in apparently identical conditions and even in the same location, a fire may behave quite differently on any given day. Importantly, conditions can change quickly and, as with surgery, apparently innocuous situations can quickly become life threatening[3].

In the past, professionals involved in emergency management have tended to develop analyses of the risk of bushfires and respond accordingly by relying on a combination of formal training, professional experience and intuition (much like anaesthetists and other clinicians have done with their "end-of-the-bed" assessments) but the catastrophic Victorian bushfires of February 2009 and the subsequent Royal Commission inquiry has led Victoria to introduce and promote more formalised techniques of risk assessment. Fire behaviour analysts have responded by developing more effective fire prediction techniques. Below we describe the development of one such technique that has emerged as an important feature of fire risk assessment and emergency management following the 2009 disaster. This account is based on standard qualitative and ethnographic data collection techniques, such as document analysis, participant observation, and interviews with key informants from the agencies in Victoria charged with environmental management and bushfire control.

THE DEVELOPMENT OF PHOENIX-RAPIDFIRE

The practice of fire behaviour analysis is not new: It grew out of decades of forestry science and has been steadily incorporated into the emergency services as Victorian agencies have sought more effective ways to manage a fire-prone environment, in and out of the fire season. The development of computational power and sophisticated predictive algorithms, however, has accelerated the pace of innovation in this arena so that that developers now claim it is possible to create detailed and realistic simulation programs to depict fire behaviour by gathering weather and topographical data, often in real-time, in order to map how, when and where a fire will spread. PHOENIX-RapidFire is one such program[8,9]. It was introduced in 2008 and was in operation in a basic form during the 2009 fires. Its main function is to produce dynamic predictions of the likely course of bushfires. As such:

> "...each fire can be given a relative weighting based on the probability of it starting at a particular point. The characteristic of a fire when it intersects with an identified value or asset is used to quantify the impact of the fire. The effects of different fire management strategies on mitigating bushfire losses can be objectively quantified with this process. A cost-benefit analysis of the different management strategies can then be undertaken[9]."

To achieve this level of analysis and prediction, fire behaviour analysts have developed and refined the basic PHOENIX-RapidFire algorithm to take into consideration the following main factors:

1. A grid of likely ignition points based on historic data and devised using a "probability of ignition" model.
2. Key fire management variables, such as the location of mobile tenders/personnel and their likely response times, based on the condition of infrastructure such as road networks.
3. Detailed weather scenarios (for example, temperature, relative humidity, wind speed, direction, etc), which can be varied across time and space at high resolution to test emergency management strategies.
4. A rating of the public and private assets at risk in a potential fire zone.

From an analysis of these data, PHOENIX-RapidFire simulates the most likely ignition point and subsequent course of a fire, thus providing critical information for emergency management agencies to plan their most effective responses. Although this approach is highly formalised and gives the impression of being precise and accurate, we would make three important caveats relating to the rationality of the process. First, much of the original input data is still based on individual expert judgment. Second, and as a corollary of the first point, there is still plenty of scope for those experts to disagree on the levels of fire risk factors. Third, there is also plenty of scope for each agency to interpret the output of PHOENIX-RapidFire program differently, depending on their own priorities. This final point is most evident in the potential conflict between those agencies charged with protecting assets, such as when it must be decided whether to divert resources to protecting private housing at the expense of protecting public infrastructure.

Taking these three points together, we draw our first important lesson for anaesthetists and other clinicians. Even before PHOENIX-RapidFire was put into operation, it was evident to us that it was beginning to take on a status of infallibility that belied the contestable character of the data upon which its predictions were based. In other words, there was a risk that emergency management agencies might unjustifiably place too much trust in its predictions. Similarly, anaesthetists must be conscious of the limitations of formalised risk assessment techniques as they go about exercising clinical judgment. From this observation, we go on to consider how the implementation of PHOENIX-RapidFire impacted the decision-making activities of emergency management experts, who came to rely on its predictive capacities.

PHOENIX-RAPIDFIRE IN USE

As part of their routine practice in emergency management during the Victorian fire season (October-April), fire behaviour analysts now draw on PHOENIX-RapidFire and other models to produce three products: 1) An hour-by-hour map detailing the progression of a fire; 2) a more general map based on a 24-hour progression of the fire; and, 3) a fire-prediction report. All three can be viewed on computers and portable handheld devices. The detailed map is distributed among planners in the emergency services to help with allocating resources. The generalised map, which shows the fire front with a dashed line, is passed to the media for public messaging. The dashed line is used to display where a fire could progress to within 24 hours (its level of precision is intentionally lower than that produced by the program). The prediction report documents the caveats and assumptions made by the analysts in outlining what data was used, how it was used and whether there are any doubts regarding its accuracy. Importantly, the assumptions are documented, not only for scientific purposes of understanding the correlation between modelling and the fire progression through the landscape, but also as part of a quality control process by the state duty officer. Planning of the emergency and resource allocation are intricately tied to the fire maps so changes in prediction need a trail for accountability purposes.

During a fire, data are arranged and entered into the PHOENIX-RapidFire algorithmic modelling program in real-time. The constant assimilation of real-time information and collation with algorithmic modelling still requires, in the words of one analyst that we interviewed, “some sort of *truthing* or validation sort of process” to filter out the noise. The quantities of data collected during an event are so copious that they require parsing to pick out the parts most relevant to an adequate mapping of the fire, using the program more as a heuristic device that informs their expert judgment rather than a definitive predictor of its future progress. Incoming data are usually delayed and of poor quality, so predictive mapping often becomes experimental. This runs contrary to the expectations of other emergency managers in the field, who are less aware of the program’s data limitations and who, therefore, take its outputs to be observations rather than predictions. For example, in the event that a fire-fighting aircraft loses sight due to thick smoke, emergency managers expect the analysts to be able to immediately situate the fire front along precise co-ordinates and predict its movements. Yet these maps are only as good as the data entered into the algorithm, including aerial photographs delivered from the very fire-fighting planes that have lost visual contact with the ground.

The complication of taking the mapped prediction for the real fire is further compounded with the advanced visually detailed features of the PHOENIX-RapidFire program, which make the maps look realistic. One informant underlined that:

> “People start to think that they’re the *truth*, that they’re *observations rather than predictions*. Meteorologists have that trouble all the time, when they put a forecast out people will read the forecast as if that was what’s actually happening out there rather than just being – often it’ll be close because the forecaster is fairly good, but when there’s a lack of information about the fire because the smoke is covering it, the aircraft has currently lost sight or whatever, they’ll come to us and say well where’s the fire now thinking that we can just predict it. We say well we need to have some *base truth* to work from, if we’ve got no more information than you then we can’t make a prediction …” (emphasis added).

Expectations are unrealistic because people do not fully understand the process. The same informant adds:

> “...on some occasions some of our predictions are pretty good so you can use them in *lieu of the truth*, if you like, until you get the truth. That’s okay if you’re doing that, the perception sometimes is that it is the truth and it gets used beyond what … the truth really is… and we’ve got even a bigger problem with our computer modelling that we now use, because it looks so realistic and detailed that it could only come from a *real fire”* (emphasis added).

With a computer-generated map, “it creates an impression of being more credible than it deserves”. To deal with this, analysts have realised the implications and “go through a smoothing routine to take out some of the detail … to roughen it up a bit”. In other words, they intentionally act to reduce the maps’ apparent authenticity so they are not interpreted too literally. Previously the analysts did all their predictions on a photocopied map in pencil and the obvious imprecision indicated this process involved uncertainties. This is why, today, a dashed line is still used for public communication to indicate that the fire *is likely to be within a boundary* but that *the boundary is not the boundary* of the fire. In verbal communication, nuances and details can be added, but, when the visual map is distributed electronically, it loses that explanation and opens the possibility for misinterpretation.

As incidents start, resources are mobilised, allocated and committed. If a critical decision is to be made whether to pull resources from one incident to another, a strong argument grounded in more accurate data is needed. Importantly, our informant asserts that resources are not allocated “based on where they’re going to reduce the risk the most”. They believe the current culture in emergency management is reactive rather than proactive and strategic. Senior emergency services managers are aware of the predictive services’ work, but are not interested because it does not affect them; it does not affect the number of trucks sent out. Fire trucks respond to calls for help and they will stop their current operation even if “it’s [not] the smartest thing to do”, according to the analyst. This analyst claims that water and trucks are not going to make much of a difference in those few hours, but reliable and credible information that can be accessed and used will. Though they caution that “you have to be aware that not everyone is going to use that information wisely”, informing the public is impossible in their opinion, because the lack of intelligence prevents you from effectively fighting the fire, let alone giving reliable forecasts.

In the heat of the moment, risk assessments are not formalised explicitly in a matrix or metric, as is commonly recommended by risk management standards. While our informant suggests that risk calculation is still happening in people’s heads, fire behaviour analysts have formalised this assessment to some extent when they provide predictions that could help in reallocating and repositioning resources. They state “it’s very hard to get strategic thinking during an incident, especially in a rapidly evolving incident”. Without it, some operations will be undertaken with a probability of success at almost zero. So, they propose to stand back, wait and then apply resources to achieve a better outcome when, for example, the “main heat of the fire has dissipated and we’ll be able to work those crews for longer into a period of time when they can be more productive”.

CONCLUSIONS AND IMPLICATIONS FOR ANAESTHESIA PRACTICE

We have seen how the fire behaviour analysts work as diagnosticians or “clinicians” of fire. By juxtaposing a set of signs or symptoms, they establish a fire’s potential spread across a landscape, and they advise on its impact and recommend certain actions. This prompts us to return to the symptomatology at work and consider the differential status of signs of fire risk developed by the fire behaviour analysts. In order to make sense of this, we have developed the following typology: 1) *icons* that are treated with unquestioning reverence because they are taken for the fire itself, rather than a mere (and potentially inaccurate) representation of the fire; 2) *symbols* that are open to subjective interpretation based on the knowledge, skill and experience of the individual observer (for example, while we might just see spots, an experienced clinician may see clear symptoms of a specific disease); and, 3) *indexes* that stand between the indeterminate status of symbols and the immutable status of icons, being based on some rational and objective, but nevertheless, fallible calculation of cause and effect.

Ideally, the goal of fire behaviour mapping can be simply stated as follows: it is to index risk. That is, the map of fire spread must be more than just a mere symbol that can easily be misinterpreted but it must not be turned into an icon that is followed by everyone without question. While the former is effective for risk assessment and planning in the sense that it helps analysts argue that fire spread prediction ought to be one of the most important tools used in emergency management, the danger of an icon is that it is followed to the letter, even when it goes against the judgment of the expert using it. Fire behaviour analysts who produce the fire maps are aware that all the data going into the PHOENIX-RapidFire is not of equal quality and they recognise the fallibility of their predictions. They are, nevertheless, useful if applied the right way and with the appropriate degree of questioning. Once they get out into the field, however, there is a real danger they become iconic and fire fighters and other emergency responders take the representation of a predicted fire front on a map to be the fire front itself. The consequences could be such that resources are allocated to fighting a fire located on the map in one place and met in actuality in another. Similarly, messages could be broadcast misinforming the population as to the amount of time they have to evacuate. These consequences could lead to disaster.

Our principal lesson for anaesthetists follows the same logic. Although it is imperative for us to develop improved methods of predicting the risk of perioperative patient morbidity and mortality, we must avoid them becoming iconic and used in a way that can undermine both individual clinical judgment on a case-by-case basis and the effectiveness of the methods themselves. This requires all concerned to be aware of the reliability and validity of the algorithms used to provide such predictions as well as the quality of the data upon which they are based. Like fire behaviour analysts and other emergency management professionals, anaesthesiologists should still be free to trust their knowledge, expertise and experience. After all, our study suggests that when experienced fire fighters sense a conflict between what the direct evidence on the ground is telling them and what a predictive fire map are saying, they become increasingly savvy about the limitations of the fire analysts’ predictions and revert to their own professional judgment.

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The big question in veterinary anaesthesia

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INTRODUCTION

Intentionally causing pain to another human, in particular children, is regarded as one of the most socially abhorrent of actions. Similarly, painful procedures performed on animals are among the most emotive of public concerns. The commonality here lies in the notion of protecting the vulnerable. Indeed, it has been said by many that the greatness of a society is judged on the basis of how it treats its weakest members.

Approaches towards treatment of pain in children are still evolving, with some arguing about the importance of pain in infants less than a year of age[1,2]. Similarly, up until the late 1980s the majority of animal researchers were not providing analgesia to laboratory animals following invasive surgical procedures.[3] Unfortunately, these disparities in the diagnosis and treatment of pain continued into the 1990s, with two major studies from tertiary teaching hospitals demonstrating significant institutional inadequacies in the teaching and clinical management of pain in veterinary patients[4,5]. Despite the aforementioned inadequacies, attitudes regarding pain and suffering in animals have shifted considerably in recent years. Most people involved with animals of any kind would have no hesitation in stating categorically that animals experience pain. The ethical aspects as well as the morbidity associated with acute and chronic pain lead more veterinarians to focus on the treatment of pain and implement defined, goal-orientated approaches to pain therapy. In accordance with the Veterinarians' Oath, each member admitted to our profession pledges to "*... use my scientific knowledge and skills for the benefit of society through ...the relief of animal suffering....*" However, even when we acknowledge the potential for animals to experience pain, appropriate treatment does not always follow. The most recent information of this type comes from surveys of the veterinary profession in France. These questionnaires established that the majority of respondents (96 per cent) were "moderately or extremely concerned about recognition and alleviation of animal pain"[6]. However, for cats and dogs, analgesic use by respondents ranged from a high of 84 per cent following orthopaedic surgery to a low of only 17 per cent following castration. The primary reasons provided for a lack of analgesic treatment were "difficulties in recognising pain" and "lack of knowledge about appropriate therapy", highlighting the need for further research and training in this area[6].

THE PRE-EMPTIVE (ASSUMPTIVE) APPROACH

Pain in man is recognised as having both a sensory and an emotional component. Treatment of pain must be tailored to the individual animal and should be based, in part, on the species, breed, age, procedure performed and degree of tissue trauma, individual behavioural characteristics, degree of pain, health status and availability of drugs and techniques.[7] It is generally assumed that if a procedure is painful in human beings, then it must also be painful in animals. However, while it may be useful to draw such parallels between humans and animals, the severity of the pain experience produced by various procedures is not always similar. Because it is difficult to compare the experience of pain in animals to that in humans, it is preferable to empirically administer analgesics pre-emptively if there is any question as to whether a procedure will induce pain in an animal patient.

In addition to measures directed towards alleviating or preventing pain, it is important to consider the overall care of the animal and the prevention of distress. The term "distress" is used in this context to describe conditions that are not in themselves painful, but are unpleasant and which the animal would normally choose to avoid; for example, emotional pain, such as the fear associated with recovering from anaesthesia in an unfamiliar environment. For the veterinary patient, which is essentially a non-consenting patient, lacking cognisance of the intervention or procedure they have received, the emergence from anaesthesia and the recovery period can elicit a great degree of distress and anxiety. The veterinary anaesthetist needs to diligently ensure that the recovery environment is such so as to minimise this. In addition to the use of an opioid, the incorporation of a sedative component (typically phenothiazine or alpha-2 agonist) to the premedication is routinely used to reduce perioperative distress and anxiety.

PROBLEMS SURROUNDING THE ASSESSMENT OF PAIN IN VETERINARY PATIENTS

Much as with human medicine, veterinary medicine lacks any major international governing body and, as such, no international standards for pain assessment. While this could be easily taken on by individual national veterinary authorities or associations, such as the Australian Veterinary Association or the American Veterinary Medical Association, these organisations tend to produce very generic policy to govern their members, most stating only that practitioners should look for pain and provide analgesia without any guidelines for the provision of such activities. In addition to this, although it is widely accepted that veterinary patients experience pain, there are no set guidelines or principles followed in the formal education of veterinarians, much less veterinary nurses, on the recognition and treatment of pain.

Pain scales are utilised commonly in human medicine and attempt to provide a measure of the subjective experience of pain. They vary in complexity as well as accuracy. Translating a human pain scale for use in veterinary patients presents one obvious barrier; human pain scales are designed in such a way that the person experiencing the pain is asked to rate their pain rather than an observer asked to interpret it. As we are not able to "ask" our patients to rank their pain, these scales immediately become more subjective when applied to veterinary patients. In early veterinary pain-assessment work, researchers therefore looked to human pain scales that were designed for use with non-verbal people. In particular, the Toddler-Preschooler Postoperative Pain Scale, the Observation Scale of Behavioral Distress, and the Children's Hospital of Eastern Ontario Pain Scale were modelled in early veterinary pain scales[8-10].

CHOOSING A PAIN SCALE

Several factors must be considered when choosing a pain scale. The first is whether the scale is appropriate for the species being evaluated. Pain behaviours vary by species and even within breeds of animals in a species. For instance, prey species tend to hide even debilitating pain instinctually and no one would argue that, within dog breeds, a miniature poodle, for instance, would be much more likely to demonstrate painful behaviours than a stoic golden retriever. Another consideration is whether the scale is designed for the type of pain the animal is experiencing. Some scales are designed specifically to evaluate acute or even post-surgical pain settings and may not be appropriate for patients suffering with more chronic pain conditions such as osteoarthritis. Another consideration is whether the scale is accurate across observers. In veterinary medicine, care is given to animals by personnel that range from highly trained specialist veterinarians to veterinary assistants who may have no formal training or background in animal health or pain assessment. This provides an added challenge of designing assessment tools that have clear instructions and result in similar scores regardless of the assessors' levels of training. We frequently use these scales as clinical monitoring devices and we cannot always guarantee in the clinical setting that the same observer will perform all the pain evaluations, so it is important that the inter-observer variability be as small as possible. Finally, one must consider the lesser of two evils: to ascribe pain to an animal that isn't actually painful, or to miss pain in an animal who is actually painful. It is generally agreed that it is better to ascribe pain and treat for it when there is no pain present than to risk missing a painful patient. As such, scales with low sensitivity are likely worse that those with low specificity.

ASSESSING VALIDITY OF PAIN ASSESSMENT TOOLS

The assessment of validity is an essential part of the development of a pain assessment tool and the foundation of adequate pain management. Validity is defined as the effectiveness with which a test or scale measures the property under investigation and the strength of the inferences that can be drawn from the application of that tool[11]. Pain measurement in humans who are incapable of self-reporting (for example, neonates, infants, people with learning disabilities or verbally handicapped patients) is exceedingly challenging. It is in this area that medical and veterinary clinicians share the challenge of establishing valid, reliable and reproducible pain assessment tools. The properties required of such scales and the validation criteria have been well documented by psychometricians[12]. Reliability and validity for pain assessment are vital for use in recognising pain, quantifying pain intensity and evaluating treatment effectiveness[13]. At present, although multiple pain assessment tools have been develop for use in various veterinary species, few have undergone the rigours of formal statistical validation.

Simple descriptive scales (SDS), numerical rating scales (NRS) and visual analogue scales (VAS) are all used in veterinary medicine; however, they are all considered to be very subjective, with lower sensitivity and some issues with inter-observer variability. Recently, multifactorial or composite pain scales (MPS) have been developed in veterinary medicine to assess pain. These scales relate several aspects of pain behaviours and species-specific normal behaviours and generate a numerical composite score. Most MPS assessments include observational as well as interactive steps and appear to improve the sensitivity and specificity of pain assessment in veterinary patients. While there are several different multifactorial pain scales, there are only two MPS scales currently validated for use in the dog – the University of Melbourne Pain Scale and the Glasgow Composite Pain Scale Short Form (CMPS-SF). The University of Melbourne Pain Scale has good inter-observer variability and appeared to have good sensitivity and specificity in the initial validation study, however, a review paper questioned this sensitivity by applying the scale to a dog with untreated post-operative pain that was quiet and withdrawn where the scale indicated there was no pain[14,15]. The CMPS-SF has been demonstrated to be valid and reliable with minimal inter-observer variability when used in the clinical acute pain setting; however, a recent university study demonstrated poor inter-observer reliability, specificity, and sensitivity between specialist anaesthetists and first and second-year veterinary students[16,17].

Until recently, there were no validated MPS devices for the cat; however, practitioners could utilise one of several tools lacking validation. In 2011, a Brazilian group developed and initially validated a multidimensional composite pain scale for acute post-operative pain in the cat[18]. In 2013, the same group refined and validated the scale and determined a recommended cut-point score above which analgesic therapy should be provided, and also validated the scale for use in English[19]. While the scale is still very new, clinical pain research in cats has been published using this scale, which suggests its potential use in the clinical setting. More recently, a group from the UK developed and partially validated a version of the CMPS-SF for acute pain in cats (CMPS-F)[20]. This tool is very similar in format to the canine version, potentially making it easier to adopt clinically for practitioners already using the canine form. In the initial validation study, scores had good agreement with scoring from a NRS tool indicating the tool was valid; however, only one observer used the tool during the study period so no clear statement about inter-observer variability can be made at this time[20].

ASSESSING CHRONIC OR ACUTE PAIN

Assessment of chronic pain in dogs and cats is often very different from that of acute pain, owing to the pathophysiology and nature of chronic pain. The validated and commonly used scale for assessment of chronic pain in dogs is the Helsinki Chronic Pain Index (HCPI)[21]. It is a questionnaire-style assessment that is administered by the veterinarian (with numerical rating) and by the owner (without numerical rating). It is similar to human Quality of Life questionnaires. The HCPI is best used as a tool for repeated measures to gauge the patient's response to a treatment. Currently there are no validated pain scales for assessment of chronic pain in the cat; a group of researchers at North Carolina State University are evaluating a tool called the Feline Musculoskeletal Pain Index, which is an owner questionnaire that has shown some promise in identifying chronic pain in cats.

One of the biggest limitations of both of these tools is their heavy slant towards musculoskeletal and osteoarthritic causes of chronic pain. This makes them less useful for more visceral or neuropathic pain conditions.

The understanding of the pathophysiology of pain in horses has led to the development of very specialised pain-scoring techniques that are applied to specific pathologies rather than general scoring scales. Although both NRS and VAS scales are frequently used to evaluate pain in horses, there are also several specialised scales available. For acute abdominal pain there are the two Equine Acute Abdominal Pain Scales (EAAPS-1 and EAAPS-2), which are behavioural-based scales to evaluate the level of pain associated with colic in the horse[22]. In the post-operative period after abdominal surgery, pain in the horse can be assessed using the Post-Abdominal Surgery Pain Assessment Scale (PASPAS), which is a multifactorial composite scale that includes physiological parameters such as heart rate[23]. For assessment of pain associated with laminitis, there are two SDS scales, the Obel score and the clinical grading scale [CGS] and some practitioners also use a VAS[24]. Lastly, a multifactorial pain scale for assessment of orthopaedic pain has also been developed[25]. This scale integrates both behavioural and physiological data.

THE "FACES" OF PAIN

Finally, current veterinary pain research has turned towards the development of scales that evaluate facial changes in response to pain. These scales originated for use in laboratory animals, where patient interaction for assessment was either impractical or could influence the assessment. These grimace scales for rats and mice are currently considered the gold standard for pain assessment in these species and are used frequently in research[26,27]. From those scales, a rabbit grimace scale was developed for use in rabbits in research and clinical practice[28]. Over the past few years, interest in developing such scales for our domestic animals has developed. In 2014, two such pain tools were published for use in horses. The Horse Grimace Scale uses changes in six facial features (such as ear carriage), recorded as photographs of actual horses, to evaluate pain following castration[29]. The scale is reasonably accurate and had minimal inter-observer variability in the study. The second is the Equine Pain Face, a tool that developed artistic renderings of specific facial expression changes (such as ear carriage and nostril shape) associated with pain in research models of induced pain (such as capsaicin)[30]. The equine pain face is not a standalone tool, but rather suggested that facial expressions be included in other composite models of pain in order to strengthen their validity. Lastly, in 2014, a group in the UK developed a series of artistic renderings of the facial expression changes (such as ear carriage) of cats with acute pain[31]. Again, the Feline Pain Face does not currently exist as a standalone tool, however, the group is currently exploring combining the CMPS-F with the Feline Pain Face for clinical assessment of acute pain in cats.

PROBLEMS SURROUNDING THE TREATMENT OF PAIN IN VETERINARY PATIENTS

Even if the presence of pain is identified in a veterinary patient, treatment of that pain remains inconsistent. A university study in the United States evaluated analgesics prescribed by dogs and cats in an intensive care setting and found that only 89 per cent of dogs and 67 per cent of cats that were admitted for traumatic injuries were prescribed analgesic medication[4]. Another older university study found that about 50 per cent of dogs whose medical records indicated moderate to severe pain had not been administered an analgesic and, in the same study, only one out of 15 cats evaluated in the post-surgical period received analgesia[5]. Several studies have attempted to elucidate potential reasons for this disparity and have suggested concerns regarding the pharmacology and side effects of potent opioids, failure to identify pain appropriately (scoring), the number of years since graduation from veterinary school, the presence or absence of a veterinary nurse, a belief that some post-operative pain was beneficial, beliefs surrounding which procedures were painful, and, interestingly, the sex of the veterinarian, with female veterinarians more likely to score and treat pain[6,32-35].

TRAINING IN PAIN RECOGNITION AND MANAGEMENT

In the authors' opinions, these reasons highlight the underlying barrier to appropriate pain assessment and treatment in veterinary medicine, which is the lack of training in this important aspect. Veterinary education is not internationally regulated and, as such, there are no meaningful attempts at standardising teaching of pain assessment and analgesic provision. One step in the right direction in this regard has been the recent focus on "day-one skills" in veterinary training. The ability to recognise and treat pain is considered a day-one skill by both the American and European accrediting boards (the jurisdiction of which many Australian schools fall under) and is starting to be included with regularity in veterinary education. Two recent studies have demonstrated the value of the addition of formal pain

assessment teaching on the attitudes, knowledge base, and confidence level of veterinary students when assessing pain in dogs and cats[36,37].

However, veterinary education does not end at graduation and continuing professional development is the key to lifelong learning and high-quality veterinary practice. In two recent surveys evaluating the recognition of pain and use of analgesia in dogs, cats, and horses by veterinary practitioners in New Zealand investigators found that more than 40 per cent of respondents felt their knowledge of the subject was inadequate[38,39]. While there is an increasing number of continuing education opportunities surrounding the assessment and treatment of pain in veterinary patients, there are no regulations or guidelines for veterinarians or nurses for the type or quality of these opportunities and, as such, no requirement to attend any that focus on pain. This is likely a contributing factor to the studies that found poor recognition and treatment of pain with increasing years since graduation from veterinary school.

Finally, veterinary medicine lacks any universal guidelines for pharmacologic intervention such as the WHO Analgesic Ladder. Although the WHO Ladder was originally intended for treatment of cancer pain, it is applied in the management of many different types of pain. There are some proponents for the application of the WHO Ladder to veterinary patients; however, as it is a human tool, it does not take into account the unique pharmacologic considerations of veterinary patients. For instance, the first level of the WHO ladder recommends administration of drugs such as paracetamol or non-steroidal anti-inflammatory medications (NSAIDs). Paracetamol is toxic to cats and NSAIDs carry many concerns and contraindications in dogs and cats including gastrointestinal ulceration and perforation, liver and kidney failure. This means that many of these medicines will not be tolerated well in patients who need them the most, owing to their underlying or concurrent disease processes. Opioid therapy is a mainstay of acute pain treatment in dogs and cats; however, due to a very high first-pass effect, oral dosing of opioids is not very effective, making them less useful outside the hospital setting. Buprenorphine can be administered transmucosally in dogs, cats, and horses for alleviation of mild to moderate pain, but is fairly expensive and, as such, is not a very cost-effective drug for longer-term therapy, especially in larger animals. Tramadol initially appeared to hold promise for dogs, however, pharmacological studies have shown that dogs do not make meaningful quantities of the mu receptor active metabolite, O-demethyltramadol, making it far less useful for acute pain in dogs[40]. Further highlighting species differences, cats form very high levels of this metabolite, but tramadol's use in them is still limited, in that both the liquid and tablet oral-dosing formulations are poorly tolerated by cats due to their bitter taste. Another interesting species difference that would apply to treatment decisions for pain in veterinary species lies in the finding that alpha-2 agonist drugs provide more effective analgesia for visceral and superficial pain than both opioids and NSAIDs in horses[41,42]. In addition, there is concern regarding decreased gastrointestinal motility seen after opioid administration, leading to a risk for development of colic in the horse. Recently drugs such as gabapentin, amantadine and maropitant have become the focus of veterinary research in the constant quest to improve our ability to treat pain in our patients.

CONCLUSION

The recognition and treatment of pain in veterinary species is a complicated matter that is evolving; however, there are still major challenges to overcome. Veterinary medicine incorporates all non-human species, all of whom are non-verbal, which makes creating any standardised methodology for assessment or treatment impossible, owing to significant differences between species in the pathophysiology, behaviour and pharmacology of pain. There are multiple tools currently used in veterinary medicine for the assessment of both acute and chronic painful conditions. One of the major underlying difficulties in the advancement of pain assessment and treatment is the lack of regulations regarding education and continuing professional development surrounding this important subject. Although significant progress has been made in the last 20 years, veterinary medicine still lags behind human medicine in its emphasis on the importance of recognising and treating pain.

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