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Review article

Risk in pediatric anesthesia

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Summary

Risk in paediatric anaesthesia can be conveniently classified as minor or major. Major morbidity includes cardiac arrest, brain damage and death. Minor morbidity can be assessed by clinical audits with small patient samples. Major morbidity is rare. It is best assessed by very large clinical studies and by review of closed malpractice claims. Both minor and major morbidity occur most commonly in infants and children under three, especially those with severe co-morbidities. Knowledge of risk profiles in paediatric anaesthesia is a starting point for the reduction of risk.

Keywords: anesthetic risk; pediatric anesthesia; morbidity and mortality; training

Introduction

Information regarding risk in pediatric anesthesia is abundant, but philosophical and methodological differences among sources make direct comparison difficult.

The purpose of this review is to examine this information with special emphasis on major morbidity and mortality. Sources will be categorized to simplify their interpretation. Common themes will be distilled from the data and their implications discussed. Risk related to specific clinical situations and the practice of regional anesthesia have been addressed in previous publications and will not be included (1–3).

This exercise will be undertaken from the perspective of full-time clinical anesthetists. However, the key findings have relevance to anesthetic training, hospital administration, health care policy and future research, and these will be discussed.

With respect to morbidity and mortality, the most useful data have come from three distinct sources: institutional audit, closed claims analysis and large-scale studies of anesthesia-related cardiac arrest.

Despite the disparate nature of these data sets, some consistent themes are discernable.

Risk of morbidity and mortality is highest for infants and patients with severe co-morbid conditions. Emergency surgery increases these risks further.

Although risk is strongly associated with patient characteristics, there remains room for improvement in anesthetic practice. This is especially true for the management of major bleeding in elective surgery.

Laryngospasm is a common occurrence in pediatric anesthesia and is usually easy to manage. It is however a significant cause of severe adverse outcome including cardiac arrest and its sequelae.

Advances in monitoring and the declining use of halothane have led to a change in the types of

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complications encountered in pediatric anesthesia over recent decades.

The value of assessing risk

Risk is defined as the chance or possibility of danger, loss or injury (4). It is therefore an ever-present part of life.

What constitutes a serious or worrying risk is dependent upon perspective. This is readily illustrated in the health care industry. Risk is viewed in quite different lights by patients, doctors, hospital managers, insurance companies and policy-makers.

While patients worry about the prospect of failed treatment and unpleasant side effects, anesthetists will be more concerned about the immediate risks of major disability and death associated with surgery.

Similarly, while individual hospital managers and insurance companies are keen to minimize their exposure to financial liability, health policy-makers aim to ensure patients' access to the most appropriate centers for their treatment.

A result of this difference in perspective among stakeholders is the inconsistent collection and presentation of the available information on risk. There is an abundance of high-quality data, but synthesis and comparison on a larger scale are made difficult by differences in study design and data processing.

It is important to differentiate between risk that can be reduced by targeting predisposing factors and that which is inherent and not amenable to such strategies. Critical and honest appraisal of the component of risk due to anesthesia is necessary to indicate where changes in clinical practice are required.

Sources of information on risk

The most useful data regarding mortality and morbidity have to date come from three distinct types of study: institutional audit, closed claims analysis and large-scale studies of cardiac arrest.

Institutional audit

Studies of this type have great utility in detecting minor complications. They provide illuminating profiles of the patient populations who suffer these adverse effects of anesthesia. They do not however produce widely applicable quantitative information, particularly with respect to major morbidity or mortality.

Rates of serious morbidity, cardiac arrest and death are not easily determined by this type of study because of a lack of statistical power: In a study of 20 000 children for example, only two or three cardiac arrests attributable to anesthesia are likely to take place.

Additionally, although authors of institutional audits have published complication rates, these statistics are not as helpful to readers as the qualitative patient profiles generated. There are two main reasons for this. The first is that events of uncertain significance may be recorded as complications. For example, an end-tidal CO_2 measurement exceeding 50 mmHg was counted as a respiratory complication by one large institutional audit (5). In the day-to-day practice of clinical anesthesia, modest hypercarbia is neither unusual nor necessarily undesirable.

The second factor limiting the usefulness of hard statistics emerging from this source is the inconsistency of definition between studies. Compounding these are significant demographic differences between patient groups studied.

Despite this, there is much to be learned from audits of anesthetic complications. They provide detailed and remarkably consistent qualitative evidence concerning the patients most likely to suffer certain types of complications.

Four large audits of anesthetic-related morbidity are summarized in Table 1. There are some marked differences between the studies.

In France, Tiret and colleagues recorded major complications, defined as those which were fatal, life-threatening, or produced severe sequelae (6). The period up to 24 h after anesthesia was included. Four hundred and forty different sites prospectively studied 40 240 anesthetics.

In Canada, Cohen *et al.* used a pediatric anesthesia follow-up database to retrospectively study 29 220 anesthetics (7). Intraoperative events were defined as those requiring intervention by the anesthetist. Recovery room events were also recorded. Postoperative events up to 72 h postoperatively were detected by a review of patients' hospital records.

Tay *et al.* in Singapore used the opening of a new hospital for women and children as an opportunity

Table 1
Institutional audit

Studies reviewed	*Complications related to anesthesia in infants and children*	*Pediatric anesthesia morbidity and mortality in the perioperative period*	*Critical incidents in pediatric anesthesia: an audit of 10 000 anesthetics in Singapore*	*Perioperative anesthetic morbidity in children: a database of 24 165 anesthetics over a 30 month period*
	Tiret *et al.*	Cohen *et al.*	Tay *et al.*	Murat *et al.*
Year of publication	1988	1990	2001	2004
Study design	Prospective survey of complications Data collection to 24 h post operatively	Retrospective review of postanesthesia database Data collected up to 3 days post operatively	Prospective data collection Data from the perioperative period	Prospective data collection Data collected until discharge from PACU
Number of patients	40 240	29 220	10 000	24 165
Age range (years)	< 15	< 16	Not stated	< 16
Incidence of events (% of anesthetics)	0.07	8.5 intraoperative 13 postoperative	8.6 infants 2.1 in older children	8.6 intraoperative 4.8 in PACU
Type of events	Mainly respiratory in infants Mainly respiratory and CVS in older children	Mainly respiratory in infants Mainly respiratory and CVS in older children Increase in PONV up to 33% over 5 year old	Respiratory 77% (laryngospasm 35%) cardiovascular 10.8%	Respiratory 53% of intraoperative cardiac 12.5% intra operatively PONV 6% overall, most common in PACU
Anesthetic mortality	1 : 40 000	Not stated	Nil	Nil
Cardiac arrest				
< 1 year	19 : 10 000	24 : 10 000	Not stated	11 : 10 000
Overall	3 : 10 000	7 : 10 000	1 : 10 000	3 : 10 000
Anesthesia related	Not stated	Not stated	Not stated	0.8 : 10 000
Risk factors (* = increased risk)	Infants (× 7) ASA 3-5(× 14) emergencies (× 3) preoperative fast < 8 h	Infants ASA 3–5	Infants (× 4) ASA 3–5 (× 4) < 2 kg (× 7)	Infants ENT surgery ASA 3–5
Comment	Majority of cases ENT Only major morbidity reported Incidence of minor morbidity not expressed	Mix of cases including cardiac events captured may not be exclusively because of anesthetic causes	Mix of cases including cardiac No comment on PONV No differentiation between minor and major	No cardiac or neurosurgery

to audit critical incidents occurring during the first 10 000 pediatric anesthetics given (8). A critical incident was defined as any which affected or could have affected the safety of the patient under anesthetic care. By contrast to the previous studies, reporting was voluntary and anonymous.

Tiret's French colleagues, led by Murat, analyzed data collected from 24 165 anesthetics conducted in a single pediatric teaching hospital (5). Their study was also prospective in design, but detected minor complications as well.

Despite substantial differences between the above-mentioned studies, it is instructive to view them as a group. This is because the risk profiles produced are nearly identical.

All four audits suggested the following:

Infants are at greatest risk of complications.

American Society of Anesthesiologists Physical Status (ASA PS) of 3 or greater increases risk substantially.

Other trends include the following:

Infants suffer predominantly respiratory complications.

Postoperative vomiting is common in older children

Closed claims analysis

In contrast to the cosmopolitan nature of the audits described earlier, analysis by anesthetists of malpractice claims is a distinctly American activity. Together with other incident reporting projects, closed claims analysis provides valuable insights into the types of events that lead to poor outcomes.

The audits described previously take an undifferentiated sample population and observe complications in the hope of identifying groups at risk. Projects such as closed claims analysis and incident reporting tackle the problem of risk stratification in the reverse order. They investigate a group of patients known to have endured an adverse event and examine the available data to identify any common characteristics.

The American society of Anesthesiologists closed claims project was initiated in 1984 and examines closed malpractice claims back as far as 1970. Two sets of data were published as shown in Table 2.

The first commentary on this data was presented by Morray *et al.* and published in 1993 (9). It compared pediatric and adult closed claims, finding the following key differences:

Table 2
Incident reporting

	A comparison of pediatric and adult anesthesia closed malpractice claims	*An update on pediatric anesthesia liability: a closed claims analysis*		
	Morray et al.	*Jiminez et al.*		
Year published	1993	2006		
Number of cases	238	532		
Age range (years)	< 15	< 16		
Cause of events		1970s	1980s	1990s
Respiratory (%)	43	51	41	23
	Most common respiratory events are laryngospasm and aspiration after ENT procedures			
Cardiac	13%	26%		
	Most common cardiovascular events are hemorrhage during craniotomy and craniostenosis repair			
Warning signs prior to cardiac arrest	Cyanosis			
	Bradycardia			
	Abnormalities of pulse oximetry			
	Difficulty measuring blood pressure			
	Most common claim is for death or brain damage			
Risk factors	Infants consistently comprise 25% of claims			
	0–3 years	0–3 years comprise 53% of claims between 1990 and 2000		
	ASA 3–5	ASA 3–5 strongly associated with claims for death and brain damage		

Claims for death were more common among pediatric patients.

Care of children was more often judged to be less than appropriate.

Pediatric plaintiffs were awarded greater payments.

Better monitoring was likely to have prevented more pediatric claims.

In 2007, Jimenez *et al.* used updated data to examine pediatric claims from the 1990s and compared these to claims from the previous two decades (10). In all three time periods, the most common cause for a claim was death or brain damage. Even in the 1990s, it accounted for 62% of claims, illustrating the strong tendency toward poor outcome in the closed claims data.

Although only 23% of claims concerned ASA 3–5 patients, this group accounted for 33% of claims for death or brain damage. Also associated with claims for death or brain damage was age < 3 years.

Events leading to claims were classified as respiratory, cardiovascular, medication-related, equipment-related or other. Of these, respiratory and cardiovascular causes were consistently the most common.

In the 1970s, respiratory events accounted for just over half of all claims, with inadequate ventilation or oxygenation the most commonly cited problem. By the 1990s, the number of claims for inadequate ventilation or oxygenation had fallen dramatically to approximately a quarter. The widespread adoption of capnography and pulse oximetry was credited with facilitating this improvement. This conclusion is supported by the early work of Cote, which showed maximal reduction in adverse events if these two modalities were used together (11). The dominant respiratory causes for claims in the 1990s were not often preventable by better monitoring. They included airway obstruction and aspiration of gastric contents.

Of the cardiovascular problems leading to malpractice claims, the most commonly identified cause was inadequate or inappropriate administration of fluids. Bleeding during craniotomies in infants was a recurring scenario. Among the cardiovascular problems that were unexplained, halothane toxicity, unsuspected heart disease, or a combination of both was thought to play a part.

Of interest, equipment-related causes for claims included not only burns and gas delivery problems but also misadventure with central and peripheral vascular cannulation.

Similar to closed claims analysis with respect to using complications and critical incidents as a starting point for risk analysis is the Australian Incident Monitoring Study (AIMS) (12). In 1993, Van Der Walt *et al.* analyzed the first 2000 incidents reported to this study, of which 207 complicated the anesthetic care of children.

Coming from a voluntary incident reporting project, AIMS data do not necessarily pertain to incidents with catastrophic outcomes in the way that closed claims data do. Even so, there is surprising concordance in the general themes arising from the two data sets. Among the principle results of the AIMS report were the following:

Respiratory problems were prominent in children

Most respiratory problems were preventable with pulse oximetry and capnography.

Head and neck procedures yielded a disproportionate number of incidents in children.

Data from closed claims analysis and incident reporting have several limitations. Neither type of data has any reliable denominator for the quantitative calculation of risk. Under-reporting is likely. In the case of closed malpractice claims analysis, it is not even risk which is assessed, but legal liability and cost of settlement.

ANotwithstanding these limitations, it is possible to draw conclusions regarding risk. It can be seen that there is convergence between the risk profiles generated by closed claims analysis and AIMS. These in turn are complementary to the profile already established by analysis of institutional audits.

Studies of cardiac arrest because of anesthetic causes

Many critical incidents follow the final common pathway of cardiac arrest. However, cardiac arrest is uncommon in the perioperative setting. Large samples are needed if trends associated with this event are to be identified.

For this reason, the most reliable data regarding anesthesia-related cardiac arrest come from only two sources as indicated in Table 3.

Table 3
Studies of cardiac arrest

	Anesthesia-related cardiac arrest in children. Initial findings of the pediatric Perioperative Cardiac Arrest (POCA) registry	*Anesthesia-related cardiac arrest in children: update from the pediatric perioperative cardiac arrest registry*	*Perioperative cardiac arrests in children between 1988 and 2005 at a tertiary referral center*
	Morray et al.	*Bhananker et al.*	*Flick et al.*
Year published	2000	2007	2007
Number of cases of anesthesia related cardiac arrest	150	193	6
Age range (years)	< 18	< 18	< 18
Definition of cardiac arrest	Initiation of chest compressions or death	Initiation of chest compressions or death	Open or closed chest compressions or death
Exclusions from anesthetic-related arrest	Failure to wean from bypass	Failure to wean from bypass	Failure to wean from bypass Must have detectable blood pressure initially Failure to discontinue ECMO Patients for organ retrieval Receiving CPR on presentation Massive transfusion and consequences
Incidence	1,4 : 10 000	Lack of denominator data	0.65 : 10 000 (if POCA definition used 1.5 : 10 000)
Mortality (%)	26	28	22
Causes of events			
Medication related	37% (halothane 66%)	18%	33%
	Reduction thought to be because of decreased use of halothane but still 6 arrests ascribed to the use of sevoflurane		Halothane nominated as causative
Cardiovascular	32%	41%	Comment made that the most common cause of arrest in noncardiac patients is hypovolemia and the consequence of massive transfusion
	Most common CVS causes are hemorrhage during craniotomies, craniectomy and spinal surgery as well as the consequences of massive transfusion		
Respiratory (%)	20	27	50
	Most common respiratory events because of laryngospasm		
Equipment (%)	10	5	17
	Half of equipment-related arrests because of anesthetic CVL insertion		
Warning signs prior to cardiac arrest	Cyanosis bradycardia		
Risk factors	Infants — 55% of arrests ASA 3–5, Emergency surgery — Both independent predictors of mortality	Infants — 38% of arrests ASA 3–5, Emergency surgery — Both independent predictors of mortality	Neonates and infants at highest risk for arrest from any cause ASA 3–5, Hemorrhage as cause of arrest, Preoperative ventilation — All predictors of mortality postarrest

The Pediatric Perioperative Cardiac Arrest Registry (POCA) was formed in 1994. Sixty-three North American hospitals were involved within the first 4 years, and data from this period were published in 2000 by Morray *et al.* (13).

Children were defined as patients under 18 years of age. Cardiac arrest was diagnosed if chest compressions were performed or if the patient died during administration of, or recovery from anesthesia.

Two hundred and eighty-nine cardiac arrests were reported to the registry in its first 4 years. During this period, there were just over one million episodes of pediatric anesthesia in participating institutions.

Reviewers classified cardiac arrests as anesthesia-related where anesthetic responsibility was thought to be major or total. A common example of major but not total responsibility was suboptimal treatment of surgical bleeding, including the metabolic consequences of transfusion. This approach to assignment of responsibility is highly subjective but has the useful consequence of highlighting areas in which improvement of anesthetic care is possible.

After analysis of reported arrests, 150 were judged to be anesthesia related, with a rate of 1.4 per 10 000 anesthetics. Over half of these arrests occurred in infants. Two thirds occurred in ASA 3–5 patients.

Causes of cardiac arrest were classified as cardiovascular, respiratory, medication-related or equipment-related, with the small remainder because of miscellaneous factors.

Medication-related problems were the commonest cause of anesthesia-related cardiac arrest, accounting for 37% of the total number. Halothane was the medication most often responsible, being implicated in over two thirds of medication-related cardiac arrests. Younger patients and those with cardiac disease were especially likely to suffer this complication.

Cardiovascular problems caused 32% of anesthesia-related arrests. The commonest identifiable causes were complications of surgical bleeding and inadequate or inappropriate fluid therapy, together accounting for nearly a third of these arrests.

Respiratory problems precipitated 20% of anesthesia-related arrests in this study. The majority were because of either laryngospasm (typically in healthy children) or trouble encountered in the management of difficult airways (macroglossia, micrognathia and papillomatosis). None of the arrests caused by laryngospasm had a fatal outcome.

Seven percent of anesthesia-related arrests were because of equipment problems. Nearly half of these were the result of complications of central venous cannulation.

Within the population of children suffering anesthesia-related cardiac arrest in the POCA registry, trends with respect to etiology and outcome of arrest are apparent. Healthy children, who accounted for a third of the sample, tended to arrest from halothane toxicity or laryngospasm. Mortality was uncommon, with only 5% of reported deaths coming from patients of ASA PA 1 or 2.

Sicker patients (ASA 3–5) accounted for the remaining two thirds of arrests, and for 95% of deaths. Expressed differently, ASA 3–5 patients had a 37% chance of dying from their anesthesia-related cardiac arrest compared to only 4% in the healthier patients. The only other independent predictor of death was emergency surgery. Arrest in such circumstances had a mortality of 52%.

In 2007, an update from the POCA registry was published (14). It analyzed anesthesia-related arrests for the period from 1998 to 2004. The main difference between the initial report and the update was a decline in halothane-induced cardiac arrest. Although there were six arrests because of sevoflurane, the overall number of medication-related arrests was reduced, suggesting that sevoflurane is indeed less cardiotoxic than halothane, which by 1998 was becoming less frequently administered in pediatric anesthesia.

As a result of the decline in medication-induced arrests, those because of hypovolemia and the consequences of perioperative blood transfusion were proportionately more common.

The other important study of cardiac arrest was conducted at the Mayo Clinic between 1988 and 2005 (15). Results were published by Flick and colleagues in 2007. Although a single-institution study, the sample size was large, at 92 881 anesthetics (about 10% of the POCA sample size). It is also likely that levels of reporting were very good, as all incidents were captured by a central register and cross-checked by the authors.

The Mayo Clinic maintains a busy cardiac surgical service, accounting for five percent of anesthetics given to patients under 18 years of age. Cardiac surgery was defined as any procedure on the heart or great vessels involving a skin incision. This cohort of patients suffered cardiac arrest at a rate of 127 per 10 000. By comparison, noncardiac procedures led to cardiac arrest at a rate of only 2.9 per 10 000.

Peri-operative cardiac arrest was defined in the Mayo study as an event that required open or closed chest compressions, or resulted in death, while the patient was in the care of the anesthetic team. In this way, arrests occurring in the postanesthesia care unit were also included. This definition is practically identical to that employed in the POCA study.

The assignment of anesthetic responsibility for cardiac arrest was significantly different in the Mayo study compared to POCA. In the Mayo study, arrests arising from the consequences of massive transfusion were not deemed anesthesia related. The statistical impact of this exclusion is large, as hypovolemia, including massive transfusion and its sequelae, was the single biggest cause of cardiac arrest in noncardiac surgery, accounting for 31% of episodes.

In addition to the exclusion of hypovolemia, several other multifactorial cardiac arrests in this study were deemed nonanesthesia related, even though anesthesia was likely to have precipitated if not caused the arrest. Examples include a hypoxic arrest during micro laryngoscopy and another on induction in a Down's syndrome child for tonsillectomy. Of the many cardiac arrests in cardiac surgery, none were deemed anesthesia related.

The rate of anesthesia-related cardiac arrest in the Mayo Clinic study was 0.65 per 10 000 anesthetics. This seems a low incidence, but when anesthesia responsibility is reassigned using the POCA criteria, the incidence of anesthesia-related cardiac arrest is 1.5 per 10 000, similar to the POCA rate of 1.4 per 10 000.

While the Mayo Clinic study allows for the estimation of the rate of anesthesia-related cardiac arrest, statistically meaningful subgroup analysis is not possible. This is because only six cardiac arrests attributable to anesthesia took place (fourteen if POCA criteria are used). Having acknowledged this limitation, the etiology of the few anesthesia-related arrests recorded conforms to the pattern observed in the POCA database: hypovolemia/massive transfusion in cranial and spinal surgery was the most important cause. Respiratory problems, halothane toxicity and equipment problems accounted for the remainder.

Mortality following cardiac arrest in the Mayo Clinic study was associated with ASA PS 3–5, the need for preoperative ventilation and hemorrhage as the precipitating cause.

Although only POCA data and the Mayo Clinic study described earlier are adequately powered to shed light on the incidence and causes of anesthesia-related cardiac arrest in children, other studies have specifically addressed this issue. Recent examples have come from Brazil and Pakistan (16,17). The common themes emerging from all inquiries into cardiac arrest are re-confirmed in these papers. Specifically, anesthesia-related cardiac arrest is most likely in patients under a year of age and those with severe preexisting disease.

Implications

Just as the concept of risk is a question of perspective, so the implications of risk are dependent on how they impact in different areas.

Implications for clinicians

The greatest value of risk profiling for individual clinicians is to allow identification of high-risk patients and situations to formulate the best possible management plan. In other words, knowledge is power.

Minor events occur with variable frequency in different institutions. The likelihood of these occurring is increased in patients under a year of age and in patients with an ASA status of 3 and above. Most events are respiratory in nature, emphasizing the importance of pulse oximetry and capnography as routine monitors in the delivery of anesthesia. Postoperative vomiting remains a common problem in older children.

Patients suffer major morbidity less frequently but the consequences are severe. The most common trigger for litigation is permanent brain damage or death. ASA status of 3 and above is strongly associated with this outcome and children under the age of 3 consistently comprise the largest number in this group.

Currently, massive hemorrhage and its consequence is the most common identifiable cause of major morbidity resulting in litigation. It is also the commonest specific cause of anesthesia-related cardiac arrest. Proactive and appropriate planning for cases with the potential for massive blood loss is essential. Craniotomy, craniofacial and spinal surgery have been identified as surgeries at risk, particularly in patients under a year of age. Warning signs for impending catastrophe are cyanosis, abnormalities of pulse oximetry, difficulty measuring blood pressure and bradycardia.

While degrees of laryngospasm frequently occur during anesthesia, it is the most common respiratory event resulting in major morbidity. It should therefore not be underestimated, and appropriate protocols for management should be in place.

Halothane's fall from grace has resulted in less medication-related cardiac arrests, but it should be noted that there are a number of reports of cardiac arrest ascribed to the use of sevoflurane.

The most common equipment-related cause of severe morbidity is the insertion of anesthetic central lines, and appropriate postprocedure monitoring is advisable.

Implications for training

Identification of risk factors is a useful exercise only if it contributes to the development of strategies that improve outcome. Adverse events in medicine have been shown to be reduced when experienced practitioners are responsible for the treatment of high-risk cases (18). It follows therefore that anesthetists with additional expertise or training would be best suited to provide anesthetic services to children who have been identified to be at increased risk.

In light of this review, it would seem that there are areas of training that require special attention. Experience with infants and patients under the age of 3 is essential in both elective and emergency settings. Areas of focus include the development of comprehensive airway management and vascular access skills. The treatment of massive hemorrhage merits specific mention as a core topic in the advanced training of anesthetic staff.

It should be pointed out that implications for training are not confined to identification of high-risk patients and improving procedural skills alone. Effective communication is essential to achieve optimal outcome (19). Development of this ability is therefore an important aspect of training programs. This will ensure that the presence and implications of anesthetic risk factors are made clear and that management plans are developed in concordance with all members of the treating team.

Implications for hospitals and credentialing

Hospital administrators are responsible for the delivery of quality care at their institutions while at the same time managing risk appropriately. There are many different types of facility providing medical services with many different combinations of patient mix. Each institution should provide policy guidelines for medical staff with respect to the profiles of patients treated and procedures undertaken.

More specifically, if infants or children under three are to be treated and surgery with the potential for major bleeding is to be undertaken, anesthetic staff should have undergone appropriate training.

Implications for health care

Developers of health care policy are responsible for overall design of systems and frameworks that interface patients with appropriate medical care. The numerous factors that pertain to the development of this kind of matrix are beyond the scope of this paper.

With reference to anesthesia, however, special consideration should be given to identified areas of high risk. In terms of this review, infants and children under three should be directed to institutions where infrastructure and expertise are in keeping with the range of treatments undertaken. This includes arrangements for the management of significant blood loss. There should be special consideration given to provision of services after hours when the sickest patients often present in an emergency situation.

Implications for research

Conclusions reached after analysis of these data have been of value in making some general statements. Difficulties were encountered in integrating information from different sources, but these were instructive in suggesting future solutions.

It is clear that infants and children under three, particularly those presenting acutely, are at high risk. Patients with co-morbid disease are at increased risk. Attention to these facts is warranted when defining demographic groups for future study.

A distinction between minor and major morbidity is useful. Attention to incidence and type of minor morbidity will result in better quality of anesthetic care. Focus on remediable factors that contribute to the most severe outcomes is of value in improving the safety of anesthesia as a whole.

Single-institution studies produce data that indicate incidence but may be more useful in describing type of minor morbidity. Careful definition of complications and patient demographics is necessary for comparisons to be made between studies in different parts of the world. This work is valuable in terms of quality assurance and benchmarking activities.

Major morbidity in single institutions is less common, and examination of data relating to this is often unrewarding. It can however be used as the basis for comparison with data from similar institutions or multicentre collaborations where statistical evaluation has been possible.

The study of malpractice claims allows examination of a group of patients who are preselected for morbidity. Analysis of events and causes has been shown to be useful in generating a profile indicative of anesthetic liability. While the majority of claims are for major morbidity, distinction between minor and major outcome in future reports would be helpful for the ease of comparison with studies using similar stratification. A valuable perspective is achieved by this retrospective analysis of a patient cohort selected on the basis of adverse outcome alone. This type of exercise will continue to be a useful guide for quality improvement initiatives.

Studies of anesthesia induced cardiac arrest suffer from a lack of common definition. The most unambiguous used invokes the initiation of chest compressions or death as an outcome. This is an easily recognizable point of entry into such studies and may be useful as a standard in future work in this area.

The contribution of anesthesia as a cause of cardiac arrest has been assessed inconsistently. It would seem reasonable to suggest that anesthesia is not a prime contributor in patients who arrest after presenting to theater in a moribund state. It would seem equally reasonable to suggest that anesthesia is a factor to a variable degree where arrest occurs as a result of massive hemorrhage or its consequences. Anesthetic cause could be regarded as a contributory factor if different anesthetic management may have been expected to alter outcome.

Regardless of differences in specific definitions, parameters and exclusions should be described in sufficient detail to allow comparison of like data between different studies. The ability to evaluate practice depends ultimately on the quality of data collected, and success in this area will ensure the accuracy of continuing audit and enhance efforts to further improve anesthetic safety.

Conclusion

Patients under a year of age and those with associated disease are at increased risk for both minor and major morbidity.

The most common cause for litigation is irreversible brain damage or death and occurs most frequently in ASA 3–5 patients who are under 2 years of age. Patients < 1 year consistently comprise half of this cohort.

Anesthesia-related cardiac arrest most commonly occurs in infants, in patients of ASA status 3–5 and in those undergoing emergency procedures. Outcome is often poor with the last two risk factors serving as independent predictors of mortality.

The most common causes of all complications are related to problems with the cardiovascular and respiratory systems. Massive hemorrhage and laryngospasm are significant contributors in the genesis of severe outcome.

Morbidity and in all likelihood mortality have been significantly reduced by the decreasing use of halothane over recent years. The widespread introduction of pulse oximetry and capnography as standard monitors has and will continue to have a major impact on improving safety in anesthesia.

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