

The Universal Protocol

The Universal Protocol is a three-step process in which each step is complementary and adds redundancy to the practice of confirming the correct patient, site and procedure.

Step 1. Verification: This consists of verifying the correct patient, site and procedure at every stage from the time a decision is made to operate to the time the patient undergoes the operation. This should be done:

- when the procedure is scheduled;
- at the time of admission or entry to the operating theatre;
- any time the responsibility for care of the patient is transferred to another person; and
- before the patient leaves the preoperative area or enters the procedure or surgical room.

The step is undertaken insofar as possible with the patient involved, awake and aware. Verification is done by labelling and identifying the patient and during the consent process; the site, laterality and procedure are confirmed by checking the patient's records and radiographs. This is an active process that must include all members of the team involved in the patient's care. When many team members are involved in verification, each check should be performed independently. Team members must also be aware, however, that the involvement of multiple caregivers in verification can make the task appear onerous and could lead to violations of the protocol. Adherence to the verification procedure can be facilitated by the use of reminders in the form of checklists or systematic protocols (11).

Step 2. Marking: The Universal Protocol states that the site or sites to be operated on must be marked. This is particularly important in case of laterality, multiple structures (e.g. fingers, toes, ribs) and multiple levels (e.g. vertebral column). The protocol stipulates that marking must be:

- at or next to the operative site; non-operative sites should not be marked;
- unambiguous, clearly visible and made with a permanent marker so that the mark is not removed during site preparation (Health-care organizations may choose different methods of marking, but the protocol should be consistent in order to prevent any ambiguity. The guidelines of the National Patient Safety Agency in the United Kingdom recommend use of an arrow drawn on the skin and pointing to the site, as a cross could denote a site that should not be operated and introduces an element of ambiguity (12). The American Academy of Orthopaedic Surgeons endorses a 'sign your site' protocol in which surgeons write their initials or name on the operative site (13).);
- made by the surgeon performing the procedure (To make the recommendations practicable, however, this task may be delegated, as long as the person doing the marking is also present during surgery, particularly at the time of incision (14).); and

- completed, to the extent possible, while the patient is alert and awake, as the patient's involvement is important.

The verification and marking processes are complementary. They are intended to introduce redundancy into the system, which is an important aspect of safety. Either one used alone is unlikely to reduce the incidence of wrong-site surgery.

Patients or their caregivers should participate actively in verification. The Joint Commission views failure to engage the patient (or his or her caregiver) as one of the causes of wrong-site surgery. The Joint Commission has published information leaflets for patients to inform them of their important role in preventing wrong-site surgery (15); patient awareness initiatives have also been adopted by the National Patient Safety Agency in the United Kingdom (16) and the Australian Commission of Safety and Quality in Healthcare (17).

Step 3. 'Time out': The 'time out' or 'surgical pause' is a brief pause before the incision to confirm the patient, the procedure and the site of operation. It is also an opportunity to ensure that the patient is correctly positioned and that any necessary implants or special equipment are available. The Joint Commission stipulates that all team members be actively involved in this process. Any concerns or inconsistencies must be clarified at this stage. The checks during the 'time out' must be documented, potentially in the form of a checklist, but the Universal Protocol leaves the design and delivery to individual organizations. The 'time out' also serves to foster communication among team members.

The Australian Commission on Safety and Quality in Healthcare uses a five-step process similar to the Universal Protocol to prevent wrong-site surgery (17):

Step 1: Check that the consent form or procedure request form is correct.

Step 2: Mark the site for the surgery or other invasive procedure.

Step 3: Confirm identification with the patient.

Step 4: Take a 'team time out' in the operating theatre, treatment or examination area.

Step 5: Ensure appropriate and available diagnostic images.

Consent is part of both protocols. It is the first step in the Australian protocol and is included as critical documentation in the Universal Protocol in the United States. While consent is being obtained, the patient must be awake and alert and have the capacity to understand the details and implications of the procedure. Consent must be obtained in a language that the patient understands or through an interpreter. It should include a clear statement of the procedure to be performed and the site of operation, including laterality or level (18). The consent protocol can, however, be waived in emergency cases with threat to life or limb.

Preoperative verification protocols have only recently been introduced in many parts of the world. Evidence of their efficacy in reducing the incidence of wrong-site surgery is lacking, although preliminary data suggest that such actions are effective. The Orange County Kaiser Permanente organization in the United States found a reduction in the incidence of wrong-site surgery after the introduction of a checklist (19). Similarly, there has been a reduction in wrong-site surgery in Western Australia, from 10 reported cases in 2004–2005 to four in 2005–2006 (20). A study by Makary et al. at Johns Hopkins hospital in the United States showed that team awareness of the correct site of operation increased with use of a checklist and briefing (21). While evidence is still being

gathered, protocols for ensuring correct patient and procedure are well established, inexpensive, recommended by many professional societies and, if followed with care and consideration, promote safe surgical practice.

Recommendations

Highly recommended:

- Before induction of anaesthesia, a member of the team should confirm that the patient is correctly identified, usually verbally with the patient or family member and with an identity bracelet or other appropriate means of physical identification. Identity should be confirmed from not just the name but also a second identifier (e.g. date of birth, address, hospital number).
- A team member should confirm that the patient has given informed consent for the procedure and should confirm the correct site and procedure with the patient.
- The surgeon performing the operation should mark the site of surgery in cases involving laterality or multiple structures or levels (e.g. a finger, toe, skin lesion, vertebra). Both the anaesthesia professional and the nurse should check the site to confirm that it has been marked by the surgeon performing the operation and reconcile the mark with the information in the patient's records. The mark should be unambiguous, clearly visible and usually made with a permanent marker so that it does not come off during site preparation. The type of mark can be determined locally (signing, initialling or placing an arrow at the site). A cross or 'X' should be avoided, however, as this has been misinterpreted to mean that the site is the one *not* to be operated on.
- As a final safety check, the operating team should collectively verify the correct patient, site and procedure during a 'time out' or pause immediately before skin incision. The surgeon should state out loud the patient's name, the operation to be performed, and the side and site of surgery. The nurse and anaesthesia professional should confirm that the information is correct.

References

1. Kwaan MR, et al. Incidence, patterns, and prevention of wrong-site surgery. *Archives of Surgery*, 2006, 141:353–8.
2. Seiden SC, Barach P. Wrong-side/wrong-site, wrong-procedure, and wrong-patient adverse events: Are they preventable? *Archives of Surgery*, 2006, 141:931–9.
3. Joint Commission. *Sentinel event statistics—December 31, 2006*. <http://www.jointcommission.org/SentinelEvents/Statistics> (accessed 5 May 2007).
4. Joint Commission. *Sentinel events alert—5th December 2001*. http://www.jointcommission.org/SentinelEvents/sentineleventalert/sea_24.htm (accessed 3 May 2007).
5. Cowell HR. Wrong-site surgery. *Journal of Bone and Joint Surgery (American)*, 1998, 80:463.

6. Dyer C. Doctors go on trial for manslaughter after removing wrong kidney. *British Medical Journal*, 2002, 324:1476.
7. Joint Commission. *National patient safety goals*. http://www.jointcommission.org/PatientSafety/NationalPatientSafetyGoals/08_hap_npgs.htm (accessed 25 January 2008).
8. Canale ST. Wrong-site surgery: a preventable complication. *Clinical Orthopaedics and Related Research*, 2005, 433:26–9.
9. Joint Commission. *Universal protocol for preventing wrong site, wrong procedure, wrong person surgery*. <http://www.jointcommission.org/PatientSafety/UniversalProtocol/> (accessed 15 February 2007).
10. American College of Surgeons. Statement on ensuring correct patient, correct site, and correct procedure surgery. *Bulletin of the American College of Surgeons*, 2002, 87:12.
11. Michaels RK, et al. Achieving the National Quality Forum's 'never events': prevention of wrong site, wrong procedure, and wrong patient operations. *Annals of Surgery*, 2007, 245:526–32.
12. National Patient Safety Agency and Royal College of Surgeons of England. *Patient briefing—correct site surgery*. 2005. http://www.rcseng.ac.uk/publications/docs/patient_briefing.html/?searchterm=patient%20safety (accessed 25 January 2008).
13. American Academy of Orthopaedic Surgery. *AAOS advisory statement on wrong-site surgery*. <http://www.aaos.org/about/papers/advistmt/1015.asp> (accessed 25 January 2008).
14. Giles SJ, et al. Experience of wrong site surgery and surgical marking practices among clinicians in the UK. *Quality and Safety in Health Care*, 2006, 15:363–8.
15. Joint Commission. *Speak up: help avoid mistakes in your surgery*. 2007. http://www.jointcommission.org/patientsafety/speakup/speak_up_ws.htm (accessed 5 May 2007).
16. National Patient Safety Agency. *Correct site surgery—making your surgery safer*. http://www.npsa.nhs.uk/site/media/documents/884_0186FEB05_01_26.pdf (accessed 3 May 2007).
17. Australian Commission on Safety and Quality in Healthcare. *Ensuring correct patient, correct site, correct procedure*. <http://www.safetyandquality.gov.au/internet/safety/publishing.nsf/content/former-pubs-archive-correct> (accessed 23 August 2007).
18. Department of Health, United Kingdom. *Reference guide to consent for examination or treatment*. http://www.dh.gov.uk/en/publicationsandstatistics/publications/publicationspolicyandguidance/dh_4006757 (accessed 28 May 2007).
19. DeFontes J, Surbida S. Preoperative safety briefing project. *Permanente Journal*, 2004, 8:21–7.
20. Department of Health. *Delivering safer healthcare in Western Australia: the second WA sentinel event report 2005–2006*. Perth, Government of Western Australia, 2006:1–25.
21. Makary MA, et al. Operating room briefings and wrong-site surgery. *Journal of the American College of Surgeons*, 2007, 204:236–43.

Objective 2: The team will use methods known to prevent harm from administration of anaesthetics, while protecting the patient from pain.

In developed countries, anaesthesia is associated with low risks for serious morbidity and mortality. Current estimates of avoidable mortality associated with anaesthesia in Australia and Europe vary from about 1:10 000 to about 1:185 000 (1–4). The rate of mortality attributable solely to anaesthesia in healthy patients undergoing minor surgical procedures is likely to be at the lower end of this range. The higher estimates tend to reflect mortality to which anaesthesia is thought to have contributed, often in patients with significant comorbidity who are undergoing major surgery. There are, however, few reliable data to determine the true rate of mortality associated with anaesthesia. A rate of 1 in 79 509 was reported in a review in Australia between 1997 and 1999 (5). In a subsequent review from the same source covering the years 2000–2002, the reported rate was 1 in 56 000, the revised estimate being based on improved data for the denominator attributable to the introduction of anaesthesia-specific coding (6). These Australian reports probably provide the best estimates of mortality associated with anaesthesia available for any nation in the world; however, the discrepancy between the rates in the two reports indicates that the mortality rate for the 1990s was unclear, and it remains so for most of the world. Lagasse (7) reviewed data on mortality during the last four decades of the twentieth century and attributed the wide variation in rates to lack of standardization of definitions. His contention that mortality had not improved was strongly challenged by Cooper and Gaba (8), who argued that there is credible evidence that mortality has decreased substantially among relatively healthy patients undergoing elective procedures, which was the initial aim of patient safety efforts in anaesthesia.

Estimation of mortality due to anaesthesia is problematic: most reporting is voluntary, the denominator is seldom a reliable figure, sedation is not routinely captured, the case mix to which the figures are applied is usually unknown, and there is no agreed definition of anaesthetic mortality. Even when clearly defined, it may be difficult to separate it from causes related to the operation and the patient's underlying condition. Nevertheless, there is good reason to believe that anaesthesia-related risks in the developed world have decreased significantly over the past two decades due to improvements in training, equipment and medications and the introduction of standards and protocols. Mandatory monitoring standards, in particular pulse oximetry and capnography, are considered particularly important (9,10).

Unfortunately, the avoidable anaesthesia-associated mortality in developing countries has been estimated at 100–1000 times the rate reported in developed countries. In published series, avoidable mortality associated with anaesthesia was as high as 1:3000 in Zimbabwe (11), 1:1900 in Zambia (12), 1:500 in Malawi (13) and 1:150 in Togo (14). The methods used in these studies are comparable, and they demonstrate a serious, sustained lack of safe anaesthesia for surgery.

Patterns of avoidable morbidity and mortality during anaesthesia

Mortality associated with anaesthesia, particularly in the developing world, is primarily related to two causes: airway problems and anaesthesia in the presence of hypovolaemia. A substantial proportion of anaesthesia-related deaths in the developed world occur in obstetric patients (15–17); reports from Nigeria (18) and Malawi (19) demonstrate that these patients account for 50% of the anaesthesia-

related deaths in developing countries. These studies also indicate that poor technique and lack of training, supervision and monitoring contribute to the high mortality. The potential for professionals to learn lessons about avoidable deaths is limited in many hospitals, as few such events are recorded or formally discussed.

These unacceptably high figures are indicative of a deteriorating situation. Information from Uganda in 2006 (20) illustrates the constraints anaesthesia providers face, including shortages of the most basic facilities, equipment and medications and few physician anaesthetists (13 for 27 million people, compared with 12 000 for 64 million in the United Kingdom); most anaesthesia is thus performed by non-physicians. This situation is similar to that in other parts of Africa (21–23). Although the situation varies widely throughout the world, anaesthesia services in many countries are extremely poor, particularly in rural areas (24,25). For the most part, deficiencies go unrecorded, as there are few systematic reviews of anaesthetic conditions and practice.

Perioperative mortality is usually due to a combination of factors related to patients (and their underlying medical condition), surgery, anaesthesia and management. In order to improve the safety of patients undergoing surgery, anaesthesia services must be made safer, especially in developing countries. This will require investment in the form of improved training of anaesthesia professionals, safer facilities, functioning equipment, adequate drug supplies and mandatory pulse oximetry. International standards play an important role in guiding the development of anaesthesia services and should be adopted by ministries of health and local professional societies.

In order that no patient be harmed by anaesthesia, several goals must be met:

- Anaesthesia services should be made safer.
- Training and facilities for anaesthesia should be improved in many parts of the world.
- Safety in obstetric anaesthesia should be a priority, as obstetric patients are at particularly high risk from anaesthesia.
- Standardized global definitions of anaesthesia mortality should be developed.
- Every avoidable death is a tragedy, and lessons should be learnt from each instance of death during anaesthesia in order to reduce the risk of recurrence.

Approaches to improving the safety of anaesthesia

Anaesthesiology has played a pioneering role in the patient safety movement and in the establishment of standards for safe practice. Anaesthesiologists first codified the concept of 'patient safety' in 1984 at the inaugural meeting in Boston (United States) of the International Committee on Preventable Anesthesia Mortality and Morbidity. The first organization devoted to the concept of patient safety was the Anesthesia Patient Safety Foundation, created in the United States in 1985. This independent organization was the result of considerable effort on the part of the medical professionals involved, with the support of related industries and government regulators. The original 'Harvard monitoring standards' for intraoperative anaesthesia care were the first formally published,

detailed medical standards of practice (26). They stimulated the American Society of Anesthesiologists to adopt their 'Standards for Basic Intraoperative Monitoring' in 1986. This initiative encouraged a cascade of standards, guidelines and protocols by professional anaesthesiology groups and societies around the world.

In 1989, the International Task Force on Anaesthesia Safety was established, comprising leaders in anaesthesia patient safety in nine countries (27). After 2 years of extensive work, the Task Force published the first *International standards for a safe practice of anaesthesia* (28). The document consisted of four printed pages and contained an outline of both general standards for the profession and practice of anaesthesiology and specific standards for peri-anaesthetic care and monitoring. Because of the variation in resources available in different locations around the world, the standards for equipment required for peri-anaesthetic care and monitoring were classified into three levels: basic, intermediate and optimal, to correlate realistically with available local resources. The essential care and monitoring concepts were universal and applicable everywhere, from the most isolated, resource-challenged locations in the developing world to the most economically and technologically advanced capitals. Ability to implement the concepts differed greatly, however. One focus was to help provide more anaesthetists in disadvantaged areas and to secure resources for improving anaesthesia quality and safety. The World Federation of Societies of Anesthesiologists formally adopted these international standards at its congress in The Hague in June 1992 and recommended them to all its member societies. The *International standards for a safe practice of anaesthesia* and 10 supporting documents were published as Supplement 7 to the *European Journal of Anaesthesiology* in January 1993 (28).

The work of the International Task Force underpins much of the current work in anaesthesia safety. At the most recent meeting of the World Federation of Societies of Anaesthesiologists, the 1992 standards were revised and updated and subsequently endorsed by the General Assembly during the 14th World Congress of Anaesthesiologists in Cape Town, South Africa, on 7 March, 2008 (29). The older standards had not, however, been actively promoted or endorsed globally. If the safety of anaesthetic services is to be improved, wide adoption of the standards is imperative. The main addition to the previous international standards is the requirement for pulse oximetry as an essential component of patient monitoring. Pulse oximetry is used almost universally in industrialized countries during the administration of anaesthesia. While strong, unequivocal evidence from a randomized clinical trial is lacking, few anaesthesia providers would willingly do without this device. As this represents a departure from the previous standards and imposes a potentially substantial cost on facilities, a full review of the evidence for this recommendation is warranted.

Evidence on monitoring with pulse oximetry and capnography

There is no evidence from randomized controlled trials that pulse oximetry or capnography has had an important effect on the outcome of anaesthesia (30). Evaluation of any safety intervention, however, requires consideration not only of the frequency of the adverse events that might be prevented but also of their potential severity. The prevention of an event may warrant considerable investment if it is serious, even if it is infrequent. Furthermore, prevention is more readily justified if the risks associated with the preventive measures are

low. The death of, or brain damage to, an otherwise healthy person due to an entirely preventable anaesthetic mishap, such as ventilator disconnection or oesophageal intubation, is catastrophic; the risks associated with pulse oximetry and capnography are exceedingly low.

Expert opinion: The anaesthesia community has led health care in the pursuit of patient safety (8). A prime example of systems improvement is the adoption of pulse oximetry and capnography as standard care in anaesthesia. In many countries today, there is a generation of anaesthetists who have never practised without pulse oximetry or capnography, and routine use of these techniques is mandated in the standards or guidelines of professional anaesthesia organizations in a number of countries (e.g. the Australian and New Zealand College of Anaesthetists, the Hong Kong College of Anaesthetists, the Malaysian Society of Anaesthesiologists, the Nigerian Society of Anaesthetists, the Association of Anaesthetists of Great Britain and Ireland, the American Society of Anaesthesiologists in the United States and the Uruguay Society of Anaesthesiologists). It is likely that pulse oximetry and capnography are used in over 99% of general and regional anaesthetics in the United States and Canada, much of Europe, Australia, New Zealand and many other countries. This level of adoption reflects an almost universal conviction on the part of anaesthesia providers that these techniques contribute substantially to the safe provision of anaesthesia. The fact that the standards in many different countries are almost identical amounts to an extended 'Delphi process' for establishing consensus among experts. The weight of international expert opinion overwhelmingly supports use of these techniques for the safety of anaesthesia.

Compliance with best-practice guidelines for health care in general is sporadic and inconsistent, even in highly developed systems of health delivery (31); however, compliance with standards, guidelines and recommendations for the use of pulse oximetry and capnography in the developed world is virtually 100%. They have not only been mandated by authorities in the anaesthetic profession, they have also been embraced whole-heartedly and unequivocally by virtually every practising anaesthetist who has access to them (32). Informal surveys indicate that anaesthetists in many parts of the world cancel elective cases rather than proceed in the absence of either of these monitors. Widespread use of pulse oximetry is the primary goal of the Global Oximetry project, a collaboration among several professional societies of anaesthesiology and industry to promote widespread adoption of pulse oximetry, with particular emphasis in developing countries. The project includes evaluation of current oximeter design and cost, the educational requirements for effective use of pulse oximeters and barriers to their widespread adoption in appropriate settings (33). The adoption of pulse oximetry by anaesthetists has been an unusual, strikingly successful example of standardization of practice in health care.

Controlled trials: A recent Cochrane review addressed the value of pulse oximetry in anaesthesia (30). The authors identified six studies of oximetry, two of which were deemed ineligible for inclusion because they lacked a control group or information on relevant postoperative outcomes. They concluded:

“The studies confirmed that pulse oximetry can detect hypoxaemia and related events. However, we have found no evidence that pulse oximetry affects the outcome of anaesthesia. The conflicting

subjective and objective results of the studies, despite an intense, methodical collection of data from a relatively large population, indicate that the value of perioperative monitoring with pulse oximetry is questionable in relation to improved reliable outcomes, effectiveness and efficiency.”

The authors, however, went on to explain that, “Due to the variety of outcome variables used in the four studies, there are no two groups which could be compared directly by formal meta-analysis.”

Thus, the conclusions of this review were not based on a synthesis of a substantial body of comparable data but rather on the only large randomized controlled trial in which pulse oximetry has been evaluated, with some reference to three much smaller studies. This trial, conducted by Moller et al. (34), involved 20 802 patients and is impressive in concept, the detail of the data collected and the care with which the findings were presented. The study, however, lacked power to show differences in mortality associated with anaesthesia between groups. Given the observed rate of one death partially associated with anaesthesia per 335 patients, 1.9 million patients would have been needed to show a significant difference in outcome. Even for myocardial infarction, 500 000 patients would have been needed to show a difference in events, on the basis of the observed rate of 1 in 650 patients. Thus, the negative findings of the Moller study—revealing no change in overall rates of respiratory, cardiovascular or neurological complications—were related to outcomes that would have required much larger numbers of participants to be detected. It did, however, demonstrate a 19-fold increase in the detection of hypoxaemia in the group monitored by oximetry ($p = 0.00001$) as well as a significant increase in the detection of endobronchial intubation and hypoventilation. In addition, myocardial ischaemia occurred in half as many patients when oximetry was used.

The theoretical value of pulse oximetry lies in its ability to provide earlier, clearer warning of hypoxaemia than that provided by clinical signs alone. This may well reduce mortality rates and catastrophic hypoxic events, but these proved too infrequent to be evaluated in a study of only 20 000 patients. While anaesthesiologists still disagree about the implications of the Moller et al. study, it confirmed unequivocally that pulse oximetry facilitates early detection of hypoxaemia. Analysis of the data strongly suggested that oximetry improves outcomes as well. In addition, all the other identified studies demonstrated at least some benefit of the use of oximetry (Table II.2.1).

The results of trials of capnography are less clear, partly because its value is too obvious to require a randomized trial. Oesophageal intubation and hypoventilation are potentially disastrous if not identified early, and they can be detected reliably and promptly by the use of capnography (9,42). This is not the case with clinical signs alone. Capnography can also facilitate the detection of endobronchial intubation and airway circuit disconnections (43). No reasonable ethics board is likely to permit a randomized trial of capnography.

Table II.2.1 – Other studies of pulse oximetry and its demonstrated benefits

| Study | Benefit |
|--|---|
| Bierman et al. (35): Blinded randomized controlled trial of 35 patients undergoing cardiac surgery | Clinically undetected episodes of arterial desaturation were observed in 7/15 patients in the control group and none in the pulse oximetry group. |
| Moller et al. (36): Blinded randomized clinical trial of 200 adult patients undergoing general surgery under general or regional anaesthesia, allocated randomly to pulse oximeter and alarms 'available' vs 'unavailable' to the anaesthesia team and recovery-room staff | The incidence of hypoxaemia was reduced significantly in the 'available' group in both the operating theatre and the recovery room. |
| Moller et al. (37): Blinded randomized clinical trial of 736 patients undergoing elective procedures under general or regional anaesthesia; oximetry used during anaesthesia and in the post-anaesthesia care unit vs not at all | No difference in cognitive function between groups |
| Coté et al. (38): Controlled study (alternating patients) in 152 children undergoing surgery allocated to pulse oximeter data and alarms 'available' vs 'unavailable' to the anaesthesia team | Hypoxic events diagnosed by the oximeter but not the anaesthetist were more common in the non-oximetry group (13 vs 5: $p = 0.05$). |
| Coté et al. (39): Blinded randomized clinical trial of 402 paediatric patients in four groups: (1) oximeter and capnography, (2) only oximeter, (3) only capnography and (4) neither | Blinding the oximeter data increased the number of patients experiencing 'major desaturation events' (31 vs 12: $p = 0.003$). Blinding the capnographic data increased the number of patients with minor capnographic events (47 vs 22: $p = 0.003$) but not the number with major capnographic events or desaturation events. More patients experienced multiple problems when neither capnographic nor oximeter data were available (23 vs 11: $p = 0.04$). The authors concluded that oximetry was superior to capnography or clinical observation in providing early warning of potentially life-threatening problems, and that use of both monitors together significantly reduced the number of problems observed in their patients. |
| Cullen et al. (40): Non-randomized study of 17 093 surgical patients | After introduction of pulse oximetry in all anaesthetizing locations (not including the recovery room), the overall rate of unanticipated admission to an intensive care unit and, specifically, the rate of admission to rule out myocardial infarction, decreased significantly. |
| Mateer et al. (41): Non-randomized study of 191 consecutive adult patients undergoing emergency endotracheal intubation | Hypoxaemia (O_2 saturation less than 90%) occurred during an intubation attempt in 30 of 111 unmonitored versus 15 of 100 monitored attempts ($p < 0.05$), and the duration of severe hypoxaemia (O_2 saturation less than 85%) was significantly greater for unmonitored attempts ($p < 0.05$). |

Incident reporting: In the seminal work of Cooper and his group (44), reporting of incidents identified failure to deliver oxygen to patients as the leading cause of mortality during anaesthesia. Over a decade ago, qualitative analysis of 2000 incidents showed a reduction in cardiac arrest when pulse oximetry was used (45), 9% of which were first detected by pulse oximetry. A theoretical analysis of the subset of 1256 incidents involving general anaesthesia showed that pulse oximetry on its own would have detected 82% of them. Of these, 60% would have been detected before any potential for organ damage occurred. Capnography alone would have detected 55% of these 1256 incidents. If both oximetry and

capnography had been used in combination, 88% of the adverse events would have been detected, 65% before potential permanent damage (46). A recent review of 4000 incidents and over 1200 medico-legal notifications reported by anaesthetists in Australia and New Zealand revealed no cases of hypoxic brain damage or death due to inadequate ventilation or misplaced tubes since the introduction of oximetry and capnography (10).

Inferences from data on anaesthesia mortality: An analysis of the effects of oximetry and capnography over time in the Closed Claim Project² of the American Society of Anesthesiologists showed that although the number of damaging events due to respiratory failure decreased, the number of cardiovascular damaging effects increased (47). A separate analysis based on changes in the patterns of incident reporting indicated, however, that catastrophic hypoxic events are much less common today than they were before the introduction of these monitors (10). Anaesthesia is safer today than it was before these techniques were introduced, particularly in the developed world, where oximetry and capnography are used with nearly 100% compliance.

Other considerations on oximetry and capnography: A key element of pulse oximetry and capnography is their safety. While either type of monitor could provide misleading information because of technical problems, this is uncommon. In the study by Moller et al., for example, it occurred in 2% of cases. Experience and training allow most problems of this type to be identified and corrected.

Use of these devices requires an understanding of the relevant physiology and pathological processes leading to the changes they indicate. Their limitations and the possibility of incorrect or artefactual readings must also be appreciated. For example, in the United Kingdom, many doctors and nurses are inadequately prepared to interpret oximetry readings accurately (48). Users must also know how to respond effectively if oxygen saturation falls, by, for example, administering supplemental oxygen. Any clinician trained to give anaesthetics safely, including those not medically licensed, should, however, be able to incorporate either or both techniques into their practice within a short time.

While the cost of pulse oximetry has fallen dramatically over the past 20 years, concern about capital outlay and resource constraints is germane. Oximeters are relatively inexpensive (e.g. less than US\$ 1000) and may be much cheaper in many places, such as China, where they are available at a fraction of this price. When calculated over the life of the machine and the number of patients on whom it can be used, this simple monitoring device becomes exceedingly cost-effective. In addition, harm due to anaesthetic mishaps is not cost-free, and a single error averted with pulse oximetry justifies its initial cost.

The devices themselves have excellent visual and auditory outputs, are reliable and robust and do not require much maintenance. The probes are, however, readily damaged and their replacement represents a relatively high proportion of the overall cost of oximetry. It is not easy to calculate the cost per

² The American Society of Anesthesiologists Closed Claims Project is an in-depth investigation of closed anesthesia malpractice claims designed to identify major areas of loss, patterns of injury, and strategies for prevention (<http://depts.washington.edu/asaccp/ASA/index.shtml> accessed 3 June 2008).

patient of use of pulse oximetry, but the cost of probes over time is likely to equal or exceed that of the actual device. Reliable, resistant probes are needed. The cost of capnography is somewhat higher, and maintenance is a little more challenging than for oximetry.

Conclusion: Mandated use of pulse oximetry and capnography in the developed world has stood the test of time. In settings with limited resources, the issue is somewhat less clear because of arguments about priorities for health-care funds. The overwhelming weight of evidence is that these techniques together improve safety, but it seems likely that much of the gain can be obtained from oximetry alone. Oximetry appears to provide early warning in a greater variety of situations than capnography (46). It will alert clinicians to problems in every situation that would be detected by capnography, perhaps later but certainly in time for action to be taken. Conversely, there are many situations in which oximetry is potentially life-saving and in which capnography alone might not be as helpful. Finally, oximetry is less expensive and less difficult to maintain than capnography.

Preparation for and delivery of anaesthesia

The provision of safe anaesthesia depends on careful preparation, which is facilitated by a systematic approach to reviewing the patient, machine, equipment and medications. This is ideally based on a formal check of the anaesthesia system. In addition to the personnel involved in delivering anaesthetic, the anaesthesia system includes:

- any machine or apparatus that supplies gases, vapours, local anaesthesia or intravenous anaesthetic agents to induce and maintain anaesthesia;
- any equipment necessary for securing the airway;
- any monitoring devices necessary for maintaining continuous evaluation of the patient; and
- the patient him or herself, correctly identified, consensual and evaluated preoperatively.

In preparing for anaesthesia, the anaesthesia system should be checked before each anaesthetic, before the start of each operating day and after any repair or maintenance to equipment or the introduction of new equipment. Figure 2.1 shows a universally applicable list of the checks to be made before anaesthetizing any patient. If the items on this list are available and functioning correctly before every anaesthetic, many mishaps can be prevented and lives will be saved. Additional checks to be undertaken before the first case of the day will depend on the level of resources available and should be decided locally.

Anaesthesia is usually administered in the operating room but may be required in intensive care units, emergency departments or other locations, such as radiology suites. There are clear requirements for the provision of safe anaesthesia services and recommended approaches for purchasing equipment. Even if there are financial constraints, it is the responsibility of the hospital management to maintain operating rooms and equipment and to provide an appropriate supply of medications and other consumables.

Facilities: The operating room should be of an appropriate size, well lit, conform to relevant electrical safety codes and meet design requirements that minimize hazards from fire, explosion and electrocution. Electricity and fresh water should always be supplied, and a back-up electrical generator should be immediately available. A maintenance programme must be established in each hospital. All anaesthetic and ancillary equipment should be inspected regularly by qualified personnel and a maintenance record kept. Ideally, routine maintenance should not interrupt clinical services.

Secure storage is required for medications, particularly opioid drugs, and anaesthetic equipment. A refrigerator is required for storing drugs such as suxamethonium. Infection control measures are required to ensure that potentially infectious materials or agents are not transferred between patients or personnel. These should include respiratory equipment (e.g. disposable filters to protect patients and circuits), syringes, infusion pump administration sets and multi-dose drug vials. Sterile practice must be followed for clinical procedures such as spinal anaesthesia or insertion of central venous lines.

Wherever obstetric anaesthesia is performed, a separate area for assessment and resuscitation of newborns, including designated oxygen, suction apparatus, electrical outlets, a source of radiant heat and equipment for neonatal airway management and resuscitation, should be provided.

Policies about the running of operating rooms should be agreed. These should include details on the composition and organization of operating schedules. A record-keeping system (paper or electronic) for anaesthesia and surgery is essential.

Anaesthesia equipment: An anaesthesia delivery system or machine is a vital part of the system but cannot function safely on its own. A professionally trained anaesthesia provider and patient monitoring devices are also mandatory for the delivery of safe care. Anaesthesia equipment should be suitable for the full range of patients treated at the facility. In addition, it should function effectively in the local environment.

Anaesthesia can be given intravenously, using agents such as ketamine, or as inhaled mixtures of volatile gases, such as halothane or isoflurane. Anaesthesia gases can be delivered through continuous flow equipment (e.g. a Boyles machine), which depends on supplies of compressed gases, or by drawover equipment (e.g. an Epstein Macintosh Oxford [EMO] system), which uses ambient air with added oxygen. In both systems, a vaporizer is needed to deliver an accurate concentration of the volatile agent.

In hospitals with unreliable compressed gas supplies, continuous-flow anaesthesia machines cannot function safely; in this situation, drawover equipment or machines based on oxygen concentrators have considerable advantages. When anaesthesia machines are purchased, the local environment must be taken into account to ensure that the machine will function correctly and can be maintained or repaired.

Gas supplies in anaesthesia: Oxygen is essential for almost all anaesthesia and must be readily available during induction, maintenance and recovery. Many patients require additional oxygen postoperatively as well. Oxygen may be

supplied to operating rooms in cylinders or via pipelines from a central oxygen distribution point. Hospital oxygen systems may be based on liquid oxygen plants, large cylinders in central banks or oxygen concentrators. Whichever system is used, there must be a method for confirming that the oxygen supplies are adequate before starting anaesthesia. There should always be a back-up source of oxygen, such as a reserve cylinder. Medical gas pipeline systems, connectors, pressure regulators and terminal units should meet national standards for identification, construction and installation. All safety regulations for the preparation, storage, identification and use of medical gases, anaesthetic drugs and related materials must be met. Wherever anaesthetic gases are used, scavenging systems within the airway circuit should be in place to reduce the risk for long-term exposure.

When oxygen concentrators are installed, users must be aware that the fraction of inspired oxygen (FiO₂) delivered can vary between 0.93 and 0.99. Concentrators differ in size: some are capable of supplying an entire hospital, while others are designed to be used as the oxygen source for a single machine.

Air is commonly used during anaesthesia. Medical air is normally supplied by pipeline from a central compressed supply and is often used for a number of other purposes in operating rooms (e.g. for power tools and tourniquets) in addition to anaesthesia. Ambient air is used in drawover anaesthesia.

Nitrous oxide is an analgesic gas often used in anaesthesia. It is supplied as a liquid in high-pressure cylinders and vaporizes to form the gas breathed during anaesthesia. Nitrous oxide is always used with oxygen. Anaesthesia machines should be designed so that it is impossible to administer a hypoxic mixture of nitrous oxide. In many countries, nitrous oxide is expensive. It is not often used in modern anaesthesia and is not classified as an essential gas. In situations of limited resources, it is safer to dispense with nitrous oxide altogether.

Monitoring: Equipment for monitoring may be integrated within the anaesthesia machine or be provided as separate modules. One monitor can display a number of parameters or have a single function. Monitors are complex, with delicate electronic components that are sensitive to heat, dust, vibration, sudden movement and rough handling.

The most important component of monitoring is the continuous presence of a trained anaesthesia professional, whose expertise is augmented by the physiological information displayed on the monitoring devices. In addition to monitoring, careful continuous clinical observation is required, because the equipment may not detect clinical deterioration as rapidly as a skilled professional.

Supplemental oxygen is also essential for all patients undergoing general anaesthesia, and the anaesthetist should verify the integrity of that supply. Ideally, the inspired oxygen concentration is monitored throughout anaesthesia with an instrument fitted with an alarm set off by a low oxygen concentration. This ensures that the patient is protected against oxygen supply failure or the delivery of a hypoxic gas mixture. Integrated and fail-safe systems, for example tank yokes and hose connections, should be used to prevent misconnection of gas sources. As an added measure, tissue oxygenation should also be monitored continuously by a quantitative monitor of blood oxygenation (e.g. pulse oximetry). This provides a secondary system to ensure that the patient does not become

hypoxic during surgery. A redundant system such as this is essential, as the consequence of hypoxia can be catastrophic. Hypoxia is highly preventable with careful planning and monitoring. Adequate illumination and exposure of the patient can also provide visual clues to hypoxia by allowing observation of the lips or nail beds.

As the adequacy of the airway, breathing and circulation is essential for safe delivery of anaesthesia, continuous monitoring is extremely important. For the first two, this can be accomplished by observation and auscultation at the very least, or by using a precordial, pretracheal or oesophageal stethoscope. When a breathing circuit is used, the reservoir bag can also be observed. The correct placement of an endotracheal tube can be confirmed, as can the adequacy of ventilation, by displaying the expired carbon dioxide waveform and concentration by capnography. When mechanical ventilation is used, disconnect alarms are essential to prevent catastrophic disconnection of the patient from the ventilator. Circulation is easily monitored by palpation, auscultation, a display of the pulse waveform or electrocardiograph trace. Pulse oximetry has the added benefit of continuous monitoring of both tissue perfusion and heart rate. Arterial blood pressure provides a measure of the adequacy of the peripheral circulation. It can be measured simply with a blood pressure cuff at appropriate intervals (usually at least every 5 minutes, and more frequently if indicated by clinical circumstances). Continuous measurement and display of arterial pressure using invasive monitoring may also be necessary in certain circumstances.

Homeostatic mechanisms for maintaining body temperature are frequently undermined during anaesthesia. Hypothermia can increase the risk for infection and cause problems of hypocoagulation. Hyperthermia can be one of the first signs of a medication or anaesthetic reaction. A means of measuring body temperature is an important component of patient monitoring and should be used at frequent intervals where clinically indicated, such as in a prolonged operation or in young children.

Finally, the depth of anaesthesia must be assessed regularly throughout the operation to ensure appropriate levels of pain control and sedation. This includes an assessment of the state of paralysis when neuromuscular blocking agents are used.

Ancillary equipment and medications: In addition to anaesthesia apparatus, ancillary equipment and medications are required to manage emergencies such as trauma, eclampsia, cardiac arrest and malignant hyperthermia. Patient warming devices, intravenous fluid warmers and special padding to support patients during surgery improve the quality of care. A self-inflating breathing bag is necessary in case of gas flow failure. Units for the care of children should have special paediatric equipment, including X-ray and ultrasound facilities.

Hospitals should ensure that adequate supplies of anaesthetic drugs are maintained. Table II.2.2 provides guidance for such materials and equipment, but each national society should have guidelines relevant to their environment. Drugs should be correctly stored, labelled in the local language and used before their expiration date. Safe methods of drug administration should be practised by all staff (see Objective 5).

Table II.2.2 – Guide to infrastructure, supplies and anaesthesia standards at three levels of health-care facilities

| Level 1 - Small hospital or health centre (Should meet at least 'highly recommended' anaesthesia standards) | Level 2 - District or provincial hospital (Should meet at least 'highly recommended' and 'recommended' anaesthesia standards) | Level 3 - Referral hospital (Should meet at least 'highly recommended', 'recommended' and 'suggested' anaesthesia standards) |
|---|---|---|
| <p>Rural hospital or health centre with a small number of beds (or urban location in an extremely disadvantaged area); sparsely equipped operating room for 'minor' procedures</p> <p>Provides emergency measures in the treatment of 90–95% of trauma and obstetrics cases (excluding caesarean section)</p> <p>Referral of other patients (for example, obstructed labor, bowel obstruction) for further management at a higher level</p> | <p>District or provincial hospital (e.g. with 100–300 beds) and adequately equipped major and minor operating rooms</p> <p>Short-term treatment of 95–99% of major life-threatening conditions</p> | <p>A referral hospital with 300–1000 or more beds and basic intensive care facilities. Treatment aims are the same as for level 2, with the addition of:</p> <p>Ventilation in operating room and intensive care unit</p> <p>Prolonged endotracheal intubation</p> <p>Thoracic trauma care</p> <p>Homodynamic and inotropic treatment</p> <p>Basic intensive care unit patient management and monitoring for up to 1 week: all types of cases, but possibly with limited provision for:</p> <p>Multi-organ system failure</p> <p>Haemodialysis</p> <p>Complex neurological and cardiac surgery</p> <p>Prolonged respiratory failure</p> <p>Metabolic care or monitoring</p> |
| Essential procedures | Essential procedures | Essential procedures |
| <p>Normal delivery</p> <p>Uterine evacuation</p> <p>Circumcision</p> <p>Hydrocoele reduction, incision and drainage</p> <p>Wound suturing</p> <p>Control of haemorrhage with pressure dressings</p> <p>Debridement and dressing of wounds</p> <p>Temporary reduction of fractures</p> <p>Cleaning or stabilization of open and closed fractures</p> <p>Chest drainage (possibly)</p> <p>Abscess drainage</p> | <p>Same as level 1 with the following additions:</p> <p>Caesarean section</p> <p>Laparotomy (usually not for bowel obstruction)</p> <p>Amputation</p> <p>Hernia repair</p> <p>Tubal ligation</p> <p>Closed fracture treatment and application of plaster of Paris</p> <p>Acute open orthopaedic surgery: e.g. internal fixation of fractures</p> <p>Eye operations, including cataract extraction</p> <p>Removal of foreign bodies: e.g. in the airways</p> <p>Emergency ventilation and airway management for referred patients such as those with chest and head injuries</p> | <p>Same as level 2 with the following additions:</p> <p>Facial and intracranial surgery</p> <p>Bowel surgery</p> <p>Paediatric and neonatal surgery</p> <p>Thoracic surgery</p> <p>Major eye surgery</p> <p>Major gynaecological surgery, e.g. vesico-vaginal repair</p> |
| Personnel | Personnel | Personnel |
| <p>Paramedical staff or anaesthetic officer (including on-the-job training) who may have other duties as well</p> <p>Nurse–midwife</p> | <p>One or more trained anaesthesia professionals</p> <p>District medical officers, senior clinical officers, nurses, midwives</p> <p>Visiting specialists, resident surgeon, obstetrician or gynaecologist</p> | <p>Clinical officers and specialists in anaesthesia and surgery</p> |
| Drugs | Drugs | Drugs |
| <p>Ketamine 50 mg/ml injection</p> <p>Lidocaine 1% or 2%</p> <p>Diazepam 5 mg/ml injection, 2 ml or midazolam 1 mg/ml injection, 5 ml</p> <p>Pethidine 50 mg/ml injection, 2 ml</p> | <p>Same as level 1, but also:</p> <p>Thiopental 500 mg/g powder or propofol</p> <p>Suxamethonium bromide 500 mg powder</p> <p>Pancuronium</p> <p>Neostigmine 2.5 mg injection</p> | <p>Same as level 2 with the following additions:</p> <p>Propofol</p> <p>Nitrous oxide</p> <p>Various modern neuromuscular blocking agents</p> |

| | | |
|---|--|---|
| Morphine 10 mg/ml, 1 ml Epinephrine (adrenaline) 1 mg Atropine 0.6 mg/ml Appropriate inhalation anaesthetic if vaporizer available | Ether, halothane or other inhalation anaesthetics Lidocaine 5% heavy spinal solution, 2 ml Bupivacaine 0.5% heavy or plain, 4 ml Hydralazine 20 mg injection Frusemide 20 mg injection Dextrose 50% 20 ml injection Aminophylline 250 mg injection Ephedrine 30/50 mg ampoules Hydrocortisone (?) Nitrous oxide | Various modern inhalation anaesthetics Various inotropic agents Various intravenous antiarrhythmic agents Nitroglycerine for infusion Calcium chloride 10% 10 ml injection Potassium chloride 20% 10 ml injection for infusion |
| Equipment: capital outlay | Equipment: capital outlay | Equipment: capital outlay |
| Adult and paediatric self-inflating breathing bags with masks Foot-powered suction Stethoscope, sphygmomanometer, thermometer Pulse oximeter Oxygen concentrator or tank oxygen and a drawover vaporizer with hoses Laryngoscopes, bougies | Complete anaesthesia, resuscitation and airway management systems including: Reliable oxygen sources Vaporizer(s) Hoses and valves Bellows or bag to inflate lungs Face masks (sizes 00–5) Work surface and storage Paediatric anaesthesia system Oxygen supply failure alarm; oxygen analyser Adult and paediatric resuscitator sets Pulse oximeter, spare probes, adult and paediatric* Capnograph* Defibrillator (one per operating suite or intensive care unit)* Electrocardiograph monitor* Laryngoscope, Macintosh blades 1–3(4) Oxygen concentrator(s) (cylinder) Foot or electric suction Intravenous pressure infusor bag Adult and paediatric resuscitator sets Magill forceps (adult and child), intubation stylet or bougie Spinal needles 25G Nerve stimulator Automatic non-invasive blood pressure monitor | Same as level 2 with these additions (per each per operating room or intensive care unit bed, except where stated): Electrocardiograph monitor* Anaesthesia ventilator, reliable electric power source with manual override Infusion pumps (two per bed) Pressure bag for intravenous infusion Electric or pneumatic suction Oxygen analyser* Thermometer (temperature probe*) Electric warming blanket Electric overhead heater Infant incubator Laryngeal mask, airways sizes 2, 3, 4 (three sets per operating room) Intubating bougies, adult and child (one set per operating room) Anaesthetic agent (gas and vapour) analyser Depth of anaesthesia monitors are being increasingly recommended for cases at high risk of awareness but are not standard in many countries. |
| Equipment: disposable | Equipment: disposable | Equipment: disposable |
| Examination gloves Intravenous infusion and drug injection equipment Suction catheters size 16 FG Airway support equipment, including airways and tracheal tubes Oral and nasal airways | Electrocardiograph electrodes Intravenous equipment (minimum fluids: normal saline, Ringer lactate and dextrose 5%) Paediatric giving sets Suction catheters size 16 FG Sterile gloves sizes 6–8 Nasogastric tubes sizes 10–16 FG Oral airways sizes 000–4 Tracheal tubes sizes 3–8.5 mm Spinal needles sizes 22 G and 25G Batteries size C | Same as level 2 with these additions: Ventilator circuits Yankauer suckers Giving sets for intravenous infusion pumps Disposables for suction machines Disposables for capnography, oxygen analyser, in accordance with manufacturers' specifications: Sampling lines Water traps Connectors Filters and fuel cells |

* It is preferable to combine these monitoring modalities in one unit.
Adapted in part from (28,49)

Infrastructure, supplies and care standards: WHO has established a list of necessary equipment for resuscitation, acute care and emergency surgery and anaesthesia in countries with limited health budgets. This is updated in Table II.2.2. The three-level model takes into account the fact that the provision of staff and equipment to meet the needs of the population served by the type of hospital considered must be within the constraints of available resources and that not all facilities can provide every service.

In the smallest units, many basic surgical procedures are undertaken with local anaesthesia. Emergency operations (notably caesarean sections and other obstetric procedures) are often performed under ketamine or regional anaesthesia without access to proper facilities or anaesthetic equipment. At times, anaesthesia is provided under the supervision of the surgeon as the most highly qualified health professional available. Despite the fundamental issue of resources, all health units should strive to meet the 'highly recommended' WHO standards listed below. They should also work to meet as many of the 'recommended' standards as possible.

In considering the formulation of standards and the requirement to balance resources against requirements, health authorities and administrators should align the standards of 'highly recommended', 'recommended' and 'suggested' with the three levels of facilities outlined in Table II.2.2. For each level of facility, it is desirable to exceed the applicable anaesthesia standard. In well-resourced locations with well-functioning facilities, professionals should be able to exceed the 'recommended' anaesthesia standard.

Recommendations

Highly recommended:

- The first and most important component of peri-anaesthetic care is the continuous presence of a vigilant, professionally trained anaesthesia provider. If an emergency requires the brief temporary absence of the primary anaesthetist, judgement must be exercised in comparing the threat of an emergency to the risk of the anaesthetized patient's condition and in selecting the clinician left responsible for anaesthesia during the temporary absence.
- Supplemental oxygen should be supplied for all patients undergoing general anaesthesia. Tissue oxygenation and perfusion should be monitored continuously using a pulse oximeter with a variable-pitch pulse tone loud enough to be heard throughout the operating room.
- The adequacy of the airways and of ventilation should be monitored continuously by observation and auscultation. Whenever mechanical ventilation is employed, a disconnect alarm should be used.
- Circulation should be monitored continuously by auscultation or palpation of the heart beat or by a display of the heart rate on a cardiac monitor or pulse oximeter.
- Arterial blood pressure should be determined at least every 5 minutes and more frequently if indicated by clinical circumstances.

- A means of measuring body temperature should be available and used at frequent intervals where clinically indicated (e.g. prolonged or complex anaesthesia, children).
- The depth of anaesthesia (degree of unconsciousness) should be assessed regularly by clinical observation.

Recommended:

- Inspired oxygen concentration should be monitored throughout anaesthesia with an instrument fitted with a low-oxygen concentration alarm. In addition, a device to protect against the delivery of a hypoxic gas mixture and an oxygen supply failure alarm should be used.
- Continuous measurement and display of the expired carbon dioxide waveform and concentration (capnography) should be used to confirm the correct placement of an endotracheal tube and also the adequacy of ventilation.
- The concentrations of volatile agents should be measured continuously, as should inspiratory or expired gas volumes.
- An electrocardiograph should be used to monitor heart rate and rhythm.
- A cardiac defibrillator should be available.
- Body temperature should be measured continuously in patients in whom a change is anticipated, intended or suspected. This can be done by continuous electronic temperature measurement, if available.
- A peripheral nerve stimulator should be used to assess the state of paralysis when neuromuscular blocking drugs are given.

References

1. Arbous MS, et al. Impact of anesthesia management characteristics on severe morbidity and mortality. *Anesthesiology*, 2005, 102:257–68.
2. Buck N, Devlin HB, Lunn JN, eds. *The report of the confidential enquiry into perioperative deaths 1987*. Oxford, The Nuffield Provincial Hospitals Trust, King's Fund, 1987.
3. Lienhart A, et al. [Preliminary results from the SFAR–INSERM inquiry on anaesthesia-related deaths in France: mortality rates have fallen ten-fold over the past two decades.] *Bulletin de l'Academie Nationale de Medecine*, 2004, 188:1429–41.
4. Mackay P, Cousins M. Safety in anaesthesia. *Anaesthesia and Intensive Care*, 2006, 34:303–4.
5. MacKay P. *Safety of anaesthesia in Australia. A review of anaesthesia mortality 1997–1999*. Melbourne, Australian and New Zealand College of Anaesthetists, 2002.
6. Gibbs N. *Safety of anaesthesia in Australia. A review of anaesthesia mortality 2000–2002*. Melbourne: Australian and New Zealand College of Anaesthetists, 2006.
7. Lagasse RS. Anesthesia safety: model or myth? A review of the published literature and analysis of current original data. *Anesthesiology*, 2002, 97:1609–17.
8. Cooper JB, Gaba D. No myth: anesthesia is a model for addressing patient safety. *Anesthesiology*, 2002, 97:1335–7.

9. Eichhorn JH. Prevention of intraoperative anesthesia accidents and related severe injury through safety monitoring. *Anesthesiology*, 1989, 70:572–7.
10. Runciman WB. Iatrogenic harm and anaesthesia in Australia. *Anaesthesia and Intensive Care*, 2005, 33:297–300.
11. McKenzie AG. Mortality associated with anaesthesia at Zimbabwean teaching hospitals. *South African Medical Journal*, 1996, 86:338–42.
12. Heywood AJ, Wilson IH, Sinclair JR. Perioperative mortality in Zambia. *Annals of the Royal College of Surgeons of England*, 1989, 71:354–8.
13. Hansen D, Gausi SC, Merikebu M. Anaesthesia in Malawi: complications and deaths. *Tropical Doctor*, 2000, 30:146–9.
14. Ouro-Bang'na Maman AF, et al. Deaths associated with anaesthesia in Togo, West Africa. *Tropical Doctor*, 2005, 35:220–2.
15. Hawkins JL, et al. Anesthesia-related deaths during obstetric delivery in the United States, 1979–1990. *Anesthesiology* 1997, 86:277–84.
16. Cooper GM, McClure JH. Maternal deaths from anaesthesia. An extract from Why Mothers Die 2000–2002, the Confidential Enquiries into Maternal Deaths in the United Kingdom; Chapter 9: Anaesthesia. *British Journal of Anaesthesia*, 2005, 94:417–23.
17. Weindling AM. The confidential enquiry into maternal and child health (CEMACH). *Archives of Disease in Childhood*, 2003, 88:1034–1037.
18. Enohumah KO, Imarengiaye CO. Factors associated with anaesthesia-related maternal mortality in a tertiary hospital in Nigeria. *Acta Anaesthesiologica Scandinavica*, 2006, 50:206–10.
19. Fenton PM, Whitty CJM, Reynolds F. Caesarean section in Malawi: prospective study of early maternal and perinatal mortality. *British Medical Journal*, 2003, 327:587.
20. Hodges SC, et al. Anaesthesia services in developing countries: defining the problems. *Anaesthesia*, 2007, 62:4–11.
21. Binam F, et al. [Anaesthesia practices in Yaounde (Cameroon)]. *Annales Francaises d'Anesthesie et de Reanimation*, 1999, 18:647–56.
22. Kimaro E, Towey RM. Anaesthesia in rural Tanzania. *Tropical Doctor*, 2001, 31:102–4.
23. Towey R, Kimaro E. Only if she has a fishing rod! *British Medical Journal*, 1998, 317:1711.
24. Mavalankar DV, Rosenfield A. Maternal mortality in resource-poor settings: policy barriers to care. *American Journal of Public Health*, 2005, 95:200–3.
25. Millar S. Obstetric care in Georgia and Armenia. *Anaesthesia News*, 2007, 235:3–5.
26. Eichhorn JH, et al. Standards for patient monitoring during anesthesia at Harvard Medical School. *Journal of the American Medical Association*, 1986, 256:1017–20.
27. Eichhorn JH. The standards formulation process. *European Journal of Anaesthesiology*, 1993, 10 Suppl 7:9–11.
28. International Task Force on Anaesthesia Safety. International standards for a safe practice of anaesthesia. *European Journal of Anaesthesiology*, 1993, 10 Suppl. 7:12–5.
29. World Federation of Societies of Anaesthesiology. 2008 International standard for safe practice of anaesthesia. <http://www.anaesthesiologists.org> (accessed 10 May 2008).

30. Pedersen T, Dyrlund Pedersen B, Moller AM. Pulse oximetry for perioperative monitoring. *Cochrane Database of Systematic Reviews*, 2003(2): CD002013.
31. McGlynn E, et al. The quality of health care delivered to adults in the United States. *New England Journal of Medicine*, 2003, 348:2635–45.
32. Eichhorn JH. Pulse oximetry as a standard of practice in anesthesia. *Anesthesiology*, 1993, 78:423–6.
33. Thoms GM, McHugh GA, O'Sullivan E. The Global Oximetry initiative. *Anaesthesia*, 2007, 62 Suppl 1:75–7.
34. Moller JT, et al. Randomized evaluation of pulse oximetry in 20,802 patients: II. Perioperative events and postoperative complications. *Anesthesiology*, 1993, 78:445–53.
35. Bierman MI, Stein KL, Snyder JV. Pulse oximetry in the postoperative care of cardiac surgical patients. A randomized controlled trial (comment). *Chest*, 1992, 102:1367–70.
36. Moller JT, et al. Hypoxaemia is reduced by pulse oximetry monitoring in the operating theatre and in the recovery room. *British Journal of Anaesthesia*, 1992, 68:146–50.
37. Moller JT, et al. Perioperative monitoring with pulse oximetry and late postoperative cognitive dysfunction. *British Journal of Anaesthesia*, 1993, 71:340–7.
38. Cote CJ, et al. A single-blind study of pulse oximetry in children. *Anesthesiology*, 1988, 68:184–8.
39. Cote CJ, et al. A single-blind study of combined pulse oximetry and capnography in children. *Anesthesiology*, 1991, 74:980–7.
40. Cullen DJ, et al. Effect of pulse oximetry, age, and ASA physical status on the frequency of patients admitted unexpectedly to a postoperative intensive care unit and the severity of their anesthesia-related complications. *Anesthesia and Analgesia*, 1992, 74:181–8.
41. Mateer JR, et al. Continuous pulse oximetry during emergency endotracheal intubation. *Annals of Emergency Medicine*, 1993, 22:675–9.
42. Holland R, Webb RK, Runciman WB. The Australian Incident Monitoring Study. Oesophageal intubation: an analysis of 2000 incident reports. *Anaesthesia and Intensive Care*, 1993, 21:608–10.
43. Russell WJ, et al. The Australian Incident Monitoring Study. Problems with ventilation: an analysis of 2000 incident reports. *Anaesthesia and Intensive Care*, 1993, 21:617–20.
44. Cooper JB, Newbower RS, Kitz RJ. An analysis of major errors and equipment failures in anesthesia management: considerations for prevention and detection. *Anesthesiology*, 1984, 60:34–42.
45. Runciman WB, et al. The pulse oximeter: applications and limitations—an analysis of 2000 incident reports. *Anaesthesia and Intensive Care*, 1993, 21:543–50.
46. Webb RK, et al. The Australian Incident Monitoring Study. Which monitor? An analysis of 2000 incident reports. *Anaesthesia and Intensive Care*, 1993, 21:529–42.
47. Cheney FW, et al. Trends in anesthesia-related death and brain damage: a closed claims analysis. *Anesthesiology*, 2006, 105:1081–6.
48. Stoneham M, Saville G, Wilson IH. Knowledge about pulse oximetry among medical and nursing staff. *Lancet*, 1994, 344:1339–42.
49. World Health Organization. *Surgical care at the district hospital*. Geneva, World Health Organization, 2003.