Anaesthesia 2016, 71, 85–93 doi:10.1111/anae.13316

Guidelines

Recommendations for standards of monitoring during anaesthesia and recovery 2015 : Association of Anaesthetists of Great Britain and Ireland*

M. R. Checketts,[1] R. Alladi,[2] K. Ferguson,[3] L. Gemmell,[4] J. M. Handy,[5] A. A. Klein,[6] N. J. Love,[7] U. Misra,[8] C. Morris,[9] M. H. Nathanson,[10] G. E. Rodney,[11] R. Verma[12] and J. J. Pandit[13]

1 Consultant, Department of Anaesthesia, Dundee, UK, and Chair of Working Party, AAGBI
2 Associate Specialist, Department of Anaesthesia, Tameside Hospital, Ashton-under-Lyne, UK and Representative, Royal College of Anaesthetists
3 Consultant, Aberdeen Royal Infirmary, Aberdeen, UK
4 Consultant, Department of Anaesthesia, North Wales Trust, North Wales, UK
5 Consultant, Department of Anaesthesia and Intensive Care, Chelsea and Westminster Hospital, London, UK
6 Consultant, Department of Anaesthesia and Intensive Care, Papworth Hospital, Cambridge, UK
7 Consultant, Department of Anaesthesia and Intensive Care Medicine, North Devon District Hospital, Barnstaple, Devon, UK, and Representative, Group of Anaesthetists in Training, AAGBI
8 Consultant, Department of Anaesthesia, Sunderland Royal Hospital, Sunderland, UK
9 Consultant, Department of Anaesthesia and Intensive Care, Royal Derby Hospital, Derby, UK
10 Consultant, Department of Anaesthesia, Nottingham University Hospitals, Nottingham, UK
11 Consultant, Department of Anaesthesia, Ninewells Hospital and Medical School, Dundee, UK
12 Consultant, Department of Anaesthesia, Derby Teaching Hospitals, Derby, UK
13 Consultant, Department of Anaesthesia, Nuffield Department of Anaesthetics, Oxford University Hospitals, Oxford, UK

Summary

This guideline updates and replaces the 4th edition of the *AAGBI Standards of Monitoring* published in 2007. The aim of this document is to provide guidance on the minimum standards for physiological monitoring of any patient undergoing anaesthesia or sedation under the care of an anaesthetist. The recommendations are primarily aimed at anaesthetists practising in the United Kingdom and Ireland. Minimum standards for monitoring patients during anaesthesia and in the recovery phase are included. There is also guidance on monitoring patients undergoing sedation and also during transfer of anaesthetised or sedated patients. There are new sections discussing the role of monitoring depth of anaesthesia, neuromuscular blockade and cardiac output. The indications for end-tidal carbon dioxide monitoring have been updated.

**This is a consensus document produced by members of a Working Party established by the Association of Anaesthetists of Great Britain and Ireland (AAGBI). It has been seen and approved by the AAGBI Board of Directors. Date of review: 2020.*
Accepted: 13 October 2015
*This Guidelines is accompanied by an editorial by Lumb and McLure, Anaesthesia, 2016; **71**: 3–6.*

Recommendations

The Association of Anaesthetists of Great Britain & Ireland regards it as essential that minimum standards of monitoring are adhered to whenever a patient is anaesthetised. These minimum standards should be uniform regardless of duration, location or mode of anaesthesia.

1 The anaesthetist must be present and care for the patient throughout the conduct of an anaesthetic.*
2 Minimum monitoring devices (as defined in the recommendations) must be attached before induction of anaesthesia and their use continued until the patient has recovered from the effects of anaesthesia. The same standards of monitoring apply when the anaesthetist is responsible for local/regional anaesthesia or sedative techniques.**
3 A summary of information provided by all monitoring devices should be recorded on the anaesthetic record. Automated electronic anaesthetic record systems that also provide a printed copy are recommended.
4 The anaesthetist must ensure that all anaesthetic equipment, including relevant monitoring equipment, has been checked before use. Alarm limits for all equipment must be set appropriately before use. The appropriate audible alarms should be enabled during anaesthesia.
5 These recommendations state the monitoring devices that are essential ('minimum' monitoring) and those that must be immediately available during anaesthesia. If it is absolutely necessary to continue anaesthesia without an essential monitor, the anaesthetist should note the reasons in the anaesthetic record.
6 Additional monitoring may be necessary as judged appropriate by the anaesthetist.
7 Minimum monitoring should be used during the transfer of anaesthetised patients.
8 Provision, maintenance, calibration and renewal of equipment are the responsibilities of the institution in which anaesthesia is delivered. The institution should have processes for taking advice from departments of anaesthesia in matters of equipment procurement and maintenance.
9 All patient monitoring equipment should be checked before use in accordance with the AAGBI guideline *Checking Anaesthetic Equipment 2012* [1].

*In hospitals employing Physician Assistants (Anaesthesia) [PA(A)s], this responsibility may be delegated to a PA(A), supervised by a consultant anaesthetist in accordance with guidelines published by the Royal College of Anaesthetists [2].
**In certain specific well defined circumstances, intraoperative patient monitoring can be delegated to a suitably trained non-physician health care worker during certain procedures performed under regional or local anaesthesia.

- *What other guideline statements are available on this topic?*
  The European Board of Anaesthesiology (2012), the American Society of Anesthesiologists (2011) and the Australian and New Zealand College of Anaesthetists (2013) have published guidelines on standards of clinical monitoring. Lessons learned from the 2014 joint Association of Anaesthetists of Great Britain and Ireland's and Royal College of Anaesthetists' 5th National Anaesthetic Project on accidental awareness during general anaesthesia were considered by the working party when updating this guideline.
- *Why were these guidelines developed?*
  It was necessary to update the 2007 4th edition of the guideline to include new guidance on monitoring neuromuscular blockade, depth of anaesthesia and cardiac output.
- *How and why does this statement differ from existing guidelines?*
  Capnography monitoring is essential at all times in patients with endotracheal tubes, supraglottic airway devices and those who are deeply sedated. A peripheral nerve stimulator must be used whenever neuromuscular blocking drugs are given. A quantitative peripheral nerve stimulator is recommended. Depth of anaesthesia monitoring is recommended when using total intravenous anaesthesia with neuromuscular blockade.

Introduction

The presence of an appropriately trained and experienced anaesthetist is the main determinant of patient safety during anaesthesia. However, human error is inevitable, and many studies have shown that adverse incidents and accidents are frequently attributable, at least in part, to error by anaesthetists [3, 4].

Monitoring will not prevent all adverse incidents or accidents in the peri-operative period. However, there is substantial evidence that it reduces the risks of incidents and accidents both by detecting the consequences of errors, and by giving early warning that the condition of a patient is deteriorating [5–11].

It is appropriate that the AAGBI should define the standards of monitoring for use by anaesthetists in the United Kingdom and Ireland. Newer monitoring modalities such as derived electroencephalogram (EEG) depth of anaesthesia and cardiac output monitors are not established as routine and the Working Party considered their place in contemporary anaesthesia practice in Appendices 1 and 2.

The anaesthetist's presence during anaesthesia

An anaesthetist of appropriate experience, or fully trained Physician Assistant (Anaesthesia) PA (A) under the supervision of a consultant anaesthetist, must be present throughout general anaesthesia, including any period of cardiopulmonary bypass. Using both clinical skills and monitoring equipment, the anaesthetist must care for the patient continuously. The same standards must apply when an anaesthetist is responsible for a local/regional anaesthetic or sedative technique for an operative procedure. In certain well-defined circumstances [12], intra-operative patient monitoring can be delegated to a suitably trained non-physician health care worker during certain procedures performed under regional or local anaesthesia. When there is a known potential hazard to the anaesthetist, for example during x-ray imaging, facilities for remotely observing and monitoring the patient must be available.

Accurate records of the values determined by monitors must be kept. Minimum monitoring data (heart rate, blood pressure, peripheral oxygen saturation, end-tidal carbon dioxide and anaesthetic vapour concentration, if volatile anaesthetic agents or nitrous oxide are used) must be recorded at least every five minutes, and more frequently if the patient is clinically unstable. It is recognised that contemporaneous records may be difficult to keep in emergency circumstances, but modern patient monitoring devices allow accurate records to be completed or downloaded later from stored data. Automated electronic anaesthetic record systems that can also make hard copies for the medical notes are recommended.

Local circumstances may dictate that handing over of responsibility for patient care under anaesthesia to another anaesthetist may be necessary. If so, a detailed handover must be delivered to the incoming anaesthetist and this should be recorded in the anaesthetic record. A handover checklist is useful, and one example of this is the 'ABCDE' aide memoir suggested in the NAP5 report [13–15]. When taking over care of a patient (including when returning after relief for a break), the incoming anaesthetist should conduct a check to ensure that all appropriate monitoring is in place with suitable alarm limits (see below).

Very occasionally, an anaesthetist working single-handedly may be called on briefly to assist with or perform a life-saving procedure nearby. Leaving an anaesthetised patient in these circumstances is a matter for individual judgement, but another anaesthetist or trained PA(A) should be sought to continue close observation of the patient. If this is not possible in an emergency situation, a trained anaesthetic assistant must continue observation of the patient and monitoring devices. Any problems should be reported to other available medical staff in the area. Anaesthesia departments should therefore work towards having an additional experienced anaesthetist available (e.g. a 'Duty Consultant' or 'floating registrar' of appropriate seniority) to provide cover in such situations.

Anaesthesia departments should make arrangements to allow anaesthetists working solo during long surgical procedures to be relieved by a colleague or PA (A) for meal and comfort breaks [16]. The 1998 European Working Time Regulation Legislation states that an individual should have an uninterrupted break of not less than 20 minutes if the working day exceeds six hours [17]. To meet this requirement, the presence of an additional experienced anaesthetist in the theatre suite, as described above is desirable.

Anaesthetic equipment

It is the responsibility of the anaesthetist to check all equipment before use, as recommended in the AAGBI guideline *Checking Anaesthetic Equipment 2012* [1]. Anaesthetists must ensure that they are familiar with all the equipment they intend to use and that they have followed any specific checking procedures recommended by individual manufacturers.

Oxygen supply

The use of an oxygen analyser with an audible alarm is essential during anaesthesia. The anaesthetist should check and set appropriate oxygen concentration alarm limits. The analyser must be placed in such a position that the composition of the gas mixture delivered to the patient is monitored continuously. Most modern anaesthetic machines have built-in oxygen analysers that monitor both inspired and expired oxygen concentrations.

Breathing systems

During spontaneous ventilation, observation of the reservoir bag may reveal a leak, disconnection, high pressure or abnormalities of ventilation. Continuous waveform carbon dioxide concentration monitoring will detect most of these problems, so this is an essential part of routine monitoring during anaesthesia. The 2011 AAGBI position statement on capnography outside the operating theatre recommended that it should be used for all unconscious anaesthetised patients regardless of the airway device used or the location of the patient [18]. There are certain circumstances in which capnography monitoring is not feasible, for example during high frequency jet ventilation.

Vapour analyser

The use of a vapour analyser is essential during anaesthesia whenever a volatile anaesthetic agent or nitrous oxide is in use. The end-tidal concentration should be documented on the anaesthetic record.

Infusion devices

When any component of anaesthesia (hypnotic, analgesic, neuromuscular blockade) is administered by infusion, the infusion device must be checked before use. Alarm settings (including infusion pressure alarm levels) and infusion limits must be verified and set to appropriate levels before commencing anaesthesia. It is recommended that the intravenous cannula should be visible throughout the procedure, when this is practical. When not practical, increased vigilance is required and correct functioning of the cannula should be regularly confirmed. It is recommended that infusion devices are connected to mains power whenever possible. When using a total intravenous anaesthesia technique (TIVA) with neuromuscular blockade, a depth of anaesthesia monitor is recommended (see below).

Alarms

Anaesthetists must ensure that all alarms are set to appropriate values. The default alarm settings incorporated by the manufacturer are often inappropriate. During the checking procedure, the anaesthetist must review and reset the upper and lower limits as necessary. It is recommended that anaesthetic departments agree consensus-based alarm limits for their monitors and ask their medical physics technicians to set these up. Audible alarms must be enabled before anaesthesia commences.

When intermittent positive pressure ventilation is used during anaesthesia, airway pressure alarms must also be used to detect high pressure within the airway and to give warning of disconnection or leaks.

Provision, maintenance, calibration and renewal of equipment are the responsibilities of the institution in which anaesthesia is delivered. Institutions should take into account (e.g., through suitably constituted equipment committees) the views of the anaesthetic department on matters relating to acquisition and maintenance of equipment.

Monitor displays

Care should be taken to configure the display setup, with attention to both the size and arrangement of on-screen data with regular updating of displayed values. An appropriate automatic non-invasive blood pressure (NIBP) recording interval should be set; NIBP monitors should not continue to display readings for longer than 5 minutes to reduce the risk of an older reading being mistaken for a recent one.

Monitoring the devices

Many devices used in anaesthetic practice need their own checks and monitoring. This includes monitoring the cuff pressure of tracheal tubes and cuffed supraglottic airway devices. Cuff pressure manometers should be used to avoid exceeding manufacturers' recommended intracuff pressures which can be associated with increased patient morbidity. When using devices where manufacturers do not specify or recommended a maximum cuff pressure, there may still be benefit in avoiding high pressure inflation, as this is associated with reduced morbidity and improved device performance [19].

Monitoring the patient

During anaesthesia, the patient's physiological state and adequacy of anaesthesia need continual assessment. Monitoring devices supplement clinical observation in order to achieve this. Appropriate clinical observations may include mucosal colour, pupil size, response to surgical stimuli and movements of the chest wall and/or the reservoir bag. The anaesthetist may undertake palpation of the pulse, auscultation of breath sounds and, where appropriate, measurement of urine output and blood loss. A stethoscope must always be available.

Monitoring devices

The monitoring devices described above are essential to the safe conduct of anaesthesia. If it is necessary to continue anaesthesia without a particular device, the anaesthetist must record the reasons for this in the anaesthetic record and only proceed where the benefits or clinical urgency outweigh the risks. The following are considered minimum monitoring for anaesthesia:

- Pulse oximeter
- NIBP
- ECG
- Inspired and expired oxygen, carbon dioxide, nitrous oxide and volatile anaesthetic agent if used (see below)
- Airway pressure
- Peripheral nerve stimulator if neuromuscular blocking drugs used (see Appendix 3)
- Temperature for any procedure > 30 min duration [20].

Monitoring must continue until the patient has recovered from anaesthesia. Anaesthesia departments must work towards providing capnography monitoring throughout the whole period of anaesthesia from induction to full recovery of consciousness as recommended by the AAGBI guideline *Immediate Post-anaesthesia Recovery 2013* [21].

During induction of anaesthesia in children and in uncooperative adults, it may not be feasible to attach all monitoring before induction. In these circumstances, monitoring must be attached as soon as possible and the reasons for delay recorded.

Recovery from anaesthesia

Minimum monitoring should be maintained until the patient has recovered fully from anaesthesia. In this context, 'recovered fully' means that the patient no longer needs any form of airway support, is breathing spontaneously, alert, responding to commands and speaking. Until this point, monitoring must be maintained to enable rapid detection of airway, ventilatory and cardiovascular disturbance. The period of transfer from theatre to recovery can be a time of increased risk depending on the local geography of the theatre complex and the status of the patient. Departments should work towards providing full monitoring, including capnography, in patients with a tracheal tube or supraglottic airway in situ, for these transfers and in the recovery area. Supplemental oxygen should routinely be given to patients during transfer to the recovery room and in the recovery room until at least after full recovery.

In summary, the minimum monitoring for recovery from anaesthesia [21] includes:

- Pulse oximeter
- NIBP
- ECG
- Capnography if the patient has a tracheal tube, supraglottic airway device in situ or is deeply sedated [17]
- Temperature

Additional monitoring

Some patients will require additional monitoring, for example intravascular pressures, cardiac output (Appendix 1), or biochemical or haematological variables depending on patient and surgical factors. The use of additional monitoring is at the discretion of the anaesthetist.

Use of depth of anaesthesia monitors, for example processed EEG monitoring, is recommended when patients are anaesthetised with total intravenous techniques and neuromuscular blocking drugs, to reduce the risk of accidental awareness during general anaesthesia (see Appendix 2). However, there is no compelling evidence that routine use of depth of anaesthesia monitoring for volatile agent-based general anaesthetics reduces the incidence of accidental awareness when end-tidal agent monitoring is vigilantly monitored and appropriate low agent alarms are set [13, 22].

Regional techniques and sedation for operative procedures

Patients must have appropriate monitoring, including [23]: pulse oximeter, NIBP, ECG and end-tidal carbon dioxide monitor if the patient is sedated.

Monitoring during transfer within the hospital

It is essential that the standard of care and monitoring during transfer of patients who are anaesthetised or sedated is equivalent to that applied in the operating theatre, and that personnel with adequate knowledge and experience accompany the patient [24].

The patient should be physiologically as stable as possible for transfer. Before transfer, appropriate monitoring must be commenced. Use of a pre-transfer checklist is recommended [13]. Oxygen saturation, ECG and NIBP should be monitored in all patients. Intravascular or other monitoring may be necessary in special cases. An oxygen supply sufficient to last the duration of the transfer is essential for all patients. If the patient has a tracheal tube or supraglottic airway in situ, end-tidal carbon dioxide should be monitored continuously. Airway pressure, tidal volume and respiratory rate must also be monitored when the lungs are mechanically ventilated.

Monitoring depth of anaesthesia is desirable when transferring anaesthetised patients who have received neuromuscular blocking drugs (TIVA is invariably used in these circumstances), but will remain difficult to provide until portable, battery-powered depth of anaesthesia monitors become widely available.

Anaesthesia in locations outside the operating suite

The standards of monitoring used during general and regional anaesthesia or sedation administered by an anaesthetist should be the same in all locations.

When anaesthetists are called to administer general or regional anaesthesia and/or sedation in locations outwith the operating theatre (for example emergency department, cardiac catheter lab, radiology, department electroconvulsive therapy suite, endoscopy, pain clinic, community dental clinic critical care, delivery suite), the same minimum essential standards of monitoring already outlined in this document should apply:

- Pulse oximeter
- NIBP
- ECG
- Inspired and expired oxygen, carbon dioxide, nitrous oxide and volatile anaesthetic agent if used
- Airway pressure
- Peripheral nerve stimulator when neuromuscular blocking drugs used (see Appendix 3)
- Temperature in procedures > 30 min duration.

Competing interests

No external funding and no competing interests declared.

References

1. Association of Anaesthetists of Great Britain & Ireland. *Checking Anaesthetic Equipment 2012*. AAGBI Safety Guideline. London, 2012. http://www.aagbi.org/sites/default/files/checking_anaesthetic_equipment_2012.pdf (accessed 07/07/2015).
2. Royal College of Anaesthetists. *PA (A) supervision and limitation of scope of practice (May 2011 revision)*. London, 2011. http://www.rcoa.ac.uk/news-and-bulletin/rcoa-news-and-statements/paa-supervision-and-limitation-of-scope-of-practice-may (accessed 24/05/15).
3. Buck N, Devlin HB, Lunn JN. *The Report of a Confidential Enquiry into Perioperative Deaths*. London: Nuffield Provincial Hospitals Trust, The Kings Fund Publishing House, 1987.

4. Webb RK, Currie M, Morgan CA, et al. The Australian Incident Monitoring Study: an analysis of 2000 incident reports. *Anaesthesia and Intensive Care* 1993; **21**: 520–8.
5. Keenan RL, Boyan CP. Decreasing frequency of anesthetic cardiac arrests. *Journal of Clinical Anesthesia* 1991; **3**: 354–7.
6. Eichhorn JH, Cooper JB, Cullen DJ, Maier WR, Philip JH, Seeman RG. Standards for patient monitoring during anesthesia at Harvard Medical School. *Journal of the American Medical Association* 1986; **256**: 1017–20.
7. Webb RK, Van der Walt JH, Runciman WB, et al. Which monitor? An analysis of 2000 incident reports. *Anaesthesia and Intensive Care* 1993; **21**: 529–42.
8. McKay WP, Noble WH. Critical incidents detected by pulse oximetry during anaesthesia. *Canadian Journal of Anaesthesia* 1988; **35**: 265–9.
9. Cullen DJ, Nemaskal JR, Cooper JB, Zaslavsky A, Dwyer MJ. 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.
10. Moller JT, Pedersen T, Rasmussen LS, et al. Randomized evaluation of pulse oximetry in 20,802 patients: I. Design, demography, pulse oximetry failure rate, and overall complication rate. *Anesthesiology* 1993; **78**: 4.
11. Thompson JP, Mahajan RP. Monitoring the monitors – beyond risk management. *British Journal of Anaesthesia* 2006; **97**: 1–3.
12. Regional Anaesthesia – UK. RA-UK Guidelines for Supervision of Patients during Peripheral Regional Anaesthesia. http://www.ra-uk.org/index.php/guidelines-standards/5-detail/274-supervision-statement (accessed 07/09/15).
13. Cook TM, Andrade J, Bogod DG, et al. 5th National Audit Project (NAP5) on accidental awareness during general anaesthesia: patient experiences, human factors, sedation, consent, and medicolegal issues. *Anaesthesia* 2014; **69**: 1102–16.
14. Pandit JJ, Andrade J, Bogod DG, et al. 5th National Audit Project (NAP5) on accidental awareness during general anaesthesia: summary of main findings and risk factors. *Anaesthesia* 2014; **69**: 1089–101.
15. Pandit JJ, Andrade J, Bogod DG, et al. 5th National Audit Project (NAP5) on accidental awareness during general anaesthesia: protocol, methods, and analysis of data. *Anaesthesia* 2014; **69**: 1078–88.
16. Association of Anaesthetists of Great Britain & Ireland. *Fatigue and Anaesthetists*. London: Association of Anaesthetists of Great Britain & Ireland, 2014. http://www.aagbi.org/sites/default/files/Fatigue%20Guideline%20web.pdf (accessed 07/07/2015).
17. The Working Time Regulations 1998. http://www.legislation.gov.uk/uksi/1998/1833/made (accessed 07/07/2015).
18. Association of Anaesthetists of Great Britain & Ireland. *The use of Capnography Outside the Operating Theatre*. AAGBI Safety Statement. London, 2011. http://www.aagbi.org/sites/default/files/Capnographyaagbi090711AJH%5B1%5D_1.pdf (accessed 24/04/15).
19. Bick E, Bailes I, Patel A, Brain AIJ. Fewer sore throats and a better seal: why routine manometry for laryngeal mask airways must become the standard of care. *Anaesthesia* 2014; **69**: 1304–8.
20. Sessler DI. Temperature monitoring and perioperative thermoregulation. *Anesthesiology* 2008; **109**: 318–38.
21. Association of Anaesthetists of Great Britain & Ireland. *Immediate Post-anaesthesia Recovery 2013*. AAGBI Safety Guideline. London, 2013. http://www.aagbi.org/sites/default/files/immediate_post-anaesthesia_recovery_2013.pdf (accessed 10/05/15).
22. American Society of Anesthesiologists Task Force on Intraoperative Awareness. Practice Advisory for Intraoperative Awareness and Brain Function Monitoring. *Anaesthesiology* 2006; **104**: 847–64.
23. Academy of Medical Royal Colleges. *Safe Sedation for Healthcare Procedures. Standards and Guidance*. London: Academy of Medical Royal Colleges, 2013. http://www.aomrc.org.uk/doc_view/9737-safe-sedation-practice-for-healthcare-procedures-standards-and-guidance (accessed 11/05/15).
24. Association of Anaesthetists of Great Britain & Ireland. *Interhospital Transfer*. AAGBI Safety Guideline. London, 2009. http://www.aagbi.org/sites/default/files/interhospital09.pdf (accessed 24/04/15).
25. Peyton PJ, Chong SW. Minimally invasive measurement of cardiac output during surgery and critical care: a meta-analysis of accuracy and precision. *Anesthesiology* 2010; **113**: 1220–35.
26. Minto G, Struthers R. Stroke volume optimisation: is the fairy tale over? *Anaesthesia* 2014; **69**: 291–6.
27. Rajaram SS, Desai NK, Kalra A, et al. Pulmonary artery catheters for adult patients in intensive care. *Cochrane Database of Systematic Reviews* 2013; **2**: CD003408.
28. Barber RL, Fletcher SN. A review of echocardiography in anaesthetic and peri-operative practice. Part 1: impact and utility. *Anaesthesia* 2014; **69**: 764–76.
29. Sharma V, Fletcher SN. A review of echocardiography in anaesthetic and peri-operative practice. Part 2: training and accreditation. *Anaesthesia* 2014; **69**: 919–27.
30. National Institute of Health and Care Excellence. Depth of anaesthesia monitors – Bispectral Index (BIS), E-Entropy and Narcotrend-Compact M. NICE diagnostics guidance [DG6], 2012. http://www.nice.org.uk/guidance/dg6 (accessed 26/04/15).
31. Pandit JJ, Cook TM. National Institute for Clinical Excellence guidance on measuring depth of anaesthesia: limitations of EEG-based technology. *British Journal of Anaesthesia* 2013; **110**: 325–8.
32. Russell IF. Fourteen fallacies about the isolated forearm technique, and its place in modern anaesthesia. *Anaesthesia* 2013; **68**: 677–81.
33. Pandit JJ, Russell IF, Wang M. Interpretations of responses using the isolated forearm technique in general anaesthesia: a debate. *British Journal of Anaesthesia* 2015; **115**(Suppl. 1): i32–i45.
34. Hemmerling TN, Le N. Brief review: neuromuscular monitoring: an update for the clinician. *Canadian Journal of Anaesthesia* 2007; **54**: 58–72.
35. Debaene B, Plaud B, Dilly M-P, Donati F. Residual paralysis in the PACU after a single intubating dose of nondepolarizing muscle relaxant with an intermediate duration of action. *Anesthesiology* 2003; **98**: 1042–8.
36. Naguib M, Kopman AF, Ensor JE. Neuromuscular monitoring and postoperative residual curarisation: a meta-analysis. *British Journal of Anaesthesia* 2007; **98**: 302–16.
37. Murphy GS, Szokol JW, Marymont JH, Greenberg SB, Avram MJ, Vender JS. Residual neuromuscular blockade and critical respiratory events in the postanesthesia care unit. *Anesthesia and Analgesia* 2008; **107**: 130–7.
38. Murphy GS, Szokol JW, Avram MJ, et al. Intraoperative acceleromyography monitoring reduces symptoms of muscle weakness and improves quality of recovery in the early postoperative period. *Anesthesiology* 2011; **115**: 946–54.

Appendix 1: Cardiac output monitors

There are a range of cardiac output monitors available – such as those estimating cardiac output from pulse pressure, carbon dioxide rebreathing, lithium dilution or oesophageal Doppler measurements – however, their routine use is uncommon. Although the literature base is large, there is little evidence that one type of monitor is consistently superior to another. Training in the use of the technique adopted is essential. Invasive methods, such as those requiring a pulmonary artery catheter, are more accurate but, because of the small risk of serious complications associated with the use of the pulmonary artery catheter, their routine use outside of cardiac surgical centres cannot be recommended.

There are concerns about accuracy and reliability with many cardiac output monitors. The percentage error of pulse contour analysis, oesophageal Doppler, partial carbon dioxide rebreathing, and transthoracic bio-impedance has been shown to be greater than 30%, a widely accepted cut-off [25]. The use of cardiac output monitoring for assessment of fluid responsiveness has been shown to be more accurate, but inter-patient variability and dynamic changes in stroke volume may be significant [26].

The cardiac output monitors currently available all have advantages and disadvantages associated with their use, and the AAGBI Working Party cannot recommend one type over another.

In summary:

- the pulmonary artery catheter is the most accurate, but less invasive monitoring has superseded its routine use outside of cardiac surgery [27];
- there is conflicting evidence about whether the use of cardiac output monitoring improves patient outcomes, and this is an area of ongoing research;
- echocardiography can be used to estimate cardiac output and allows cardiac function and filling status to be directly observed - however, training and experience in its use is required [28, 29];
- there remains doubt about the accuracy of all cardiac output monitoring devices currently available, and data are mostly confined to patients whose lungs are mechanically ventilated;
- the use of cardiac output monitors to assess fluid responsiveness has some evidence base.

Appendix 2: Depth of anaesthesia monitors

EEG-based depth of anaesthesia monitors have been variously recommended as an option in patients at greater risk of awareness or those likely to suffer the adverse effects of excessively deep anaesthesia, and also in patients receiving TIVA [30]. Data on the efficacy of these devices in correctly predicting accidental awareness during general anaesthesia (AAGA) or correctly predicting an adequate level of anaesthesia, remains inconsistent and debated [31]. However, data from these monitors may provide an additional source of information on the patient's condition.

The NAP5 project published in 2014 made a number of recommendations on risk factors for AAGA and the place of depth of anaesthesia monitoring [13], which can be summarised as:

- the incidence of reports of AAGA was 1 in 8000 when neuromuscular blocking drugs were used (as high as 1:670 in caesarean section) and 1 in 136 000 when they were not (i.e., implying a focus should specifically be on paralysed patients);
- about half of the reports of AAGA occurred around the time of induction of anaesthesia and transfer from anaesthetic room to the operating theatre.
- almost 20% of AAGA reports occurred at the time of emergence from general anaesthesia and were commonly if not universally related to inadequate reversal of neuromuscular blockade

Building on these recommendations, the AAGBI Working Party makes the following recommendations:

- Depth of anaesthesia monitoring is recommended when neuromuscular blockade is used in combination with TIVA;
- Depth of anaesthesia monitoring should logically commence from induction of anaesthesia and be continued at least until the completion of surgical and anaesthetic interventions (i.e., up to the point where it is intended to awaken the patient);

- Depth of anaesthesia monitoring is recommended during transfer of patients receiving TIVA and neuromuscular blockade, but presents difficulties, because portable battery powered depth of anaesthesia monitors are not widely available. Such devices may come to the market in the future and their efficacy will need to be separately evaluated;
- during inhalational anaesthesia, end-tidal anaesthetic vapour monitoring with preset low agent alarms appears a suitable and effective means of estimating depth of anaesthesia;
- The isolated forearm technique is another technique to monitor depth of anaesthesia [32]. If used as a 'depth of anaesthesia monitor', care should be taken to ensure its safe conduct, especially in relation to avoiding excessive, prolonged cuff inflation. The interpretation of a positive movement to command with isolated forearm technique needs careful interpretation, as does the subsequent management of a patient who has moved in response to spoken command [33].

Appendix 3: Monitoring of neuromuscular blockade during induction, maintenance and termination of anaesthesia

A measure of neuromuscular blockade, using a peripheral nerve stimulator, is essential for all stages of anaesthesia when neuromuscular blockade drugs are administered. This is best monitored using an objective, quantitative peripheral nerve stimulator. Ideally the adductor pollicis muscle response to ulnar nerve stimulation at the wrist should be monitored. Where this is not possible, the facial or posterior tibial nerves may be monitored [34].

There is variability in the duration of action of non-depolarising neuromuscular blocking agents. Residual neuromuscular blockade can be detected in up to 40% patients for up to two hours after their administration [35, 36]. Patient harm may result from postoperative hypoxaemia in the post anaesthesia care unit [37, 38] and a risk of AAGA at extubation [13].

The NAP5 project on AAGA reported on the role of neuromuscular blockade in contributing to AAGA, and how patients interpret unintended paralysis in extremely distressing ways.

Recommendations:

- a peripheral nerve stimulator is mandatory for all patients receiving neuromuscular blockade drugs
- peripheral nerve stimulator monitors should be applied and used from induction (to confirm adequate muscle relaxation before endotracheal intubation) until recovery from blockade and return of consciousness;
- while a 'simple' peripheral nerve stimulator allows a qualitative assessment of the degree of neuromuscular blockade; a more reliable guarantee of return of safe motor function is evidence of a train-of-four ratio > 0.9.
- a quantitative peripheral nerve stimulator is required to accurately assess the train of four ratio [34], but other stimulation modalities (e.g. double burst or post tetanic count) can also be used for assessment. Anaesthetic departments are encouraged to replace existing qualitative nerve stimulators with quantitative devices.

