Supporting technologies — computers and information technology

Department of Anaesthesia,
Nottingham University Hospitals,
City Hospital Campus,
Nottingham, UK.

dick@nickalls.org
www.nickalls.org

9 Supporting technologies **177**
9.8 Computers & information technology 177
9.8.1 History of the anaesthesia record . 177
9.8.2 The anaesthesia workstation 179
9.8.3 References 183

FROM: Nickalls RWD. *Notes on thoracic anaesthesia*
http://www.nickalls.org/dick/papers/thoracic/book-thorax.pdf
REVISION: March 2011

9

Supporting technologies

9.8 Computers & information technology

The first anaesthetic machine to incorporate a microprocessor was in 1976 (Katz 2006), and since then computers have progressively influenced anaesthesia delivery and patient safety. One of the next major influences on anaesthesia practice is likely to be related to data processing, particularly in the areas of smart alarms and decision support. While development and take-up in the operating theatre is almost imperceptible just now, the future surely lies in computers offering anaesthetists seriously useful facilities. The initial motivation with regard to data handling lay in automating the anaesthesia record. However, while this technology has been effectively solved for over 15 years (see Kenny 1990), the take-up by anaesthetists in the UK remains almost zero.

9.8.1 History of the anaesthesia record

The documentation of events, procedures undertaken, physiological parameters (*vital signs*) which are associated with the process of anaesthesia (for example, in conjunction with surgery or an intensive care setting) is known as the Anaesthesia Record. This record serves two main functions, namely (a) medical (the moment-to-moment drug history and vital-signs serves as a useful practical aid), and (b) medico-legal (the anaesthesia record is a legal document in its own right, setting out the facts as they unfold during an anaesthetic).

Background

Effective surgical anaesthesia using inhaled diethyl-ether ("*ether*") was first established in 1842 by Crawford Long (1815–1878) in a handful of unpublicised cases. Some four years later in 1846 ether anaesthesia was rediscovered and popularised by William Morton (1819–1868), who gave a public demonstration on 16th October 1846 at the Massachusetts General Hospital (Boston, USA).

Subsequently, John Snow (1813–1858), Joseph Clover (1825–1882), and Mounier (1855) demonstrated the importance of monitoring the pulse and respiration during anaesthesia (Ellis 1995; Rushman, Davies and Atkinson 1996), but it was not until 1894, at the Massachusetts General Hospital, Boston, that surgeons Ernst A Codman (1869–1940) and Harvey Cushing (1869–1939) established the practice of keeping a careful *written* record (on graph paper) of the patient's pulse and respiration rate during operations—known as the 'ether chart' (Beecher 1940; Hirsch and Smith 1986). Apparently this was prompted by a death under anaesthesia in 1893 (Rushman, Davies and Atkinson 1996, p. 128). In 1901 they started including measurements of the arterial blood pressure using the newly described apparatus of Scipione Riva-Rocci (1863–1937) of Turin (Cushing 1902; Cushing 1903; Rushman, Davies and Atkinson 1996, p. 157).

Ralph Waters (1936; 1942) championed and emphasised the importance of written anaesthetic records, and later Noseworthy (1945) produced special cards on which to record anaesthetic details (see Rushman, Davies and Atkinson 1996, p. 111, for an illustration).

Automation

An automated anaesthesia record is significantly superior to the usual hand-written record, since it samples data much more frequently and more accurately, and hence it has significant medico-legal advantages regarding the documentation of patient care, particularly during complicated and/or unstable cases.

The first mechanical device capable of printing an anaesthetic record was the *Nargraf* machine of 1930 developed by EI McKessons (Westhorpe 1989), which generated a semi-automated record of inspired oxygen, tidal volume and inspiratory gas pressure.

After this little of real technological significance was developed in the area of anaesthesia monitoring until the 1970s, when advances in chip technology gave rise to clinically useful portable electronic devices for measuring such things as arterial and central venous blood pressure, breath-by-breath concentrations of oxygen, carbon dioxide and inhalational anaesthetics, pulse oximetry, and of course, small computers.

From an interfacing point of view, a very significant and far reaching feature was incorporated into virtually all early medical monitoring devices, namely a specialised serial communications interface known as the RS-232 port.[1] Equally significant, therefore, was the decision by IBM to incorporate the RS-232 port into the IBM Personal Computer which appeared in 1981. Fortunately all IBM-compatible PCs since then have also incorporated the RS-232 serial port.

Owing to the widespread use of the RS-232 interface in medical equipment it soon became a relatively easy matter to use a PC to access the numerous measured and derived parameters output by patient monitoring devices, and consequently anaesthetists increasingly explored methods for automating data collection and processing, with a view

[1] The Electronic Industries Association Recommended Standard 232. In 1986 the prefix RS was superceded by the prefix EIA. In 1988 the Telecommunications Industry Association (TIA) was formed by the merger of the US Telephone Suppliers Association and EIA/ITG, and subsequent documents are therefore prefixed by EIA/TIA. The 1991 revision was EIA/TIA-232-E. (Nickalls and Ramasubramanian 1995).

to developing useful trend displays of measured data, real-time calculation of derived parameters, and hard-copy data printouts.

The RS-232 interface is likely to be replaced at some stage by the Medical Interface Bus (MIB; IEEE-1073). This is a high-tech high-speed medical plug-and-play version of the familiar domestic USB interface, and will greatly facilitate medical device inter-connectivity, largely by allowing the relevant interface software to be more easily standardised.

Guidelines

The Royal College of Anaesthetists has published a summary of what data ought to be collected (in addition to the electronic data from the anaesthesia monitors) as part of the Anaesthesia Record (Adams 1996), building on the work of Lack *et al.* (1994). The extent to which these guidelines are actually being met has also been looked at (Smith 1997). The required record set which appears to be emerging, consists of a number of fields within the following general categories: pre-, per- and postoperative information, untoward events and hazard flags.

9.8.2 The anaesthesia workstation

It is clear that computerisation, both in the operating theatre and in ITU, has the potential to free anaesthetists and nurses from much of the work of documentation (e.g., drug doses, procedures, measured parameters etc.), releasing significant amounts of time which is better spent on direct patient care. Anaesthesia Information Management Systems (AIMS) which incorporate sophisticated record-keeping systems clearly offer the advantage of allowing the anaesthetists to concentrate fully on the patient, leading to enhanced vigilance and improved patient care and safety.

Much work has gone into studying the anaesthetists's workload (Weinger *et al.* 1997; Byrne, Sellen and Jones 1998; Leedal and Smith 2005). For example, Kennedy *et al.* (1976) showed that anaesthetists commonly spend 10–15 % of their time producing the handwritten record. Similarly, Smith (1997) pointed out that about 10 % of the anaesthetists' time was related to record keeping, and that if this were to increase then this would likely be to the patient's detriment. A similar study by Wong *et al.* (2003) showed that an ICU information system reduced the time spent by nurses on documentation by 31 %, with the significant benefit being that almost half of the time saved was transferred to patient assessment and direct patient care.

Secondary data processing by anaesthetists in the UK is well behind other countries, with electronic data collection being actively supported by foreign health organisations. For example, in 2001 the 'summer' newsletter of the Anesthesia Patient Safety Foundation (APSF) was devoted to *Information systems in anaesthesia* (Thys, 2001). In 2002 the APSF formally endorsed the use of automated anesthesia information management systems (AIMS) as the following quote indicates.

> In this context it is heartening that the ... APSF has recently endorsed the use of automated anesthesia information management systems (AIMS): "The Anesthesia Patient Safety Foundation endorses and advocates the use of automated record keeping in the perioperative period and the subsequent retrieval and analysis of that data to improve patient safety."
>
> Gage (2002)

Anaesthetists urgently need to harness the power of computing technology in a way which can help both in the operating theatre and in the clinic, most likely via some form of anaesthesia workstation. While such systems will probably be commercial, this is not necessarily the only route. Providing anaesthetists take some interest in the details, it is quite possible for useful systems to be developed along the Open Source model, as for example, the immensely successful Linux operating system, and the excellent software tools TEX, LATEX, Perl and others.

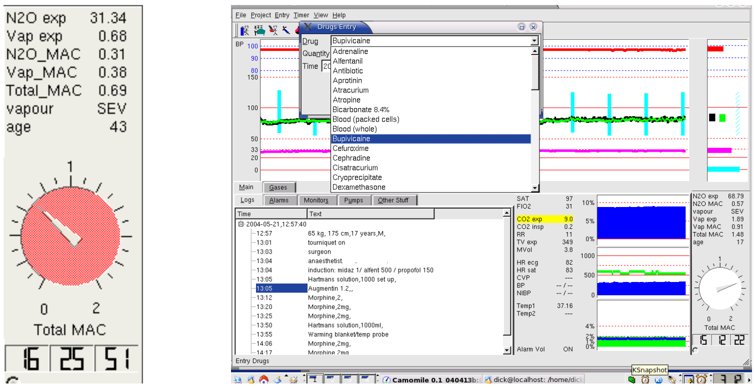

Figure 9.1:
Left: Example of the real-time age-corrected MAC-widget displayed by the author's open-source anaesthesia workstation software[a] interfaced to the Datex S/5 monitor. If the corrected MAC is too low (as shown in this case—total MAC ≈ 0·7) then, in addition to sounding an audible alarm, the dial of the MAC-widget turns red.
Right: Screenshot showing the MAC widget displaying a white dial (corrected MAC in the normal range). The MAC-widget software can easily be run on a laptop interfaced to an anaesthesia monitor.

[a] © Nickalls RWD, Dales S and Nice AK (1996–2011).

The emphasis for such a workstation needs to be on helping the anaesthetist give a safe anaesthetic during difficult circumstances. It would access data from a range of sources via the Medical Interface Bus (e.g., anaesthesia monitors, HIS) and then process the data in various ways; for example, generating the anaesthesia record, offering smart alarms, decision support and predictive physiological and pharmacokinetic modelling, as well as enabling data export, data storage and emergency communications.

For a long time now, even with a modest PC, it has been a simple matter to access high quality data from anaesthesia monitors (Nickalls and Ramasubramanian 1995; Nickalls 1998, Nickalls, Dales and Nice 2010) and create excellent anaesthesia records offering medico-legal security. These are relatively straightforward to write and get up and running, as, for example, the graphic record shown in Figure 9.2 (page 182) generated by the author's open-source anaesthesia workstation software.[2] With little additional work a theatre-based PC can also display warnings, equipment status information and value-added parameters; for example, real-time age-corrected MAC (Nickalls and Mapleson 2003), smart diabetes monitoring & management, as well as extensive general and drug information support (see Figure 9.1, page 180).

Although there has been widespread uptake of AIMS technology by anaesthetists, it is clear that the optimum interface design to facilitate easy and intuitive use is difficult to achieve. Interface design must minimise keyboard/mouse entries by the anaesthetists while maximising information display. All too often the user interface is awkward to use with the effect that time is wasted and data collection is incomplete (Driscoll *et al.*, 2007). However, since anaesthesia practice is much the same the world over, it is to be expcted that with sufficient computer-engineering research an optimum and intuitive interface will emerge given time. A typical example of current progress in making practical automated anaesthesia records and the involvement of XML is that described by Meyer-Bender *et al.* (2010). The wider adoption of AIMS technology also has the potential to bring about a significant reduction of intraoperative awareness (Nickalls and Mahajan 2010).

Of course commercial AIMS technology is available and can be extremely useful (for example, the NarKoData system[3]—see Benson *et al.* 2000, and the Saturn Information System, Dräger—see Driscoll *et al.* 2007), but some can be far from ideal, and relatively unhelpful in facilitating anaesthesia-related activities, or even generating good quality records. These latter failings largely account for the poor take-up of commercial systems by anaesthetists in the UK. That said, improvements are of course being made all the time.

Computerisation also offers a significant research benefit. For example, in a study by Müller *et al.* (2002) anaesthetists were able to search the database of their automated anaesthesia record-keeper and establish useful risk factors predictive of subsequent inotropic support requirement following cardio-pulmonary bypass. Driscoll *et al.* (2007) used AIMS data to establish underdosage as the cause of awareness in three patients.

[2] Xenon5; © Nickalls RWD, Dales S and Nice AK (1996–2011) —see Figure 9.1, (page 180) and Figure 9.2 (page 182).

[3] IMESO, GmbH, Huttenberg, Germany.

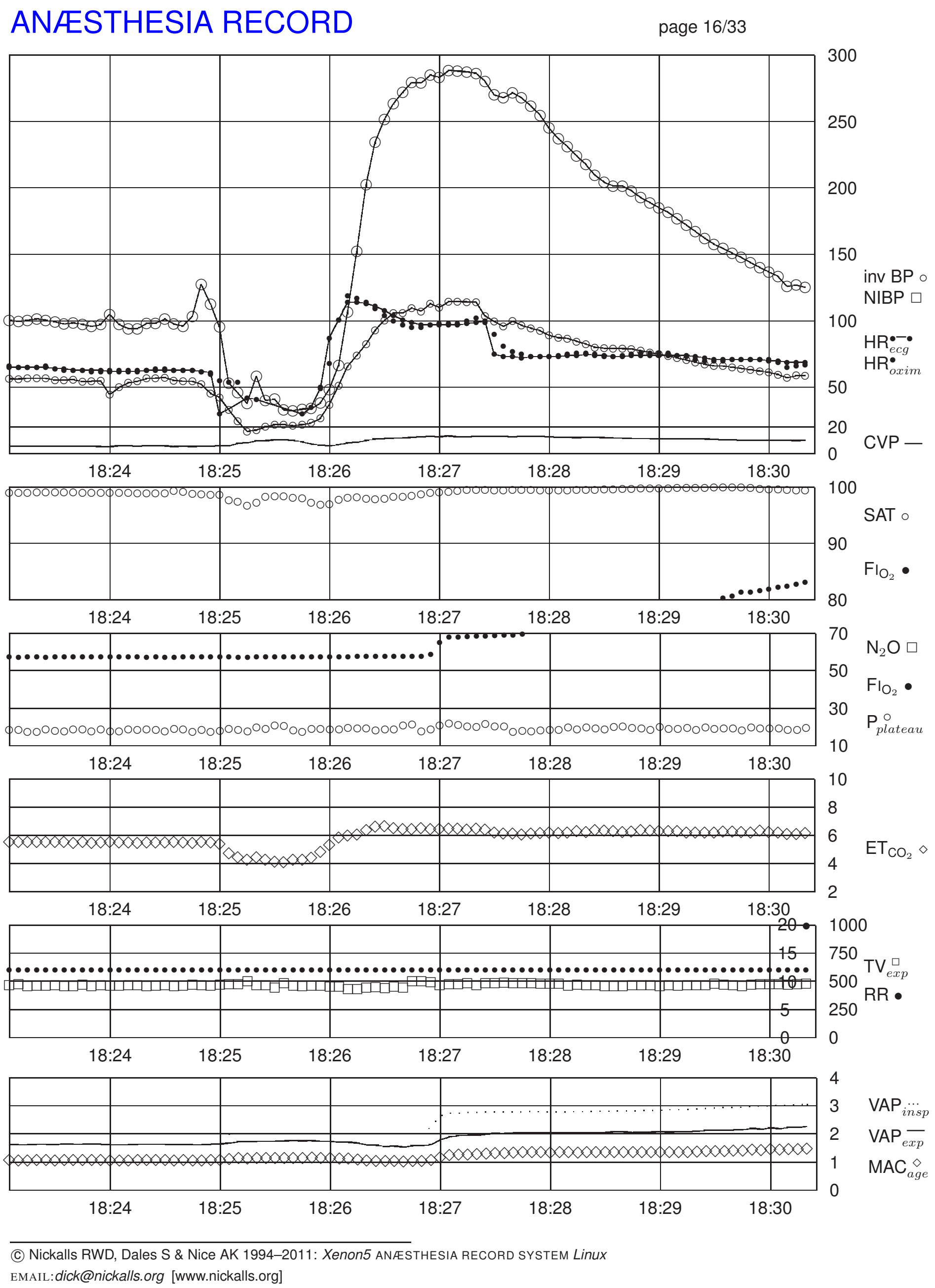

Figure 9.2: Anaesthetic record during a thoracic carcinoid resection in an adult, showing an episode of bradycardia and extreme hypotension which responded to cardiac massage, bolus of adrenaline (2 ml 1/10,000) and 20 µg octreotide—see text. Notice the transient reduction in ET_{CO_2} due to low cardiac output associated with the period of hypotension. The patient made a full and uneventful recovery. Datex AS/3 monitor; data points at 5 sec intervals; BP, NIBP, CVP mmHg; $P_{plateau}$ cm H_2O; TV mls; SAT, FI_{O_2}, ET_{CO_2}, FI_{N_2O}, MAC_{age}, VAP (sevoflurane) %.

Databases

Extracting data from big databases requires a good data dictionary (Sanderson and Monk 2003) as, for example, the currently well advanced SNOMED Clinical Terms program (SNOMED-CT),[4] which is a dynamic health care terminology infrastructure being developed as part of the NHS National Program for Information Technology (NPfIT). A demonstration program can be accessed from the SNOMED-CT home page.

Another NPfIT dictionary database of interest to anaesthetists is the Dictionary of Medicines and Devices (dm+d).[5] This consists of a number of coordinated XML-encoded pharmaceutical databases, which also incorporate the associated SNOMED encoding. Of particular interest to anaesthetists is the Virtual Therapeutic Moiety (VTM) database of approximately 2000 official drug names which are to be used henceforth in all European computer interactions relating to drugs. This list is updated frequently and can be downloaded from the website (password required). This useful list was incorporated into the author's experimental anaesthesia workstation used in the CHN thoracic theatres.

The future

The future holds the exciting prospect of developing sophisticated (and possibly Open Source) anaesthesia workstations giving anaesthetists access to good data displays and trends, sophisticated alarms (smart-alarms), real-time predictive modelling for drugs and physiological parameters, information management and decision-support systems (Sanderson, Watson and Russell 2005; Tarassenko, Hann and Young 2006, Berkenstadt *et al.* 2006). A possible view of the future was presented recently by John, Peter, Chacko *et al.* (2009). Finally, we note that since 2010 the NHS has been embracing the Open Source domain—this can only be a good sign for anaesthetists (see http://www.ehealthopensource.org/).

9.8.3 References

- Adams AP (1996). A revised anaesthetic record set. *Royal College of Anaesthetists' Newsletter* 27 (1996); 8–9.
- Beecher HK (1940). The first anesthesia records (Codman, Cushing). *Surg. Gynecol. Obstet.*, 71, 689–693.
- Benson M, Junger A, Fuchs C, Quinzio L, Bottger S and Hemplemann G (2000). Use of an anesthesia information management system (AIMS) to evaluate physiologic effects of hypnotic agents used to induce anesthesia. *J. Clin. Monit. Comput.*; 16, 183–190.

[4] http://www.ihtsdo.org/snomed-ct/

[5] http://www.dmd.nhs.uk/

- Berkenstadt H, Yusim Y, Katznelson R, Ziv A, Livingstone D and Perel A (2006). A novel point-of-care information system reduces anaesthesiologists' errors while managing case scenarios. *European Journal of Anaesthesiology*, 23, 239–250.
- Byrne AJ, Sellen AJ and Jones JG (1998). Errors on [handwritten] anaesthetic record charts as a measure of anaesthetic performance during simulated critical incidents. *Br. J. Anaesth.*;80, 58–62.
- Cushing HW (1902). On the avoidance of shock in major amputation by cocainization of large nerve trunks preliminary to their division. With observations on blood pressure changes in surgical cases. *Annals of Surgery*, 36, 321–345. [from Hirsch & Smith (1986)]
- Cushing HW (1903). On routine determinations of arterial tension in operating rooms and clinic. *Boston Med. Surg. Journal*, 148, 250–256. [from Hirsch & Smith (1986). Reproduced in 'Classical File', *Survey of Anesthesiology* (1960); 4, 419]
- Driscoll WD, Columbia MA and Peterfreund RA (2007). An observational study of anesthesia record completeness using an Anaesthesia Information Management System. *Anesthesia and Analgesia*; 104, 1454–1461.
- Ellis RH (1995). *The Casebooks of Dr John Snow*. (Wellcome Institute for the History of Medicine); p. 22, p. 30.
- Fulton JF (1946). Harvey Cushing: a biography. (C Thomas, Springfield, IL, USA).
- Gage JS (2002). Anesthesia Informations Management Systems (AIMS). *ASA Newsletter*, June 2002. (http://www.asahq.org/).
- Hallén B (1990). The value of anaesthetic records for morbidity and mortality studies. In: Kenny GNC [Ed.], Automated Anaesthetic Records; *Baillière's Clinical Anaesthesiology*; 4 (June), pp. 7–16.
- Hirsch NP and Smith GB (1986). Harvey Cushing: his contribution to anesthesia. *Anesthesia and Analgesia*; 65, 288–293.
- John G, Peter JV, Chacko B, Pichamuthu K, Rao A, Subbalakshmi K, George KE, Agarwal SK, Anouncia SM, Sunderraj E, Siromoney A (2009). A computer-assisted recording, diagnosis and management of the medically ill system for use in the intensive care unit: A preliminary report. *Indian J Crit Care Med*; 13, 136–42. (http://www.ijccm.org/text.asp?2009/13/3/136/58538)
- Kennedy PJ, Feingold A, Wierner EL and Hosek RS (1976). Analysis for tasks and human factors in anaesthesia for coronary-artery bypass. *Anesthesia and Analgesia*; 55, 374–377.

- Kenny GNC [Ed.] (1990). Automated anaesthesia records. *Bailliere's Clinical Anaesthesiology*; 4 (June).

- Kitz RJ (2006). World's first computer-controlled anesthesia machine donated to WLM [6] *ASA Newsletter*, 70 (September). (http://www.asahq.org/).

- Kofke WA and Nadkarni VM [Eds.] (2007). New vistas in patient safety and simulation. *Anesthesiology Clinics*; 25 (June), 209–390 (Elsevier, Inc)

  [chapters: Anesthesiology national CME program and ASA activities in simulation / Does simulation improve patient safety?: self-efficacy, competence, operational performance, and patient safety / Simulation applications for human factors and systems evaluation / Credentialing and certifying with simulation / Statewide simulation systems: the next step for anesthesiology? / Crew resource management and team training / Simulation: translation to improved team performance / Virtual worlds and team training / Virtual reality simulations / Procedural simulation / Debriefing with good judgment: combining rigorous feedback with genuine inquiry / Integration of standardized patients into simulation]

- Lack JA, Stewart-Taylor M and Tecklenburg A (1994). An anaesthesia minimum data set and report format. *Br. J. Anaesth.*;73, 256–260.

- Leedal JM and Smith AF (2005). Methodological approaches to anaesthetists' workload in the operating theatre. *Br. J. Anaesth.*; 94, 702–709.

- Meyer-Bender A, Spitz R, Pollwein B (2010). The anaesthetic report: custom-made printouts made from anaesthesia-information-management-systems using extensible stylesheet language transformation. *Journal of Clinical Monitoring and Computing*; 24, 51–60.

- Middleton H (1957). *Proc. Roy. Soc. Med.*; 50, 888. [from Middleton (1958a)]

- Middleton H (1958a). A cumulative anaesthesia record system. *Anaesthesia*; 13, 337–340.

- Middleton H (1958b). *Brit. Med. Bull.*; 14, 42. [from Middleton 1958a]

- Mounier CCR (1855). *Acad. Sci. Paris*; 40, 530. [from Rushman, Davies and Atkinson (1996)]

- Müller M, Junger A, Bräu M, Kwapisz MM, Schindler E, Akintürk, Benson M and Hempelmann G (2002). Incidence and risk calculation of inotropic support in patients undergoing cardiac surgery with cardiopulmonary bypass using an automated anaesthesia record-keeping system. *Br. J. Anaesth.*; 89, 398–404.

[6] Wood Library-Museum of Anesthesiology.

- Nickalls RWD (1998). TEX in the operating theatre: an anaesthesia application. *TUGBOAT*; 19, 239–241. http://www.tug.org/TUGboat/Articles/tb19-3/tb60nick.pdf

- Nickalls RWD (1999). mathsPIC: a filter program for use with PICTEX. *EuroTEX'99 Proceedings* 1999; p 192–210. http://www.uni-giessen.de/~g029/eurotex99/nickalls.pdf

- Nickalls RWD (2000). mathsPIC 2·1
  http://www.ctan.org/tex-archive/graphics/mathspic/

- Nickalls RWD (2003). Age-related iso-MAC charts for download.
  http://www.nickalls.org/dick/papers/rwdnPapers.html#anes-general

- Nickalls RWD, Dales S and Nice AK (2010). A Linux-based anaesthesia workstation, ESCTAIC-2010 conference (Amsterdam; October 2010).
  http://www.nickalls.org/dick/xenon/ESCTAIC2010abstract.pdf

- Nickalls RWD and Mahajan RP (2010). Awareness and anaesthesia: think dose, think data. *Br. J. Anaesth.*; 104, 1–2. [Editorial]
  http://dx.doi.org/10.1093/bja/aep360

- Nickalls RWD and Mapleson WW (2003). Age-related iso-MAC charts for isoflurane, sevoflurane and desflurane in man. *Br. J. Anaesth.*; 91, 170–174.
  http://dx.doi.org/10.1093/bja/aeg132

- Nickalls RWD and Ramasubramanian R (1995). *Interfacing the IBM-PC to medical equipment: the art of serial communication.* ISBN 0-521-46280-0; 402 pp. (Cambridge University Press).

- Noseworthy M (1937). *St. Thomas's Hospital Reports (London)*; 2, 54. [from Rushman, Davies and Atkinson (1996)]

- Noseworthy M (1943). *Br. J. Anaesth.*; 18, p. 160). [from Oldham (1963)]

- Noseworthy M (1945). *Anesthesia and Analgesia*; 24, 221. [from Rushman, Davies and Atkinson (1996)]

- Noseworthy M (1953). *Anaesthesia*; 8, 43. [from Noseworthy (1963)]

- Noseworthy M (1963). Anaesthetic record card. *Anaesthesia*; 18, 209–212.

- Oldham KW (1963). Anaesthetic and operation records. *Anaesthesia*; 18, 213–216.

- Rushman GB, Davies NJH and Atkinson RS (1996). *A short history of anaesthesia: the first 150 years.* (Butterworth-Heinemann, Oxford, UK).

- Sanderson IC and Monk TG (2003). Standard anesthesia terminologies: how can we avoid wasting the data we collect? *ASA Newsletter*; 67, November. http://www.asahq.org/
- Sanderson PM, Watson MO and Russell WJ (2005). Advanced patient monitoring displays: tools for continuous informing. *Anesthesia and Analgesia*; 101, 161–168.
- Smith A (1997). New college guidelines for anaesthesia records: how do current forms measure up? *Royal College of Anaesthetists' Newsletter* 36 (1997); 3–6.
- Syropoulos A and Nickalls RWD (2000). A perl port of the mathsPIC graphics package. *TUGboat*; 21: 292–7. http://www.tug.org/TUGboat/Articles/tb21-3/tb68syro.pdf
- Tackley R (2006). Integrating anaesthesia and intensive care into the National Care Record. *Br. J. Anaesth.*; 97, 69–76.
- Tarassenko L, Hann A and Young D (2006). Integrated monitoring and analysis for early warning of patient deterioration. *Br. J. Anaesth.*; 97, 64–68.
- Thrush DN (1992a). Are automated anesthesia records better? *J. Clin. Anesth.*; 4, 386–389.
- Thrush DN (1992b). Automated anesthesia records and anesthetics incidents. *J. Clin. Monit.*; 8, 59–61.
- Thys DM (2001). The role of information systems in anesthesia. Anesthesia Patient Safety Foundation (APSF), Summer 2001 Newsletter (http://www.apsf.org/newsletters/html/2001/summer/03Infosys.htm).
- Waters RM (1936). The teaching value of records. *Journal of the Indiana Medical Association*; 29, 110. [from Hallén 1990]
- Waters RM (1942). The evolution of anaesthesia. *Proceedings of the Mayo Clinic*; 17, 40. [from Hallén 1990]
- Weinger MB, Herndon OW and Gaba DM (1997). The effect of electronic record keeping and transesophageal echocardiography on task distribution, workload, and vigilance during cardiac anesthesia. *Anesthesiology*; 87, 144–155.
- Westhorpe R (1989). McKesson 'Nargraf' anaesthetic record. *Anaesthesia and Intensive Care*; 17, 250.
- Wong DH, Gallegos Y, Weinger MB, Clack S, Slagle J and Anderson CT (2003). Changes in intensive care unit nurse task activity after installation of a third-generation intensive care unit information system. *Critical Care Medicine*; 31, 2488–2494.