

Getting Capnography to the Front Lines

Robert J. McDougall, MBBS, FANZCA,* Wayne W. Morriss, MBChB, FANZCA, †‡ Priya K. Desai, MPH, § and Natsagdorj Batgombo, MD||

See Article, page 917

GLOSSARY

AC = alternating current; **CFC** = Coalition for Capnography; **DC** = alternating current; **G4 Alliance** = Global Alliance for Surgical, Obstetric, Trauma and Anesthesia Care; **HICs** = high-income countries; **LMICs** = low- and middle-income countries; **NGO** = nongovernmental organizations; **NSOAP** = National Surgical, Obstetric, and Anesthesia Plan; **RFP** = request for proposals; **WFSA** = World Federation of Societies of Anaesthesiologists; **WHO** = World Health Organization

For anesthesiologists working in high-income countries (HICs), pulse oximetry and capnography have become an indispensable part of safe anesthetic practice. In 2023, it is inconceivable that HIC anesthesia providers would feel comfortable providing anesthesia without the benefit of these devices. Pulse oximetry has also become a standard of care in many low- and middle-income countries (LMICs) but anesthesiologists do not have access to capnography. It is time to close the capnography gap.

The introduction of pulse oximetry and capnography helped revolutionize modern anesthesia in the 1980s. At the time, both monitoring modalities were relatively expensive and level 1 evidence supporting their use was limited. Yet, it was obvious that these 2 monitors allowed anesthesia providers to have greater understanding of oxygen delivery to the tissues, metabolic state, cardiac output, airway security and patency, respiratory function, and the effects of anesthesia medications on the body. HICs quickly included these

new monitors in their standards for the safe practice of anesthesia, found funding to ensure patients and providers had access, and included training in curricula.

The Global Oximetry Project was established in 2004 with the aim of developing a robust, low-cost oximeter, and led to the establishment of Lifebox, which has improved access to oximeters by donating or working with other nonprofits to distribute more than 33,000 oximeters, usually with education on their use, to LMICs since 2011.^{1,2} The inclusion of pulse oximetry on the World Health Organization (WHO) Safe Surgery Checklist and inclusion of oximetry as “highly recommended” by the International Standards for a Safe Practice of Anesthesia (2010) created the urgency for Lifebox and other organizations to procure and supply oximeters.³

The spread of capnography has been more problematic. Capnography has been available commercially since the 1950s, but early devices were impractical due to their size, cost, and lack of mobility. Their use became more widespread in HICs in the 1980s as newer technology allowed for portable, robust devices. In 1986 the “Standards for Patient Monitoring During Anesthesia at Harvard Medical School” were first published and stated that “Monitoring of end-tidal carbon dioxide is an emerging standard and is strongly preferred.”⁴ By the early 1990s, most professional bodies in HICs included capnography in minimum standards for anesthesia. Subsequent analyses of critical incidents justified the inclusion of capnography as an essential monitor.⁵

Unfortunately, access to capnography in LMICs has not matched access in HICs. Expense, maintenance, and supply of consumables are just some of the barriers. Medical technology companies have been reluctant to develop suitable devices for LMICs as the market is not perceived as being profitable. Standard setting bodies

*Department of Anaesthesia and Pain Management, The Royal Children’s Hospital Melbourne, Parkville, Victoria, Australia; †Department of Anaesthesia, University of Otago, Christchurch Hospital, Christchurch, New Zealand; ‡World Federation of Societies of Anaesthesiologists, London, United Kingdom; §Smile Train, New York, New York; and ||Department of Anesthesiology and Intensive Care, Intermed Hospital, Ulaanbaatar, Mongolia.

Accepted for publication July 26, 2023.

Funding: None.

Conflicts of Interest: See Disclosures at the end of the article.

Listen to this Article of the Month podcast and more from OpenAnesthesia.org® by visiting <http://journals.lww.com/anesthesia-analgesia/pages/default.aspx>.

Reprints will not be available from the authors.

Address correspondence to Robert J. McDougall, MBBS, FANZCA, Department of Anaesthesia and Pain Management, The Royal Children’s Hospital Melbourne, 50 Flemington Rd, Parkville, VIC 3052, Australia. Address e-mail to rob.mcdougall@rch.org.au

Copyright © 2023 International Anesthesia Research Society

DOI: 10.1213/ANE.0000000000006690

(eg, World Federation of Societies of Anaesthesiologists [WFSA] and WHO) have been reluctant to mandate this monitoring modality, partly due to concerns about price and access to consumables, and the possibility that absence of capnography could prevent provision of emergency or essential anesthesia care. The WHO-WFSA International Standards for a Safe Practice of Anesthesia (2018) also noted the lack of availability of appropriately robust and suitably priced devices.⁶

There is good evidence that capnography can be introduced and sustained in LMICs. The Global Capnography Project successfully introduced 40 capnography devices to 8 hospitals in southern Malawi and trained 32 anesthesia providers in their use. In the 6 months after implementation, 77% of the providers reported recognizing complications including 44 esophageal intubations and 90% of providers believed that capnography had saved lives.⁷

In 2021 Smile Train and Lifebox launched a request for proposals (RFP) for a suitable capnography device based on specifications developed from the WFSA Minimum Capnometer Specifications 2021—A Guide for Health Care Decision Makers.⁸ A combined capnography and oximetry unit produced by Zug Medical Systems was selected and is currently being trialed in a limited number of locations. Lifebox and Smile Train have developed an education package, outlined below, in preparation for capnometer distribution.

The time for closing the capnography gap is now. Once considered too expensive, fragile, and high maintenance, new compact, and robust devices are available at a modest cost. The success of oximetry distribution has set an example. A coalition of enthusiastic partners must be built and a clear strategy developed. This will attract the donors and volunteers that are needed to make capnography available to every patient in the world, every time. This special article describes such a strategy and is a call to action for perioperative health care workers, professional bodies, nongovernmental organizations (NGOs), and governments.

DETERMINING THE CAPNOGRAPHY GAP

Now that low-cost capnography devices exist, a traditional approach would commence with a needs analysis to determine the worldwide capnography gap as was done for oximeters.⁹ We prefer a regional/national approach because experience has shown that a singular approach will not work in all regions. Detailed needs analyses are essential but ideally should have a regional focus to allow tailored regional planning and all-important budgeting.

BUILDING THE COALITION

The capnography project requires partners with expertise in fundraising, procurement, distribution,

advocacy, and education. A suitable name for this coalition could be the Coalition for Capnography (CFC). It is vital that the coalition has reach to the very frontlines of health care, beyond teaching hospitals in major centers, to the district and rural hospitals.

Lifebox, WFSA, and Smile Train are likely to be key partners in the CFC, but other partners will be essential, including industry, governments, academic institutions, and professional societies.

Lifebox, itself, was founded by a coalition (Association of Anaesthetists, Brigham and Women's Hospital, Harvard T.H. Chan School of Public Health, and WFSA) and through partnerships with organizations such as Smile Train has achieved great success.

The WFSA will be a key partner in the CFC. It is a federation of 134 member societies representing anesthesiologists in more than 140 countries worldwide. Because of this, WFSA has unparalleled reach to a vast network of anesthesiologists—the clinicians who will need to drive initiatives to improve the availability of capnography in individual countries. WFSA has also been closely involved in the distribution of Lifebox oximeters and the delivery of educational programs worldwide.

National societies of anesthesia and other professional bodies are critical as they have excellent working knowledge of local resources and can work with health services and governments to perform needs analyses and assist in provision of training. For example, the Mongolian Society of Anesthesiologists has worked with local and international partners to dramatically improve the access and safety of anesthesia in Mongolia and has already expressed enthusiasm for this project.¹⁰

Smile Train, the largest global cleft nonprofit organization, uses a model of establishing partnerships with treatment centers and health care workers in LMICs. Smile Train has a presence in more than 70 countries and provides comprehensive cleft care. With a goal of reducing disparities in access to quality surgical, anesthesia, and medical care, Smile Train strengthens partners with training, education, equipment, and patient support grants. Smile Train will be a critical partner in the CFC and is currently part of the Smile Train-Lifebox Safe Surgery and Anesthesia Initiative. Smile Train has been closely aligned with Lifebox in the distribution of more than 11,000 pulse oximeters to 20 countries and has ordered the first 300 capnography devices for distribution, training, and research in LMICs.

SETTING THE STANDARD

When the WHO-WFSA International Standards for a Safe Practice of Anesthesia were published in 2018, an appropriately robust and suitably priced capnography device was not available. The next update of the International Standards should upgrade

continuous waveform capnography from “recommended” to “highly recommended” now that suitable devices are available. In the language of the WHO, “highly recommended” is the functional equivalent of mandatory, and this change will provide a powerful driver to improve the availability of capnography, similar to placing a medication on the WHO Essential Medicines List.

Resourcing for capnography, along with other recommended anesthesia monitors, should be included in the National Surgical, Obstetric, and Anesthesia Plan (NSOAP). As part of the process, it will be important to conduct a needs analysis and quantify the capnography gap in each country.

Just as oximetry benefited from inclusion in the WHO Surgical Safety Checklist, consideration must also be given to the inclusion of capnography.

MAKING THE CASE

Once formed, the CFC must be able to advocate at local, regional, national, and global levels for standards to include capnography and funding. Key partners for this project, including (but not limited to) Lifebox, Smile Train, and WFSA, all have extensive advocacy skills and well-developed relationships.

Health services will need convincing that capnography is an essential part of safe surgery. This may be a challenge as it is difficult to explain its value to those with a limited knowledge of physiology. For example, the role of capnography in detecting a misplaced tracheal tube is relatively easy to understand, but the role of the capnograph as an assessment of cardiac output requires more advanced learning in physiology. Oximetry has the advantage of a simple percentage readout that is readily understood by those with no medical background.

Advocacy must be pitched as a surgical safety initiative rather than simply safer anesthesia, and it is vital that surgical professional bodies are engaged. The Global Alliance for Surgical, Obstetric, Trauma and Anesthesia Care (G4 Alliance) is the largest multidisciplinary advocacy group of its type and has a vision of universally available, accessible, acceptable, and quality emergency and essential surgical, obstetric, trauma, and anesthesia care.¹¹ Working with the G4 Alliance would allow access to many professional bodies that would assist the CFC in project implementation.

Advocacy to potential donors requires a specific skill set, and our belief is that the obvious partners for the CFC, including Lifebox, Smile Train, and WFSA, have the skills necessary to raise the funds needed.

SECURING THE FUNDING

Finding funding to close the current global capnography gap will be an enormous challenge. There are

few private funders supporting global surgery and anesthesia, and states are reluctant to prioritize access to safe surgery in their health funding objectives. Recently, the Global Surgery Foundation established SURGfund, a funding mechanism for supporting surgery and anesthesia in LMICs. Smile Train, WFSA, and Lifebox are partners of the Global Surgery Foundation, and this initiative has great potential to assist capnography provision.¹²

The lack of funding should not deter starting small-scale project implementation. Success will breed success. There is no single solution to the problem of funding. Different models will be needed—in some sites, governments will assist, but the CFC will need to engage donors. Pool purchasing can be a key factor in promoting access to devices and in lowering the cost per unit. Funding requirements do not stop at the purchase of devices, and a strategy should be developed to ensure that costs related to user training, device transportation and in-country customs clearance, purchase of consumables, and ongoing maintenance and repair are considered over the shelflife of the product.

DEVELOPING THE TRAINING TOOLS

Education must go hand in hand with device distribution. Many LMIC anesthesia training programs already teach the use of capnography and many teaching hospitals in training centers have capnography available. Regional and remote settings may have limited or no access to capnography and anesthesia providers may not have current experience in capnography use.

Education should be delivered locally in partnership with national and regional anesthesiology societies, other professional organizations, and academic institutions rather than relying on HIC “experts” flying in for short visits.

A capnography training package must deliver an understanding of the basic sciences, including the physiology of carbon dioxide, cardiorespiratory physiology, and cellular metabolism. Education must also include instructions on how to use and care for the device. The Lifebox oximetry education program has been very effective in the rollout of oximetry.¹³ Modeling this program, the Smile Train Lifebox Capnography Project has developed a capnography package that is aimed at small groups and includes 5 modules: The Capnography Project, Physiology of Carbon Dioxide, Using Your Capnograph, Cases for Scenario Teaching, and Care of Your Capnograph. During the development of these tools, it was realized that the physiology of carbon dioxide is challenging to understand for non-anesthesiologists. This education package was trialed in Ethiopia in January 2023 and feedback received allowed for the modification of the different modules and ways

to amend the training workshops. Capnography training will be rolled out alongside device distribution at various partner facilities in LMICs.

MANUFACTURING THE HARDWARE

The development of the Zug Medical Systems device followed an RFP process by Smile Train and Lifebox. The Zug unit is a portable sidestream sampling device with a continuous waveform, alarms, a lithium battery, and alternating current (AC)/direct current (DC) power adapter. It also incorporates an oximeter. Although this does not preclude other units from being developed and distributed, the RFP ensured that the device was of high quality, affordable, and suitable for use in LMICs.

Appropriately priced, easily accessible, and well-designed consumables (eg, sampling lines and water traps) will be a key part of the manufacturing process. Ideally, these consumables should be able to be used with devices made by different manufacturers.

ESTABLISHING DISTRIBUTION SYSTEMS

Logistics are a priority for this project. Attention must be paid to matching orders with supply and ensuring that customs can be cleared with minimal cost. Local biomedical approval and support is also essential. A warranty that handles faulty units and repairs must also be included in the purchase price. Establishing access to these essential devices will be key as will the continuous supply of consumables. This can be challenging for proprietary parts for instance. Equally, finding spares can be a challenge for remote facilities. The question of the product's "afterlife" should also be considered, especially in areas where recycling programs may not exist.

SUSTAINING THE GAINS

Introducing capnography in Smile Train—affiliated centers should result in some early "easy wins." More complex and larger projects can be devised as different project delivery models are evaluated. Modest key performance indicators should initially be set as part of the strategic plan.

A robust monitoring and evaluation system will be needed to ensure agreed CFC targets are met and adjusted.

The issue of consumable funding and supply will need careful thought. Should this be part of the donation contract, or should hospitals or ministries of health find their own solutions?

SUMMARY

For most anesthesiologists working in HICs, capnography is an essential monitoring tool: they would not consider providing general anesthesia or sedation without it. Unfortunately, for many anesthesiologists working in LMICs, the reality is very different:

capnography is simply not available. There is a wide capnography gap between countries with more resources and those with less.

Oximetry has shown us that it is possible to narrow the gap with clear standard setting, development of a suitable device, identifying funding sources, finances, and a plan for education and distribution.

For too long, the absence of appropriate technology has limited greater use of capnography in LMICs, but this situation has changed and we now have devices that are fit for purpose. Capnography is now within reach of all and it is time for capnography to be seen as an essential tool for patients everywhere, not just for patients lucky enough to live in well-resourced countries. It is time for the global anesthesiology community to close the capnography gap. ■

ACKNOWLEDGMENTS

The authors thank Mr Remy Turc, MA, Programme Manager, Medical Technologies, Lifebox, London, United Kingdom, for his assistance with information provision.

DISCLOSURES

Name: Robert J. McDougall, MBBS, FANZCA.

Contribution: This author helped in the preparation and writing of the article.

Conflicts of Interest: R. J. McDougall is a member of the Global Governance Council of Lifebox and a member of the World Federation of Societies of Anaesthesiologists (WFSA) Ad Hoc Equipment Committee.

Name: Wayne W. Morriss, MBChB, FANZCA.

Contribution: This author helped in the preparation and writing of the article.

Conflicts of Interest: W. W. Morriss is the president of the World Federation of Societies of Anaesthesiologists (WFSA).

Name: Priya K. Desai, MPH.

Contribution: This helped in the preparation and writing of the article.

Conflicts of Interest: P. K. Desai is employed by Smile Train as senior vice president, Research, Data & Evaluation.

Name: Natsagdorj Batgombo, MD.

Contribution: This author helped in the preparation and writing of the article.

Conflicts of Interest: None.

This manuscript was handled by: Angela Enright, MB, FRCPC.

REFERENCES

1. Thoms GM, McHugh GA, O'Sullivan E. The Global Oximetry initiative. *Anaesthesia*. 2007;62(suppl 1):75–77.
2. Pulse Oximetry. Lifebox. Accessed June 26, 2023. <https://www.lifebox.org/our-work/pulse-oximetry/>.
3. Merry AF, Cooper JB, Soyannwo O, Wilson IH, Eichhorn JH. International standards for a safe practice of anesthesia 2010. *Can J Anaesth*. 2010;57:1027–1034.
4. Eichhorn JH, Cooper JB, Cullen DJ, Maier WR, Philip JH, Seaman RG. Standards for patient monitoring during anesthesia at Harvard Medical School. *JAMA*. 1986;256:1017–1020.
5. Webb RK, van der Walt JH, Runciman WB, et al. The Australian incident monitoring study. Which monitor? An analysis of 2000 incident reports. *Anaesth Intensive Care*. 1993;21:529–542.

6. Gelb AW, Morriss WW, Johnson W, et al; International Standards for a Safe Practice of Anesthesia Workgroup. World Health Organization-World Federation of Societies of Anaesthesiologists (WHO-WFSA) international standards for a safe practice of anesthesia. *Anesth Analg*. 2018;126:2047–2055.
7. Jooste R, Roberts F, Mndolo S, et al. Global Capnography Project (GCAP): implementation of capnography in Malawi: an international anaesthesia quality improvement project. *Anaesthesia*. 2019;74:158–166.
8. Gelb AW, McDougall RJ, Gore-Booth J, Mainland PA; WFSA Ad Hoc Capnometry Workgroup. The World Federation of Societies of Anaesthesiologists Minimum Capnometer Specifications 2021: a guide for health care decision makers. *Anesth Analg*. 2021;133:1132–1137.
9. Funk LM, Weiser TG, Berry WR, et al. Global operating theatre distribution and pulse oximetry supply: an estimation from reported data. *Lancet*. 2010;376:1055–1061.
10. Lundeg G, Baric A, Pescod DC, Pescod K. Anesthesia development in Mongolia: strengthening anesthesia practice in Mongolia through education and continuing professional development. *Anesth Analg*. 2018;126:1287–1290.
11. Haider A, Scott JW, Gause CD, et al. Development of a unifying target and consensus indicators for global surgical systems strengthening: proposed by the Global Alliance for Surgery, Obstetric, Trauma, and Anaesthesia Care (the G4 Alliance). *World J Surg*. 2017;41:2426–2434.
12. SURGFund. The Global Surgery Foundation. Accessed June 26, 2023. <https://www.globalsurgeryfoundation.org/surgfund>.
13. Albert V, Mndolo S, Harrison EM, O’Sullivan E, Wilson IH, Walker IA. Lifebox pulse oximeter implementation in Malawi: evaluation of educational outcomes and impact on oxygen desaturation episodes during anaesthesia. *Anaesthesia*. 2017;72:686–693.