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Editorial

The global capnography gap: a call to action

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In the past decade, numerous studies have helped to better characterise shortages of anaesthesia and surgical equipment in low- and middle-income countries and identify areas for intervention [1–3]. Many such efforts have focused on pulse oximetry (LifeBox, World Health Organization checklist) and for good reason [4]. Pulse oximetry is relatively inexpensive, easy-to-use, low maintenance, versatile, instantaneous and considered essential by all existing national and international anaesthesia guidelines, including the recently published World Health Organization – World Federation of Societies of Anaesthesiologists (WHO-WFSA) standards [5]. Capnography is another important anaesthesia monitor that has received relatively less attention despite having many of these same characteristics.

Unlike pulse oximetry, capnography is utilised in fewer healthcare fields (e.g. predominantly in intensive care units (ICUs), operating theatres and procedure rooms), employed by fewer cadres (e.g. primarily anaesthesia providers, intensivists and proceduralists) and has been relatively more expensive to purchase and is thus uncommon in low-income countries. Pulse oximetry is a sensitive and rapid test for hypoxemia, but it is not the earliest direct detector of potentially fatal airway problems as hypoxia is a relatively late feature of airway misadventures [6–8]. Averting these failures to rescue situations with capnography can likely prevent significant anaesthetic morbidity and mortality from, for example, oesophageal intubation, tracheal tube obstruction and bronchospasm [7, 9, 10]. In low- and middle-income countries, a large proportion of peri-operative and anaesthetic mortality is known to be avoidable, and airway complications, such as undetected oesophageal intubation, are likely a major contributor [11]. Capnography also has important uses in spontaneously-breathing patients whose tracheas are not intubated. Such patients may experience respiratory depression and/or airway obstruction, which are poorly detected by oximetry if oxygen is administered concurrently [12, 13].

Few data exist to quantify morbidity and mortality avertable with end-tidal CO_2 detection, and as a result, there are limited efforts to increase access to capnography. Although availability of capnography should be an aspiration for the safe practice of anaesthesia everywhere, we do not argue that immediate expansion of capnography use should be the highest or the only priority for expanding access to safe and affordable anaesthetic care. Rather, we encourage the global anaesthesia community to pursue research that better quantifies the scope and scale of the problem and to identify proportional and context-appropriate interventions that should be included among the priorities.

Resource-constrained countries

Up to now, there are no data to evaluate the cost effectiveness or feasibility of capnography in the resource-constrained practice setting. High costs, inadequate supply chains especially for disposable components, lack of provider training and lack of devices designed for the resource-constrained context are among many factors limiting access to capnography. The study by Jooste et al. published in this issue of *Anaesthesia* not only highlights the capnography gap by assessing the prevalence of capnography in a low-income country (Malawi) but also is the first to report the feasibility of implementing capnography among anaesthesia providers and the potential for averting significant morbidity and mortality by increasing access to capnography in operating theatres, ICUs and emergency departments worldwide [14]. The authors are to be congratulated on this achievement.

When considering the expansion of capnography utilisation in resource-constrained settings, one central issue is the availability of context-appropriate devices. Few if any devices are designed specifically for the challenges or viable price point for most low- and middle-income country practice settings. The International Organisation for Standardization (ISO) establishes recommendations for the manufacture of CO_2 sensing devices (ISO 80601-2-55:2018). However, for many applications in low- and middle-income countries, several additional considerations are required, including: increased durability; lower costs; limited dependence on disposables; easy operability; flexible power supply options; easy cleaning; and practical maintenance and calibration requirements. Four capnography techniques currently exist to detect or measure carbon dioxide in the clinical setting: colorimetric, transcutaneous, mainstream and sidestream [15].

1. Colorimetric end-tidal CO_2 detection is simple and requires no power but lacks waveform or quantification of CO_2, and more notably is designed for single use, thus limiting its applicability in settings with underdeveloped supply chains.
2. Transcutaneous capnography is expensive and not appropriate to quickly detect most of the potentially avertable anaesthetic morbidities, including oesophageal intubation.

3–4. Mainstream and sidestream capnography can provide accurate quantification of CO_2 and waveforms, and also can operate with only battery power. However, currently available devices usually depend on disposable filters, tubing and/or proprietary connectors. Additional considerations include interference by condensation or secretions. Inspissated secretions deserve special mention as it is a relatively common cause of tracheal tube obstruction in resource-constrained environments where filters and heated and humidified circuits are often unavailable. A few additional considerations that must be accounted for when using sidestream capnography include dead space of the sample tubing and sampling rate, especially for paediatric patients with low-flow circuits. Microstream technology is advantageous in this patient population.

Benefits of capnography

General anaesthesia in low- and middle-income countries is frequently administered by providers with very limited training. Respiratory complications are a relatively common adverse event [11, 14]. The study by Jooste et al. estimates a rate of 11.7 oesophageal intubations per million population per year (44 oesophageal intubations for a population of 7.5 million during the 6-month study period) in Southern Malawi [14]. When extrapolated to the entire African continent this equates to over 11,000 oesophageal intubations per year. As access to surgical and anaesthetic services are expanded, this number is likely to increase significantly. Intubations per million population is probably not the best metric and does not mean much for most anaesthesia providers. Oesophageal intubations per number of anaesthetics or per number of intubations would likely resonate more. Not all oesophageal intubations lead to poor outcome, that is, if recognised and corrected in a timely manner, so that the success of implementing capnography should not be assessed solely by a reduction in morbidity and mortality. Perhaps the number of adverse outcomes averted would be a more useful metric. However, many studies currently underway looking at peri-operative outcomes should include greater emphasis on intra-operative events so as to detect and quantify potentially avertable causes of morbidity and mortality, such as failed intubation.

The importance of propagating capnography is an important WFSA agenda item [5]. The WHO does not use the word 'mandatory' and instead uses 'highly recommended' as the functional equivalent. The WHO-WFSA Standards document states "*If a tracheal tube is used, correct placement must be verified by auscultation (HIGHLY RECOMMENDED). Confirmation of correct placement by carbon dioxide detection (i.e., non-waveform capnography or colourimetry) is also HIGHLY RECOMMENDED. Continuous waveform capnography …will be HIGHLY RECOMMENDED when appropriately robust and suitably priced devices are available. Equipment manufacturers are encouraged to urgently address this deficiency*". To move this global agenda forward, the WFSA in partnership with the University of California San Francisco Anesthesia division of Global Health Equity and others will be surveying a large sampling of anaesthesia providers in multiple countries coupled with onsite evaluations to further define the global capnometry gap and better characterise potentially avertable morbidity and mortality through increased implementation of capnography. Identifying and correcting shortfalls in equipment is best done with a standardised inventory tool as that allows monitoring over time and also comparisons among institutions, regions and countries. The WFSA and partners have developed a novel standardised anaesthetic facility assessment tool (AFAT – www.wfsahq.org/resources/anaesthesia-facility-assessment-tool). The survey tool is open access and available for independent implementation, or data can be entered directly via the web.

In tandem with this effort, the WFSA Equipment Committee will be working closely with researchers, engineers, manufacturers and practitioners from low- and middle-income countries to develop recommendations beyond the ISO's specifications that highlight key device features related to usability and robustness in resource-constrained settings. This will hopefully foster development of context-appropriate devices at an accessible price point that can be used to augment inferior approaches such as auscultation that are currently being used out of necessity. A similar approach has been successfully utilised to increase access to pulse oximetry in low and middle-income countries through the Lifebox initiative [4]. One consideration will be whether an inline device with digital readout of CO_2 but without waveform would be a useful interim step as it would detect the majority of oesophageal intubations and could be cheaper to produce.

Saving lives

Ultimately, the success of any anaesthesia monitoring technology depends on the presence of a trained anaesthetic provider. Training must encompass when to use the technology, how to interpret the information and what actions are indicated. One of the merits of the Jooste et al. study is that they used a simple tool for interpreting the capnography curves which allowed for rapid training of anaesthesia providers with various levels of knowledge [14]. However, it is unclear if the 6-month follow-up questionnaire used in this study assessed knowledge retention, as this would be key for ongoing, accurate incident recognition and reporting. We encourage further development of such tools to foster recognition of common airway problems including leak, obstruction, rebreathing and to ensure that they are context appropriate for providers in different parts of the world.

The excellent study by Jooste et al. addressed both human resources, competencies and equipment issues but does have several noteworthy limitations which are addressed and should serve as impetus for future studies and initiatives [14]. The project sponsor donated 40 units and 2000 sets of disposable tubing. Although costs were not provided in the paper, they would likely be considerable if these were to be purchased and scaled. The authors report a massive capnography gap, which is consistent with that reported anecdotally in other low-income countries, yet the discussion states that facilities were chosen by convenience and for facilities with a 'known lack of capnography'. This latter criterion may have biased the capnography gap findings.

Capnography, much like pulse oximetry, has significant potential to save lives, as nicely demonstrated by Jooste et al. [14] Nonetheless, capnography remains a relatively high-cost technology for most low- and middle-income countries, with limited data available to quantify the magnitude of disease burden this technology can avert. We call upon the global anaesthesia community (i.e. providers, researchers, national societies, manufacturers and donors) to accelerate research, education and development, manufacture and distribution to make capnography accessible to anaesthesia providers in all practice settings.

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ML is on the WFSA Scientific Affairs Committee; PM chairs the WFSA Equipment Committee; AG is Secretary of WFSA.

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