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Anaesthesia 2014, 69, 445–451 doi:10.1111/anae.12632

Original Article

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L. C. Finch,[1] R. Y. Kim,[2] S. Ttendo,[3] J. K. Kiwanuka,[4] I. A. Walker,[5] I. H. Wilson,[6] T. G. Weiser,[7] W. R. Berry[8] and A. A. Gawande[9]

1 Anaesthesia Speciality Registrar, University Hospital Southampton NHS Foundation Trust, Southampton, UK
2 Research Fellow, 8 Chief Scientific Officer, 9 Director, Ariadne Labs: A Joint Center for Health Systems Innovation, Brigham and Women's Hospital and Harvard School of Public Health, Boston, Massachusetts, USA
3 Head, Department of Anaesthesia, 4 Assistant Lecturer, Mbarara University of Science and Technology, Mbarara, Uganda
5 Consultant Anaesthetist, Great Ormond Street Hospital NHS Foundation Trust, London, UK
6 Consultant Anaesthetist, Royal Devon and Exeter NHS Foundation Trust, Exeter, UK
7 Assistant Professor, Stanford University School of Medicine, Stanford, California, USA

Summary

Pulse oximetry is widely accepted as essential monitoring for safe anaesthesia, yet is frequently unavailable in resource-limited settings. The Lifebox pulse oximeter, and associated management training programme, was delivered to 79 non-physician anaesthetists attending the 2011 Uganda Society of Anaesthesia Annual Conference. Using a standardised assessment, recipients were tested for their knowledge of oximetry use and hypoxia management before, immediately following and 3–5 months after the training. Before the course, the median (IQR [range]) test score for the anaesthetists was 36 (34–39 [26–44]) out of a maximum of 50 points. Immediately following the course, the test score increased to 41 (38–43 [25–47]); $p < 0.0001$ and at the follow-up visit at 3–5 months it was 41 (39–44 [33–49]); $p = 0.001$ compared with immediate post-training test scores, and 75/79 (95%) oximeters were in routine clinical use. This method of introduction resulted in a high rate of uptake of oximeters into clinical practice and a demonstrable retention of knowledge in a resource-limited setting.

Correspondence to: A. A. Gawande
Email: agawande@partners.org
Accepted: 4 February 2014

Introduction

The safety of modern surgical and obstetric care owes much to improvements in anaesthesia. Adoption of safety standards in anaesthesia in high-income countries was associated with a reduction in anaesthesia mortality from 1 to 12 deaths per 10 000 anaesthetics in the mid-twentieth century to estimates of 1 per 100 000 anaesthetics currently [1–3]. The rate of avoidable death associated with anaesthesia in low-income countries remains 100–1000 times higher than that of high-income countries [4–8]. A shortage of trained anaesthetists and a lack of access to monitoring are two factors known to contribute to this disparity [9–14].

There are no adequately powered randomised clinical trials in low-income settings to support the use of peri-operative oxygen saturation monitoring [15]. However, continuous monitoring using pulse oximetry is widely accepted as a standard of care by

all professional anaesthesia organisations with national safety guidelines [16]. A recent trial in a low-income setting demonstrated a significant reduction in major complications from 24.3% to 8.9% ($p < 0.001$) following introduction of the use of routine pulse oximetry as part of a safety checklist programme [17].

Uganda is an East African country with healthcare expenditure and outcomes typical of other low-income countries in sub-Saharan Africa. The under-five mortality rate is 69 deaths per 1000 live births, life expectancy at birth is 54 years, and the fertility rate is 6.1 children born per woman [18]. Due to a shortage of healthcare providers, emergency surgical and obstetric procedures are frequently performed by non-surgeon physicians. Similarly, anaesthesia is mainly provided by non-physician anaesthetists who undergo 6–24 months of training following the completion of high school [19, 20]. In 2007, there were 13 physician anaesthetists and 330 non-physician anaesthetists in Uganda for a population of 27 million [14]. Surveys of hospital facilities have previously shown that 65–76% of operating theatres in Uganda do not have a pulse oximeter [12, 14, 21]. Worldwide, it is estimated that there are 77 700 operating theatres that similarly lack a pulse oximeter [16].

Simple donation of equipment to improve access to pulse oximeters, whilst appealing, may be problematic for a number of reasons. Donated equipment may not be appropriately designed for the environment, particularly where there is no routine maintenance, users may lack training, or there may be problems with batteries or the electrical supply [22–24].

The Lifebox Foundation® (see http://www.lifebox.org) is a charity dedicated to improve the safety of surgery globally by increasing access to pulse oximetry for patients undergoing surgery and promoting introduction of the World Health Organization (WHO) surgical safety checklist. The Foundation has undertaken an international procurement exercise to source a high-quality, low-cost oximeter suitable for anaesthesia in austere environments. Professional networks have been used to identify and distribute pulse oximeters and oximetry training directly to anaesthetists who do not have access to this equipment. The aim of this study was to evaluate the effectiveness of a large-scale donation of pulse oximeters to non-physician anaesthetists working in rural hospitals in Uganda, by assessment of oximetry usage and knowledge of oximetry and hypoxia management at follow-up after training.

Methods

Ethics approval was sought and granted by the Harvard School of Public Health and Mbarara University of Science and Technology. All participants gave informed consent before taking part in the study. Individual anaesthetists' test scores and responses were coded to ensure confidentiality.

The pulse oximeter used was selected following a Request for Proposals issued by the World Federation of Societies of Anaesthesiologists for medical-grade oximeters conforming to WHO specifications [25]. The Lifebox handheld oximeter (Model No. AH-M1; Acare Technology Co., Ltd, New Taipei City, Taiwan) conforms to relevant IEC, CE and ISO 9919 standards. It is a lightweight, medical-grade oximeter with a protective rubber casing, digital monitor with numeric output of heart rate, oxygen saturation, and a pulse waveform. It has an audible heart rate tone that varies with oxygen saturation and an alarm with configurable limits. The oximeter is supplied with a rechargeable lithium-ion battery and AC/DC charger, but can be run on alkaline batteries. The probe can be replaced with any locally available generic sensor and the device has been found to be accurate in detecting hypoxia [26].

A representative of the Uganda Society of Anaesthesia (ST) created a list of all healthcare facilities in Uganda by contacting the Ugandan Ministry of Health and faith-based organisations (via the Protestant, Catholic and Muslim Medical Bureaus). Three years of clinical activity data were reviewed to identify which hospitals provided surgical care. Hospital superintendents from institutions providing surgical care were contacted to determine the availability of pulse oximeters in theatre, and to define the study population of anaesthetists. Hospitals undertaking surgery where there was less than one pulse oximeter per anaesthesia provider were eligible to take part in the study, and one anaesthetist from each target hospital was invited to participate.

Anaesthetists taking part in the study intervention were invited to attend a Lifebox training course at

Mbarara University of Science and Technology in June 2011, which coincided with the Uganda Society of Anaesthesia Annual Meeting. At the end of the course, they received a donation of a pulse oximeter from Lifebox (funded by a grant from the Association of Anaesthetists of Great Britain & Ireland (AAGBI)), and a follow-up site visit 3–5 months later.

Five UK-based anaesthetic consultants and registrars, representatives of the AAGBI, delivered the Lifebox training course. Oximetry and hypoxia management training was delivered in small groups over two half-days using a training package provided by the Lifebox Foundation [21]. Trainers used standard presentations and conducted small group discussions, a practical demonstration of the oximeter, and clinical scenarios. Participants were taught basic cardiopulmonary physiology, management strategies for acute hypoxia in the anaesthesia/surgical setting, and practical use of the pulse oximeter. Delegates were given a printed training manual and a DVD with each oximeter, and were encouraged to complete a logbook of cases when back at their place of work to record the saturation of consecutive patients and interventions required if the oxygen saturation dropped to < 94%. All participants completed a pre- and post-course standardised assessment test [21].

Follow-up site visits commenced at 3 months post-intervention and were made at the participants' places of work by a single investigator (LF). If a site visit was not possible, the study method allowed focused follow up to be carried out by telephone. Three months were available to undertake as many site visits as possible; all were completed by 5 months post-intervention. During these visits, the pulse oximeters were examined to ensure that they were functional. The participants repeated an identical knowledge test to assess retention of the educational content of the training course.

Data were collected in three forms: a hospital survey; oximetry and hypoxia management assessment tests; and pulse oximeter feedback forms. All participants, each representing a separate healthcare facility, completed the hospital survey at the start of the Lifebox training course. The hospital survey included information of the anaesthetist's level of training, the hospital's characteristics and infrastructure, the availability of equipment and medication, access to facilities for maintenance and repair of equipment, and an estimation of hospital caseload. Information in the survey was confirmed during the follow-up site visits. The oximetry and hypoxia management assessment test was based on the training programme and included questions about normal physiology in a 10-item multiple-choice questionnaire. It was administered to participants at the start and on completion of the training course, and during the follow-up visit. Lastly, the anaesthetist completed the pulse oximeter feedback form during the follow-up visit.

The Lifebox educational package and assessment tests used were developed by an international expert panel of anaesthetists with experience working in sub-Saharan Africa, and tested in pilot sites in Uganda and Vietnam with groups of non-physician anaesthetists [21]. Anaesthetists who had been part of the pilot study in Uganda were ineligible for inclusion in this study.

Data analysis was performed using STATA 9.0 (STATA Corporation, College Station, TX, USA). A priori testing of the respiratory management assessment test scores at different time points (at the start of the training, at the end of the training, and during the follow-up period) was the main analysis of interest. Wilcoxon (paired) signed-rank tests were used for comparison of two time points. The same anaesthetists were surveyed at all three time points, hence adjustment analysis for provider characteristics was not required. Results were subjected to longitudinal data analysis via a generalised estimating equations approach.

The sample size of this study was determined by the number of non-physician anaesthetists who were working without a pulse oximeter in Uganda, and post-hoc power calculations were performed. With eight providers, using the Wilcoxon signed-rank test, our study had 80% power (alpha = 0.05) to detect a minimum difference of three points in the oximetry and hypoxia management test scores between any pair of time points. A Bonferroni-corrected p value of 0.01666 was used to support statistical significance for the main analysis comparing the respiratory management assessment test scores at pairs of time points. Qualitative data from open-ended questions were manually theme-analysed.

Results

The Lifebox training programme was attended by 120 non-physician anaesthetists, representing 36% of the estimated total of 330 non-physician anaesthetists in Uganda. Pulse oximeters were donated to 79 non-physician anaesthetists, representing 24% of the total number working in the country. At the time of the follow-up visit, these 79 anaesthetists were working at 75 healthcare facilities, undertaking an estimated total of 1100 major procedures under general anaesthesia per week. Seventy-two of these facilities were located in rural areas spread throughout Uganda. Sixteen anaesthetists were working in hospitals where 1–3 oximeters were already present, but these either required electricity to function (frequently unavailable) or were shared between several theatres. The other 62 anaesthetists worked in hospitals with no oximeter. The characteristics of the anaesthetists who received a donation of a pulse oximeter are presented in Table 1.

The availability of equipment and medication at the recipients' healthcare facilities in the preceding 3 months is shown in Table 2. There was limited availability of electricity and running water in many of these rural health centres and district hospitals. Most recipients reported consistent availability of intravenous fluids, ketamine and ether, whilst access to halothane and isoflurane was more limited. Basic monitoring devices such as stethoscopes and sphygmomanometers were available to almost all providers (Table 3). Capnography was rarely available. Supplemental oxygen was available in theatre during the week before assessment for 55/62 (89%) anaesthesia providers.

Seventy-five out of 79 (95%) pulse oximeters were located during the follow-up visit, and were found to be clinically functional and in routine use by the anaesthetists. One anaesthetist had reportedly moved to the Sudan for work and had taken the pulse oximeter with her. Two pulse oximeters had malfunctioning probes, although only one was not being used as a result. The other oximeter had been fitted with a locally available generic probe and was still in routine use at the time of the follow-up visit.

Oximetry and hypoxia management test scores increased at both assessment times (Table 4). On longitudinal analysis, statistical significance of the time trend did not change even after taking into account other characteristics of the anaesthetist, such as training

Table 1 Characteristics of pulse oximeter recipients and their healthcare facilities. Values are number (proportion) or median (IQR [range]).

Training qualification recipients	
Anaesthetic officer or assistant	49 (70%)
Clinical officer	9 (13%)
Nurse trained on the job	8 (11%)
Student or other	4 (6%)
Medically qualified	0
Never taught to use an oximeter	28 (42%)
Used a pulse oximeter once or less	27 (40%)
Type of healthcare facility	
Governmental district hospital	26 (37%)
Health centre	17 (24%)
Mission hospital	17 (24%)
Referral, university, or other hospital	11 (16%)
Healthcare facility (n = 75)	
Inpatient bed number	100 (100–200 [17–500])
Operating theatres	2 (1–2 [0–5])
Cases performed per week	13 (6–23 [0–95])
Medically trained surgeons	3 (1–4 [0–11])
Anaesthesia providers	2 (1–3 [0–10])

Table 2 Reported availability of equipment and medication at recipients' healthcare facilities during the preceding 3 months. Values are number (proportion).

Equipment	
Sterile gloves	46 (73%)
Mains electricity or generator	41 (63%)
Running water	33 (52%)
Staffed recovery room	9 (14%)
Medication	
Intravenous fluids	60 (92%)
Ketamine	60 (92%)
Atropine	57 (88%)
Adrenaline	53 (83%)
Ether	37 (58%)
Halothane	30 (48%)
Isoflurane	6 (10%)

Table 3 Reported availability of monitoring devices at recipients' healthcare facilities in the previous week. Values are number (proportion).

Stethoscope	65 (99%)
Blood pressure measurement	63 (99%)
Thermometer	41 (63%)
Capnography	1 (2%)

Table 4 Respiratory management test scores (maximum 50) before and after training, and during the follow-up period.

Before training	After training	Follow-up period
36 (34–39 [26–44])	41 (38–43 [25–47])*	41 (39–44 [33–49])*†

*$p < 0.0001$ compared with before training.
†$p = 0.001$ compared with after training.

Table 5 Reported impact of pulse oximeter on clinical practice. Values are number (proportion) of participants agreeing or strongly agreeing with the statements shown.

The oximeter improves the safety of my patients	68 (100%)
The oximeter acts as an early warning to me	67 (99%)
Using an oximeter makes me feel less stressed	66 (97%)
The oximeter tells me when I need to give oxygen	59 (87%)
The oximeter acts as a warning signal to the surgeon	53 (78%)
The oximeter saves me from wasting oxygen	48 (71%)

qualification ($p = 0.72$), prior oximetry use ($p = 0.60$), prior oximetry teaching ($p = 0.12$) or the pre-donation reported frequency of oximetry use ($p = 0.20$).

Seventy-four out of 79 (94%) recipients completed a pulse oximeter feedback form. All respondents who used the oximeters felt that the oximeter improved the safety of their patients (Table 5). Portability, ease of use and interpretation, the rechargeable battery, and the audible tone were four themes most commonly mentioned as advantages of the pulse oximeter. All anaesthesia providers stated that they would recommend the Lifebox oximeter to their colleagues. Themes mentioned regarding the anaesthetists' change in practice since receiving the pulse oximeters included: (i) pre-oxygenation of sick and emergency patients; (ii) efficient and economical use of oxygen; (iii) better tailoring of interventions; and (iv) early and rapid assessment of patients' respiratory status in both the ward and the theatre environments.

Discussion

This project was undertaken as a collaboration between the AAGBI and the Uganda Society of Anaesthesia. Our most important finding was that oximetry and hypoxia management test scores improved after training and continued to improve at the follow-up visit. Anecdotally, most recipients felt that the oximeters aided in clinical decision-making and allowed for timely and effective use of manoeuvres to treat hypoxaemia promptly, even when supplemental oxygen was not available, for instance by suctioning the airway or manually assisting ventilation in room air.

The technique used in this study, of donating appropriately designed equipment to individual providers rather than institutions, coupled with an integrated training programme, succeeded in introducing this technology into clinical practice in hospitals in predominantly rural areas. The results of this study could have policy implications for donation of equipment to resource-constrained environments.

The challenges of providing safe surgical and anaesthesia services in sub-Saharan Africa have been well documented [27, 28], and previous survey data have described a shortage of essential drugs and equipment [12, 14, 19, 20, 29, 30]. However, simple donation of medical equipment may not result in a sustainable change in practice, and may be associated with problems [22, 31–33]. According to the WHO, nearly 80% of healthcare equipment in developing countries is funded by international donors or foreign governments [22], but many of these donations do not function at their intended destination. Common problems include: incompatibility with the local electrical supply, or an unreliable electrical supply; improper specifications such that heat, humidity and dust of the local environment render the equipment unusable; a lack of spare parts or local expertise to install or repair the equipment; a lack of a user's manual in the local language; and a lack of training in the use of equipment [23, 34]. The importance of training was highlighted by Malkin and Keane [33], who examined 2849 requests for equipment repair from 60 resource-poor hospitals in 11 nations in Africa, Europe, Asia and Central America. That study showed that 25% of equipment reported to be out of service was actually working, but could not be used as it had not been installed properly or the user had not been trained how to use it [33]. In our study, 75 out of 79 oximeters had been incorporated

into routine clinical use at the time of the follow-up visit.

The Lifebox Foundation oximeter proved suitable for use in theatre by anaesthetists in resource-limited countries, and the Lifebox training, delivered at the same time as the equipment donation, includes instruction in the practical use and care of the device, as well as training in clinical aspects of oximetry. The donation of pulse oximeters in this intervention was directly to the providers rather than their healthcare institutions. Fear of theft or misuse often results in the locking of equipment donated to institutions in offices where they may remain unused. In addition, health facilities may intermittently cease to provide surgical services due to limited supplies or personnel. The Ministry of Health and national anaesthesia society were aware where the donations had been made, but we found that donation of the oximeters directly to the anaesthetists had the advantage of allowing them to be relocated to areas where they were going to be used in clinical practice.

There are several limitations to this study. Firstly, the assessment test had not been validated in terms of improving clinical outcomes. However, as the oximetry and hypoxia training material, including the assessment test, was designed by an expert panel of anaesthetists with experience working in resource-limited settings, we suggest that the test has content and construct validity. Secondly, examination of clinical outcomes is exceptionally difficult in this setting and this was not addressed directly in this study; thus, we are unable to infer a definite improvement in anaesthesia management associated with the use of pulse oximetry or increased knowledge as a result of training. However, the anaesthetists anecdotally described changes in clinical practice that were consistent with appropriate use of the equipment. Thirdly, the study is limited in the relatively short follow-up period for evaluating the pulse oximeter. The oximeter and probe have a 2-year and 1-year manufacturer's warranty, respectively. Any electrical or mechanical malfunctions are unlikely to present themselves until near or after this timeframe. The durability of the specific pulse oximeter, probe and battery is the subject of ongoing follow-up.

The high rates of oximetry uptake into clinical practice suggest that the design and specifications of the Lifebox pulse oximeter are appropriate for rural Uganda. Knowledge of oximetry and hypoxia management, as measured by the assessment test, improved after training and this improvement was sustained through follow-up at 3–5 months. With this intervention, we were able to increase use of pulse oximetry by non-physician anaesthetists in rural hospitals in Uganda, at least on a temporary basis. This study describes an effective model for large-scale pulse oximeter distribution and training in a resource-limited setting.

Acknowledgements

This study was supported, in part, by grants from the AAGBI Foundation. IAW, JKK, LCF and ST received funding from AAGBI to conduct the study; the Lifebox oximeters and training course were funded by a donation from the AAGBI; IHW is ex-President of the AAGBI, and IAW is Vice President of the AAGBI, but neither participated in the decision to award grant funding; AAG, IAW and IHW are founding trustees and board members of the Lifebox charity.

Competing interests

The study sponsors had no role in: design of the study; collection, analysis or interpretation of the data; writing of this manuscript; or the decision to submit the article for publication.

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