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Article *in* World Journal of Surgery · October 2017

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ORIGINAL SCIENTIFIC REPORT

Impact of Surgical Lighting on Intraoperative Safety in Low-Resource Settings: A Cross-Sectional Survey of Surgical Providers

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Abstract

Background Safe surgery requires high-quality, reliable lighting of the surgical field. Little is reported on the quality or potential safety impact of surgical lighting in low-resource settings, where power failures are common and equipment and resources are limited.

Methods Members of the Lifebox Foundation created a novel, non-mandatory, 18-item survey tool using an iterative process. This was distributed to surgical providers practicing in low-resource settings through surgical societies and mailing lists.

Results We received 100 complete responses, representing a range of surgical centres from 39 countries. Poor-quality surgical field lighting was reported by 40% of respondents, with 32% reporting delayed or cancelled operations due to poor lighting and 48% reporting electrical power failures at least once per week. Eighty per cent reported the quality of their surgical lighting presents a patient safety risk with 18% having direct experience of poor-quality lighting leading to negative patient outcomes. When power outages occur, 58% of surgeons rely on a backup generator and 29% operate by mobile phone light. Only 9% of respondents regularly use a surgical headlight, with the most common barriers reported as unaffordability and poor in-country suppliers.

Conclusions In our survey of surgeons working in low-resource settings, a majority report poor surgical lighting as a major risk to patient safety and nearly one-third report delayed or cancelled operations due to poor lighting. Developing and distributing robust, affordable, high-quality surgical headlights could provide an ideal solution to this significant surgical safety issue.

Paper will be presented at the 18th COSECSA Scientific Conference in Maputo, Mozambique, December 4–8.

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Published online: 19 October 2017

Introduction

Surgical volume has increased dramatically in the past decade [1] [2], yet there are the estimated 140 million additional operations required annually to meet the minimum need for operative care [3]. The Lancet Commission for Global Surgery and the Disease Control Priorities programme evidenced the need for increasing surgical services and capacity, while also necessitating assurance for the quality of surgical care delivered [4, 5]. Surgical safety in low- and middle-income countries (LMICs) is a major, but poorly recognized public health issue that requires urgent attention.

Along with well-trained healthcare providers, certain fundamental equipment and infrastructure requirements are essential for delivering safe surgical care. High-quality lighting of the surgical field is one such requirement and is usually dependent on a reliable electricity supply. The World Health Organization (WHO) Service Availability and Readiness Assessment (SARA) classifies essential electrical equipment into: (1) infrastructure, (2) medical devices, and (3) support appliances for specific health services [6, 7]. Surgical lighting is part of both the infrastructure and support appliances for health services; therefore, it is a fundamental component of safe surgical care.

Electricity outages are common in low-resource settings and severely impact surgical lighting. In a study of eleven sub-Saharan African countries, only 28% of health facilities and 34% of hospitals had reliable access to electricity, defined as no outages of greater than 2 h in the past week [8]. High-quality theatre lights are nearly universally available in high-resource settings, yet many surgeons also wear headlights specifically designed to improve illumination of the surgical field. Such headlights are expensive, and their availability is limited in LMICs. Improving the consistency of surgical field illumination may have multiple benefits, such as reducing morbidity and increasing surgical volume through reduction in delays and cancellations.

Despite known unreliability of electricity in LMICs and the recognized need for quality lighting to provide surgical care, there is a paucity of literature on how electricity failures impact surgical lighting or how operating theatre lighting affects patient care. This study, through surveying surgical providers working in LMICs, aimed to assess the current state of surgical lighting and its perceived impact on surgical care.

Materials and methods

Definitions

For this study, quality of surgical lighting was defined as the ability to consistently illuminate the surgical field. LMICs were defined by standard economic criteria [9].

Questionnaire design and distribution

A novel, 18-item questionnaire survey was developed in English consisting of free text, binomial, and Likert-like scale responses [Appendix]. The questionnaire was designed with reference to previously published guidelines on questionnaire-based research [10, 11]. The survey tool was pilot-tested by surgeon and anaesthesia members of the study team with experience practicing in LMICs; content validity was ensured by this iterative process, and the feedback received was then used to further refine the question items. Individual question items were compulsory. Identifiable information collected (e.g. email address) was voluntarily provided. No incentives were offered for participation.

A link to the online survey (SurveyMonkey.com, LLC, Palo Alto, California, USA) was distributed to the members of different surgical societies through the College of Surgeons of East, Central, and Southern Africa (COSECSA), including the Surgical Society of Ethiopia, surgical specialty associations, and local and international surgical mailing lists. Individuals were also encouraged to share the link with their colleagues in a "snowball" recruitment strategy. Data collection took place from 17 December 2016 to 9 May 2017. Due to this snowball strategy, the survey response rate was not captured. The ethical dimensions of this voluntary evaluation survey were considered, and no concerns were identified; completion of the questionnaire was taken as implied consent to participation in this study; and IRB approval was not pursued.

This study was undertaken by the Lifebox Foundation (http://www.lifebox.org), a non-profit, charitable organization registered in the UK and USA. The Lifebox Foundation works to implement sustainable changes of practice that will ultimately raise the safety and quality standards of global surgery and anaesthesia.

Data analysis

Only fully completed questionnaires were included in the analysis. Mann–Whitney U test was used where appropriate for comparison between groups, and $p < 0.05$ was considered significant. Microsoft Excel (Microsoft, 2013, Redmond, Washington, USA) was used to calculate descriptive statistics. Free-text responses were independently categorized by theme into groups for analysis by four of the authors, with differences resolved by discussion.

Results

Respondent demographics

A total of 100 surveys were fully completed and included in the analysis. Respondents represented 39 countries, 85%

Table 1 Respondent demographics and practice settings

Demographic	Regional/National centres ($n = 67$)		Smaller referral centres ($n = 28$)		Others ($n = 5$)		Total ($n = 100$)
	N	%	*N*	%	*N*	%	*N*
Hospital setting							
Regional/national referral hospital	67	100	0	0.0	0	0	67
First referral hospital	0	0	9	32.1	0	0	9
District hospital	0	0	8	28.6	0	0	8
Private hospital	0	0	6	21.4	0	0	6
Other	0	0	0	0.0	5	100	5
Rural health clinic/health centre	0	0	3	10.7	0	0	3
Private clinic/health centre	0	0	2	7.1	0	0	2
Surgeon practice location							
Permanent	59	88	22	78.6	4	80	85
Visiting	6	9	5	17.9	0	0	11
Other	2	3	1	3.6	1	20	4
Surgical specialty							
General	39	58.2	18	64.3	3	60	60
Other	7	10.4	3	10.7	0	0	10
OB/GYN	7	10.4	2	7.1	0	0	9
Orthopaedic	4	6.0	3	10.7	0	0	7
Paediatric surgery	6	9.0	0	0.0	0	0	6
Plastic surgery	2	3.0	0	0.0	1	20	3
Cardiothoracic surgery	1	1.5	1	3.6	1	20	3
Neurosurgery	1	1.5	0	0.0	0	0	1
ENT	0	0.0	1	3.6	0	0	1

Legend. OB/GYN = obstetrician and gynaecologist; ENT = otolaryngologist. Smaller referral centres include first referral hospitals, district hospitals, private hospitals, rural health clinic/health centres, private clinic/health centres. Note: For categories of "hospital setting" and "surgeon practice location", respondents instructed that if working at many hospitals, it is the hospital where they work the most. If the respondent is a visiting surgeon, it is the main hospital where the respondent is visiting

being permanent practitioners in LMICs. The remainder were visiting surgeons who practice in LMICs, responding for the main LMIC hospital where they practice. A wide variety of surgical disciplines and surgical practice settings were represented with the majority practicing in regional/national referral hospitals (67%) (Table 1).

Current status of surgical lighting

40% of respondents reported the quality of the surgical lighting in their operating theatre as either poor or very poor, with no significant difference between surgical setting sizes (41.8% in regional/tertiary centres and 42.9% in smaller referral centres, $p = 0.87$) (Fig. 1). Electrical power failures were common. Almost half of respondents (48%) reported main power failure at least once per week, with nearly one-third of the respondents (32%) reporting operation delays or cancellations due to poor lighting. Most respondents reported their hospitals possess a backup generator (94%), though of those only 48% noted this backup to be always available. During power outages and

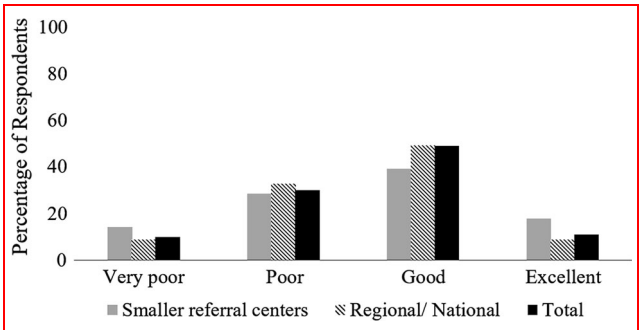

Fig. 1 Quality* of surgical lighting

the resultant failure of surgical field illumination, respondents reported a variety of solutions in the operating theatre, most commonly relying on the backup generator (58%) or the using a mobile phone light (29%). Only 9% reported using a surgical headlight regularly, with unaffordability (65%) and poor in-country suppliers (43%) being the most common barriers to headlight use (Table 2).

Table 2 State of surgical lighting in LMICs

Question	Regional/National centres (n = 67)		Smaller referral centres (n = 28)		Others (n = 5)		Total (n = 100)
	N	%	N	N	N	%	N
How often do you experience main electricity power failures while operating?							
Many times per day	6	9.0	5	17.9	1	20	12
Most days	15	22.4	2	7.1	0	0	17
Weekly	11	16.4	7	25.0	1	20	19
Monthly	4	6.0	1	3.6	1	20	6
Less often than monthly	17	25.4	5	17.9	0	0	22
Never	13	19.4	7	25.0	1	20	21
Other	1	1.5	1	3.6	1	20	3
Does your facility have a backup generator?							
Yes—always available	29	43.3	15	53.6	4	80	48
Yes—sometimes available	28	41.8	8	28.6	0	0	36
Yes—very unreliable	6	9.0	4	14.3	0	0	10
No	1	1.5	0	0.0	0	0	1
Do not know	2	3.0	0	0.0	0	0	2
Other	1	1.5	1	3.6	1	20	3
What do you do in your operating theatre when there is a main power failure?*							
Rely on backup generator	41	61.2	15	53.6	2	40	58
Use mobile phone light	22	32.8	6	21.4	1	20	29
Use torch/other battery-operated light	16	23.9	8	28.6	1	20	25
Use headlight	13	19.4	9	32.1	3	60	25
Stop operating	16	23.9	4	14.3	0	0	20
Not applicable (No power cuts)	9	13.4	6	21.4	1	20	16
Other	2	3.0	2	7.1	0	0	4
Do you ever delay or cancel operations due to poor lighting?							
Yes	26	38.8	4	14.3	2	40	32
No	41	61.2	24	85.7	3	60	68
Do you use a surgical headlight for operating?							
Yes, always	4	6.0	5	17.9	0	0	9
Yes, occasionally	26	38.8	13	46.4	3	60	42
No	37	55.2	10	35.7	2	40	49
What do you see as the main barrier(s) for having a surgical headlight?*							
The cost makes it unaffordable	44	65.7	19	67.9	2	40	65
Poor suppliers in my country	29	43.3	12	42.9	2	40	43
Only poor-quality/unsuitable headlights available to me	13	19.4	6	21.4	1	20	20
Not applicable/there are no barriers/I already own one	10	14.9	4	14.3	0	0	13
Never thought of this as a solution to poor lighting	10	14.9	2	7.1	0	0	12
Uncomfortable to use in my environment	8	11.9	4	14.3	1	20	13
Other	6	9.0	2	7.1	0	0	8
I do not want one	3	4.5	1	3.6	1	20	5

Legend. * = Multiple response question. Smaller referral centres include first referral hospitals, district hospitals, private hospitals, rural health clinic/health centres, private clinic/health centres

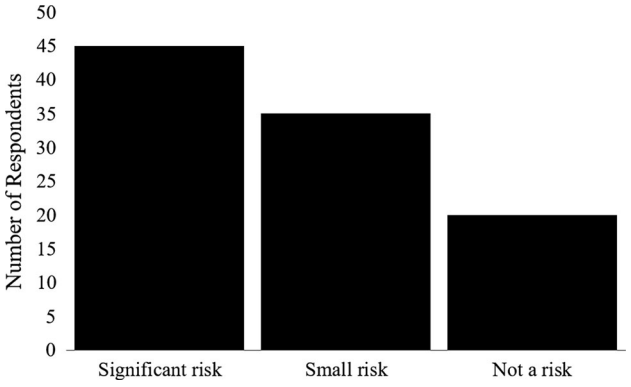

Fig. 2 Does the quality* of surgical lighting impact the safety for your patient?

Impact on patient safety

The majority of respondents (80%) reported the quality of surgical lighting in their operating theatre presented a patient safety risk. Eighteen per cent of respondents reported direct experience of adverse intraoperative events due to poor surgical lighting (Fig. 2) with two-thirds of these substantiated in qualitative comments. Of these responses, qualitative analysis revealed major themes with issues including unintended blood loss (5), inadvertent intestinal spillage/injury (4), and inadvertent nerve damage (1). A representative sample of qualitative comments received is provided in the text box [Box 1].

Discussion

Despite the known deficiencies of infrastructure in low-resource settings, this is the first study to investigate the extent and impact of surgical lighting on surgical capacity and patient safety and the effect of electrical power outages on surgical lighting. Surgical practitioners working in low-resource settings overwhelmingly report that poor-quality surgical field lighting is a major patient safety issue and decreases surgical capacity through delayed and cancelled operations.

Electricity is an essential component of basic hospital infrastructure [12]. In a study of sub-Saharan African facilities, less than 65% of all hospitals, and even fewer clinics, fulfil this basic infrastructural requirement [13]. In another study, all surveyed hospitals in Uganda reported frequent power outages [14]. At one centre in Uganda, 13% of operating days had at least one main operating theatre power outage, with a mean duration of 6 h and 40 min [15]. Operating theatre lighting is fundamentally reliant on a dependable electricity infrastructure [16].

In this survey, 40% of surgeons working in LMICs reported their operating theatre lighting as poor at best, with no statistical difference between the different levels of health facility. For our study, we defined quality of operating theatre lighting as the ability to consistently illuminate the surgical field, which incorporates both power (a representation of the lighting intensity) and time (consistency of availability). Poor-quality operating theatre lighting, either from low intensity or inconsistency, can lead to delays and cancellations, as reported by a third of the respondents.

The impact of unreliable electricity on patient safety is recognized, but poorly reported with only a few case reports highlighting this critical patient safety issue [17, 18]. A global literature review identified only two papers out of over 1500 linking electricity reliability and health outcomes [19]. Likewise, a WHO global literature review identified only a dozen of over 400 titles reporting the impact of electricity access on health outcomes, with no studies linking electricity access to health outcomes as a primary study objective [12].

Box 1 Representative qualitative comments from respondents regarding the harm to patients due to poor surgical lighting

Unintended blood loss

"During a caesarean section, there was excessive haemorrhage following a power cut as the surgeon could not control the bleeder [bleeding blood vessel] with the torches used. The patient needed a [blood product] transfusion which otherwise was totally unnecessary"

"We were trying to control bleeding in a case of a trauma due to road traffic accident. [The] patient did not pass, but we could have done better if there was adequate lighting"

"The patient had severe haemorrhage, and it was not possible to cauterize due to lack of electricity"

"Blood loss from inability to see bleeders [blood vessels]"

Inadvertent intestinal spillage/injury

"The patient had an iatrogenic bowel perforation that was missed"

"During a Hartman procedure [sigmoidectomy and colostomy], we [were] stuck in total shade, the backup generator was out of gasoline, and I had a little spillage of the colon [colonic contents] into the abdominal cavity"

"Injury to the bowel"

Inadvertent nerve damage

"While I was ligating a patent ductus arteriosus (PDA), I damaged the recurrent laryngeal nerve of a young girl because of poor visibility due to lack of good illumination"

Poor-quality surgical lighting is seen as a patient safety risk, as reported by 80% of respondents. Nearly one-fifth reported direct knowledge of an adverse patient outcome due to poor surgical lighting. Surgeons most commonly reported uncontrolled haemorrhage or inadvertent bowel injury, both indicative of lighting failures at crucial times during surgery. Also of importance, power outages, and subsequent surgical lighting issues, can affect surgeon safety. Almost 70% of surgical residents at a large referral centre in Ethiopia reported a needle-stick injury in the operating theatre during their training. The lack of appropriate operating equipment was cited as the most frequent cause for injury [20]. Given the low rate of surgeon hepatitis B vaccination [21] and the higher prevalence of human immunodeficiency virus (HIV) and hepatitis B in patients in LMICs, power cuts impacting surgical lighting present a substantial occupational work hazard.

Reliance on a backup generator is the most common solution when surgical lighting is affected by electricity failures, supporting the previous literature [12, 14, 22, 23]. Despite the overwhelming dependence on backup generators, over half of respondents reported they are not consistently available. In a previous survey of six sub-Saharan African countries, less than 29% were functional with fuel available on the day of the survey [12]. Even when generators are available, there are financial and time constraints. Issues with equipment repair, limitations in fuel supply, and the high cost of fuel can all impact the reliability of generators [12]. Additionally, there can be delays between the electricity failure and backup generator functioning, averaging 30 min at one large Ugandan referral hospital [15].

It is important to note that surgical lighting is more complex than simply ensuring reliable electricity supply. Surgical operating theatre lights in low-resource settings are often of poor quality and may not be present or work at all. Additionally, many battery-powered portable lights are of poor design and of little help, even if available. Surgical infrastructure, including ceiling lights, suction machines, diathermy, and anaesthesia machines, might be redesigned in such a way to improve durability and functioning with the inconsistent electricity supply of LMICs. In lieu of this, we argue that countries should have a standard when procuring medical equipment.

Non-generator solutions for illuminating the surgical field when electricity failures impact surgical lighting include headlights, cell phone lights, flashlights, and natural lighting through windows [24]. In our study, surgical providers were most likely to use mobile phone lights, followed by using another battery-powered light or a headlight. Many visiting surgeons working in LMICs bring battery-powered headlights with which to operate. These surgical headlights are common practice in high-resource settings, but affordability, poor in-country suppliers, and inappropriate design limit their use in low-resource settings. Providers have reported altering or fashioning camping headlights in order to better illuminate the surgical field [25, 26]; however, they are fraught with problems of poor design, light quality, and battery life. Other solutions include solar power: We Care Solar is an example of a non-profit specifically working to improve lighting for health facilities where power infrastructure is lacking [27].

Surgery requires reliable and high-quality lighting. Unreliable electricity supplies are common in LMICs with resultant negative consequences on surgical lighting. Importantly, poor surgical lighting negatively impacts patient and surgeon safety. Improving surgical lighting through more consistent electricity supply is important for surgical care, yet remains a challenging and complex infrastructural component to achieve. Dependable surgical lighting options are critical in order to deliver safe surgical care. Avenues for further investigation include lighting options independent of an existing power grid and purpose-built for functioning in these low-resource settings.

Limitations

There are limitations to the study. First, as with all research of this nature, the results may reflect an element of responder bias. Though given the paucity of previous research on this aspect of essential surgical infrastructure, these results provide an important baseline and thematic analysis to guide future work. Second, electrical power supply for operating theatre lighting is only one aspect of a much wider set of complex issues that need to be addressed in order to build surgical capacity in these settings. However, surgical field lighting has a potentially simple solution that can be addressed without an infrastructural overhaul of electricity supply. Third, although the number of responses received is relatively low, the wide distribution of the survey responses with representation of all hospital settings across a range of LMICs helps mitigate against undue focus on any one subgroup.

Conclusion

In LMICs, the majority of respondents report poor surgical lighting as a major risk to patient safety and nearly one-third report delayed or cancelled operations due to poor lighting. Improving electricity supply is a complex issue to address, and while most surgeons rely on a backup generator, they are often unreliable. A purpose-built lighting element independent of an existing power grid would be a viable option for operating in these settings. The

development of robust, affordable, high-quality surgical headlight could provide an ideal solution to the substantial surgical safety issue.

Acknowledgments The authors would like to thank the survey respondents; Luca Koritsanzky, Sibonile Mathe, and Sarah Kessler for their coordination of efforts within the Lifebox Foundation; and Rosemary Mugwe, Chief Executive Officer of COSECSA, for help in the questionnaire distribution.

Compliance with ethical standards

Conflict of interest All authors have been involved in Lifebox activities. JAF is a current Lifebox fellow; NJB and JEFF were former fellows; JEFF is currently an honorary clinical fellow; IHW and TGW are trustees of Lifebox UK and US, respectively; AB is the Ethiopia Lead for Clean Cut, a Lifebox programme to improve surgical safety. There was no funding for this project.

Appendix: Lifebox surgical lighting survey

1. Which of these best describes your hospital?
If you work in many hospitals, please complete for the hospital where you work the most. If you are a visiting surgeon, please complete for the main hospital you visit.

- ○ Rural health clinic / health centre
- ○ District hospital
- ○ First referral hospital
- ○ Regional / national referral hospital
- ○ Private clinic / health centre
- ○ Private hospital
- ○ Other (please specify)

Please answer all the following questions based on this hospital

2. Overall, how would you rate the quality of the lighting in your operating theatre?
By quality, we mean the ability to consistently illuminate the surgical field

- ○ Very poor
- ○ Poor
- ○ Good
- ○ Excellent

3. How often do you experience main electricity power failures while operating?

- ○ Many times each day
- ○ Most days
- ○ Weekly
- ○ Monthly
- ○ Less often than monthly
- ○ Never
- ○ Other (please specify)

4. Does your facility have a backup generator?

- ○ Yes - always available
- ○ Yes - sometimes available
- ○ Yes - very unreliable
- ○ No
- ○ Do not know
- ○ Other (please specify)

5. What do you do in your operating theatre when there is a main power failure?
(check all that apply)

- ☐ Use mobile phone light
- ☐ Use a torch / other battery operated light
- ☐ Use a headlight
- ☐ Stop operating
- ☐ Rely on the backup generator
- ☐ Not applicable (No powercuts)
- ☐ Other (please specify)

6. Do you ever delay or cancel operations due to poor lighting?

- ○ No
- ○ Yes

If yes, how often do you have to do this?

7. Do you use a surgical headlight for operating?

- ○ Yes, always
- ○ Yes, occasionally
- ○ No

If No, please explain why

8. What 5 features would be most important to you for a surgical headlight?
Please select 5 options from the 10 available

- ☐ Rechargeable battery
- ☐ Ability to adjust diameter of light focus
- ☐ Ability to change brightness of the light
- ☐ Compatibility with eyeglasses and surgical loupes
- ☐ Separate belt/pocket battery pack
- ☐ Lightweight on head
- ☐ Easy to carry around
- ☐ Durable
- ☐ Pure white light
- ☐ Comfortable fit

Other (please specify)

9. How much would you spend on a high quality headlight with the above features, in USD ($)?

10. What do you see as the main barrier(s) for having a surgical headlight?
(check all that apply)

- ☐ The cost of specific surgical headlights make it unaffordable for me
- ☐ Never thought of this as a solution for poor lighting
- ☐ Poor suppliers in my country
- ☐ Only poor quality/unsuitable headlights available to me
- ☐ Uncomfortable to use in my environment
- ☐ I do not want one
- ☐ Not applicable (there are no barriers / I already have one)
- ☐ Other (please specify)

11. In general, does the quality of surgical lighting impact the safety for your patients?
By quality, we mean the ability to consistently illuminate the surgical field

- ○ The quality of lighting in my theatre(s) is a ***significant risk*** to the safety of my patients
- ○ The quality of lighting in my theatre(s) is a ***small risk*** to the safety of my patients
- ○ The quality of lighting in my theatre(s) is ***not a risk*** to the safety of my patients

12. Do you know of a patient who has come to harm because of poor lighting? (eg. during a power failure)
This can be a patient of yours or a case you heard about

- ○ No
- ○ Yes
- ○ Do not know

If possible, can you describe what happened

13. What country do you work in?
Please complete for the hospital you referred to in question 1

14. Are you permanently based here or a visiting surgeon?

- ○ Permanent (or long term resident in this country)
- ○ Visiting surgeon
- ○ Other (please specify)

15. What surgical specialty do you practice?
Please choose one that BEST describes your practice

16. What is your email address? (optional)

17. Would you like to be included on the Lifebox mailing list to receive updates on this and other projects?

Yes

No

18. Any other comments you would like to add?

Respondents agree to anonymous use of responses in scoping provision of a Lifebox headlight device for surgeons, and to presentation and/or publication of the results where appropriate. No individual will be identified as part of this survey.

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