

Improving productivity, costs and environmental impact in International Eye Health Services: using the 'Eyefficiency' cataract surgical services auditing tool to assess the value of cataract surgical services

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To cite: Goel H, Wemyss TA, Harris T, *et al.* Improving productivity, costs and environmental impact in International Eye Health Services: using the 'Eyefficiency' cataract surgical services auditing tool to assess the value of cataract surgical services. *BMJ Open Ophthalmology* 2021;**6**:e000642. doi:10.1136/bmjophth-2020-000642

Received 21 October 2020
Revised 30 March 2021
Accepted 29 April 2021



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ABSTRACT

Objective Though one of the most common surgeries, there is limited information on variability of practices in cataract surgeries. 'Eyefficiency' is a cataract surgical services auditing tool to help global units improve their surgical productivity and reduce their costs, waste generation and carbon footprint. The aim of the present research is to identify variability and efficiency opportunities in cataract surgical practices globally.

Methods and Analysis 9 global cataract surgical facilities used the Eyefficiency tool to collect facility-level data (staffing, pathway steps, costs of supplies and energy use), and live time-and-motion data. A point person from each site gathered and reported data on 1 week or 30 consecutive cataract surgeries. Environmental life cycle assessment and descriptive statistics were used to quantify productivity, costs and carbon footprint. The main outcomes were estimates of productivity, costs, greenhouse gas emissions, and solid waste generation per-case at each site.

Results Nine participating sites recorded 475 cataract extractions (a mix of phacoemulsification and manual small incision). Cases per hour ranged from 1.7 to 4.48 at single-bed sites and 1.47 to 4.25 at dual-bed sites. Average per-case expenditures ranged between £31.55 and £399.34, with a majority of costs attributable to medical equipment and supplies. Average solid waste ranged between 0.19 kg and 4.27 kg per phacoemulsification, and greenhouse gases ranged from 41 kg carbon dioxide equivalents (CO₂e) to 130 kg CO₂e per phacoemulsification.

Conclusion Results demonstrate the global diversity of cataract surgical services and non-clinical metrics. Eyefficiency supports local decision-making for resource efficiency and could help identify regional or global best practices for optimising productivity, costs and environmental impact of cataract surgery.

INTRODUCTION

Cataract surgeries are one of the most extensively performed surgical procedures in the

Key messages

What is already known about this subject?

- ▶ Global healthcare emits nearly 5% of all greenhouse gases. Given the number of cataract and other ophthalmic procedures conducted, more should be done to understand and mitigate the footprint of ophthalmic services. The few studies that exist for ophthalmology have only analysed the environmental footprint of phacoemulsification (phaco), but have found large variations in emissions—a single phaco at a high-volume Indian eye care centre emits about 5% of the greenhouse gases of a phaco performed in the UK.

What are the new findings?

- ▶ This study reports the productivity, costs, carbon emissions and waste generation from nine global cataract surgical facilities that participated in beta testing of a new surgical services auditing tool called Eyefficiency. Results from the site show large variation in non-clinical outcomes for phaco and manual small incision cataract surgery approaches, including case-to-case duration ranging between 13 and 72 min for phaco and a 22-fold difference in solid waste generation between the lowest and highest generating sites.

world. With over 65 million people experiencing cataracts, the WHO and International Agency for Prevention of Blindness (IAPB) pledged support to eliminate avoidable blindness by 2020 as part of the 'Vision 2020: The right to sight' initiative,^{1 2} but increasing elderly populations and inadequate services mean that this goal has not been achieved and the problem is worsening. The goal is to build strong and equitable eye health systems by training more eye doctors, nurses



Key messages

How might these results change the focus of research or clinical practice?

- ▶ These results show that effective cataract removal can be achieved with large variability in non-clinical outcomes, pointing towards opportunities to optimise or reduce the environmental and public health impact of eye care. As ophthalmologists and the general public become more concerned about environmental and public health issues like climate change, more must be done to understand where clinical and operational improvements can be made. The Eyeefficiency auditing tool demonstrates such opportunities to individual surgical teams whilst also providing a larger dataset on regional variation or variation by surgical approach.

and optometrists and performing more surgeries worldwide to provide comprehensive eye care services to all. According to the 2019 World Report on Vision, the use of eye care services is governed by availability, affordability, accessibility and acceptability.³ Shortage of trained human resources, socioeconomic status, direct and indirect costs, and cultural factors are some principal barriers to eye care services. A study conducted in Nepal showed that by employing simplified surgical techniques, developing local lens factories and through implementing teaching programmes, cataract surgeries can be done in higher volumes at lower costs.⁴

Unfortunately, healthcare services are also major consumers of finite resources and significantly contribute to environmental emissions such as greenhouse gases (GHGs) that impact public health.^{5–8} Global healthcare emits nearly 5% of all GHGs, with country variations.⁹ Developed countries' healthcare sectors are responsible for a greater share of emissions, with 10% of the US's emissions coming from healthcare, 7% of Australia's and nearly 5% of Canada's, Japan's, and the UK's.^{10–15} As a commonly performed procedure and with increasing numbers globally, cataract extraction should be a target for reducing resource use and emissions; however, not many tools exist to measure and compare cataract and other surgical emissions, especially in low-income settings.

Where cataract surgery's footprint has been measured, phacoemulsification (phaco) was found to have large variations in GHG emissions. According to Thiel *et al*, a phaco procedure at Aravind emits only about 5% of the GHGs of a phaco performed in the UK.^{16 17} Other approaches to cataract surgery, such as manual small incision cataract surgery (MSICS), femtosecond laser-assisted cataract surgery, extracapsular cataract extraction (ECCE) and same-day bilateral surgery have not been studied at all, and may present opportunities to improve throughput and reduce costs and emissions.^{18–20} A broader approach to sustainability in eye care appears to be a timely topic, with national surveys in the USA, Australia, and New Zealand identifying waste and carbon emissions as a concern to a majority of participating ophthalmologists and ophthalmic nurses.^{21 22}

Despite much progress in increasing cataract surgical rates (or productivity) and associated cost containment, there is no audit tool which facilitates capture of routine cataract surgical productivity, carbon and cost-related data which could be used for global benchmarking, learning and improvement. The ability to identify environmentally effective surgical processes may help with global knowledge sharing to reduce the environmental burden of medical services. The Eyeefficiency tool calculates and benchmarks the throughput, cost, waste generation and the life cycle assessment (LCA)-based carbon footprint of surgical services at units worldwide.

DESIGN AND METHODS**Website and application design**

The Eyeefficiency tool consists of a website and mobile phone application (app) with a built-in toolkit on how to use the tool, thus avoiding the need for external support.²³ The Eyeefficiency tool successfully completed its first phase of piloting at four sites from the UK, India and South Africa in 2017.²³ On confirming its feasibility, Eyeefficiency garnered further support for continued development from the IAPB and Standard Chartered Bank's Seeing is Believing grant. This helped the tool move on to its second phase of beta testing, which has completed two rounds, to date. This study reports the results of the second round of beta testing.

Beta sites were identified and each created a site-specific account on the website into which they entered facility-level data. The data entries were divided into five categories: basic information, which consisted of variables like facility location, number of operating theatres (OTs) used and number of cataract surgeries performed per year; patient pathway, which consisted of the number of appointments before and after surgery, number of patients on waiting list; staffing, where they entered information on the number and salary of staff involved in cataract surgical care; building where information on energy sources and the prices paid for them was collected; and materials which took into account the cost of surgical supplies and pharmaceuticals and end-of-life processes.

The sites then used the Eyeefficiency app to record time-and-motion (TAM) data for their cataract surgeries. This phone app allowed the designated point person tasked with collecting TAM data to select the surgical procedure type and then press the time-stamp button at different milestones throughout the procedure. The procedural milestones are: (1) the patient is on the operating table, (2) the surgical drape is on the patient, (3) the first incision is made, (4) the incision is closed, (5) the drape is removed and (6) the patient is off the operating table. This allows the Eyeefficiency tool to differentiate between the time spent physically operating on the patient and the time spent 'turning over' the OT in between patients. At the end of each surgical session, the surgical site can also record the total weight of surgical waste produced, using the Eyeefficiency app. Prior to and after recording each case's milestones, the user inputs data on additional

factors that may impact this specific case, including the presence of clinicians-in-training and any operative complications that arose during the case.

Beta site selection and timeline

To test if the tool is universally accessible and acceptable and to capture regional variation, we sought to beta test at least one site in each of the seven IAPB/WHO regions. We contacted IAPB regional representatives to suggest surgical facilities that may have the capacity to test the tool, and out of the 28 shortlisted facilities, 24 met the requirements of the audit and agreed to participate. A point person at each beta site created a profile on the Eyeefficiency website and downloaded the app, leading the beta testing at their facility. Of these initial 24 sites, 12 successfully completed the first audit round from October to December of 2018. This initial beta testing was used to improve the functionality and performance of Eyeefficiency.

A second round of beta auditing ran from April through May 2019, with nine sites successfully completing the testing. Eight of the sites completed the first audit round and one site was new to Eyeefficiency. Site attrition was primarily due to a lack of personnel available to conduct the in-surgery audit. In this paper, we report only the results of the second round of beta testing, from these nine sites spread throughout five IAPB regions.

The time spans were chosen to align with periods when all sites would be operating on cataracts (non-holiday times) and in a long enough window to ensure each site completed 1 week of, or at least 30 cases, whichever came first. The time between the two audit periods was used to improve Eyeefficiency.

The beta test sites entered data about their facility into the Eyeefficiency website and used the Eyeefficiency app on a phone/tablet to gather information on their phaco, MSICS or ECCE cataract surgical sessions. After each audit round, the participating sites were administered an online qualitative survey asking them questions about their experiences using the tool. Two members of the Eyeefficiency team also conducted semistructured interviews with each site, either in person or through video-conference calls, to discuss and validate the site's results clarify any unexpected data, and enquire about strategies the site was developing to reduce their costs and carbon footprint or improve productivity.

Beta site data analysis

Case-to-case duration at each site was calculated by separating the type of procedure (phaco, MSICS, etc) and measuring the average number of minutes needed for each procedure step (ex: preoperative preparation in the OT, cut-to-close operating time, postoperative clean up where the patient is still in the OT and turnover time where no patients are present in the OT). SDs of each duration were calculated for each site for each type of procedure. The 'cases per hour' metric was calculated by taking the total recorded operating minutes and dividing

by the total number of cases. In surgical lists that had both MSICS and phaco, MSICS cases per hour were calculated by separating out the MSICS cases and assigning half of the turnover time from before and after the MSICS case to that case. The remaining half of turnover time was assigned to the phaco case before and after the MSICS.

Supply and pharmaceutical costs per case were directly input by users. Cost of salaries per case was calculated using the user's estimate of how long each staff member spent with a patient on the day of surgery and that staff member's annual salary. Electricity costs were calculated by estimating the electricity intensity in kWh/m² of the OT from the facility's electricity bill and multiplying by an OT intensity factor from literature. Based on the number of cases performed yearly in that OT, the average kWh per case was calculated and multiplied by the local price per kWh. This approach allocates OT downtime, that is, times when the OT is operational but not in use, to every case. Cost of laundry and sterilisation was either directly input by the user, or estimated based on assumed electricity use of the cleaning process and local price per kWh. Waste disposal costs were calculated based on prices input by the user and the amount of waste generated per case.

Carbon footprint or GHG emissions from activities at each site were calculated using a hybrid environmental LCA approach according to ISO 14040 standards. The LCA used both process LCA with physical data (including electricity use, commuting of staff and patients, reusable supply production and sterilisation, and waste treatment) and an environmentally extended input-output LCA with financial data (including the production of single use supplies) to estimate average emissions per case from each site. Further details on the methods can be found in Thiel *et al's* 2020 article.²³

After calculating the productivity (case duration), cost per case and GHG emissions per case, we compared across sites using descriptive statistics.

RESULTS

Site demographics

Of the initial 24 sites invited to participate in this second round of beta testing, 14 initiated the auditing process on either the Eyeefficiency website or the app, and 9 sites fully completed the audit. The nine sites were located in five of the IAPB/WHO regions (with no sites from North America and Eastern Mediterranean Regions), and use seven different currencies (table 1, figure 1). Five of the sites have 'dual bed' systems, where each surgeon alternates operations on two side-by-side beds.

Eyeefficiency was used to monitor 475 cases across all beta sites and 30–187 cases per site, representing 0.4%–6.7% of each site's annual caseload. Annual caseload of beta site locations ranges from 565 cataract surgeries per year to 47 102. All nine sites perform phaco, six perform MSICS, four perform ECCE and two perform 'other' approaches (such as cataract surgery with the femto-second laser). The number of phacos each site measured

Table 1 Summary of data and results from the nine beta test sites

| Country | Mexico, 1 | Mexico, 2 | Chile | Swaziland | South Africa | India | New Zealand | UK | Hungary |
|---|-----------------------|-----------------------|-----------------------|----------------------|-----------------------|-------------------------|----------------------|-----------------------|-----------------------|
| Total cases: monitored, conducted annually (% monitored) | 30/4414 (0.68) | 31/1128 (2.75) | 50/1002 (4.99) | 32/862 (3.71) | 30/2200 (1.36) | 187/47102 (0.40) | 38/565 (6.73) | 40/4792 (0.83) | 37/1630 (2.27) |
| <i>Phaco</i> | 30/3485 (1) | 26/807 (3) | 50/1000 (5) | 10/147 (7) | 28/2000 (1) | 53/14 543 (0) | 33/530 (6) | 40/4786 (1) | 37/1600 (2) |
| <i>MSICS</i> | 0/476 (0) | 5/321 (2) | 0/0 (0) | 22/715 (3) | 1/200 (1) | 133/32 335 (0) | 5/35 (14) | 0/0 (0) | 0/0 (0) |
| <i>ECCE</i> | 0/453 (0) | 0/0 (0) | 0/2 (0) | 0/0 (0) | 0/0 (0) | 0/0 (0) | 0/0 (0) | 0/6 (0) | 0/20 (0) |
| <i>Other</i> | 0/0 (0) | 0/0 (0) | 0/0 (0) | 0/0 (0) | 0/0 (0) | 0/224 (0) | 0/0 (0) | 0/0 (0) | 0/10 (0) |
| Floor area: m ² OT/m ² hospital | 35/3000 | 35/1700 | 35/6940 | 102/7192 | 35/8600 | 35/21897 | 35/425 | 35/100 000 | 35/100 000 |
| Renewable energy? (annual %) | No | No | No | No | No | 0.2 | No | No | No |
| Regular diesel use? (annual %) | No | No | No | No | No | 0.0 | No | No | 0.0 |
| Dual bed system? | Yes | Yes | No | Yes | Yes | Yes | No | No | No |
| Average days per week operating on cataracts | 4 | 5 | 2 | 2 | 5 | 6 | 3 | 5 | 4 |
| Average preoperative appointments (phaco) | 2 | 2 | 5 | 2 | 1 | 1 | 1 | 2 | 1 |
| Average postoperative appointments (all types) | 3 | 3 | 3 | 3 | 2 | 1 | 1 | 1 | 2 |
| Total number of staff present on day of surgery | 6 | 7 | 6 | 6 | 5 | 10 | 6 | 9 | 9 |
| Phaco | | | | | | | | | |
| Phaco cases per hour | 2.92 | 1.51 | 4.48 | 3.14 | 2.01 | 4.25 | 1.70 | 1.94 | 3.61 |
| Phaco case-to-case duration: minutes (SD) | 38.9 (23.3) | 70.6 (18.4) | 13.4 (4.4) | 25.7 (12.6) | 57.5 (28.0) | 38.1 (39.8) | 35.3 (19.6) | 29.9 (16.5) | 16.4 (11.5) |
| <i>Preoperative</i> | 16.80 | 25.69 | 4.45 | 7.02 | 16.38 | 10.86 | 10.35 | 4.18 | 1.85 |
| <i>Operating</i> | 14.59 | 22.39 | 6.27 | 11.36 | 14.54 | 1.94 | 13.30 | 12.05 | 9.18 |
| <i>Postoperative</i> | 3.86 | 13.05 | 2.02 | 1.97 | 3.43 | 2.11 | 2.43 | 2.70 | 1.55 |
| <i>Turnover</i> | 3.69 | 9.51 | 0.65 | 5.34 | 23.12 | 23.15 | 9.22 | 10.98 | 3.79 |
| Phaco cost per case: £ | 162.36 | 365.74 | 69.72 | 66.29 | 79.48 | 31.55 | 399.34 | 211.87 | 278.52 |
| <i>Staff salaries</i> | 13.24 | 23.93 | 13.77 | 30.15 | 14.72 | 0.56 | 60.56 | 43.85 | 21.43 |
| <i>Reusable supplies</i> | 1.76 | 0.12 | 2.30 | 0.30 | 2.83 | 0.09 | 4.82 | 16.62 | 0.20 |
| <i>Disposable supplies</i> | 144.66 | 338.38 | 50.16 | 25.36 | 60.43 | 30.72 | 331.91 | 146.86 | 254.39 |

Continued

Table 1 Continued

| Country | Mexico, 1 | Mexico, 2 | Chile | Swaziland | South Africa | India | New Zealand | UK | Hungary |
|--|------------|---------------|------------|--------------|--------------|--------------|---------------|------------|------------|
| Waste treatment | 0.82 | 2.46 | 1.38 | 0.51 | 0.76 | 0.04 | 0.00 | 1.25 | 0.47 |
| Energy | 1.87 | 0.86 | 2.11 | 9.99 | 0.74 | 0.14 | 2.05 | 3.29 | 2.03 |
| Phaco GHGs per case: kg CO₂e | 114 | 121 | 86 | 98 | 55 | 41 | 123 | 67 | 130 |
| Patient and staff travel | 73.20 | 34.48 | 62.30 | 37.16 | 20.90 | 28.80 | 32.62 | 19.20 | 50.10 |
| Reusable supplies | 2.44 | 1.22 | 1.68 | 2.91 | 4.70 | 3.16 | 3.39 | 2.55 | 3.59 |
| Disposable supplies | 34.45 | 80.59 | 12.21 | 6.03 | 14.45 | 7.32 | 81.25 | 35.95 | 61.84 |
| Waste treatment | 1.33 | 3.99 | 2.29 | 0.82 | 1.24 | 0.07 | 0.65 | 2.09 | 0.78 |
| Energy | 2.98 | 0.64 | 7.32 | 51.45 | 13.33 | 1.43 | 4.84 | 7.67 | 13.40 |
| One case equivalent to driving X km | 460 | 487 | 345 | 396 | 220 | 164 | 494 | 271 | 522 |
| Phaco garbage per case: kg (SD) | 0.67 | 2.23 | 1.32 | 0.19 | 1.06 | 0.87 | 0.33 | 4.27 | 0.71 |
| MSICS | | | | | | | | | |
| MSICS cases per hour per surgeon | N/A | 0.69 | N/A | 1.95 | 0.77 | 2.77 | 1.82 | N/A | N/A |
| MSICS case-to-case duration: minutes (SD) | | 87.52 | | 30.82 | 77.74 | 21.65 | 32.91 | | |
| Preoperative | | 14.62 | | 9.39 | 16.92 | 7.95 | 11.44 | | |
| Operating | | 51.03 | | 17.41 | 41.07 | 1.36 | 14.63 | | |
| Postoperative | | 17.80 | | 2.41 | 2.95 | 1.89 | 2.69 | | |
| Turnover | | 4.07 | | 1.62 | 16.79 | 10.44 | 4.15 | | |
| MSICS cost per case: £ | | 252.40 | | 51.70 | 79.48 | 30.32 | 385.22 | | |
| Staff salaries | | 23.93 | | 30.15 | 14.72 | 0.56 | 60.56 | | |
| Reusable supplies | | 0.12 | | 0.30 | 2.83 | 0.08 | 4.81 | | |
| Disposable supplies | | 225.04 | | 10.77 | 60.43 | 29.50 | 317.81 | | |
| Waste treatment | | 2.46 | | 0.51 | 0.76 | 0.04 | 0.00 | | |
| Energy | | 0.86 | | 9.99 | 0.74 | 0.14 | 2.05 | | |
| MSICS GHGs per case: kg CO₂e | | 93.93 | | 94.90 | 54.63 | 40.44 | 119.26 | | |
| Patient and staff travel | | 34.48 | | 37.16 | 20.90 | 28.80 | 32.62 | | |
| Reusable supplies | | 1.22 | | 2.91 | 4.70 | 3.11 | 3.36 | | |
| Disposable supplies | | 53.60 | | 2.56 | 14.45 | 7.03 | 77.79 | | |

Continued

Table 1 Continued

| Country | Mexico, 1 | Mexico, 2 | Chile | Swaziland | South Africa | India | New Zealand | UK | Hungary |
|--|-----------|---------------|-------|---------------|---------------|---------------|---------------|----|---------|
| <i>Waste treatment</i> | | 3.99 | | 0.82 | 1.24 | 0.07 | 0.65 | | |
| <i>Energy</i> | | 0.64 | | 51.45 | 13.33 | 1.43 | 4.84 | | |
| One case equivalent to driving X km | | 377.90 | | 381.81 | 219.80 | 162.69 | 479.87 | | |
| MSICS garbage per case: kg (SD) | | 2.29 | | 0.18 | 0.00 | 0.00 | 0.19 | | |

Entries in italics represent broken-down components of key results (in bold).

CO₂e, carbon dioxide equivalent; ECCE, extracapsular cataract extraction; GHGs, greenhouse gases; MSICS, manual small incision cataract surgery; N/A, not available; OT, operating theatre; phaco, phacoemulsification.

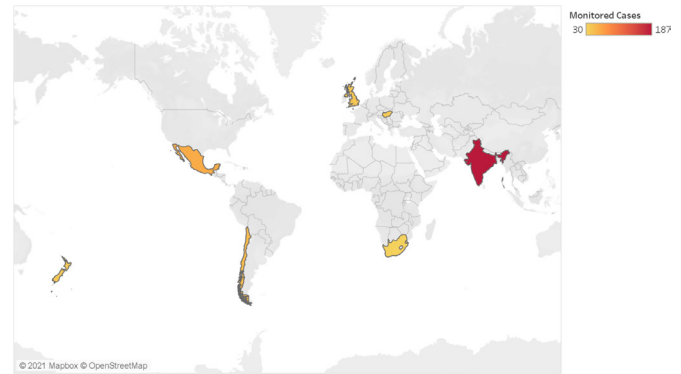


Figure 1 Eyeefficiency beta test site locations and number of cases monitored.

using Eyeefficiency ranged from 10 to 52 per site. Of the MSICS sites, one site logged only 1 case through Eyeefficiency, two sites logged 5 cases, one site logged 22 cases and one site logged 133 cases (table 1). After data validation, no ECCE cases were recorded. Given the lack of data on ECCEs, their results are not discussed further in this paper. Other approaches, such as the femtosecond laser, are not yet supported in Eyeefficiency and were not measured.

Every site reported surgeries conducted by trainee surgeons, with 123 out of the 475 recorded cases having a trainee involved. At each site, trainee cases ranged from 3 to 54 cases per site or 6%–48% of total cases recorded per site. The Eyeefficiency tool also allows sites to record common surgical complications that may occur. These complications include phaco wound burn and posterior capsule rupture. Of all 475 recorded cases, there were 45 cases (9%) with complications. Three sites reported 0 complications, two reported 1 case with complications (0.5%–2% of recorded cases), one reported 3 cases (10%), one reported 7 (18%), one reported 12 (32%) and one reported 21 (66%).

Sites operate on cataracts between 2 and 6 days a week (average and median of 4). For patient pathways, the beta sites conduct between one and five preoperative visits (median of 2) with each patient (separate from the day of surgery) for average cases. Postoperative visits range between one and three visits per site, with a median of 2. For staffing needed prior to surgery, an average of two nurses per site saw patients preoperatively, with a maximum of four (India) and a minimum of zero (Mexico 2). Other staff members required for preoperative appointments, including booking or administrative personnel, ranged from one to five people per site, with a median of 1. On the day of surgery, the total number of staff that came into contact with the patient was highest for India, at 10 staff members, and lowest for South Africa with 5 staff members. The median number of staff members for across all sites was 6.

Productivity, throughput or use of operating time

Average case-to-case duration across sites ranged from 13 min (Chile) to 71 min (Mexico 2) for phaco, with a

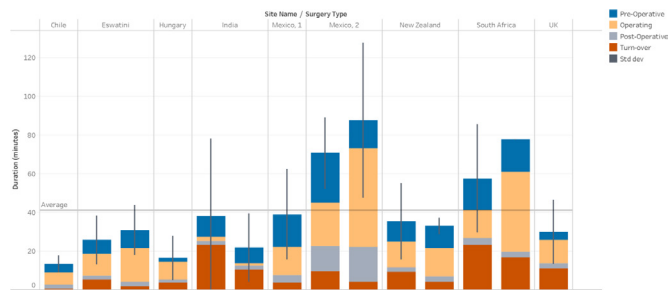


Figure 2 Average case-to-case duration per bed for phacoemulsification (phaco) and manual small incision cataract surgery (MSICS) at all beta site locations. Error bars represent SD in case-to-case duration at each site. Sites with no MSICS results did not conduct MSICS cases.

cross-site average of 36 min. For MSICS, average case-to-case duration ranged between 22 min (India) and 88 min (Mexico 2), with an average of 50 min (figure 2). Of note, the case-to-case duration looks only at a single bed and does not account for the potential efficiencies of a dual bed system. Of the sites operating on a single bed, surgical teams spent an average of 25% (South Africa phaco) to 56% (Hungary phaco) of the case-to-case duration actually operating (cut-to-close). Turnover time (time without the patient in the operating room (OR)) accounted for 5% (Chile phaco) to 40% (South Africa and UK phaco) of total case-to-case duration at each single-bed site. Cases per hour (for combined phaco and MSICS) ranged from 1.7 to 4.48 at single-bed sites and from 1.51 to 4.25 at dual-bed sites.

Average cost per case

Converting all local currencies to 2017 Great British pound (GBP) (prior to the COVID-19 pandemic and any economic or supply issues therein), price per case ranged between £31.55 (India) and £399.34 (New Zealand), with the price of disposable supplies making up more than 70% of expenditures per case (both phaco and MSICS) at all sites except Eswatini (also known as Swaziland), where supply spending makes up 38% of all measured

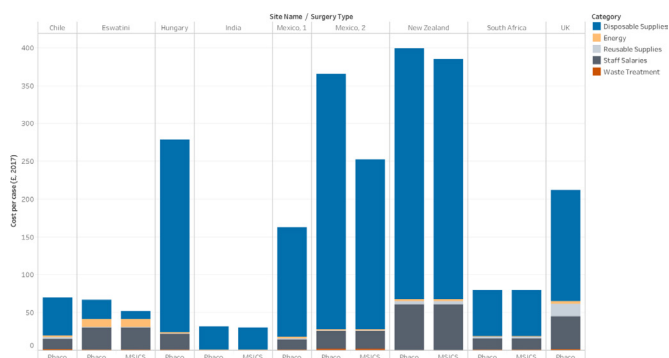


Figure 3 Average costs per case for phacoemulsification (phaco) and manual small incision cataract surgery (MSICS) at all beta site locations in 2017 Great British pounds. There are no error bars as data were collected only as an average. Sites with no MSICS results did not conduct MSICS cases.

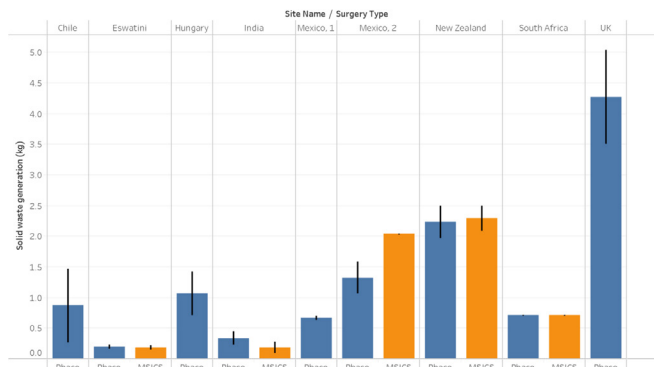


Figure 4 Average weight of solid waste generation for phacoemulsification (phaco) and manual small incision cataract surgery (MSICS) at all beta site locations. Error bars represent SD in waste generation at each site. Sites with no MSICS results did not conduct MSICS cases.

expenses (figure 3). The next highest category of expenditures at all sites was for staff salaries, ranging from 2% (India; and still the second highest spending category) to 45% of per-case expenditures. For Eswatini, staff salaries represented the highest spending, at 45% of per-case expenses. Energy expenses per case ranged from 15% of total expenses (Eswatini), to less than 3% at all other sites.

Environmental footprint

Average weight of solid waste generation per phaco ranged between 0.19 kg per case (Eswatini) and 4.27 kg (UK), a 22-fold difference between the lowest generating and highest generating sites. For MSICS, solid waste at each site ranged between 0.18 kg per case (Eswatini) and 2.29 kg (New Zealand), shown in figure 4.

Average per-case GHG emissions ranged from 41 kg carbon dioxide equivalent (CO₂e) (India) to 130 kg CO₂e (Hungary) for phaco. This is equivalent to driving a passenger vehicle between 164 and 522 km.²⁴ For MSICS, GHG emissions ranged between 40 kg CO₂e (India) and 119 kg CO₂e (New Zealand), shown in figure 5. This is equivalent to driving a car between 163 and 480 km. At four sites (Mexico 1, Chile, India and South Africa), majority of emissions for phaco and MSICS originated from patient and staff travel (38%–73% of per-case emissions). The procurement of single-use or disposable supplies (including their manufacturing and upstream logistics) made up the largest proportion of GHGs at four other sites (the UK, Hungary, Mexico 2 and New Zealand), ranging from 48% to 67% of per-case emissions at each site. The exception is Eswatini, where energy production made up 52% of their GHG emissions (more than commuting and procurement of supplies), though this may be due to this site operating only 2 days a week and the assumptions made within the EyeEfficiency tool about OT downtime. At all sites, the relative impact of reusable supplies and waste treatment was minimal, with less than 9% and less than 3%, respectively.

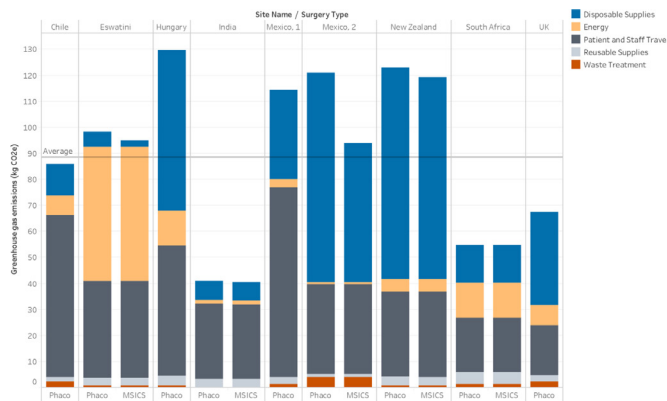


Figure 5 Average greenhouse gas emissions in kilogram carbon dioxide equivalents (CO₂e) for phacoemulsification (phaco) and manual small incision cataract surgery (MSICS) at all beta site locations. There are no error bars as data were collected only as an average.

Qualitative feedback on Eyeefficiency

After testing the tool, the beta sites provided feedback to the Eyeefficiency team via an informal online survey. Overall, every site was pleased with the Eyeefficiency tool. Some commented that the tool was ‘easy to use and good for monitoring our performance and time management’, and that ‘it was very helpful in guiding us to become more efficient and thinking of ways to make cataract surgeries greener.’ Each site also provided suggestions to improve the user experience of the app and website, which was incorporated into further development of the app in order to increase user engagement. In particular, we aimed to reduce the possibility of data loss through regularly saving studies to the cloud and allowing clinicians to resume recording from another device in the event of their device failing. The TAM recording software was also changed in order to automatically sync studies with the website, rather than requiring an additional manual process. These changes resulted in reduced user frustration. Further validation of data inputs was also introduced, in order to make sure that answers to the Eyeefficiency questionnaire were within valid ranges. This was in response to user errors that were noticed during manual validation of the forms by the research team, such as the use of multiple currencies.

DISCUSSION

Productivity, throughput or use of operating time

Operating time, cut-to-close, represented a relatively small proportion of case-to-case duration (only 25%–56% at single-bed sites), while some sites spent 20%–40% of case-to-case duration in turnover with no patient present in the room. More ‘productive’ surgical practices would logically seek to minimise the time spent in non-surgical activities such as turnover, as this maximises the use of ‘high-value’ components such as the surgeon, capital equipment and the use of the OR. While some sites are able to achieve faster turnover times, this is dependent on a variety of factors including regulatory requirements

especially related to infection control activities, restocking supplies, staff training and scheduling.

Dual bed systems are thought to optimise turnover time by conducting preoperative and postoperative activities on the second bed simultaneously while the surgeon is still performing the surgery on the first bed. However, some dual-bed sites performed fewer surgeries an hour than single-bed sites. This may be the result of variation in data entry, as some sites may have monitored their top physicians while others may have monitored trainees or a mix of skills. It could also be indicative of other issues in the service. For example, if the surgery is delayed due to staffing shortages, missing supplies, equipment malfunction or tardy patients, a dual bed system will not improve throughput.

Average cost per case

Costs are one major factor limiting access to cataract surgery globally, and results show large variability in per-case costs at each site. This variation could be due to differences in supply selection and utilisation at each site. It could also be due to differences in procurement practices and local market capabilities that allow certain sites to optimise costs. In more developed countries, unused items and partially used items are thrown away with greater frequency.^{25 26} In addition, national and/or regional policies and approaches may encourage local manufacturing or economies of scale (ie, group purchasing organisations) to reduce spending.

Some variability may be the result of the methods used to analyse the data. In generating reports for individual sites, Eyeefficiency maintains local currencies. However, for comparing across sites, Eyeefficiency converts local currencies into GBP or £. Converting currencies certainly has limitations, especially in light of the global economic issues caused by the COVID-19 pandemic. Prices paid for supplies are also highly variable, affected by international trade agreements, global supply chains, availability of vendors, local manufacturing capability and availability, and contract negotiations. It is unclear how much of the variability between Eyeefficiency sites is tied to resource utilisation (quantity of supplies used) or the economic situation of the test site.

Though the sample sizes are small, there were minimal differences in the price of supplies between phaco and MSICS approaches, which goes against published evidence of the cost efficiency of MSICS versus phaco.^{27–29} Eyeefficiency asks users to input aggregated supply costs for an average case, rather than the individual costs of each case monitored, which could lead to the difference in previously published findings. That said, MSICS tended to be slightly less expensive at sites where both are conducted, mainly due to smaller reported supply costs.

Waste generation may be a better metric to compare the use of physical supplies, as it directly measures the physical consumption of supplies. For example, the New Zealand site has the highest expenditures on disposable supplies but its waste generation is relatively low,

suggesting supply spending may be disproportionately high. Conversely, though the UK site ranks in the middle on its supply spending, its waste generation per case is nearly double that of the next highest site.

Environmental footprint

Results show limited variability in GHGs between study locations and between phaco and MSICS, which is likely due to the methods used to calculate GHGs. For example, supply prices are used to calculate GHGs from supply manufacture and these models are not as accurate as country-specific input-output models or process-based LCA methods.²³ The energy calculations are made by allocating the hospital's total electricity use to the floor area and case duration of the surgery, rather than some metering in greater detail. In addition, energy usage does not include non-electric heating sources, meaning GHGs in colder climates will likely be underestimated.

Eyeefficiency's GHG estimates for phaco are also different for the two beta sites previously studied, as covered in the Eyeefficiency methods paper.²³ Accuracy between GHG models has always been an issue in LCA methodology, which is why most standards suggest minimising this variability as much as possible.³⁰ The accuracy of Eyeefficiency's GHG estimates is purposely limited, in order to make data collection reasonable for most clinical sites. Despite this limitation in the accuracy of GHG calculations, Eyeefficiency enables a consistent methodology, applied to all sites. While Eyeefficiency's GHG calculations will not be useful for micro-level improvements at each site (for example, choosing one surgical supply item over another), understanding the relative GHG emissions between sites will help identify larger opportunities for improvements at each site and more broadly, across regions.

User impressions and improvements to the tool

Based on qualitative feedback received from the sites, Eyeefficiency appears to be a useful auditing tool that brings awareness to the resources needed to provide cataract surgery and the processes employed. As a beta test, there are several future improvements the team would like to make to Eyeefficiency, as more users use the tool. One important issue is to re-evaluate the importance of individual user inputs (questions) in generating the Eyeefficiency report. The more user inputs requested, the more likely we are to lose potential sites. However, we do not want to further limit the accuracy or usefulness of the reports. The Eyeefficiency team would also like to build statistical methods into the tool's backend to automatically analyse results and compare across site, while keeping sites anonymous. This would expand individual site's reports by comparing with other similar facilities, while also enabling larger reporting for regional best practices or policy development.

CONCLUSION

With improved efficiency, surgical facilities can treat more patients using fewer resources, thus helping achieve the primary goals of the previous WHO and IAPB's 'Vision 2020: A right to sight' global initiative. To date, there are very few tools that enable global sites to audit their cataract surgeries, and none that we know of that report productivity, costs and environmental impact. In the beta test for Eyeefficiency, test users found that the tool helped them improve their performance by inspiring them to re-evaluate their practices and develop or use strategies to increase their operational efficiency while being environmentally friendly. As an audit tool, Eyeefficiency allows users to track their performance over time, giving them a benchmark from which they can track improvements.

Eyeefficiency also provides a rare data repository of global cataract surgical services for sustainability or operations research and efficiency improvement tracking. Through Eyeefficiency, many sites now have a consistent method for tracking productivity, cost and carbon emissions in cataract surgery. These results across sites can be used to encourage friendly competition between or within sites and to encourage shared incremental learning. With more sites using the tool, Eyeefficiency could also be used to analyse global trends in cataract surgery, identify top performers for future study, and develop regional policies or strategies for improved ophthalmic care. The COVID-19 pandemic has caused a cessation or reduction in elective cataract surgery globally with infection control initiatives also reducing productivity and likely adding to increased environmental emissions and plastics waste disposal.^{31 32} The resulting growth of services such as teleophthalmology may produce opportunities to reduce the number of steps in the pre-cataract and post-cataract surgical pathway.³³ The Eyeefficiency tool provides an opportunity to track elective service 'restarts' and monitor efficiencies, costs and carbon footprint as ophthalmologists aim to get back to business as usual.

The Eyeefficiency tool has some notable limitations. Foremost, Eyeefficiency relies on individual sites and users to enter their own data. The tool has purposely been designed to try to minimise data entry fatigue, but some users may find accurate data entry a significant barrier to use. Validation of data is being integrated where possible to avoid accidental data entry errors, but sites are ultimately responsible for the accuracy of their own data. This includes how they sample their cases when using the TAM app, as some sites may sample from procedures performed by all surgeons while some may select their top surgeons only. As such, international comparisons using the Eyeefficiency dataset may always have some substantial limitations. Unfortunately, due to the limited sample size of just nine participating case locations, this study did not achieve statistical power to conduct more rigorous comparative statistics. It is our hope that as more locations use the Eyeefficiency tool, we can use regression analyses and other statistical methods to assess

correlations and trends in results across sites, perhaps analysing by region, bed systems or other factors.

The methods used to calculate GHG emissions have been purposely selected to reduce the burden of data collection for the user and to reduce the cost of the Eyefficiency tool; however, this limits the accuracy and usefulness of the GHG estimates. Despite this, GHG estimates have never before been calculated across international sites for the same procedure at this scale. Having a standardised method enables some cross-site comparisons, makes the tool accessible (despite its limits), and helps educate and engage more clinicians on the issue of climate change and resource consumption. While it will not help the end user make detailed decisions, it will help them understand, generally, where their carbon emissions are most likely to occur (for example, through supply production, as with four of the sites, or through patient travel with four other sites.)

As we set global goals to increase access to healthcare services (such as Vision 2020) or to mitigate or adapt to climate change, surgical services auditing tools like Eyefficiency help empower individual surgical teams worldwide to measure and change at the local level. The data collected can help identify those sites that have developed effective means of optimising productivity, costs and carbon, which can be shared to increase efficiency of medical practice broadly. Though Eyefficiency is currently geared toward cataract care, it can easily be adapted for other eye care pathways or surgical procedures, and the team is currently modifying Eyefficiency to analyse intravitreal injections. Eyefficiency is a globally accessible cataract surgical services auditing tool that helps illustrate the great variability in global cataract surgical operations. Eyefficiency can help identify strategies that work better for specific regions, while also engaging local clinicians and administrators to innovate and improve based on local contexts and results, to help achieve our larger goals of increasing access to care and minimising our environmental footprint.

Patient and public involvement

It was decided not to involve patients or the public in the design, conduct, reporting or dissemination plans of our research because the research is focused on collecting quantitative data about existing clinical workflow, which largely did not require patient or public input. Only a small subset of the modelling data was the result of activity on the part of the patient (in particular, their travel distance and modality); however, collecting this data (rather than having the user input an estimate for their average patient) would disrupt established patient–clinician workflow and provide an excessively detailed segment of data collection relative to other data inputs. Future Eyefficiency research will likely require substantial public and patient input, particularly as increased datasets elucidate potential ‘best practices’. Patient and public input will be required to determine how they feel about initiatives that improve: (a) productivity, for example, twin-bed

ORs that might impact privacy, patient opinions about inefficient or even wasteful units; (b) costs, anything that reduces cost while maintaining or improving quality is a widely recognised factor in improving access to prevention of blindness surgery; and (c) carbon footprint and environmental impacts. Patients are important drivers to redesign towards more sustainable healthcare.

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Funding This study was funded by the International Agency for the Prevention of Blindness (Seeing Is Believing (pilot and continuing grants)) and NIHR Biomedical Research Centre, Moorfields Eye Hospital NHS Foundation Trust and UCL Institute of Ophthalmology.

Map disclaimer The depiction of boundaries on the map(s) in this article does not imply the expression of any opinion whatsoever on the part of BMJ (or any member of its group) concerning the legal status of any country, territory, jurisdiction or area or of its authorities. The map(s) are provided without any warranty of any kind, either express or implied.

Competing interests None declared.

Patient consent for publication Not required.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement All data relevant to the study are included in the article.

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