Research Square

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A Mixed-Methods Analysis of a Novel Low-Cost Simulation Eye for Retinal Laser Training and Assessment

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Additional Declarations: Competing interest reported. AB is seconded to the University of St Andrews from NHS Fife. The University owns a social enterprise subsidiary company, for which AB acts as an

unpaid adviser. The social enterprise business sells the Arclight to users in high resource countries with all profits being used to fund distribution and education exercises of the device in low-income countries via the Global Health Implementation team at the University of St Andrews.

Abstract

Purpose

Simulation-based training is essential for acquiring ophthalmic skills, particularly those which pose significant risks to patients. Retinal laser, an example of such a skill, is vital in treating conditions such as diabetic retinopathy and retinopathy of prematurity that must be performed safely and accurately. Wide-field, low-cost and high-fidelity laser simulation are lacking. This study aimed to ascertain the validity of a novel retinal laser simulation eye meeting these criteria.

Methods

This study had two parts. Firstly, 40 ‘experts’ performed retinopexy and panretinal photocoagulation (PRP) laser procedures using the simulation eye. They rated the tool’s fidelity and utility on a Likert scale and provided qualitative feedback. Secondly, 23 novice trainees completed a three-stage retinal laser training course using the simulation eye with guided exercises, unsupervised practice, and supervised patient treatments. Outcomes measured included treatment completion and confidence levels.

Results

Experts rated the simulation highly for fidelity (median 6/7) and utility (median 7/7), noting its realistic laser appearance, fluence settings, and retinal response. Trainee completion rate of PRP and retinopexy in the supervised sessions with patient treatments was 91.3% and 95.6% respectively, while expressing a high degree of confidence.

Conclusion

This study validates a new low-cost retinal laser simulation eye with high-fidelity, adaptability, and affordability. Through implementation in structured training programmes, this tool addresses unmet needs in ophthalmology and supports training in both high- and low-income countries. It also enables a staggered approach to training, where basic lasering skills can be refined prior to delivering complete treatments, improving laser outcomes globally.

INTRODUCTION

Simulation-based training (SBT) is now a fundamental part of ophthalmic skill acquisition [1, 2]. It allows for safe teaching and assessment of potentially hazardous procedures [3]. Expertly delivered retinal laser is essential to preventing sight loss in several common conditions, such as diabetic retinopathy (DR), vascular occlusions, retinopathy of prematurity (ROP), and retinal tears. If performed inadequately

or incorrectly, laser can lead to poor outcomes and blindness, and thus demonstrates an important example of a procedure in which patients stand to gain from SBT.

To deliver retinal laser SBT, a high-fidelity simulation eye is essential. There is also a need to make it affordable given the emerging epidemic of blindness from ischaemic retinal conditions due to diabetes and premature birth, which disproportionately affects low- and middle-income countries (LMICs) [4, 5].

Several different retinal laser simulation eyes have been described in the literature [6–11]. Only one of these models is on the market [6]. In addition, many of the described retinal laser models require three-dimensional printing technology that is inaccessible to most [9, 11]. Importantly, there are no low-cost high fidelity retinal laser simulation eyes with the flexibility of exchanging the fundi to allow tailoring of teaching in different conditions. Furthermore, none of these simulation devices have been validated for their efficacy and utility as pedagogical tools.

To address this unmet need, we have developed a frugal retinal laser simulation eye [12].

There are several design choices of this simulation eye that have been deliberately incorporated to maximise fidelity and increase its potential for wider adoption and implementation. The optics of the simulation eye are based on a ‘reduced’ model of an emmetropic eye with linear dimensions increased by factor of 1.76. Because of this, the field of view, magnification, and relative position of anatomical landmarks are identical to the examination of a real eye. This is independent of the device (slit lamp biomicroscope or indirect ophthalmoscope) or lens design and power being used. The three-dimensional fundus is created by goring wide-field flat images using a computer algorithm and then printing these on matte photographic paper with a domestic colour printer. This inexpensive approach creates high-resolution, anatomically accurate, ora to ora fundi. Mounting a pair of simulation eyes in a typical anatomical position to a laser slit lamp is also simple and quick using a low-cost pre-formed Styrofoam template (see Supplementary Material 1, video demonstrating the simulation eye assembly and setup).

In this work, we aim to ascertain the validity of this new frugal retinal laser simulation eyes as a teaching and assessment tool.

METHODS

Part One:

40 participants who were competent in performing PRP and retinopexy (‘experts’) were recruited (16 consultant ophthalmologists, 24 ophthalmology trainees). All experts performed retinopexy and a panretinal photocoagulation in the simulation eyes using a slit-lamp based laser. 34 experts used 532nm double frequency Nd-YAG green laser and 7 used 577nm diode yellow laser. 15 experts also used binocular indirect ophthalmoscope laser.

Experts recorded the laser setting they used for retinopexy and PRP.

After performing the laser, the experts qualitatively rated the fidelity of the simulation eye and the utility of it as a training and assessment tool by giving feedback on a 7-point Likert scale. The experts were also granted the opportunity to give free text feedback.

Part Two:

23 ophthalmology trainees with no previous experience of retinal lasers were trained to do laser PRP and retinopexy for retinal tear using the laser simulation eyes. It was ensured that the trainees were proficient in examining the retina on a slit-lamp with contact and non-contact condensing lens prior to participation in the study. The course was delivered in three stages.

The first stage included a 30-minute presentation accompanied by a handout covering the basics and practicalities of PRP and retinopexy for retinal tears including consenting, laser settings, and laser safety (Supplementary Material 2).

The second stage entailed a practical session with two trainees per trainer. This session included working through PRP and retinopexy exercises on the simulation eyes and performing a full PRP and retinopexy on a simulation eye with minimal guidance from the instructor (Fig. 2).

- **Panel A**: *Laser training exercises including: (i) evenly spaced laser spots applied one diameter away from the central circle; (ii) confluent laser burns applied within the gaps between concentric circles; (iii) evenly spaced laser spots avoiding an imaginary (undrawn) central circle by one disc diameter; and (iv) evenly spaced laser spots avoiding the central circle boundary (indicated by a semi-circle)*
- **Panel B**: *Grid and titration patterns including: (v) even spot allocation with one-spot spacing while avoiding retinal vessels; (vi) laser application restricted inside the designated grid boundaries; (vii) power titration task to recreate the reference laser intensity from the upper circles within the lower circles; and (viii) focal laser targeting directly on the indicated dots*
- **Panel C**: *Peripheral treatment simulation: (ix) simulated laser retinopexy targeting all localized horseshoe tears*
- **Panel D**: *Global treatment simulation: (x) full panretinal photocoagulation (PRP) application across the baseline template*

The exercises initially focussed on different facets of lasering such as accuracy of placement, intensity, spacing, and coverage of burn placement separately before bringing combining all skills for a complete treatment. At the end of the session, the trainees were given simulation eyes to practice their PRP and retinopexy skills at their discretion over a period of two weeks. At the end of this period, they were tasked to perform a full PRP and retinopexy independently on a simulation eye without supervision, which was consequently assessed by the trainer who provided feedback for further improvements. The treatment was determined to be complete or incomplete.

The third stage involved a practical session with one trainee per trainer. The trainee joined the trainer in a dedicated half-day laser clinic where the trainee performed PRP and retinopexy under the trainer's supervision. At the end of this stage and if the trainee and trainer agreed, the trainee was tasked to perform a retinopexy and full PRP independently with appropriate supervision on a patient. The patients were examined by the trainer at the end of treatment for assessment and feedback. The treatment was considered as complete or incomplete.

At the end of the course, the trainees were asked to complete a questionnaire that ascertained their confidence in their PRP and retinopexy lasering skills. The questions included a) knowledge and indications, b) consenting process, c) preparing and positioning the patient, d) selecting appropriate laser settings, and e) delivering complete treatment.

RESULTS

This work was carried out as part of improving quality of retinal laser teaching and was approved by NHS Tayside Clinical Governance and Ethics Committee. Informed consent was obtained from all participants. This work followed the tenets of the Declaration of Helsinki.

Part One:

For retinopexy laser, the mean power was 590mW (standard deviation (SD) = 352), mean pulse duration = 31ms (SD = 25), and mean spot diameter = 200μm (SD = 0). For PRP the mean power was 556mW (SD = 352), mean pulse duration = 28ms (SD = 20, and mean spot diameter = 200μm (SD = 0).

Overall, the fidelity of the retinal laser simulation eye simulating lasering the real eye was scored median = 6 out of 7 with range = 5–7. The median score on specific facets of fidelity is shown in Fig. 3.

Overall, the usefulness of the retinal laser simulation eye as training and assessment tool was scored median = 7 out of 7 with range = 5–7. The median score for individual aspect of training and assessment is shown in Fig. 4.

Free text feedback:

36 participants elected to give feedback, 33 of whom praised high fidelity and realism of the simulation eye. It was noted that the simulated "retina", when lasered, responds similarly in appearance to a real retina. It was noted that at lower fluence faint blanching develops but as power increases white marks are seen progressing to 'pigmented' burns with supratherapeutic fluences. In addition, the fluence values required to create appropriate laser burns are representative of therapeutic settings. The experts highly recommended the simulation eye as a first step before attempting to laser a real retina. Suggested improvements included improving the slit-lamp mount to allow for simulating eye movement better and addition of a cornea to allow for using contact laser lens.

Part Two:

At the conclusion of the course, 82.6% of full PRPs on simulations eyes were considered as complete at the end of the second stage of the course, improving to 91.3% complete full PRPs in patients at the end of the third stage of the course. For retinopexy, the completion rate was 91.3% on simulation eyes and 95.6% in patients.

Upon completing the course, the participants felt confident in their laser skills (Fig. 5).

DISCUSSION

Laser treatment of the retina, despite being a modality intentionally causing focal tissue destruction, remains the mainstay of treatment of a number of retinal conditions, including DR, ROP and peripheral retinal breaks. The Diabetic Retinopathy study (DRS) recommended 800 burns of 500μm spot size as a minimum for initial PRP [13] which equates to approximately 5,000 burns with modern 200μm diameter burns. Total retinal area is between 1,100 and 1,368mm^2 [14] and the DRS and Early Treatment of Diabetic Retinopathy Study (ETDRS) recommendations equate to a minimum laser ablation area of 236mm^2 (range 157–314mm^2) for standard PRP [15]. In the UK, a snap-shot of single-session PRP reported a median treatment area of 98.2mm^2 (range 6.7–682.5mm^2) [16], and the Royal College of Ophthalmologists national audit found that for eyes where the new vessels had regressed fully, the area of retina ablated at the first session was significantly greater than for the group where new vessels persisted [17]. In the national audit of diabetic retinal laser the mean number of burns given was 2,300 (range 700-6,771) over a median of three sessions [17]. Assuming all administered burns are effective at the retinal surface, this is 289mm^2 of ablation. It is arresting that over time and in different contexts the effective PRP dose is remarkably consistent.

And yet, reluctance to administer the correct dosing of PRP proportionate to severity of retinopathy is ubiquitous and is likely multifactorial [18]. This hesitancy stems partly from a lack of familiarity regarding published evidence, which supports single session treatment efficacy and the lower incidence of complications associated with this [19, 20]. Additionally, the training methods and perceived difficulty of administration of the correct treatment also contribute towards this resistance. These latter factors are corrigible to simulation training that models and exemplars correct treatment intensity.

Atul Gawande observed that “We want perfection without practice. Yet everyone is harmed if no one is trained for the future” and discussed the anachronism of learning craft skills on patients without simulation [21]. Simulation offers the very real possibility of lowering the probability of error in treatment of patients where techniques are first acquired and refined on models. Access to SBT is now widely established in ophthalmic education in high resource countries where trainees enjoy access to many expensive and highly sophisticated simulation tools. Most devices have, however, tended to focus on the safe acquisition of surgical skills such as those needed to perform cataract, glaucoma, corneal, and strabismus operations [22–24]. Despite the potential for poorly performed retinal laser to cause loss of

vision and litigation there is a dearth of affordable and accessible simulation eyes suitable for training and assessment of retinal laser skills. In LMICs the need is enhanced where the demand for retinal laser is growing due to the epidemic of retinal blindness from non-communicable diseases and premature birth. There is consequently a pressing need for low-cost high fidelity simulation tools to train and assess the next generation of eye care professionals, especially in low resource settings, if equitable healthcare agendas are to be pursued.

In the first part of the study, we have shown that this new frugal retinal laser simulation eye has high fidelity as determined by user experience in terms of form of the retina, the field of view, appearance of laser on the retina, as well as the reaction of the fundus when applying laser. Importantly, the laser settings required to create burns in the simulation eye are comparable to those needed to treat a retina in vivo, which adds a greater sense of legitimacy to the model. Furthermore, the simulation eye works equally well with both green and yellow lasers.

The experts rated the simulation eyes ‘very highly’ as a training and assessment tool for both retinopexy and PRP. The simulation eye is theoretically infinitely adaptable to mimic pathology or direct abstract designs by printing specific patterns, enabling trainees to learn lasering for various types of retinal disease. For example, a ‘retina training gym’ can be created to deliberately segregate and refine the aspects of photocoagulation that together constitute accurate delivery of therapeutically meaningful amounts of treatment. Thus, teaching different lasering skill domains such as accuracy, burn spacing, burn intensity, and efficiency of laser application required for safe and effective retinopexy, PRP, and confluent photocoagulation required for ROP treatment can be individually refined. These isolated skills can then be combined to deliver a complete therapeutic laser procedure. This also opens the possibility of trainee assessment and credentialing using these approaches.

In the second part of the study, using the simulation eyes allowed the training to take a staged approach, where lasering skills were broken down and improved individually before combining them into a full treatment in a safe environment. Additionally, we were able to assess the learned skills and provide feedback for improvement. Furthermore, the trainees were given the opportunity to train in their own time. This ensured that the trainees only started training on patients once they mastered basic lasering skills. Ultimately, this allowed for efficient training of full PRP and retinopexy.

One aspect that participants suggested improvements to include a more flexible slit-lamp mount to allow the simulation eye to be rotated and variably positioned. In addition, retinal laser can require both a contact lens to be placed on the cornea as well as indentation of the globe. As the simulation eye does not have a cornea and is not malleable for indentation neither of these important skills can be trained or assessed with this model, although we note the high rating scores from experts as to the utility and fidelity of the model. Furthermore, no laser simulation eye with a cornea or that allows scleral indentation has been described elsewhere.

In conclusion this new frugal retinal laser simulation eye was perceived by users to have high fidelity for teaching and assessment of retinal laser skills. Combined with its low-cost and simplicity, it is suitable

for use in both high and low resource settings to facilitate effective and safe laser retinal skill acquisition.

Declarations

Competing Interests

AB is seconded to the University of St Andrews from NHS Fife. The University owns a social enterprise subsidiary company, for which AB acts as an unpaid adviser. The social enterprise business sells the Arclight to users in high resource countries with all profits being used to fund distribution and education exercises of the device in low-income countries via the Global Health Implementation team at the University of St Andrews.

Ethics Approval:

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the NHS Tayside Clinical Governance and Ethics Committee.

Consent to Participate:

Informed consent was obtained from all individual participants included in the study.

Consent to Publish:

The authors affirm that human research participants provided informed consent for publication of the data and images included in this article.

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Author Contribution

OK drafted the manuscript, designed the simulation eye, designed the study and collected data. LG analysed and curated the data. CS, JH and ST collected the data. JE and AB helped with study design and had supervising role. All authors critically reviewed the manuscript.

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Figures

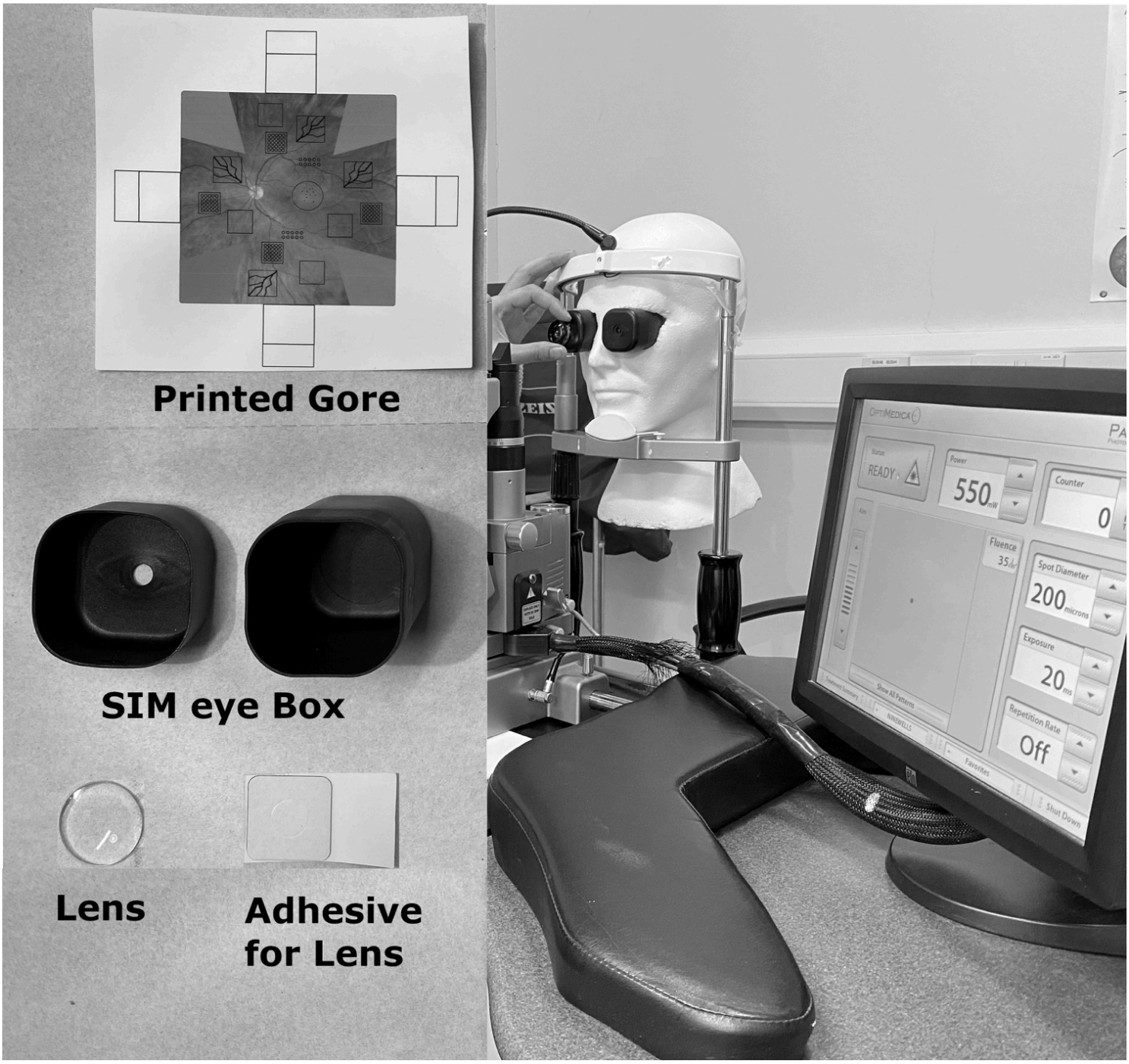


Figure 1

Experimental setup of the retinal laser simulation eye. Component parts shown include: (1) the printed gore of the simulation eye, (2) the simulation eye box, and (3) the lens and lens adhesive. The complete, finalized integration with the retinal laser system is demonstrated on the right

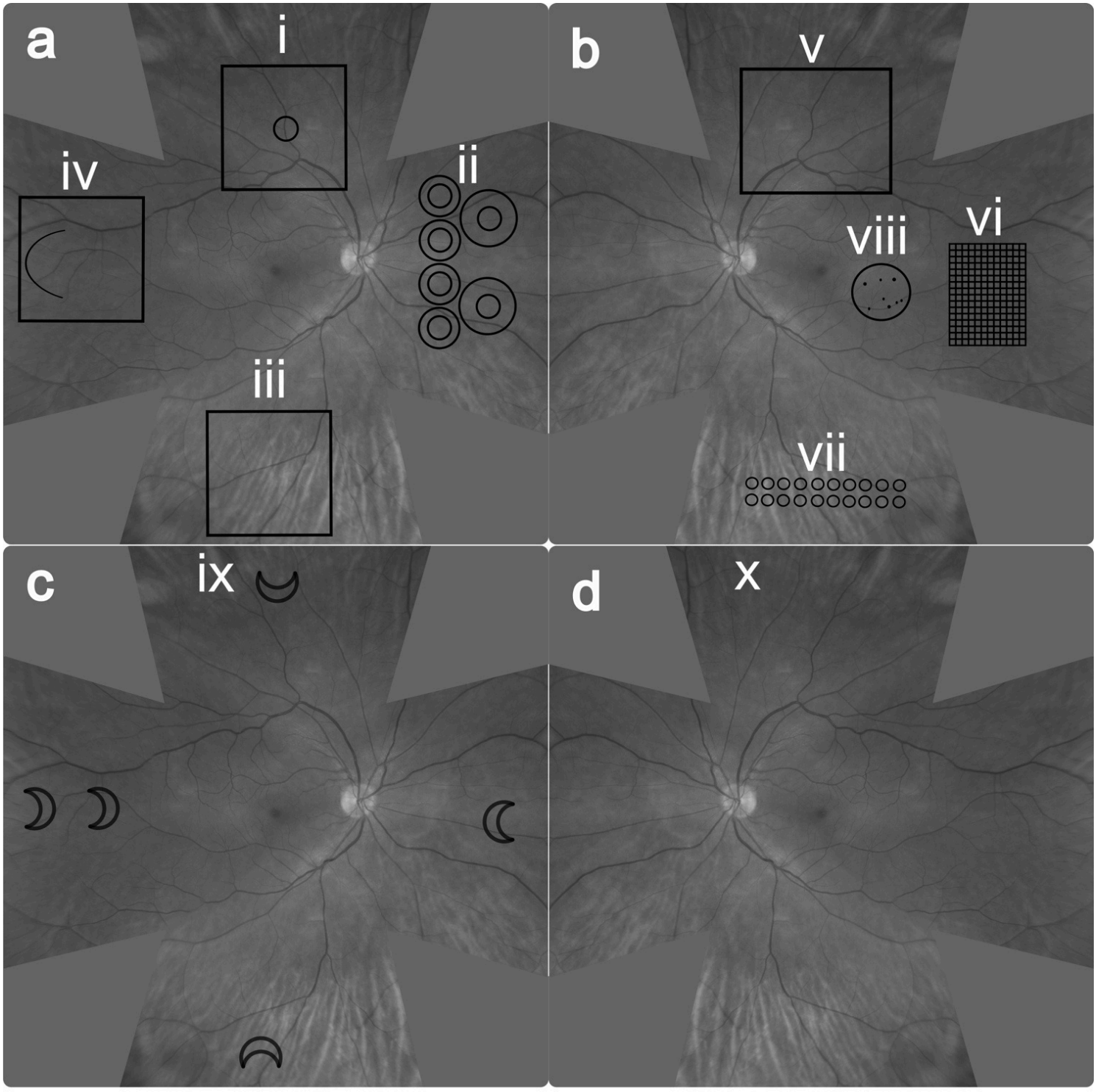


Figure 2

Laser treatment tasks and specific clinical simulation protocols evaluated on the retinal gore template

· **Panel A:** Laser training exercises including: (i) evenly spaced laser spots applied one diameter away from the central circle; (ii) confluent laser burns applied within the gaps between concentric circles; (iii) evenly spaced laser spots avoiding an imaginary (undrawn) central circle by one disc diameter; and (iv) evenly spaced laser spots avoiding the central circle boundary (indicated by a semi-circle)

· **Panel B:** Grid and titration patterns including: (v) even spot allocation with one-spot spacing while avoiding retinal vessels; (vi) laser application restricted inside the designated grid boundaries; (vii) power titration task to recreate the reference laser intensity from the upper circles within the lower circles; and (viii) focal laser targeting directly on the indicated dots

· **Panel C:** Peripheral treatment simulation: (ix) simulated laser retinopexy targeting all localized horseshoe tears

· **Panel D:** Global treatment simulation: (x) full panretinal photocoagulation (PRP) application across the baseline template

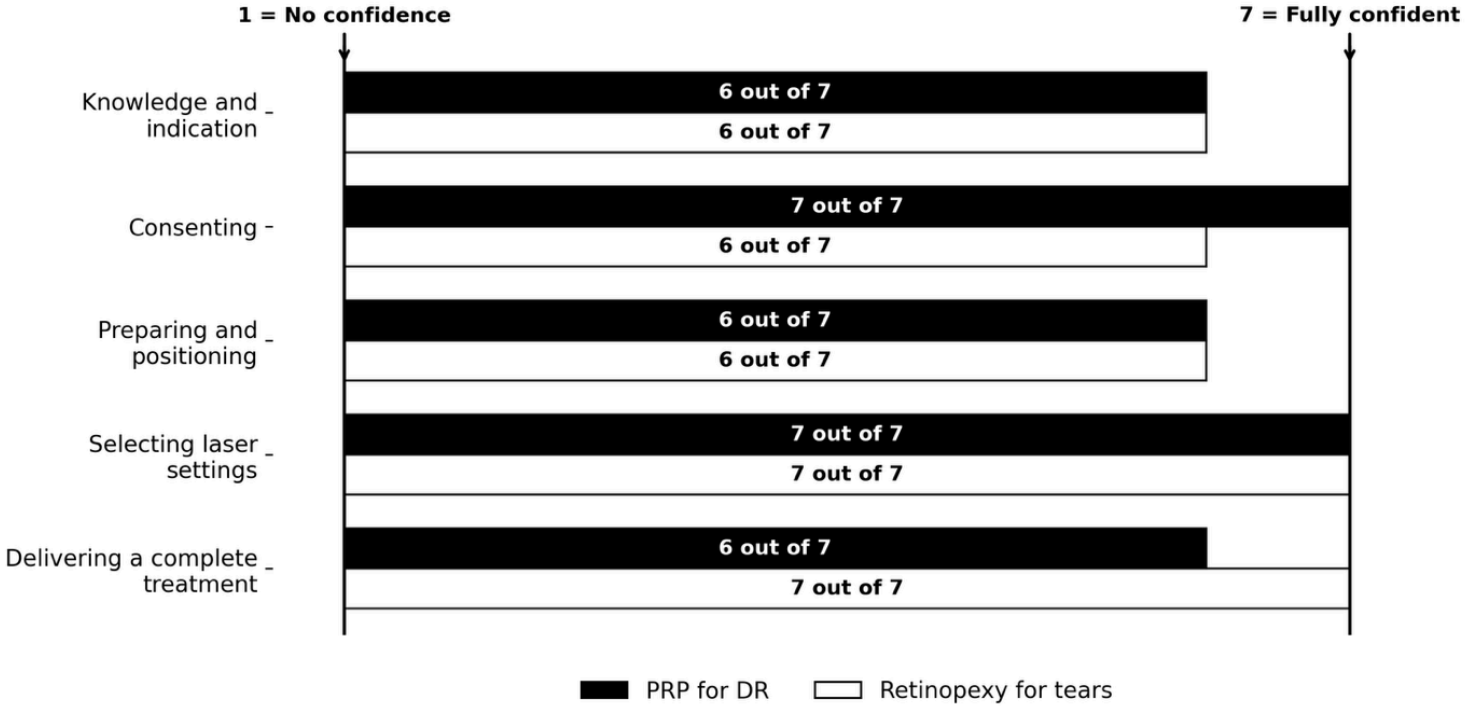


Figure 3

Trainee self-reported confidence scores across core competencies for retinal laser procedures. Confidence is rated on a 7-point Likert scale ranging from 1 (No confidence) to 7 (Fully confident). Mean scores are displayed for both panretinal photocoagulation (PRP) for diabetic retinopathy (DR) and retinopexy for retinal tears across five domains: knowledge and indication, patient consenting, preparation and positioning, laser parameter selection, and complete treatment delivery

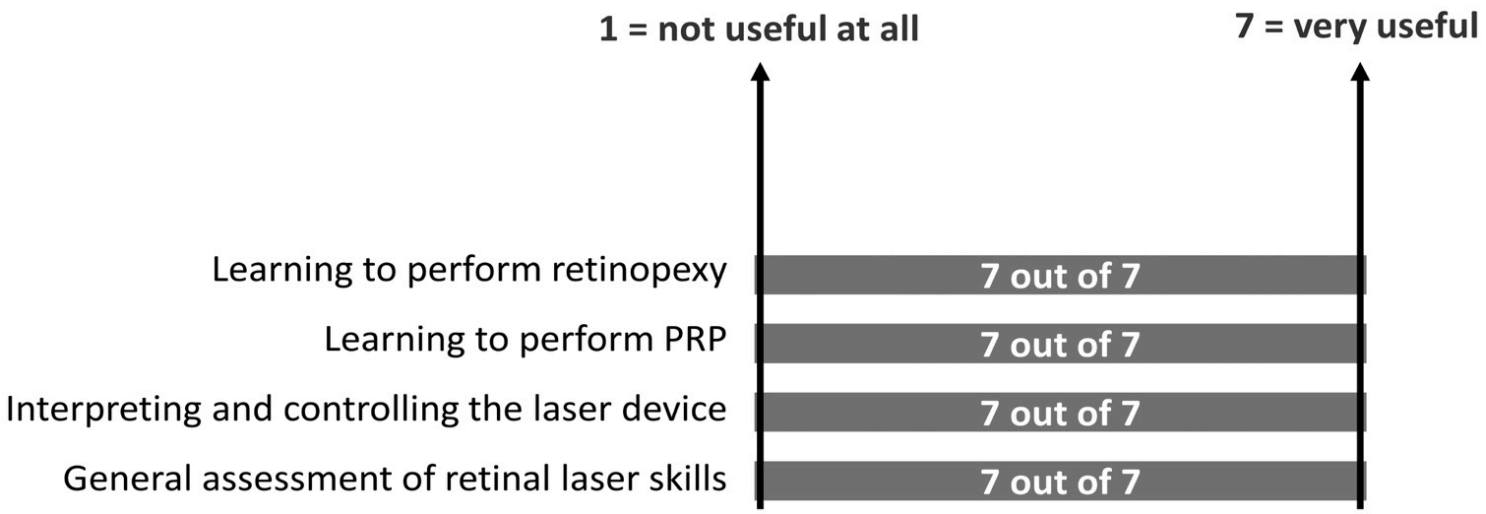


Figure 4

Trainee evaluation of the simulation model's perceived utility for retinal laser training. Usefulness is rated on a 7-point scale ranging from 1 (not useful at all) to 7 (very useful). Perfect scores (7 out of 7) were reported across all assessed metric

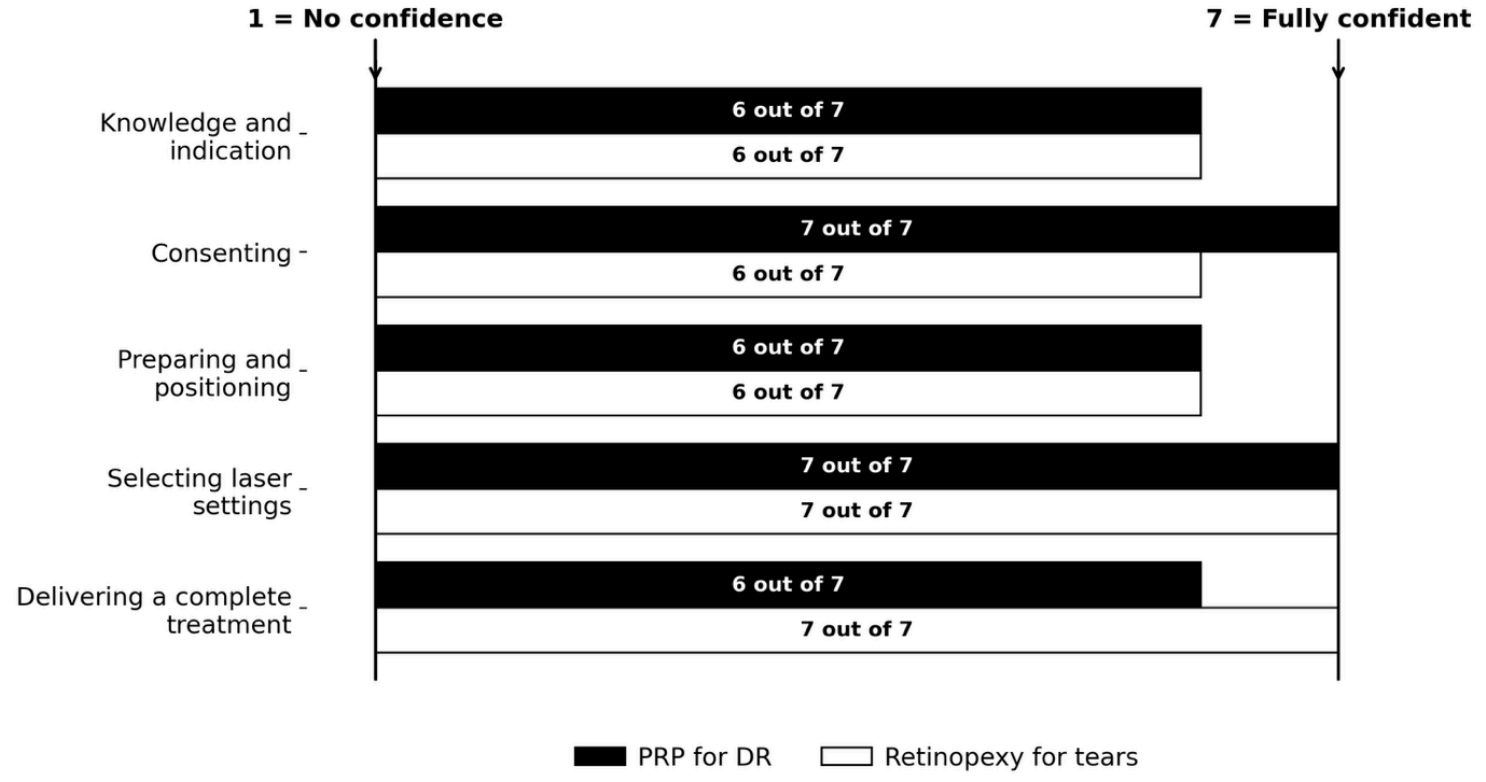


Figure 5

Trainee self-reported confidence scores across core competencies for retinal laser procedures. Confidence is rated on a 7-point Likert scale ranging from 1 (No confidence) to 7 (Fully confident). Scores are displayed for both panretinal photocoagulation (PRP) for diabetic retinopathy (DR) and

retinopexy for retinal tears across five domains: knowledge and indication, patient consenting, preparation and positioning, laser parameter selection, and complete treatment delivery

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- ESM2.pdf
- ESM1.mp4