High-Fidelity Cataract Surgery Simulation and Third World Blindness

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Abstract
The burden of global cataract blindness continues to rise, because the number of surgical ophthalmologists is insufficient, and they are unevenly distributed. There is an urgent need to train surgeons quickly and comprehensively in high-quality, low-cost cataract removal techniques. The authors suggest manual small-incision cataract surgery as a safe alternative to phacoemulsification cataract surgery in the developing world. They discuss the development of a novel, full-immersion, physics-based surgical training simulator as the centerpiece of a scalable, comprehensive training system for manual small-incision cataract surgery.

Keywords
cataract blindness, manual small-incision cataract surgery, surgical simulators

Introduction
Cataract surgery is one of the most successful and frequently performed surgical procedures in the world. Modern medicine has made great advances in this technique. Ophthalmic surgeons can now offer patients a wide variety of intraocular lens implants. Following cataract removal, the implantation of intraocular lenses that offer simultaneous near and distance vision correction is now routine.¹

It is estimated that 20 million people worldwide are blind because of bilateral cataracts. This number is expected to rise to 32 million by 2020. More than half of all global blindness is cataract induced.² The majority of this visually impaired population is in developing countries, where access to cataract surgery is more limited.³ Because safe and predictable cataract surgery outcomes are available only in the developed world, the rates of postoperative blindness are startling in the developing world. It has been reported that nearly half of all cataract operations in China result in blindness.⁴ Almost half of all cataract operations in Nigeria entail the centuries-old technique of “couching.”⁵ Couching is a primitive and unsterile technique whereby a probe is introduced into the eye and into the cataractous lens in an attempt to dislodge it from its natural position and into the vitreous cavity. Postprocedural success is judged by the patient’s ability to see light again. However, once the procedure is performed, the outcome is usually irreversible blindness from infection or intractable inflammation. Even in “successful” cases, vision is hand motion at best.

Safe and successful cataract surgery remains unavailable for a significant part of the population that needs the procedure. Reported barriers to increasing the number of cataract operations around the world are costs, transportation, cultural beliefs, surgeon availability and training, facilities, supplies, equipment, and compensation for individuals who deliver health care.⁶

According to recent and reliable global surveys, the number of ophthalmologists who provide eye care worldwide is 204,909.³ A smaller proportion of this number provide surgical services. In some nations that were former socialist economies, only 15% of ophthalmologists perform surgery. These surgeons are unevenly distributed across developed and developing nations. Fifteen countries worldwide concentrate two-thirds of the global ophthalmic population. In some sub-Saharan African countries, there is on average 1 ophthalmologist per million individuals.³,⁶ This inequality in distribution is compounded by the inequality and variability in the levels of training of surgeons in developing countries. Inadequate training results in outcomes that are inconsistent and unpredictable.⁴,⁵

Choice of a Cost-Effective Cataract Surgical Procedure
There are essentially 2 types of cataract surgical techniques in use today: phacoemulsification (PE) cataract

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surgery and conventional extracapsular cataract extraction (ECCE) surgery. A popular variant of ECCE surgery that can be performed without sutures is known as manual small-incision cataract surgery (MSICS). Almost all cataract operations in North America and Europe are performed by using the PE technique. Although PE cataract surgery is considered the gold standard for cataract removal, it requires expensive machinery and an uninterrupted power source. The overall cost and maintenance of machinery and supplies for PE make it cost prohibitive for regions with inadequate infrastructure.7

Eye surgeons who use the PE technique intervene early, when the cataract is relatively easy to remove. Patients in Africa and Asia seek visual rehabilitation much later in the course of visual impairment, when the cataract has become dense and hard. PE techniques are not ideally suited to deal with advanced cataracts and may lead to serious surgical complications in eyes that have very advanced cataracts.1 MSICS is suited for any level of cataract density.

MSICS and ECCE are widely practiced outside North America and Europe. A distinct advantage of MSICS over ECCE is that a smaller incision is used to remove the cataractous natural lens and implant the IOL. The smaller incision is also fashioned to be self-sealing and sutureless. This translates into shorter healing times, significantly less astigmatism, reduced intraoperative risk, and overall shorter postoperative recovery. ECCE and MSICS are not dependent on any powered machinery other than an operating microscope.7

Detailed and comparative research on the MSICS procedure suggests that it is possible to reduce poor surgical outcomes without raising costs. A number of studies have compared MSICS and PE and have confirmed the safety and efficacy of MSICS. Gogate et al8 ran a 6-week trial comparing PE and MSICS. At the end of 6 weeks, 78% of eyes that had undergone PE had best corrected visual acuity > 20/30, compared with 86% of eyes in the MSICS group.

Safety and efficacy profiles of MSICS are almost identical to those of PE.9 No clinical or statistically significant difference in the rate of corneal endothelial cell loss was noted in eyes that had undergone MSICS procedures compared with eyes that had undergone PE, with both procedures performed by experts in the techniques.10

When comparing rates of intraoperative anterior chamber contamination, no significant difference was noted between the 2 surgical procedures.11,12

A more recent study suggests that MSICS could be the procedure of choice to train novice surgeons, as it has lower complication rates compared with complications caused by trainees performing PE cataract surgery.13 These data suggest that MSICS may be a safer initial procedure for inexperienced ophthalmic surgeons.

Like any complex surgical procedure, MSICS outcomes are highly dependent on surgeons’ skills. Compared with other surgical techniques for cataract removal, MSICS surgeons must be skilled at constructing a partial-thickness scleral tunnel into the eye that serves as a 1-way valve (and is thus self-sealing). Once in the eye, a surgeon must manually control the anterior chamber depth throughout the procedure. In PE, anterior chamber depth is controlled by continuous irrigation from a machine, and cataract material is removed from the eye by ultrasonic breakdown and aspiration using a probe. Although the final outcome of both procedures is the same, the techniques are remarkably different. When comparing different surgical techniques and circumstances of application in different parts of the world, MSICS is often the preferred technique for high-volume cataract surgery in the developing world.7

Variability in Training of Eye Surgeons

Cataract surgical training curricula in different parts of the world are highly variable. Trainees in the developing world face a lack of availability of consumables, poor quality of training equipment, inadequate training faculty members, and high costs of equipment maintenance. In ophthalmology residency programs in the United States, surgical numbers are closely monitored by the Accreditation Council for Graduate Medical Education, and standardized testing is required. These training programs are well funded and must adhere to strict training guidelines laid down by the Accreditation Council for Graduate Medical Education and the American Board of Ophthalmology. However, this level of highly supervised training and close monitoring by expert surgeons is unavailable in the developing world. It is difficult to make training a priority, as it is not financially rewarding. Furthermore, resources and personnel in most health care establishments in Asia and Africa are stretched beyond their limits. Competent surgeons who have an established presence in communities are reluctant to train residents and medical postgraduates, as they see these trainees as direct future competition. Attempts to standardize the requirements for ophthalmologic licensing by organizations such as the International Council of Ophthalmology are voluntary and largely ignored.

Even within developed nations, the surgical training experience is variable. Many programs emphasize “observation,” whereas others offer more “hands-on” training. There is wide disparity in the quality and commitment of training staff members.

Efforts to replicate traditional Western training methods in developing nations are often met with resistance or apathy. Traditional surgical training is steeped in Halstead’s
Simulator Technology for Training

Simulator training offers objective and performance-based training progression. A trainee can undergo a controlled introduction of variables and sequences. Simulation gives the option of multiple repetitions of skills with objective measures of performance. Trainees experience a wide range of scenarios without risk to patients. This prevents the reinforcement of less desirable trainee habits.

A large number of validated data on virtual reality (VR) training can be attributed to the general surgery literature. Some of the most significant steps in surgical simulator development and strides in simulator validation have been in the areas of endoscopic and laparoscopic surgery. After 1989, as increasingly greater numbers of general surgeons adopted minimal-access surgical techniques, it became clear that this approach resulted in significantly higher rates of complications. These complications were more evident during the learning curve for laparoscopic surgeons. The shift to minimal-access surgery and the associated high morbidity necessitated the development of a tool that would significantly reduce errors while performing minimal-access surgery. In a landmark study, Seymour et al. demonstrated that VR surgical simulation training improved the operating room performance of residents during laparoscopic cholecystectomy. Since that study, multiple studies on VR training have tested various platforms, such as bronchoscopy, colonoscopy, sigmoidoscopy, ureteroscopy, and carotid artery stenting. All of these studies demonstrated that medical students, residents, and fellows had significant improvement in performance in the operating room following VR training compared with untrained controls.

It is important to note that successful skills transfer depends on both the realism of the simulation and the training curriculum used to support the simulator. These studies raise questions about the best practices for skills transfer. These studies also raise questions about the methods of testing surgical performance as well as testable variables. Various assessment tools have been used to assess operative performance, such as video recordings, live observation, and operative performance assessment methods that use motion analysis. A simulator training platform can be used to test performance but is limited by the inability to correlate performance with outcomes.

Current Status of Simulator Training in Ophthalmology

At present, 3 cataract surgery simulators have been studied, and data related to their performance have been published in the peer-reviewed literature. The Eyesi (VRmagic Holding AG, Mannheim, Germany), PhacoVision (Melerit Medical, Linköping, Sweden), and MicrovisTouch (ImmervisTouch, Chicago, Illinois) are all PE cataract surgical technique simulators. Construct validity has been demonstrated for different tools and modules for cataract surgery available in the Eyesi simulator. This simulator can differentiate between the skill levels of novices and experienced surgeons. It includes a training platform as well as the simulation. The international forum of ophthalmic simulation has published the results of a structured, supervised cataract surgery simulation program. Ophthalmic surgeons in their first year of training were tested to evaluate the level of skill transfer. That study showed the beneficial effect of close supervision and training based on an ophthalmic simulation training program.

McCannel et al. studied the rate of errant capsulorhexis in residents before and after the introduction of a capsulorhexis-intensive training curriculum on a VR surgical simulation training platform (Eyesi). They found a 3.2-fold (68%) reduction in the rate of errant capsulorhexis in the postintervention cohort. The authors suggested the incorporation of a formal program for surgical training using a VR simulation platform in ophthalmology residency programs.

Although some residency programs have been quick to embrace this expensive technology, it remains to be
seen if simulator-based training on a larger scale will improve patient safety outcomes. Current simulation does not include a realistic surgical feel, and the graphics are clear but generally not photorealistic. Curricula to support these simulations are limited, with an emphasis on modules to support specific, simulated, task-training goals and general microsurgical skills rather than comprehensive training. By design, these commercially available systems are intended to fit into existing training curricula. Furthermore, it is difficult to objectively measure a positive impact of simulation training on traditional training outcomes because of the subjective nature of the assessments and the variability in how the simulators are actually used in each institution. As Naseri and Chang pointed out, studies that find beneficial effects of simulator-assisted training do not control for other variables that may have improved trainees’ performance. It would be difficult to account for the value of other learning sources, such as reading textbooks, viewing teaching videos, attending meetings, and the influence of a dedicated teaching surgeon who points out the finer aspects of the surgical procedure the trainee surgeons adopted. Rigorous testing of this technology specific to ophthalmic surgery will answer the fundamental questions about its benefits and clinical impact.

**Advances in Simulator-Based Cataract Surgical Training**

The ideal ophthalmic surgical simulation trainer would give trainees a virtual eye world indistinguishable from the living eye in both look and feel and a standardized, comprehensive curriculum to support it. Training metrics would accurately reflect students’ performance and predict surgical performance in live patients. The effect of full-immersion training could be studied more accurately if variables were controlled using a standardized, comprehensive curriculum. Currently, such a simulator and curriculum do not exist. However, significant progress is being made in the development of haptic (tactile) realism and tissue interaction and the development of a new curriculum to support it. This work is specifically designed for MSICS training of surgeons in developing nations.

In conjunction with engineering teams at Moog Inc (New York, New York), InSimo (Strasbourg, France), and SenseGraphics (Kista, Sweden), Help Me See (HMS) is building a training simulator system designed to provide both haptic and graphical realism in the performance of MSICS. This simulator is based on a carefully designed, peer-reviewed set of performance parameters determined by the complete deconstruction of a standardized MSICS technique and surgical force data measured during actual cataract surgery. Surgical variables and complications are included.

To fully exploit the potential of this high level of realism for training in the context of developing nations, a comprehensive, customized MSICS training curriculum has been developed. The centerpiece of the curriculum is a new textbook written specifically to build the cognitive foundation for full-immersion simulation training. A novel ab initio approach was chosen for the content to ensure thorough training for surgeons who may not have had access to training in programs in which Western standards of curriculum are maintained. All text is written at an eighth grade English level, because most students will have English as a second language. Each trainee’s skills, knowledge, and attitude will be assessed by objective simulator metrics, written comprehension testing, and trainer evaluation. Live surgical training will begin only after successful completion of the skills and cognitive training. The MSICS technique was chosen as the most practical solution to tackle the problem of global cataract blindness for the simulator platform.

The HMS MSICS simulator is designed around 5 major elements:

1. It is a physics-based, computer-generated, anterior segment model.
2. It has a high-definition (HD) stereoscopic binocular visual image generator.
3. The simulator produces bimanual force feedback with surgical instruments in 3 degrees of freedom.
4. The simulator is designed for full-immersion simulation, including realistic operating room setup, virtual patient interaction, and patient complications.
5. The simulation platform has an instructor workstation and learning management system to facilitate proficiency-based progression through several levels of simulation.

By adding haptic simulation and increasing the level of tissue interaction realism, it is hoped that the simulator will approach the goal of simulator realism that makes full-immersion training possible. Comprehensive full-immersion training and a rigorous preformatted training curriculum may make this a scalable training system, ideal for rapid and effective capacity building in developing nations.

Following validation, the HMS organization will provide comprehensive MSICS specialty training to individuals who qualify for its training program. The emphasis will be on the recruitment of surgeons from developing nations. Training will be offered at specialized simulation training centers using the customized curriculum. HMS-trained surgeons and HMS supported programs will primarily target the continents with the greatest burden of cataract blindness. This program can also provide off-site support to existing MSICS training centers to reduce
training costs, increase the number of procedures, and improve the quality of MSICS surgery. The training curriculum will also provide entrepreneurial development and clinical practice–building skills. After trainees have established themselves in communities, it will provide a network to keep these surgeons well equipped. HMS will partner with other local organizations to significantly reduce and eliminate global blindness.

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