Original Article

Effectiveness of Simulator-Based Training for Cataract Surgery in Postgraduate Ophthalmology Residents

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ABSTRACT

Purpose: To compare the impact of virtual reality–based cataract surgery training versus conventional patient-based training on surgical performance, confidence, and self-efficacy among postgraduate residents.

Study Design: Quasi experimental study.

Place and Duration of Study: A multicentered study conducted from October 2023 to March 2024.

Methods: Thirty-two second-year FCPS trainees were enrolled and divided equally into two groups. The simulator-trained group practiced cataract surgical steps on a virtual reality simulator and progressed to real patients only after achieving ≥60% accuracy in each step. The conventional group received traditional training through the master-apprenticeship model, starting surgical steps on cataract patients under supervision. Both groups were later assessed while performing cataract surgery under consultant supervision using a structured proforma.

Results: Simulator-trained trainees performed significantly better in basic steps such as incision and paracentesis, viscoelastic injection, and initiation of Capsulorhexis ($p = 0.028$, 0.042, and 0.050, respectively). No statistically significant difference was observed in more advanced steps, including Capsulorhexis completion ($p = 0.11$), hydro-dissection ($p = 0.60$), phacoemulsification ($p= 0.57–0.72$), nucleus manipulation ($p = 0.68$), cortex removal ($p = 0.81$), intraocular lens placement ($p = 0.48$), and wound closure ($p = 0.27$). Simulator-based trainees outperformed in 3 of 13 steps, while differences in the remaining steps were not significant.

Conclusion: Simulator training improves basic cataract skills but not advanced maneuvers; it is a useful adjunct for early skill acquisition.

Key words: Cataract, Ophthalmology, Simulation training.

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INTRODUCTION

A key element of postgraduate surgical education is simulator-based training, which provides an organized method of improving technical proficiency in a risk-free setting. Before performing surgery on actual patients, trainees can refine their abilities and gain confidence thanks to simulators, which are a crucial link between theoretical knowledge and practical clinical application in surgical specialties.[1–4] Computer-based simulations and virtual reality (VR) provide clear benefits over conventional training techniques. These include a lower chance of patient injury, a secure and regulated learning environment, more effective training, and increased competence and confidence among trainees.[5] Despite these advantages, there is still little data on how well simulator-based teaching works in ophthalmic surgery.

One notable advancement in ophthalmic surgical simulation is the EyeSi Surgical Simulator (VRmagic GmbH, Tübingen, Germany), widely used for training ophthalmology residents.[6] Through the integration of a binocular surgical microscope, bimanual instrumentation, and an anatomically precise prosthetic eye, the EyeSi platform simulates a realistic surgical environment. Its construct validity and beneficial effects on surgical performance, such as shorter procedure times, less intraoperative problems, and better execution of particular surgical processes, have been shown in studies.[7–9] Without requiring direct supervision, the simulator provides automatic performance indicators and a defined curriculum covering key cataract surgery skills. These tests, which may be saved and retrieved whenever needed, provide insightful information about the readiness and progress of trainees.[10] While this study focuses on cataract surgery, the simulator also includes modules for anterior and posterior segment procedures.

The “master-apprentice” paradigm, which is based on the tenets of “see one, do one, teach one,” has historically been used in surgical training. There are several drawbacks to this patient-dependent strategy, such as a higher chance of problems, time constraints for supervisors and trainees, resource consumption, and possible patient discontent. Research suggests that inexperienced surgeons are more prone than their more seasoned peers to face intraoperative problems.[11] Given the complexity and steep learning curve of ophthalmic surgeries, there is growing interest in integrating simulation-based approaches into training programs.[12] Virtual reality simulation offers objective and standardized assessments without the need for human evaluators, whereas traditional training depends on mentor input, frequently utilizing inanimate or animal eyes.[13]

The objective of this study is to assess whether cataract surgery training with a virtual reality simulator, as compared to conventional patient-based training, leads to superior outcomes in surgical performance, confidence, and self-efficacy among postgraduate trainees. The results will aid in the formulation of recommendations based on evidence for incorporating simulation into ophthalmology courses. The study specifically supports the use of simulator-based evaluations to ascertain when trainees have attained a level of proficiency that allows them to safely switch to real surgery. The study also fills in existing gaps in the literature about the efficacy of training in cataract surgery using a simulator. Personalized learning routes, curriculum integration, skill transferability, and handling challenging surgical situations are some of these issues. The study will advance existing understanding and facilitate the wider adoption of simulation-based learning in postgraduate ophthalmology education by tackling these problems.

METHODS

This was a multicentered study conducted from October 2023 to March 2024. Purposive sampling was used in this quasi-experimental investigation, which was carried out at the Postgraduate Medical Institute (PGMI), Peshawar. Second-year postgraduate trainees (PGY-2) from Hayatabad Medical Complex (HMC), Peshawar and Khyber Teaching Hospital (KTH)were part of the study population. Following written informed permission, participants were enrolled, and ethical approval was received from Khyber Medical University (KMU) Research and Ethics Board **(Reference No: 1-11/IHPER/MHPE/KMU23-51)** and the Khyber Medical University (KMU). Advanced Studies and Research Board **(ASRB Approval No: ASRB002044/ES/IHPE).** To ensure equal representation from both institutions, 32 trainees in total were recruited and divided into two equal groups (n = 16 each). HMC trainees who received simulator-based training made up Group 1 (intervention group), while KTH trainees who received traditional instruction constituted Group 2 (control group). At PGMI, the EyeSi Surgical Simulator was used to provide the intervention group with structured simulator-based cataract surgery training. The simulator's built-in assessment software established a performance threshold of ≥60% accuracy for each of the steps of cataract surgery that were covered in the training program. Each surgical step had to be repeated by the trainees until the desired score was consistently attained. Over the course of three months, or until proficiency in every phase was shown, the simulator training continued.

On the other hand, without any prior simulator exposure, the control group had conventional training that included supervised hands-on experience with actual patients. In their respective institutions, both groups then carried out cataract surgical procedures on real patients while being supervised by consultants.

The following surgical tasks were the subject of the operating room performance evaluation:

- Paracentesis and incisions.
- Insertion of viscoelastic.
- Continuous curvilinear Capsulorhexis (beginning, making the flap, and finishing it).

- Nuclear rotation and hydro-dissection.
- Placing and managing the second instrument and phacoemulsification probe.
- Cutting and shaping of the nucleus.
- Nuclear fragment rotation, cracking, and emulsification.
- Aspiration and cortical irrigation.
- Rotation, placement, and insertion of intraocular lenses (IOLs).
- Closure of wounds.

Consultant ophthalmologists blind to the trainee group assessed and recorded performance for each step using a standardized proforma.

SPSS version 23 was used to examine quantitative data. For continuous variables, descriptive statistics such as means and standard deviations were calculated. The mean performance scores of the two groups were compared using an independent samples t-test. The homogeneity of variance was evaluated using Levene's test for equality of variances. Uneven variances between groups were shown by a statistically significant Levene's test result, which supported the use of adjusted t-test results.

RESULTS

The mean age of participants was 28.25 ± 1.43 years and males were in majority (n=17,53.1%).

Table 1 represents the results of surgical steps evaluated among male and female trainees participated in the study. There were some differences in mean scores between male and female in certain surgical steps, but these differences were relatively small and not statistically significant (p>0.05). The study found no significant gender differences in the performance of the evaluated surgical techniques. The data suggested that both male and female participants performed similarly across these procedures, as indicated by the non-significant p-values.

Table 2 displays the group statistics for all surgical steps, categorized by whether the resident received training on a simulator or not. In all the steps, the trainees who were trained on simulator and achieved the required score performed comparatively better in all

Table 1: *Gender-wise analysis of surgical performance (N=32).*

S. No	Surgical Steps	Gender	n	Mean	SD
1.	Incision and paracentesis: Formation and technique	Male	17	2.12	.993
		Female	15	2.33	1.113
2.	Viscoelastic: Appropriate use and safe insertion	Male	17	2.53	1.231
		Female	15	2.53	.834
3.	Capsulorhexis: Commencement of flap	Male	17	2.18	1.015
		Female	15	2.20	.941
4.	Capsulorhexis: Circular completion	Male	17	2.00	.935
		Female	15	2.00	.845
5.	Hydro-dissection: Free nuclear rotation	Male	17	2.18	1.015
		Female	15	2.40	.986
6.	Phacoemulsification probe and second instrument insertion in the eye	Male	17	2.06	.899
		Female	15	2.13	.990
7.	Phacoemulsification probe and second instrument: Effective use and stability within the eye	Male	17	1.94	.827
		Female	15	1.80	.941
8.	Nucleus: Sculpting or primary chop	Male	17	1.35	.493
		Female	15	1.47	.516
9.	Nucleus: Rotation and manipulation	Male	17	1.24	.437
		Female	15	1.20	.414
10.	Nucleus: Cracking and chopping with safe phacoemulsification of segments	Male	17	1.29	.470
		Female	15	1.27	.458
11.	Irrigation and aspiration technique with adequate removal of cortex	Male	17	1.71	.686
		Female	15	1.73	.799
12.	Lens insertion, rotation and final position of intraocular lens	Male	17	2.29	1.047
		Female	15	2.47	.915
13.	Wound closure (Hydration / suturing)	Male	17	2.12	.993
		Female	15	2.13	.915

N=total sample size, n= frequency, SD=standard deviation

Table 2: *Group-wise analysis of surgical performance (N=32)*

S. No	Surgical Steps	Has the resident received training on simulator	Mean	SD	P value
1.	Incision and paracentesis: Formation and technique	Yes No	2.50 1.94	.966 1.063	0.028
2.	Viscoelastic: Appropriate use and safe insertion	Yes No	2.88 2.19	1.088 .911	0.042
3.	Capsulorhexis: Commencement of flap	Yes No	2.50 1.88	1.033 .806	0.05
4.	Capsulorhexis: Circular completion	Yes No	2.25 1.75	1.000 .683	0.109
5.	Hydro dissection: Free nuclear rotation	Yes No	2.38 2.19	1.088 .911	0.601
6.	Phacoemulsification probe and second instrument insertion in the eye	Yes No	2.19 2.00	.911 .966	0.576
7.	Phacoemulsification probe and second instrument: Effective use and stability within the eye	Yes No	2.13 1.63	.957 .719	0.105
8.	Nucleus: Sculpting or primary chop	Yes No	1.44 1.38	.512 .500	0.729
9.	Nucleus: Rotation and manipulation	Yes No	1.25 1.19	.447 .403	0.681
10.	Nucleus: Cracking and chopping with safe phacoemulsification of segments	Yes No	1.31 1.25	.479 .447	0.705
11.	Irrigation and aspiration technique with adequate removal of cortex	Yes No	1.75 1.69	.775 .704	0.813
12.	Lens insertion, rotation and final position of intraocular lens	Yes No	2.50 2.25	1.033 .931	0.478
13.	Wound closure (Hydration/ suturing)	Yes No	2.31 1.94	1.014 .854	0.267

N=total sample size, n= frequency, SD=standard deviation

steps than those who were not trained on simulators, though the difference was not statistically significant.

Table 2 indicates that simulator-trained participants outperformed non-trained participants in certain cataract surgery steps with statistically significant differences ($p < 0.05$). In other steps, although simulator-trained participants performed better, the differences were not statistically significant ($p > 0.05$).

DISCUSSION

Our study showed that when postgraduate trainees start their training on a surgical simulator, they perform better in initial steps of phacoemulsification. Depending on individual differences in theoretical knowledge, hand-eye coordination, dexterity, and procedural comprehension, different accuracy scores were obtained during simulator-based practice. The EyeSi surgical simulator used in this study uses integrated software to objectively evaluate performance in terms of accurate job execution and safe tool handling.

In the first year of residency, trainees usually participate in small, supervised procedures after watching peers or supervisors. This stage makes it easier to become acquainted with ophthalmic tools and adjust to the fine motor control and depth perception needed for microsurgical procedures. Along with other operative skills, students start performing proper cataract surgery in the second year, according to the College of Physicians and Surgeons Pakistan (CPSP) curriculum. A high-fidelity virtual reality platform that mimics actual surgical procedures is provided by the EyeSi simulator. It is well known for both general and specialist training in ophthalmology. Before exposing second-year FCPS residents to actual patients, we used this platform at PGMI to teach them the fundamentals of cataract surgery. Because of their intrinsic complexity, ophthalmic procedures need a great deal of precision and have a steep learning curve. The early stages of surgical training are generally characterized by worry, a lack of confidence, and even depression. Before working on actual people, ophthalmology students used to practice on animal eyes. But because of their structural variations and inability to regularly perform actions, animal models were not ideal, which limited their usefulness and accessibility. Simulators have helped to lessen these difficulties by allowing trainees to practice difficult surgical procedures indefinitely until they become proficient. Every step is automatically rated, offering unbiased feedback without the need for continual oversight. Training with a simulator speeds up the learning of new skills, especially for procedures that are usually challenging to master in the operating room. Conventional approaches are linked to higher rates of complications when procedures are carried out by inexperienced personnel and require a substantial investment in time from both trainers and trainees. These dangers can be decreased with prior simulation training. In order to minimize difficulties and enhance results, McInerney et al, stressed that simulation should come before actual patient exposure.[14]

In our study, trainees who started cataract surgery on simulators showed better performance in viscoelastic insertion, incision and paracentesis, and the start and finish of Capsulorhexis. This could be explained by the steps' relative simplicity and their capacity for repeated practice. Feudner et al, also pointed out that before moving on to live surgery, Capsulorhexis can be successfully learned in both wet and simulated lab settings.[15] There were no statistically significant differences between the two groups for more complex stages ($p > 0.05$). According to Vergmann et al, some steps have limited transferability from the simulated to the real-world setting.[16] On the other hand, Ong et al, highlighted the importance of repeated simulation to enhance skill acquisition and ensure patient safety.[17] Multiple sessions and increasing exposure to a range of case complexities are beneficial to trainees. During actual surgeries, trainees frequently face new difficulties that are not entirely simulated in simulations, which can compromise their performance and confidence. This concept is echoed in studies by Bergquist et al,[18] and Saleh et al,[19] who advocated for longitudinal simulator training using varied modules. The relative inexperience of second-year trainees who might not have had enough exposure to cataract surgeries yet is another possible explanation. Third-year residents outperformed their junior counterparts in terms of performance and skill transfer, according to Roohipoor et al.[20] Before completing steps on actual patients, simulator participants had to meet our training protocol's minimum 60% accuracy score. Thomsen et al, likewise applied this criterion, using performance thresholds to establish pass/fail results.[21]

Compared to traditional training, simulator-based cataract training has been linked to less complications. When trainees had previous simulator exposure, Lucas et al, found that complication rates decreased from 27.14% to 12.8% ($p = 0.031$).[22] Additionally, simulators aid in reducing the psychological strain that comes with performing in an operating room, which can impede surgical proficiency. Although crucial, senior expert supervision may potentially exacerbate performance anxiety when doing microsurgical procedures. As Tjønnås et al, pointed out, a trainee's personality, capacity for managing stress, and past experiences all affect how well they do.[23] When supervisory resources are limited or patient availability is restricted, simulator training is very beneficial. Another benefit was when ophthalmology services were reduced during the COVID-19 pandemic, simulators offered a crucial teaching platform.[24]

The study has certain limitations, primarily its small sample size, which affects the generalizability of the findings. To avoid overlapping between groups, trainees were selected from multiple hospitals; however, future studies should ensure balanced representation from all institutions to minimize selection bias. Additionally, the present research focused only on cataract surgery steps. Future investigations should extend simulator-based evaluations to other ophthalmic procedures, particularly those with steep learning curves. The limited study duration also restricts the assessment of long-term outcomes. Longer studies encompassing the entire residency period are needed to evaluate the sustained impact of simulation-based training. Including trainees from all residency years would provide a more comprehensive understanding of its effectiveness.

Since the EyeSi system includes modules for both anterior segment and retinal surgeries, simulator-based training should be explored for a wider range of ophthalmic procedures. Institutions such as the CPSP and PGMI may consider formally integrating simulator-based modules into the FCPS curriculum across all subspecialties. It is further recommended that trainees achieve defined competency benchmarks on simulators before performing procedures on real patients under supervision.

CONCLUSION

The simulator group performed better in some fundamental surgical steps. Higher performance scores were often linked to simulator-based training, albeit this relationship was not consistently statistically significant across all tasks. In surgical specialties with steep learning curves, a hybrid paradigm that combines simulation-based and traditional apprenticeship training may be the most effective way to acquire skills.

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Conflict of Interest: Authors declared no conflict of interest.

Ethical Approval: The study was approved by the Institutional review board/Ethical review board **(ASRB002044/ES/IHPE).**

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Imran Ahmad; Associate Professor: *Concepts, Design, Literature Search, Data Acquisition, Manuscript Preparation, Manuscript Editing, Manuscript Review.*

Yousaf Jamal Mahsood; Associate Professor: *Design, Literature Search, Data Acquisition, Data Analysis, Statistical Analysis, Manuscript Preparation, Manuscript Editing, Manuscript Review.*

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