· Clinical Research ·

Utility of real-time 3D visualization system in the early stage of phacoemulsification training

Zhe Xu[1,2,3,4], *Dan Chen*[1,2,3,4], *Jing–Wei Xu*[1,2,3,4], *Yi–Xuan Feng*[1,2,3,4], *Ce Shi*[1,2,3,4], *Li Zhang*[1,2,3,4], *Wen Xu*[1,2,3,4]

[1]Eye Center, the Second Affiliated Hospital, School of Medicine, Zhejiang University, Hangzhou 310009, Zhejiang Province, China
[2]Zhejiang Provincial Key Laboratory of Ophthalmology, Hangzhou 310009, Zhejiang Province, China
[3]Zhejiang Provincial Clinical Research Center for Eye Diseases, Hangzhou 310009, Zhejiang Province, China
[4]Zhejiang Provincial Engineering Institute on Eye Diseases, Hangzhou 310009, Zhejiang Province, China
Co-first authors: Zhe Xu and Dan Chen
Correspondence to: Wen Xu and Li Zhang. Eye Center of the Second Affiliated Hospital, School of Medicine, Zhejiang University, No.88 Jiefang Road, Hangzhou 310009, Zhejiang Province, China. xuwen2003@zju.edu.cn; zhangli1@zju.edu.cn
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Abstract
● **AIM:** To determine the teaching effects of a real-time three dimensional (3D) visualization system in the operating room for early-stage phacoemulsification training.
● **METHODS:** A total of 10 ophthalmology residents of the first-year postgraduate were included. All the residents were novices to cataract surgery. Real-time cataract surgical observations were performed using a custom-built 3D visualization system. The training lasted 4wk (32h) in all. A modified International Council of Ophthalmology's Ophthalmology Surgical Competency Assessment Rubric (ICO-OSCAR) containing 4 specific steps of cataract surgery was applied. The self-assessment (self) and expert-assessment (expert) were performed through the microsurgical attempts in the wet lab for each participant.
● **RESULTS:** Compared with pre-training assessments (self 3.2±0.8, expert 2.5±0.6), the overall mean scores of post-training (self 5.2±0.4, expert 4.7±0.6) were significantly improved after real-time observation training of 3D visualization system (*P*<0.05). Scores of 4 surgical items were significantly improved both self and expert assessment after training (*P*<0.05).
● **CONCLUSION:** The 3D observation training provides novice ophthalmic residents with a better understanding of intraocular microsurgical techniques. It is a useful tool to improve teaching efficiency of surgical education.
● **KEYWORDS:** 3D visualization system; phacoemulsification training; wet lab
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INTRODUCTION
Phacoemulsification is the preferred technique for treating cataracts, with smaller incisions and better uncorrected visual acuity than previous methods[1-2]. Apprenticeship learning is the most traditional model of phacoemulsification training. Primarily, only one trainee can obtain similar surgical field and visual depth through a teaching microscope, and getting real-time introduction during surgery, which reduces the teaching efficiency. The residents usually learn surgical procedures by observing external monitors or reviewing surgical videos[3-5]. However, the eye is a complex three-dimensional (3D) organ. The narrow intraocular space and delicate tissues hardly allow any error of judgment and procedure. Two-dimensional (2D) videos potentially miss important spatial information of key surgical steps[6-8]. The perception of surgical steps in the operating room on a 2D screen differs from the teaching microscope. Therefore, 3D visualization presents a promising way to understand precise intraocular surgical maneuvers in ophthalmic surgery[7,9-10].

The development of 3D digital vision technology shows efficient applications in vitreoretinal, cataract, and corneal surgeries[11-13]. The surgical treatment effects of 3D visualization system were confirmed, which is currently encouraged to be widely used. Wearing passive polarized 3D glasses, surgeons perform microsurgical procedures by viewing a 3D external monitor with high resolution. Meanwhile, the 3D monitor can also be shown to one or more residents[6,9]. Real-time 3D visualization, connecting with the surgical microscope and displaying the operation lively, might be conducive to understand conceptualization of surgical procedures and

Resident Evaluator	N/P (0)	Novice (1)	(2)	Beginner (3)	(4)	Advanced Beginner (5)	(6)	Competent (7)
Incision & Paracentesis (Formation and technique)	☐	Inappropriate -Incision -Architecture -Location -Size	☐	-Leakage -Provides poor surgical access to capsule and bag	☐	-Either well-placed or non-leaking (but not both)	☐	-Parallel to iris -Self-sealing -Adequate size -Provides good access for surgical maneuvering
Viscoelastic (Appropriate use and safe insertion)	☐	Has difficulty accessing anterior structure through paracentesis	☐	-Knows when to use but administers incorrectly (amount or location)	☐	-Uses at appropriate times -Administers an adequate amount -Cannula tip in a good position	☐	-Viscoelastic are administered in an appropriate amount and at appropriate time -Cannula tip clear of the lens capsule and endothelium
Capsulorrhexis (Flap and follow-through)	☐	-Tentative -Chases rather than controls rhexis	☐	-Predominantly in control -Occasional loss of control of rhexis	☐	-In control -Few awkward or repositioning movements	☐	-Delicate approach and confident control of the rhexis
Capsulorrhexis (Formation and circular completion)	☐	-Size and position inadequate for nucleus density and implant type -Tear may occur	☐	-Size and position are barely adequate for nucleus density and implant type -Difficulty achieving circular rhexis -Tear may occur	☐	-Size and position are almost exact for nucleus density and implant type -Show control of radialization	☐	-Adequate size and position -No rears -Rapid -Show control of radializaion -Maintains control of the flap and anterior chamber

Figure 1 Modified ICO-OSCAR for wet-lab performances of 4 surgical items N/P: Not performed. ICO-OSCAR: International Council of Ophthalmology - Ophthalmology Surgical Competency Assessment Rubric.

intraocular anatomy for ophthalmic residents.

The purpose of this prospective study is to determine the teaching effects of real-time 3D visualization system in the early stage of phacoemulsification training. We hope our study can improve ophthalmic residents' cognition of intraocular anatomy and microsurgical techniques.

SUBJECTS AND METHODS

Ethical Approval This study was approved by the Animal Ethical Committee of the Second Affiliated Hospital of Zhejiang University School of Medicine (Approval No.2023-011). The written consent form was obtained from all subjects before participation. A total of 10 novice ophthalmology residents of the first postgraduate year (PGY-1), who had no experience of intraocular surgery and had never performed any steps of cataract surgery, participated to ensure the baseline level unified.

Surgical Skill Assessment The study used pretest–posttest design of one group in which subjects served as their own controls[14]. The study procedures were performed in 3 steps as follows: pre-training assessment (baseline), real-time observation using a 3D visualization system (training), and post-training assessment (outcome). A modified International Council of Ophthalmology - Ophthalmology Surgical Competency Assessment Rubric (ICO-OSCAR; Figure 1) used to assess the pre and post wet-lab surgical performance contained 4 specific steps of cataract surgery: wound construction, viscoelastic injection, capsulorhexis formation (commencement of flap and follow through), and capsulorhexis formation (formation and circular completion)[15-17]. An orientation was an offer to show the participants how to perform the assessments.

Porcine eyes were used to perform wet-lab surgery. Each participant was asked to perform 2 attempts of 4 surgical steps pre and post training of real-time 3D visualization system observation. Each attempt was scored by the participant (self-assessment) and the same expert surgeon (expert-assessment). The self-assessment was unmasked. The expert-assessment was masked. The mean score of each step was obtained for each resident.

Participants accepted the real-time cataract surgical observation training performed by one surgeon (Xu W) using a custom-built 3D visualization system[9]. All participants watched the 3D monitor wearing passive polarized glasses. The surgeon explained the surgical details during real-time 3D visualization training. The training schedule is twice a week and continuing 4h for each time. Each resident was given a total of 4wk of training (32h).

Statistical Analysis Results are described using means± standard deviations. Data analysis was performed by the Statistical Package for the Social Sciences software (ver. 27, SPSS Inc., Chicago, IL, USA). Paired *t*-test was used to compare the scores pre and post-training of 3D visualization system observation and the difference between self and expert-assessment. $P<0.05$ was defined as statistically significant.

RESULTS

Study participants included 10 PGY-1 residents (7 females and 3 males; 29.3±1.6y). A total of 40 attempts were video-recorded. The overall mean scores of pre-training self and expert assessments were 3.2±0.8 and 2.5±0.6 showed no significant difference. After real-time observation of the 3D visualization system, the overall mean scores of post-training self and expert assessments were 5.2±0.4 and 4.7±0.6, which were significantly improved (paired *t*-test, $P<0.05$; Table 1). The mean self-assessment score was higher than the expert-assessment score post-training (paired *t*-test, $P<0.05$; Table 1). Comparing with pre-training status, scores of 4 surgical items significantly improved in both self and expert-assessment

Table 1 Overall mean scores for self and expert-assessment pre and post 3D visualization system training

Parameters	Self-assessment	Expert-assessment	Difference self *vs* expert
Pre-training	3.2±0.8	2.5±0.6	0.7±0.6
Post-training	5.2±0.4[b]	4.7±0.6[a,b]	0.6±0.5
Improvement	2.0±0.7	2.1±0.9	0.1±1.0

[a]*P*<0.05 statistically different between self-assessment and expert-assessment. [b]*P*<0.05 statistically different between pre-training and post-training. Self: Self-assessment; Expert: Expert-assessment.

after training (paired *t*-test, *P*<0.05; Figure 2). As to the score of capsulorhexis (flap & follow-through), the self-assessment (2.8±0.9) was higher than the expert-assessment (1.6±0.6) pre-training (paired *t*-test, *P*<0.05; Figure 2; Table 2). Similarly, as to the same surgical item, the self-assessment (4.5±0.4) was higher than the expert-assessment (3.7±0.5) post-training (paired *t*-test, *P*<0.05; Figure 2; Table 2). The improved scores of 4 surgical items were parallel with no statistical difference (Figure 3; Table 2).

DISCUSSION

This study applied the real-time 3D visualization system to surgical teaching in the early stage of phacoemulsification training. As the wet-lab results of self and expert-assessments performed for the first basic procedures of phacoemulsification, real-time 3D visualization was beneficial to surgical improvements of novice residents.

Most residency programs focus on the surgical training of residents. Objective evaluation and feedback on surgical performances are critical during resident surgical education. The validated assessment tools for cataract surgery in the operation room include: ICO-OSCAR, Global Rating Assessment of Skills in Intraocular Surgery (GRASIS), Objective Assessment of Skills in Intraocular Surgery (OASIS), Human Reliability Analysis of Cataract Surgery (HRACS), and Subjective Phacoemulsification Skills Assessment (SPESA)[17-22]. However, these are designed for real surgical training, but not wet lab teaching in the novice stage. Farooqui *et al*[16] suggested a modified ICO-OSCAR to be used in a wet-lab for phacoemulsification training. The modified ICO-OSCAR was helpful in developing self-awareness and leading a professional development plan. Cheon *et al*[15] developed a modified ICO-OSCAR for simulation laboratory assessment for residents who were novices to cataract surgery. Using the modified ICO-OSCAR, self-assessment, peer-assessment, and expert-assessment were performed. In this current study, we verified a real-time 3D visualization system's teaching effect through pre and post wet-lab training. Therefore, as Cheon *et al*[15] reported, we used a modified ICO-OSCAR, which was designed for novice residents. The modified ICO-OSCAR offered a reliable tool to objectively assess surgical

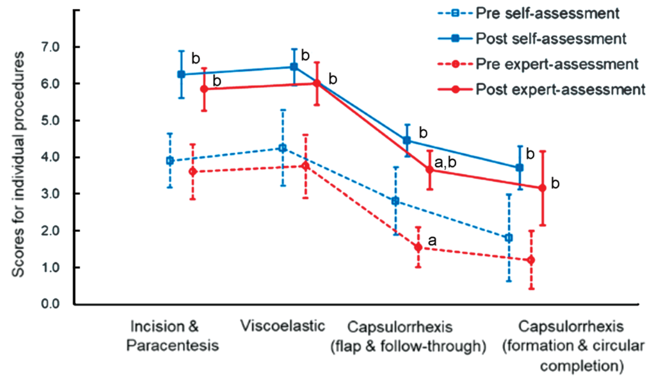

Figure 2 Illustration of surgical items scores for self and expert-assessment pre and post 3D visualization system training [a]Statistically different between self-assessment and expert-assessment, *P*<0.05. [b]Statistically different between pre-training and post-training, *P*<0.05. Pre self-assessment: Self-assessment before 3D visualization system training; Pre expert-assessment: Expert-assessment before 3D visualization system training; Post self-assessment: Self-assessment after 3D visualization system training; Post expert-assessment: Expert-assessment after 3D visualization system training.

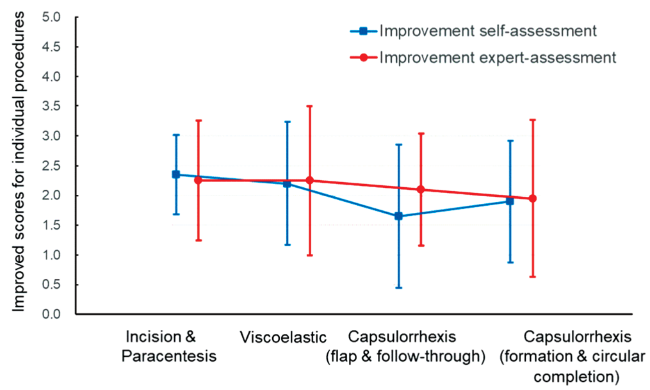

Figure 3 Improved scores for surgical items for self and expert-assessment pre and post 3D visualization system training Improvement self-assessment: Improved scores for surgical items for self-assessment; Improvement expert-assessment: Improved scores for surgical items for expert-assessment.

skills. In the future, assessment tools might be further modified to standardize resident education toward the goal of more uniform surgical skills in the wet-lab curriculum.

Learning to accurately evaluate the performance of cataract surgery by reviewing videos is an integral part of ophthalmology residency education[23-24]. Trainees are expected to make rigorous self-evaluations as an index of professional competence[25]. As to simulated surgery, Cheon *et al*[15] found expert scores were higher than self-scores in the following items: viscoelastic, capsulorhexis (commencement of flap and follow through), and capsulorhexis (formation and circular completion). In wet-lab training, Farooqui *et al*[16] reported that self and expert assessment matched closely in the steps of instrument handling and wound construction but varied in capsulorhexis. Our study also detected that the self-assessment

Table 2 Scores of surgical items for self and expert-assessment pre and post 3D visualization system training

Parameters	Self-assessment	Expert-assessment	Difference self *vs* expert
Pre-training			
Incision & paracentesis	3.9±0.7	3.6±0.7	0.3±0.8
Viscoelastic	4.3±1.0	3.8±0.9	0.5±0.7
Capsulorrhexis (flap & follow-through)	2.8±0.9	1.6±0.6[a]	1.3±0.8
Capsulorrhexis (formation & circular completion)	1.8±1.2	1.2±0.8	0.6±0.6
Post-training			
Incision & paracentesis	6.3±0.6[b]	5.9±0.6[b]	0.4±0.6
Viscoelastic	6.5±0.5[b]	6.0±0.6[b]	0.5±0.6
Capsulorrhexis (flap & follow-through)	4.5±0.4[b]	3.7±0.5[a,b]	0.8±0.5
Capsulorrhexis (formation & circular completion)	3.7±0.6[b]	3.2±1.0[b]	0.6±0.7
Improvement			
Incision & paracentesis	2.4±0.7	2.3±1.0	-0.1±1.0
Viscoelastic	2.2±1.0	2.3±1.3	0.1±0.9
Capsulorrhexis (flap & follow-through)	1.7±1.2	2.1±0.9	0.5±1.2
Capsulorrhexis (formation & circular completion)	1.9±1.0	2.0±1.3	0.1±1.0

[a]Statistically different between self-assessment and expert-assessment, $P<0.05$. [b]Statistically different between pre-training and post-training, $P<0.05$. Self: Self-assessment; Expert: Expert-assessment.

was higher than the expert assessment in the surgical item of capsulorhexis (flap & follow-through). Reasonably, trainees might be overconfident and overcritical when evaluating themselves. The appropriate evaluation of cataract surgery is challenging, which requires careful behavioral observation, interpretation of the observation, and objective assessment. Incorrect assessment at any stage will introduce unwanted error variance. Thus, residents must assess their performance accurately for surgical improvement[23].

The 3D technology provides an ergonomic way of learning and performing surgery to avoid surgeon fatigue and improve speed and precision[6]. Using a real-time 3D visualization system in the operating room, residents see exactly what the surgeon sees under the microscope with the same depth and focus[7,9]. The best audience for 3D technology is the first and second-year residents who need in-depth ophthalmology training[6]. Chhaya *et al*[6] demonstrated that medical students vitreoretinal surgeries by watching 3D video recordings. Wang *et al*[9] proved that 3D visualization system were not only efficient and safe in cataract surgery, but also showed a significant advantage in medical education. In the current study, our results showed the scores of 4 surgical items were significantly improved in both self and expert-assessment. These studies demonstrate 3D visualization system helps in understanding complex intraocular anatomy for microsurgical techniques. Besides, observational learning activates were reported to occupy the same cortical motor regions as physical practice[25]. Real-time observation using a 3D visualization system would bridge theoretical learning and clinical practices[26-27]. In the future, 3D visualization system can be widely used for various education of ophthalmic surgery and other medical disciplines.

There are some limitations in our current study. We included only 10 novice residents, which were relatively small. Enrolling multiple subgroups of ophthalmology residents at different stages, the benefits of a real-time 3D visualization system might be more convincing. Moreover, the standard ICO-OSCAR contains 20 surgical items. This study only focused on the first 4 steps of cataract surgery and tested the teaching effects of real-time 3D visualization system in the relevant early stage of phacoemulsification training. Other cataract surgery training components, such as surgical complications and perioperative managements, should also be further evaluated[26,28-30]. In the future, it is essential to conduct an intensive study covering the entire phacoemulsification surgery using a 3D visualization system attached to more trainees.

This study verified the teaching effects of a real-time 3D visualization system in the early stage of phacoemulsification training. The 3D observation training provides novice ophthalmic residents a better understanding of ophthalmic structures and microsurgical techniques, which is a valuable tool to improve intraocular surgical education teaching efficiency.

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