Influence of surgery simulator training on ophthalmology resident phacoemulsification performance

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PURPOSE: To determine whether the use of an eye-surgery simulator during ophthalmology residency training improves cataract surgery performance.

SETTING: Department of Ophthalmology, Medical Faculty Associates, George Washington University, Washington, DC, USA.

DESIGN: Comparative case series.

METHODS: Residents were divided into a simulator group and a nonsimulator group based on the inclusion or absence of the eye-surgery simulator in residency training. Consecutive resident cataract surgeries with the same attending surgeon were retrospectively reviewed. The phaco time and percentage power and intraoperative complications in each case were recorded. The adjusted phaco time in each case was calculated.

RESULTS: The study reviewed 592 surgeries. The mean values for phaco time, percentage phaco power, adjusted phaco time, complication rates, and complication grade were 1.88 minutes (range 0.11 to 7.20 minutes), 25.32% (range 2.2% to 50.0%), 47.58 minutes (range 0.24 to 280.80 minutes), 0.04, and 2.33, respectively, in the simulator group ($n = 17$) and 2.41 minutes (range 0.04 to 8.33 minutes), 28.19% (range 8.0% to 70.0%), 71.85 minutes (range 0.32 to 583.10 minutes), 0.06, and 2.47, respectively, in the nonsimulator group ($n = 25$). The Student *t* tests showed a statistically significant between-group difference in mean phaco time ($P<.002$), adjusted phaco time ($P<.0001$), and percentage phaco power ($P<.0001$). Regression analysis showed a significantly steeper slope of improvement in mean phaco time and power in the nonsimulator group than in the simulator group ($P<.0001$).

CONCLUSIONS: Residents who trained using the simulator had shorter phaco times, lower percentage powers, fewer intraoperative complications, and a shorter learning curve.

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Learning to perform the phacoemulsification technique of cataract extraction is a standard part of ophthalmology residency training, although the number of cases performed by a single resident varies from 50 to 300.[1] The use of surgery simulators in resident training offers the potential for better outcomes and decreased complication rates in resident phacoemulsification cases given its ability to develop the 2-hand and 2-foot coordination required during cataract extraction surgery in a setting that is safe for patients. Results in studies of surgery-simulator incorporation in nonophthalmologic residency training programs have been encouraging. In a randomized double-blinded study using the MIST-VR system to simulate cholecystectomies, Seymour et al.[2] found that residents who had simulator training performed the operation 29% faster than residents who were not trained using virtual reality.

The first eye-surgery simulators were for vitreous surgery and laser photocoagulation.[3,4] The Eyesi surgery simulator (VRmagic Holding AG) provides a simulation of the curvilinear capsulorhexis technique performed during cataract extraction, a skill that is known to be difficult for new ophthalmic surgeons to master (Figure 1).[5]

The Eyesi has been shown in virtual-reality and wetlab settings to improve surgical skills.[6–8] For example,

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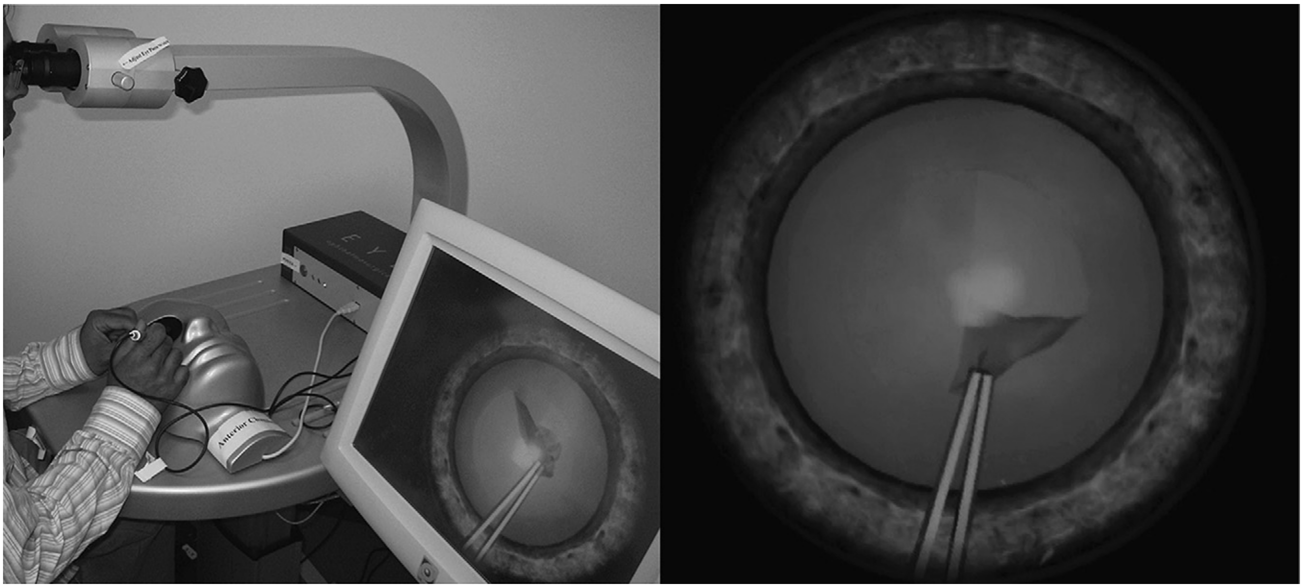

Figure 1. The eye surgery simulator (*left*) and a screen capture of the capsulorhexis simulation module (*right*) (courtesy of Brad Feldman, MD).

Feldman et al.[7] found a trend toward improved microsurgical skills among medical students who had 4 hours of virtual-reality training. Feudner et al.[8] report superior wet-lab capsulorhexis performance in virtual reality–trained students and residents after structured capsulorhexis training on the Eyesi system. The system has also been shown to differentiate between novice and experienced surgical skill; this capability can be applied to evaluate performance and progress of trainees.[6,9]

Limitations to surgical training in ophthalmology residency programs primarily include financial costs, human costs, and time constraints.[10] A major benefit of surgery simulation is that there is no risk for harm to patients. It is possible, therefore, that increased use of virtual-reality training can help reduce patient morbidity in ophthalmologic surgeries performed by residents.[11,12] The acceptance and appreciation of virtual-reality training has recently been documented in experienced ophthalmologists and resident trainees.[13]

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The gold standard in virtual-reality surgery trials is to show the effect of virtual training on live surgical performance (ie, virtual reality to operating room).[9] To our knowledge, there have been no studies showing the effects of virtual-reality training on actual surgical performance by ophthalmology residents in the operating room.

PATIENTS AND METHODS

The study was approved by the Institutional Review Board of George Washington University School of Medicine and Health Sciences. Surgical logs of consecutive resident cases performed with the same attending ophthalmologist (D.A.B.) at George Washington University were retrospectively reviewed. The inclusion criteria were phacoemulsification cases in which a third-year ophthalmology resident was the primary surgeon working under the supervision of the same attending ophthalmologist who used the same technique of instruction and instrumentation throughout the study period. Operations other than phacoemulsification or cases in which the resident was not the primary surgeon were excluded. The primary outcome measures were phaco time, percentage phaco power used, and intraoperative complications. The adjusted phaco time for each case was calculated by multiplying the phaco time by phaco power.

The procedure technique and instrumentation for all surgeries remained constant. Systemic monitors were placed, intravenous sedation was administered, and retrobulbar anesthesia was given without complication, resulting in good akinesia and anesthesia to the surgical eye. The eye was prepared and draped in a sterile fashion. A lid speculum was applied. Two side-port incisions were made with a paracentesis knife to prepare for a second instrument during phacoemulsification lens removal and eventual bimanual irrigation and aspiration of cortex. A 2.75 mm keratome corneal incision was made into the anterior chamber to facilitate use of the phacoemulsification needle and sleeve. A conical 30-degree beveled needle was used with the Series 20000 Legacy phaco

Table 1. Phacoemulsification settings used during all cases throughout the study.

Step	Phaco Power	Vacuum (mm Hg)	Aspiration (cc/min)	Pulse	Bottle Height (cm)
Divide x2	40–60	40–60	30–40	—	65–78*
Vacuum phaco	40–60	300–400	30–40	5	70–78*

*Or maximum bottle height

machine (Alcon Surgical). The anterior chamber was filled with an ophthalmic viscosurgical device (OVD). A capsulotomy was performed using a bent 25-gauge needle attached to a syringe and was completed with the capsule forceps. Gentle hydrodissection of the nucleus was performed. When possible, the cornea was covered with a blocking shield to protect the macula from the microscope light. The phacoemulsification tip was placed in the anterior chamber. The lens was sculpted and cracked into 4 quadrants using a second instrument, a nucleus ball-tip rotator. Table 1 shows the technique of vacuum phacoemulsification settings for nucleus quadrant removal. This cataract removal technique required the simultaneous use of the surgeon's 2 hands and 2 feet while the surgeon viewed through a light microscope. Residual cortex was removed with bimanual irrigation/aspiration instruments. The OVD was placed in the capsular bag. A foldable intraocular lens (IOL) was inserted in the capsular bag and rotated into good position. The wounds were closed with 10-0 nylon if necessary. The OVD was removed from the anterior chamber and around the IOL with a bimanual technique. Antibiotic–steroid ointment was placed on the eye and the eye patched and shielded.

Intraoperative complications that were recorded at the time of surgeries were used to calculate the complication rate in each study group. Complications were assigned a grade on a scale from 1 to 4. A grade 1 complication was defined as a Descemet tear or detachment. A grade 2 complication included an anterior chamber or posterior chamber capsule tear without vitreous loss. Vitreous loss automatically elevated the grade of the complication above 2. A grade 3 complication was defined as an anterior chamber or posterior chamber dehiscence with vitreous loss and sulcus IOL placement. Anterior chamber IOL placement and vitrectomy were considered a grade 4 complication.

The George Washington University Department of Ophthalmology purchased the Eyesi in 2006 and began incorporating virtual-reality training into the residency program at that time. All residents in the program were expected to spend a minimum of 2 hours per year using the simulator as verified by a login record. The residents who operated with the attending surgeon before virtual-reality training (before 2006) were placed in the nonsimulator-use group, and those who operated after the incorporation of virtual-reality training were placed in the simulator-use group. The initial Eyesi software for anterior segment procedures included a capsulorhexis module only and later incorporated phacoemulsification. The posterior segment module requires the use of 2 hands and 2 feet and closely simulates the 2-hand and 2-feet technique discussed in this paper; it was also included in resident training from the start of the study period.

Results of each outcome measure in the 2 resident groups were compared using Student *t* tests. Regression analyses of phaco time, phaco power, and adjusted phaco time were performed to compare the rates of progression in surgical skill over the course of the third year of ophthalmology residency training in the 2 groups. Statistical analysis was performed using SPSS software (version 19, SPSS, Inc.).

RESULTS

Five hundred ninety-two consecutive third-year resident cataract surgeries were performed with the same attending surgeon using the same technique and instrumentation. Surgeries performed by 42 third-year George Washington University ophthalmology residents (22 men, 20 women) were reviewed. Within that group, 17 residents (8 men, 9 women) had virtual-reality training using the simulator and 25 residents (14 men, 11 women) were not exposed to the simulator during their residency. Of the 592 cases included, 286 were performed by residents in the simulator group and 306 cases by residents in the nonsimulator group. All residents had performed a mean of 16 phacoemulsification cases (range 12 to 20 cases) before the start of their third year. The mean number of cases per resident in the simulator and nonsimulator groups was 16.8 (range 5 to 45) and 12.2 (range 4 to 28), respectively.

Table 2 shows the outcome parameters in each group. The simulator group had a statistically significantly lower mean phaco time ($P<.002$), adjusted phaco time ($P<.0001$), and percentage phaco power ($P<.0001$). There was no statistically significant between-group difference in mean complication rate ($P=.443$) or mean complication grade. Eight (47%) of the 17 residents and 12 (48%) of the 25 residents in the nonsimulator group had no complications.

Figure 2 shows the regression analysis results. There were significant differences in the slope values (M) between the 2 groups for each of the 3 phacoemulsification parameters.

One hundred twenty-six cases (44.1%) in the simulator group and 34 cases (43.8%) in the nonsimulator group were performed in the first half of the year (July through December). There was no significant difference in phaco time, phaco power, adjusted phaco time, or complication grade between the cases

Table 2. Phacoemulsification performance and intraoperative complication results by group.

Parameter	Simulator Group	Nonsimulator Group	*P* Value
Phaco time (min)			.002
Mean	1.88	2.41	
Range	0.11, 7.20	0.04, 8.33	
Mean phaco power (%)			.0001
Mean	25.32	28.19	
Range	2.2, 50.0	8.0, 70.0	
Mean adjusted phaco time (min)			.0001
Mean	47.58	71.85	
Range	0.24, 280.80	0.32, 583.10	
Mean complication rate (%)	0.04	0.06	.443
Mean complication grade	2.33	2.47	.701

performed in the first half of the year and those performed in the second half of the year in the simulator group or in the nonsimulator group. Overall, in both groups there was an increase in the complication rate between cases performed in the second half of the year and cases performed in the first half ($P = .0001$). When cases in the simulator group were isolated, however, cases performed in the second half of the year had a statistically significantly lower complication rate than those performed in the first half of the year ($P = .0001$). Linear regression showed weak positive correlations (mean $R = 0.189$) of no statistical significance between the number of cases per resident and all outcome parameters (phaco time, phaco power, adjusted phaco time, complication rate, and complication grade) in both groups.

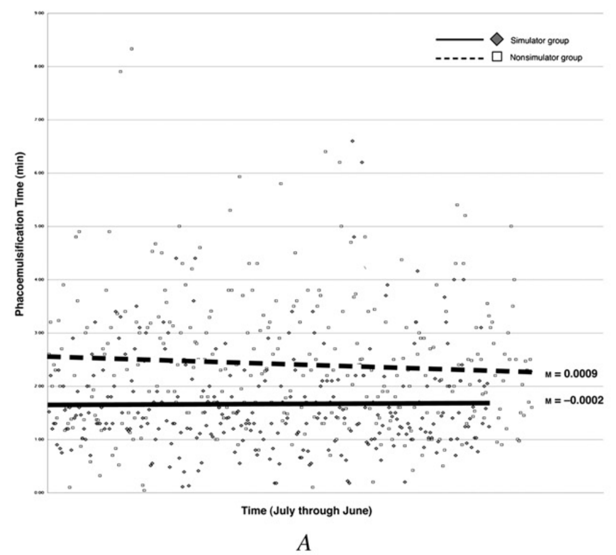
DISCUSSION

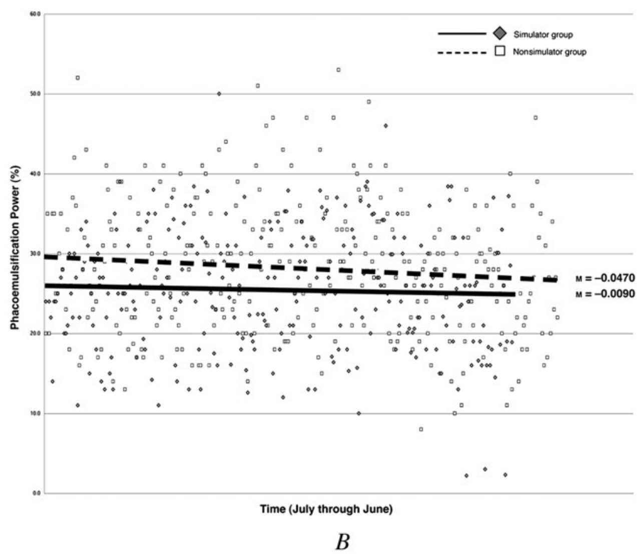
Surgery-simulation training has been shown to offer the potential for improved resident performance in the operating room and enhanced patient outcomes. Thus far in ophthalmic surgery, multiple studies have shown improved performance measured with the use of a simulator device or in the wet lab. For example, Feldman et al.[7] found a trend toward improved suturing skill in porcine eyes by medical students who trained for 4 hours using the Eyesi eye surgery simulator, although the results were not significant. In addition, in the setting of increased use of robotics to diminish the effect of physiologic tremor, virtual training increases a novice surgeon's awareness of tremor and offers a safe environment to test biofeedback or β-blocker therapy.[14]

Many have proposed that virtual-reality training would be most successful if it were integrated into a systematic training program.[15] Feudner et al.[8] showed the beneficial effects of virtual-reality training with the Eyesi system; the training required specific target criteria to be met, and results suggest that surgical novices can be trained to an objectively measured skill level before operating on patients. Another potential role of virtual-reality training for ophthalmology residents is to use the virtual-reality simulator to help reinforce procedures. This would require that residents spend multiple hours using a virtual-reality simulator after completing a wet-lab experience and assisting in the operating room.[9]

A disadvantage of wet-lab procedures is that the porcine eye, although anatomically similar, is not identical to the human eye. The porcine lens capsule is very elastic and tense, making capsulorhexis more difficult to perform than in human eyes.[8] Also, the porcine cornea becomes less transparent postmortem and the porcine nucleus is very soft. The Eyesi eye-surgery simulator requires the simultaneous use of both hands and both feet in the simulation training modules, which mimics the technique required to remove the lens nucleus described in this study. Thus, virtual reality-to-operating room is the gold standard in studies of surgery simulators.[10] Our results provide virtual reality-to-operating room evidence of the potential benefit of the eye-surgery simulator in resident education.

In our study, residents who trained using the eye-surgery simulator performed phacoemulsification more rapidly, used lower percentage powers, and had fewer intraoperative complications. This study also suggests that residents who had simulator training had a flatter learning curve, as indicated by the smaller slope values of the regression lines for each outcome. The lines for the 2 groups seem to be converging, indicating that both groups will ultimately reach the same level of surgical skill. All surgeries included in this analysis were performed under the supervision of the same attending physician who used the same technique of instruction and instrumentation throughout the study period, which minimized the





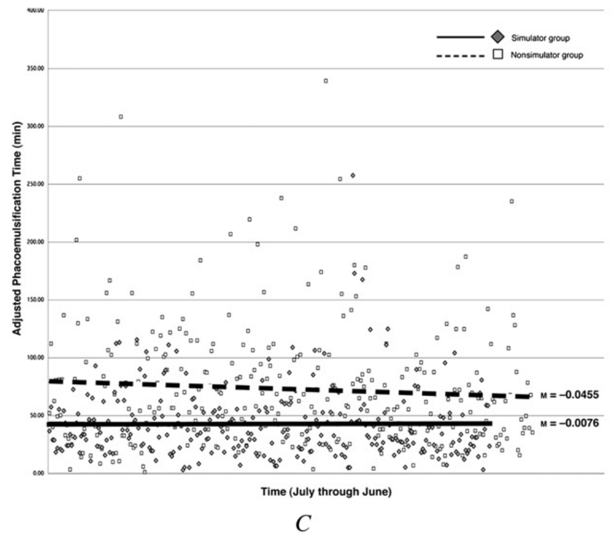


Figure 2. Regression analysis results showing phaco times (*A*), percentage power (*B*), and adjusted phaco time (*C*) of residents throughout the 12 months of their senior year.

effect of disparate teaching styles and technologies between different faculty members.

The Eyesi system includes modules that simulate capsulorhexis and a posterior segment module that requires the simultaneous use of both hands and both feet, thus simulating the phacoemulsification cataract 2-hand and 2-feet surgical technique described in this paper. We believed that simulation training using 4 extremities was key in our clinical experience as well as in the difference in surgical performance between the 2 resident groups. Our study retrospectively analyzed the impact of simulator training on overall phacoemulsification performance. Although the simulation did not precisely mirror the actual operation, we believe that the psychomotor coordination acquired through simulator use is the most important factor in improving surgical skill. We hypothesize that using the simulator to practice intraocular surgery can increase a trainee's speed and precision in the operating room, regardless of the specific procedure, especially when the new surgeon is required to simultaneously use both hands and feet while viewing through a high-powered microscope. A prospective study to determine the critical number of hours and number of cataract cases required to significantly improve surgical skill and reach competency would be useful in making recommendations for resident education.

Randleman et al.[16] showed that early resident cases are more likely than later cases to be associated with vitreous loss. There was a significant reduction in vitreous loss and mean adjusted phaco time after the first 80 cases performed by a single resident. In our study, there was a similar number of resident cases performed in the first half and in the second half of the year in each group, and there was no significant difference in the outcome parameters between the first half and second half of the year overall and in each group. Therefore, it is reasonable to suggest that virtual-reality training improved resident skill level and efficiency in the operating room, especially in the earlier cases.

Limitations of our study include its retrospective design and the review of a single attending physician's technique. However, consistency in technique and instrumentation was important to analyze the impact of the simulator on residency cataract surgery training. There were also difficulties in determining the percentage of time spent on anterior segment versus posterior segment modules, even though instructions were to use both modules equally and a total of 4 hours per resident was spent on the simulator over the first 2 years of residency. In addition, confounding data, such as ocular comorbidities and cataract characteristics of patients, were not accounted for in this study.

To our knowledge, this study is the first to provide evidence that the use of a surgery simulator during ophthalmology residency training will improve operative performance and decrease intraoperative complications. Further investigation analyzing the effect of resident surgery simulator training on final corrected visual acuity is warranted at this time.

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