Ophthalmic Surgery Simulator Training Improves Resident Performance of Capsulorhexis in the Operating Room

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Purpose: To assess the effect of a Capsulorhexis Intensive Training Curriculum (CITC) on the rates of errant, continuous, curvilinear capsulorhexes (CCCs) during cataract surgery among resident surgeons at a teaching hospital.

Design: Retrospective educational interventional case series.

Participants and Controls: A total of 1037 consecutive cataract surgeries performed at Harbor-UCLA Medical Center during 4 consecutive academic years were considered. The baseline cohort consists of 434 cataract surgeries performed during the 2 academic years before the intervention. The postintervention cohort consists of 603 cataract surgeries performed during the following 2 consecutive academic years.

Intervention: The principal intervention was the introduction of the CITC for residents on the Eyesi (VRmagic, Mannheim, Germany) ophthalmic virtual reality surgical simulator.

Main Outcome Measures: The main outcome measure was the rate of errant CCCs among the capsulorhexes performed during resident surgical cases. Errant CCCs were defined as attempted CCCs that resulted in the attending physician taking over, radialization of the CCC, conversion to can-opener capsulorhexis, or any combination of the 3 aforementioned conditions. Secondary measures included the use of trypan blue during CCC and correlating errant CCC and surgeons' level of training (postgraduate year [PGY]).

Results: There were 68 errant CCCs (15.7%) in the baseline cohort and 30 errant CCCs (5.0%; $P < 0.0001$) in the postintervention cohort, a 3.2-fold or 68% reduction. The use of trypan blue increased from 55.3% in the baseline cohort to 76.0% in the postintervention cohort ($P < 0.00001$), but within each cohort there was no significant difference in the rate of errant CCCs whether trypan blue was used or not. In the baseline cohort, there was a statistical trend toward fewer errant CCCs among PGY 4 (14.6%) compared with PGY 3 (22.8%) surgeons ($P = 0.12$). The postintervention cohort showed no significant difference in errant CCC rates between PGY 3 (4.4%) and PGY 4 (5.1%) surgeons ($P = 1.00$).

Conclusions: This study strongly suggests that virtual reality surgical simulation training with the CITC on the Eyesi reduces the rate of errant capsulorhexes. The incorporation of a formal program for surgical training via virtual reality simulation should be strongly considered in ophthalmology resident surgical education to reduce the unnecessary risk of complications for live patients.

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It is generally understood that a successful continuous curvilinear capsulorhexis (CCC) during phacoemulsification surgery reduces the rate of subsequent surgical complications, including posterior capsular tears and associated vitreous loss. Accordingly, when CCCs are attempted, and the capsular tear radializes, there is an increased risk of capsular tear extension to the posterior capsule with resulting vitreous loss and dropped lens fragments. As such, it is considered crucial for resident cataract surgeons to master the CCC as best and as soon as possible to minimize the rates of cataract surgery complications. However, teaching the capsulorhexis technique outside of the operating room remains a challenge.

The Eyesi virtual reality ophthalmic surgical simulator (VRmagic, Mannheim, Germany) has been studied, and both construct validity and some effect on surgical performance by residents in the operating room have been demonstrated. Mahr and Hodge[1] showed construct validity by demonstrating that there is significantly less variance in scores among experts than novices for the level 1 forceps training, antitremor, and navigation modules. Privett et al[2] compared experienced surgeons with medical students and residents and showed construct validity for the capsulorhexis module at the "easy" and "medium" levels.

With regard to cataract surgery performance in the operating room, Belyea et al[3] showed that Eyesi-trained surgeons had shorter phacoemulsification times and lower percentage phacoemulsification powers. In their study, there was no significant difference in complication rates between Eyesi-trained and Eyesi-naïve residents. Pokroy et al[4] showed that virtual reality surgical simulator training shortens the learning curve for the first 50 cataract surgery cases and noted that less adept residents seem to benefit most early in the training. Their study did not show a difference in

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posterior capsular rupture or anterior vitrectomy rates between simulator-trained and nonsimulator-trained surgeons.

The purpose of this study was to assess the effect of the introduction of an intensive capsulorhexis training curriculum on the rates of errant capsulorhexes in the operating room among resident cataract surgeons at a teaching hospital.

Materials and Methods

The study was performed in accordance with the US Health Insurance Portability and Accountability Act of 1996, and an investigational review board exemption was granted by the Office of the Human Research Protection Program at Harbor-UCLA Medical Center and Los Angeles Biomed.

The Eyesi ophthalmic microsurgical simulator with software versions 2.4 and 2.5 was used during the study. A Capsulorhexis Intensive Training Curriculum (CITC) was developed by one of the study authors (C.A.M.). The curriculum represents skill-based, compared with time-based, completion of learning; in other words, regardless of the time taken, the learners must achieve a certain skill level to go through and complete the curriculum. Key features of the 33-module curriculum consist of gated progression, with increasingly higher scores required, and an increasing number of successful repetitions required to progress through the curriculum. Details of the curriculum are summarized in Figure 1.

Because use of the Eyesi and the completion of the CITC was encouraged but not required during the study period, there was variation in Eyesi use. The simulator logs were reviewed, and residents were categorized into 1 of 3 groups. Residents who did not use the simulator at all were placed in the "no Eyesi use" group. Residents who used the simulator but did not complete or nearly complete the CITC were placed into the "some Eyesi, no CITC" group. Residents who used Eyesi and completed or nearly completed the CITC were placed into the "Eyesi and CITC" group. Many of the residents in the postintervention cohort were part of a study in which they were asked to complete the CITC 4 times. Those who performed the CITC as part of the study did so twice before 2 of their first 4 cataract surgeries, but not more than once per week to achieve temporal separation of the learning experience and thus training repetition over time. Furthermore, residents were encouraged to not complete the entire curriculum in a single session to further spread the learning experience over time. However, this was not tracked for any circumstance, whether in the study or not. In any case, additional Eyesi training was allowed using any of the modules or curriculae provided by VRmagic or by repeating all or parts of the CITC.

A cataract surgery quality improvement (QI) database kept at the teaching hospital was mined for relevant data, including

Step 1 Cataract Anti-Tremor Training Level 1 req. 30	**Step 8** Cataract Bimanual Training Level 2 req. 50	**Step 15** Cataract Anti-Tremor Training Level 5 req. 50x3	**Step 22** Cataract Forceps Training Level 4 req. 70x3	**Step 29** Capsulorhexis Level 7 req. 30x3
Step 2 Cataract Navigation Training Level 1 req. 30	**Step 9** Capsulorhexis Level 1 req. 30	**Step 16** Cataract Navigation Training Level 3 req. 50x3	**Step 23** Cataract Bimanual Training Level 5 req. 70x3	**Step 30** Capsulorhexis Level 8 req. 30x3
Step 3 Cataract Forceps Training Level 1 req. 30	**Step 10** Cataract Anti-Tremor Training Level 3 req. 50x2	**Step 17** Cataract Forceps Training Level 4 req. 50x3	**Step 24** Capsulorhexis Level 2 req. 30x3	**Step 31** Capsulorhexis Level 9 req. 50x3
Step 4 Cataract Bimanual Training Level 1 req. 30	**Step 11** Cataract Anti-Tremor Training Level 4 req. 50x2	**Step 18** Cataract Bimanual Training Level 5 req. 50x3	**Step 25** Capsulorhexis Level 3 req. 30x3	**Step 32** Capsulorhexis Level 10 req. 50x3
Step 5 Cataract Anti-Tremor Training Level 2 req. 50	**Step 12** Cataract Navigation Training Level 3 req. 50x2	**Step 19** Capsulorhexis Level 1 req. 50x3	**Step 26** Capsulorhexis Level 4 req. 30x3	**Step 33** Capsulorhexis Level 8 req. 70x5
Step 6 Cataract Navigation Training Level 2 req. 50	**Step 13** Cataract Forceps Training Level 3 req. 50x2	**Step 20** Cataract Anti-Tremor Training Level 6 req. 50x3	**Step 27** Capsulorhexis Level 5 req. 30x3	
Step 7 Cataract Forceps Training Level 2 req. 50	**Step 14** Cataract Bimanual Training Level 4 req. 50x2	**Step 21** Cataract Navigation Training Level 3 req. 70x3	**Step 28** Capsulorhexis Level 6 req. 30x3	

Figure 1. The Capsulorhexis Intensive Training Curriculum consists of 33 steps. Throughout the curriculum, there is gated progression. The gates consist of minimum scores and required repetitions. The required score to pass to the next level is indicated by the number after "req.", and the number of repetitions required is after the "x". As the curriculum progresses, the gates are set to be more difficult to achieve by increasing the required score and the number of repetitions at that minimum score. The modules that the steps consist of become more difficult.

postgraduate year (PGY) level of the surgeon, academic year, and whether there was an errant capsulorhexis. The inclusion criteria were that the cataract surgery was performed by an ophthalmology resident and that a CCC was planned. Cases that included a planned can-opener capsulorhexis or were aborted or cancelled for any reason before the capsule was breeched were excluded. The data were grouped by cohort. The baseline cohort consisted of all cataract surgeries performed during the 2008−2009 and 2009−2010 academic years. The postintervention cohort consisted of all cataract surgeries performed during the 2010−2011 and 2011−2012 academic years.

The primary outcome measure for this study was the rate of errant capsulorhexes. An errant capsulorhexis was defined as an attempted CCC that resulted in the attending physician taking over, radialization of the capsulorhexis, conversion to can-opener capsulorhexis, or any combination of the 3 aforementioned conditions. Secondary outcome measures included the rate of errant CCC stratified by Eyesi use and trypan blue use during capsulorhexis, the number of cases performed during the study period, and the rate of errant capsulorhexis stratified by Eyesi use, regardless of cohort assignment.

The rates of errant capsulorhexes between the cohorts were compared. Statistical analyses were performed using the two-tailed Fisher exact test.

Results

During the study, 38 residents performed surgery at Harbor-UCLA Medical Center, and because of the sequential nature of the study years and residency training, many of them contributed to more than 1 PGY or cohort. The baseline cohort consisted of 25 residents, who contributed to the cohort as PGY 2 (3 residents), PGY 3 (15 residents), and PGY 4 (14 residents). In the postintervention cohort, there were 23 residents who contributed to the cohort as PGY 3 (16 residents) and PGY 4 (16 residents). In each cohort, there was 1 residency class contributing to each consecutive 2-year cohort as both PGY 3 and PGY 4 residents, which accounts for the total of PGY 2, 3, and 4 residents contributing to each cohort being larger than the actual number of residents. There were 3 cataract surgeries performed by 3 PGY 2 residents in the baseline cohort. These were added to the PGY 3 group in the data analysis because the group was too small for separate analysis and excluding these cases did not follow the spirit of the study. None of these 3 cases had an errant CCC. The amount of Eyesi training each resident underwent varied. Table 1 summarizes the number of residents and the corresponding number of surgeries categorized by the Eyesi exposure.

A total of 1037 cataract surgeries met inclusion criteria. The baseline cohort consisted of 434 cataract surgical cases with 68 errant CCCs (15.7%). In comparison, the postintervention cohort consisted of 603 cataract cases with 30 errant CCCs (5.0%; $P < 0.0001$), a 3.2-fold or 68% reduction. The total case volume increase from baseline to the postintervention cohort was 38.4%. Trypan blue was used in 240 of the baseline cases (55.3%) and 458 of the postintervention cases (76.0%; $P < 0.0001$). Table 2 demonstrates further details of the results. Figure 2 shows errant CCC rates stratified by cohort and PGY level. In the baseline cohort, there was a statistical trend toward fewer errant CCCs among PGY 4 (55/377 [14.6%]) compared with PGY 3 (13/57 [22.8%]) surgeons ($P = 0.12$). The postintervention cohort showed no significant difference in errant CCC rates between PGY 4 (25/490 cases [5.1%]) and PGY 3 (5/113 cases [4.4%]) surgeons ($P = 1.00$). Figure 2 includes the results of the statistical comparison between cohort subgroups (PGY levels). Table 3 shows the rates of errant CCC stratified by use of trypan blue.

Table 1. Use of the Eyesi Simulator and Completion of Capsulorhexis Intensive Training Curriculum (CITC) by Cohort

	Baseline Cohort		Postintervention Cohort	
	Residents	*Cases*	*Residents*	*Cases*
All	25	434	23	603
No Eyesi use	14 (56%)	352 (81.1%)	1 (4.3%)	56 (9.3%)
Some Eyesi use, no CITC	4 (16%)	55 (12.7%)	2 (8.6%)	59 (9.8%)
Eyesi use and CITC	7 (28%)	27 (6.2%)	20 (87.0%)	488 (80.9%)

The total data set consisting of all 3 cohorts stratified by Eyesi use demonstrated that when the residents had no Eyesi training at all, there were 56 errant CCCs in 408 surgeries (13.7%). When there was some Eyesi use but the CITC was not completed, there were 14 errant CCCs in 114 cases (12.3%). When the residents completed the CITC at least once as part of their Eyesi use, there were 28 errant CCCs among 515 cataract surgeries (5.4%; Fig 3).

Discussion

The introduction of the CITC on the Eyesi virtual reality ophthalmic microsurgical simulator was associated with a statistically significant 68%, or 3.2-fold, reduction in errant capsulorhexis rates among ophthalmology residents performing cataract surgery at a teaching hospital. Furthermore, in the baseline cohort, there were fewer errant CCCs among the group of PGY 4 residents compared with the group of PGY 3 residents (Fig 2). In contrast, the postintervention cohort showed no difference in errant CCC rates between PGY 3 and PGY 4 surgeons. Given the same low rates of errant CCCs in both PGY 3 and 4 in the postintervention cohort, it is likely that the PGY 3 residents started their surgical careers as already being proficient in CCC. On the basis of these data, preparing resident cataract surgeons with the CITC on the Eyesi results in improved resident performance of CCC in the operating room.

Two years of data were evaluated both before and after the introduction of the CITC to minimize the effect of resident talent on the results. Given the relatively large size of the Jules Stein Eye Institute residency program at 8 residents per academic year, combining 2 years of data for the baseline cohort resulted in 25 different residents

Table 2. Characteristics of Baseline and Postintervention Cohorts

	Baseline Cohort	Postintervention Cohort	*P* Value
No. of residents	25	23	
Mean no. of cases per resident (range)	16.7 (1−36)	25.1 (1−56)	
No. of cataract surgeries performed	434	603	
Errant CCC	68 (15.7%)	30 (5.0%)	<0.0001
Use of trypan blue during CCC	240 (55.3%)	458 (76.0%)	<0.0001

CCC = continuous curvilinear capsulorhexis.

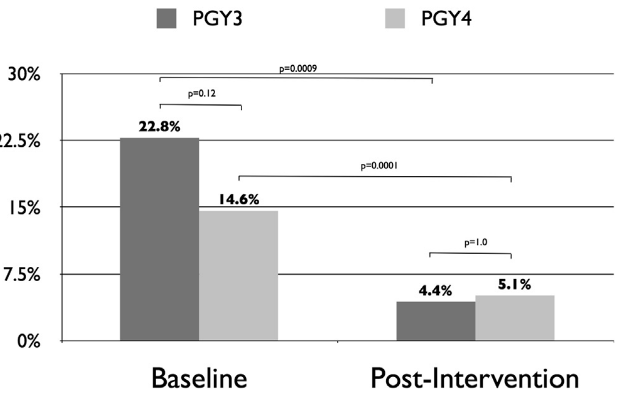

Figure 2. Errant continuous curvilinear capsulorhexis (CCC) rate stratified by cohort and postgraduate year (PGY). The graph demonstrates that the rate of errant CCCs decreased dramatically from the baseline cohort to the post-intervention cohort for each PGY. In the baseline cohort, there was a trend toward more errant CCCs among the PGY 3 than the PGY 4 residents ($P = 0.12$). However, after initiation of the Capsulorhexis Intensive Training Curriculum, the rate of errant CCCs was nearly equal between the PGY 3 and PGY 4 residents, suggesting that the PGY 3 residents already performed CCCs at a PGY 4 skill level.

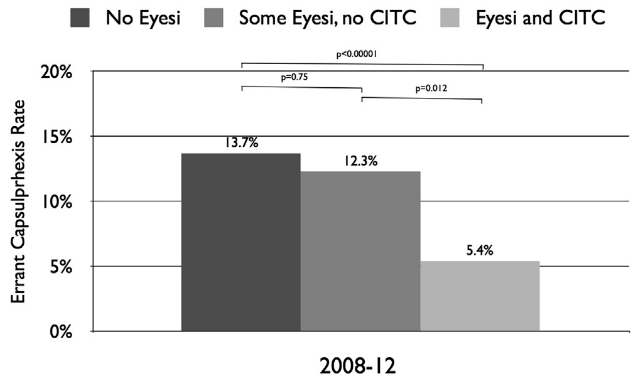

Figure 3. Errant continuous curvilinear capsulorhexis (CCC) rate stratified by Eyesi simulator use, including whether the Capsulorhexis Intensive Training Curriculum (CITC) was completed. The graph demonstrates that the absence of Eyesi use or Eyesi use in an unstructured manner had similar rates of errant CCCs. Structured use of the Eyesi with the CITC resulted in substantially lower rates of errant CCCs compared with either of the aforementioned situations.

contributing to the data pool and 23 residents contributing to the postintervention cohort. The number of residents measured is not the theoretic 32 because 8 of the residents are measured during both their PGY 3 and PGY 4 years. This results in an unavoidable slight skew of the data toward those residents' abilities.

During the study period, there were no major changes in technique or instrumentation for capsulorhexis performance, except for the increased use of trypan blue. Trypan blue for anterior capsular staining to facilitate CCC was first described in 1999 and has become an established and widely used technique.[5] At the beginning of the 2010–2011 academic year, it was emphasized to the residents that trypan blue should be used liberally for anterior capsular staining to facilitate the performance of the capsulorhexis. It was commonly performed throughout the 4 years assessed in this study, but there was a 1.38-fold increase in use from 55.3% to 76.0% from the baseline to the post-intervention cohort, respectively. However, this increase in

Table 3. Errant Continuous Curvilinear Capsulorhexis (CCC) Stratified by Trypan Blue Use

	Baseline Cohort (n=434)	Postintervention Cohort (n=603)
Trypan blue used		
Errant CCCs	44 (18.3%)	22 (4.8%)
CCCs	240	458
No trypan blue used		
Errant CCCs	24 (12.4%)	8 (5.5%)
CCCs	194	145
Errant CCC trypan blue used vs. not used statistical comparison (*P* value)	0.11	0.67

trypan blue use is unlikely to explain the 3.2-fold reduction in errant CCCs, from 15.7% to 5.0%, observed between these cohorts.

Contrary to what one might expect, the rates of errant CCCs were not significantly different in the baseline or the postintervention cohorts when comparing those cases in which trypan blue was used with those cases in which it was not used (Table 3). Because the use of trypan blue would be expected to facilitate the completion of an error-free CCC, the rates of errant CCCs should theoretically be lower among these cases. This was not observed, so a strong differential effect of trypan blue use on errant CCCs was not clearly observed. To the contrary, in the baseline cohort, there was a nonstatistically significant trend toward a higher rate of errant CCCs when trypan blue was used, the opposite of what one might have expected. This may be in part because trypan blue is used more commonly when the cataract is more advanced and the red reflex is poor, resulting in an overall more difficult surgical procedure, possibly including the CCC. Nonetheless, the possibility of the trypan blue use alone having a significant effect on errant capsulorhexis rates cannot be completely excluded. However, the analysis of the use of trypan blue does not support the notion that its increased use contributed significantly or dramatically to the reduced rate of errant CCCs.

It is difficult to ascertain whether and to what extent attending physicians affected the performance of the capsulorhexis. At the teaching hospital where this study was performed, there are many attending physicians who supervise resident surgery. The number of surgeries each attending physician supervises varies greatly. There was also variation of the attending physicians over the 4 years of the study; however, this was not further quantified.

In the Jules Stein Eye Institute residency program, there are ample opportunities to learn the technique of capsulorhexis construction in a practice situation. There is a microsurgical education course in the beginning of the first year of ophthalmology residency, there are weekend phacoemulsification training courses with wet laboratories that residents are required to attend at least once per year, and there is a fully equipped microsurgical laboratory that is available 24 hours per day for practice surgery on porcine eyes. During the 4 years that the cohorts span, there was no significant change in the cataract teaching curricula other than the Eyesi introduction under study in this report. However, it is difficult to ascertain to what extent any given resident takes advantage of these learning opportunities, given that these training methods do not have recordable accountability measures. Thus, microsurgical teaching could not be controlled for and could be a significant confounder in this study. However, it is unlikely that entire classes used the microsurgery laboratory as a group significantly more or less. Individual variability in the intensity of use of these educational opportunities is unlikely to affect the results significantly.

The data used for this study were from a QI database that was used as part of a QI project. Confounders of the outcome in this study include other initiatives resulting from the QI project that were undertaken in an attempt to reduce complication rates in the Jules Stein Eye Institute residency program. These initiatives included revising established guidelines and emphasizing that they should be adhered to for resident case selection to match resident skill and anticipated case difficulty better, encouraging cataract surgery attending physicians to have a lower threshold for taking over or intervening during cases, encouraging those being assisted by residents to give residents more hands-on experience in such cases, and to use trypan blue more liberally, as mentioned earlier.

It is likely that these initiatives had little effect on CCC performance. The anticipated difficulty of cataract surgery cases relates to the lens density, which may affect the red reflex or the lens removal steps. Because trypan blue was used liberally during the study periods, the lack of red reflex was adequately compensated for. The lens removal portion of the cases was not assessed in this study, only the CCC. In this article, the attending physician taking over during CCC is part of the errant capsulorhexis definition; therefore, an increase in attending physicians taking over during CCC would result in more rather than fewer errant CCCs. The increased use of trypan blue has been discussed. So, overall, the initiatives that were part of the QI project likely had little confounding effect on the primary outcome measure of the study, that is, CCC performance by the resident.

There was some Eyesi use among the baseline cohort's residents. In the second academic year of the baseline cohort, residents had access to the Eyesi. Those who wanted to use it were given a password with access to all modules, including the CITC. Eyesi use was highly variable among the residents during that time. Thus, the baseline cohort incorporates residents who had variable Eyesi exposure. Likewise, the postintervention cohort includes 1 resident who never used the Eyesi and 2 residents who used the Eyesi variably but never completed the CITC. Figure 3 illustrates that there is almost no difference in errant capsulorhexis rates between those who did not use the Eyesi and those who used it but did not complete the CITC. However, there are significantly lower errant capsulorhexis rates among those residents who completed the CITC on the Eyesi at least once compared with either of the other 2 groups. The significantly better performance of CCC among those who used the Eyesi suggests that a structured curriculum, the CITC in this case, that is completed early or before the residents' surgical experience is key to successful learning of the CCC and perhaps microsurgical skills in general.

The total case volume increase from the baseline to the postintervention cohort was 169 cases or 38.4%. This increase was not associated with increased operating room time or availability. Thus, the operations likely were performed more efficiently, that is, in less time or with reduced turnover times. It is not likely that the turnover times over the span of 4 years were significantly altered; however, there are no data regarding this metric available. If turnover times were more or less constant over the 4-year span, then reduced case duration is likely the main reason for the residents being able to perform more cases without having more operating room availability. It could be speculated that the Eyesi training resulted in more efficient and thus shorter surgeries, perhaps partly because there were fewer complications resulting in prolonged surgeries. Other studies have described shorter operative times among Eyesi-trained residents than among non−Eyesi-trained residents. Pokroy et al[4] showed that that there was a statistically significant reduction in case time between cases 11 and 50 when comparing Eyesi-trained versus Eyesi-naïve residents. However, this difference did not hold up in their study when considering all cases 1 to 50 for each resident.

The major strength of this study is the large number of participants (i.e., resident surgeons) because of the large size of our residency program. The more study participants there are the less likely individual outliers are likely to affect the study results and thus the more generalizable the study conclusions. The weaknesses of this study are the retrospective nature of the cases and the confounding factors described previously.

It is difficult to know whether the CITC on the Eyesi is the sole or main reason for the reduction in errant CCCs observed. There are many confounders that are nearly impossible to control for, including, but not limited to, residents' talent, change in instrumentation and techniques during the study period, attending physician's ability to guide the resident, microsurgical practice laboratory use by the residents, and the Hawthorn effect.

The Hawthorn effect is defined as improved performance due to having a context of a study situation or scrutiny alone, in an effect independent of any intervention or change in performance requirements.[6] This improvement regresses when study or scrutiny ceases. The Hawthorn effect may be responsible for confounding in our study. With the introduction of the Eyesi for surgical training at the Jules Stein Eye Institute in 2009, the attention to cataract surgery and teaching surgery in general has received heightened awareness than in years past. The Eyesi simulator tracks individual use, and residents are aware that their simulator training time and performance may be reviewed by faculty. Although this could be considered one of the beneficial aspects of the Eyesi simulator, namely, that it incorporates use tracking and training requirement completion can be documented with printable training reports, it also may contribute toward the influence of the Hawthorne effect. Other residency-wide educational efforts that were part of a QI initiative to improve cataract surgery outcomes may have had additional effects. Thus, there may be some improvement in resident performance due to these nonmeasurable confounders that are inherent to the use of the Eyesi simulator and, in the case of this study, to the overall increased attention to cataract surgery education and outcomes.

In conclusion, our report uniquely demonstrates that a focused simulator intervention, in this case capsulorhexis training, may have a dramatic effect on the in-operating room performance of trainees. We achieved a 68%, or 3.2-fold, reduction in errant capsulorhexes after the introduction of the CITC with the Eyesi surgical simulator. The simulator-prepared residents may be more efficient surgeons. Further research is warranted to study the potential magnitude of the benefit offered by virtual reality simulation training on resident learning, surgical competence, and ultimately improved patient care.

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Footnotes and Financial Disclosures

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