Effect of surgical simulation training on the complication rate of resident-performed phacoemulsification

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ABSTRACT

Objective To study the effect of additional training with ophthalmic surgical simulation on the intraoperative complication rates of phacoemulsification performed by residents.

Methods and materials This was a retrospective study of phacoemulsification surgeries performed by third-year residents at Siriraj Hospital. The operations were classified into two groups according to the experience of the surgeon in simulation training, that is, trained vs untrained. The main outcome was the total rate of complications. Other outcomes, including posterior capsule rupture, anterior capsulorhexis tearing, zonular dehiscence, retaining of lens material and intraocular lens (IOL) implantation methods, were also analysed.

Results In total, 2971 operations were performed, comprising 1656 operations by 21 residents in the trained group, and 1315 by 20 residents in the untrained group. The total rate of complications in the simulator-trained group was lower than in the untrained group (13.6% vs 17.3%, p=0.005). Only the rate of retaining lens material showed a statistically significantly reduction (p<0.001); however, the rates of posterior capsule rupture, anterior capsulorhexis tearing and zonular dehiscence were not significantly different (p=0.08, 0.17, 0.23, respectively). The IOL implantation methods and surgical aphakia rate between the two groups were similar (p=0.44). In the subgroup analysis, the posterior capsule rupture rate in the first half of all cases performed by the residents was lower in the trained group (8.8% vs 12.4%, p=0.02).

Conclusion Ophthalmic simulation training reduces the total rate of complications of resident-performed phacoemulsification. It also shortens the learning curve for cataract surgery training, as indicated by the decreased posterior capsule rupture rate in the initial cases of cataract surgery.

INTRODUCTION

Phacoemulsification is a kind of cataract surgery, which is the most commonly performed surgery in the ophthalmology field. The complication rate in this surgery is higher among surgical trainees because becoming an expert in cataract surgery requires learning experience and the development of complex visuospatial skills. Many studies on resident-performed

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Ophthalmic surgical simulation training could reduce complications and the posterior capsule rupture rate of phacoemulsification surgery performed by residents.

WHAT THIS STUDY ADDS

⇒ Simulation training reduced the overall intraoperative complications and posterior capsule rupture in the first half of cases of phacoemulsification surgeries performed by residents.
⇒ Simulation training improved residents' surgical performance by shifting the learning curve of trainee surgeons.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE AND/OR POLICY

⇒ The supplementation of simulation training to conventional training is beneficial for residents and can improve patient safety.
⇒ Further studies need to be done to evaluate the effect of the duration of training and the simulator tasks scores on the actual proficiency of residents in performing real surgeries.

phacoemulsification have reported varying complications, and it has been reported that resident-performed surgery is an independent risk factor of posterior capsule rupture,[1] with the posterior capsule rupture rate ranging from 1.8% to 14.7%.[2 3]

The ophthalmic surgical simulator Eyesi (VRmagic, Mannheim, Germany) was first introduced to the market in 2001 and later used in cataract surgery training in 2003. It simulates cataract surgery through the use of 3D virtual reality technology and enables residents to practice each step in phacoemulsification. Many studies have demonstrated the construct validity of the simulator.[4–8] Recent research has aimed to evaluate the correlation between ophthalmic simulation training and real-life surgery outcomes and complications. A few studies have reported that simulation training can reduce complications and the posterior capsule rupture rate

of phacoemulsification surgery performed by trainee surgeons.[9–12] In contrast, one study found that simulation training did not reduce the complication rate but did shorten the learning curve in real-life surgeries.[13]

The aim of this study was to demonstrate the effect of surgical simulation training on the complication rate of phacoemulsification surgery performed by third-year residents.

METHODS AND MATERIALS

The electronic medical records of Siriraj Hospital were reviewed to identify all the patients who had underwent phacoemulsification by third-year residents from 2010 to 2017.

In the Siriraj Hospital residency programme, second-year residents begin by performing extracapsular cataract extraction surgery and then take a phacoemulsification wet LAB instruction course using pig eyes in the middle of their second academic year. In their third year, the residents begin performing phacoemulsification cataract surgery. The ophthalmic surgical simulator was introduced to Siriraj Hospital in 2012 and has been used since as a supplement to traditional training. Initially, from 2012 to 2014, simulation training was not a formal requirement before real surgery. In 2015, the simulation training curriculum was developed and completion of the standard simulation training course, comprising three categories (categories A, B and C), became mandatory before residents are allowed to perform real surgeries. Details of the curriculum are shown in figure 1.
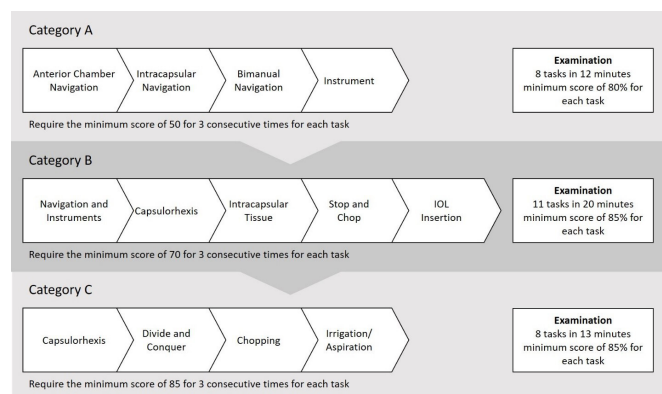

Figure 1 Surgical simulation training curriculum. The standard courseware consists of three categories. In each category, regardless of the time taken, the trainee is required to achieve the minimum score three consecutive times in each step before proceeding to the next task (minimum score of 50 for category A, 70 for category B and 85 for category C). After completion of all the tasks in each category, the learner must pass the examination before they are permitted to start training in the next category. The exam consists of multiple tasks that are randomly selected by the instructor and a time limitation is set. To pass the exam, the trainees are required to finish all the tasks in the time limit with a higher score than the minimum criteria. IOL, intraocular lens.

Because of the variation in the simulation training of residents in 2012–2014, we excluded all resident operations performed during this period. We separated the remaining cases into two groups. The first group was the trained group and included cases performed during the 2015–2016 academic year by 21 residents who had additional training with the simulator. The second group was the untrained group and included cases performed by 20 residents who had no experience with simulation training during the 2010–2011 academic year, that is, before the simulator was introduced to Siriraj Hospital.

Between 2010 and 2017, there were no major changes in the wet lab curriculum, surgical equipment and surgical technique. The wet lab course was instructed by the same instructor and followed the core curriculum. Surgeons in both groups performed the operation by creating a 3 mm temporal limbal corneal incision. A peristaltic-pump-system phaco machine, 30° straight phaco tip and coaxial I/A tip were used in the surgeries.

The patients' demographics, including age, gender and systemic disease, were recorded. The LogMAR visual acuity, ocular comorbidity, cataract grading and ocular biometry measured by the IOLMaster instrument or ultrasonography were also collected. The operation information was retrospectively reviewed for the date of the operation, laterality of the eye, anaesthetic method, phaco time and intraoperative complications.

The main outcome sought was the total rate of complications. Other outcomes, including the posterior capsule rupture rate, anterior capsulorhexis tearing, zonular dehiscence, retaining of lens material and intraocular lens (IOL) implantation methods, were also studied.

Statistical analysis was performed using SPSS statistics software. The total rate of complications and specific complications in each group were compared using χ^2 test. ORs were reported as OR (95% CI). Statistical significance was defined as $p < 0.05$. The nominal data were also compared by χ^2 test and the mean interval scale data were compared using independent t-test. Logistic regression analysis was performed and multivariable regression analysis was done using the forward stepwise method.

RESULTS

In this study, 41 residents performed 2971 operations at Siriraj Hospital, Mahidol University. Of these, 21 residents in the trained group performed 1656 phacoemulsification surgeries and 20 residents in the untrained group performed 1315 operations. The number of surgical cases per resident was higher in the former group. The laterality was similar in both groups but the anaesthetic method was different. The number of subconjunctival and topical anaesthesia cases were higher in the trained group, while the number of retrobulbar anaesthesia cases was lower. There were no differences in terms of age, gender, preoperative best-corrected visual acuity (BCVA), ocular pathology, axial length and anterior chamber

depth between the groups of patients. The number of patients with diabetes in the trained group was greater, but the number of patients with hypertension and heart disease in the trained group were lower than in the untrained group. The degree of nuclear cataract grading was also different; whereby the number of patients with nuclear sclerosis grade 1 in the trained group was greater, while nuclear sclerosis grade 3 was lower in the trained group than in the untrained group (table 1).

In the total 2971 cataract surgeries included in this study, there were 453 cases of complications: 225 in the trained group and 228 in the untrained group. The total rate of complications in the trained group was lower compared with in the untrained group (13.6% vs 17.3% OR=0.75; 95% CI 0.61 to 0.92, p=0.005) (table 2). Although the number and rate of posterior capsule rupture, anterior capsule tear, zonular dialysis, retaining of lens material and other complications seemed to be lower in the trained group, only the rate of retaining lens material was statistically significantly reduced (p<0.001). Most cases achieved IOL implantation in the bag. The IOL implantation methods were not different (p=0.44) and the rate of surgical aphakia was similar (0.4% vs 0.8%) (table 2).

The operations were split for each resident into two proportions: the first half of cases performed by the residents and then the second half. Subgroup analysis of the first and second halves of the total operations was then performed. Among the first halves of the operations, the posterior capsule rupture rate in the trained group was significantly lower than in the untrained group (8.8% vs 12.4%, p=0.02). In contrast, the posterior capsule rupture rate in the latter halves of the total cases was not significantly different (8.1% vs 8.2%, p=0.93) (table 3).

Logistic regression analysis was conducted to determine how several factors affected the total rate of complications of the resident-performed phacoemulsification. Preoperative BCVA, anaesthetic methods, and simulation training were factors that affected the complication rate in the univariable analysis. However, only preoperative BCVA and simulation training were significantly correlated with the complication rate in the multivariable analysis. Patients with a poorer preoperative BCVA had higher odds of developing complications (OR=1.32; 95% CI 1.10 to 1.59, p=0.003), while simulation training was associated with lower odds of complications (OR=0.75; 95% CI 0.61 to 0.92, p=0.005) (table 4).

DISCUSSION

The main goal of this research was to demonstrate the effectiveness of ophthalmic surgical simulation training in resident-performed cataract surgery. The results supported the belief that simulation training is related to a lower total rate of complications. Although the rate of posterior capsule ruptures was not significantly different, it was lower in the first half of the surgeries performed. To the best of our knowledge, there are five studies that have

compared the effect of simulation training on the rate of complications of resident-performed cataract surgery.[9–13]

Lucas et al found that simulation training significantly reduced the total complications and posterior capsule ruptures in the first 10 cataract surgeries performed by residents.[11] In a larger sample size study, Staropoli et al showed a significant reduction in total complications and posterior capsule ruptures after simulator training had been added as a supplement to traditional cataract surgery training.[10] Ferris et al also found that the posterior capsule rupture rate was reduced by 38% following the implementation of a simulator.[12] In contrast, Pokroy et al did not demonstrate a difference in the total complication and posterior capsule rupture rates after simulation training.[13]

Simulation training allows residents to gain hands-on and situational experience. Pokroy et al found that it could shorten the learning curve of residents for performing phacoemulsification.[13] This supports the reason why simulation training reduced the total complications in our study. Although our study did not demonstrate a difference in the overall posterior capsule rupture rate, it was found to be significantly lower in the trained group for the first half of the residents' total cases but was not different in the latter half of the cases according to the subgroup analysis (table 4). This may be explained by the learning curve effect. Residents with experience of simulation training will have built up some skills and experience before performing real surgery, which shifted the learning curve in the first half of cases. In later operations, both groups of residents had now gained more experience and become more proficient in surgery and thus their proficiency reached a plateau. Moreover, this study involved a greater number of surgical cases than other single-centre studies and included all phacoemulsification surgeries performed by third-year residents in both a trained and untrained group. Therefore, the untrained residents could gain more experience by performing real surgery and they could catch up with simulation-trained residents in the later performed surgeries. This relationship between increasing surgical experience and lower complications in later cataract surgery performed by residents was also demonstrated in previous studies.[3 14]

We reviewed the baseline clinical characteristic data (table 1) that could confound the total rate of complications. We also performed multivariable analysis in order to minimise the limitations of this retrospective study. Most the characteristics of the cases in the trained and untrained group were similar except for the anaesthetic method, and incidence of diabetes mellitus, hypertension, coronary artery disease, and degree of nuclear sclerosis. The higher number of subconjunctival and topical anaesthesia cases in the trained group may imply that simulation training could increase confidence and surgical skills. However, in previous studies, the anaesthetic factor was not reported to be associated with the complication and posterior capsule rupture

Table 1 Comparison of the operation data, patients' demographics and baseline characteristics between the trained and untrained group

Clinical characteristic	Trained group	Untrained group	P value
Operation data			
No of operations	1656	1315	
No of surgeons	21	20	
No of cases per surgeon, mean (SD)	78.9 (15.3)	65.8 (16.2)	0.01
Laterality (%)			
Right	838 (50.6)	685 (52.1)	0.41
Left	818 (49.4)	630 (47.9)	
Anaesthetic method* (%)	1557	1110	
Topical	133 (8.5)	29 (2.6)	<0.001
Subconjunctival	273 (17.5)	37 (3.3)	
Retrobulbar/peribulbar	1116 (71.7)	1033 (93.1)	
General anaesthesia	35 (2.2)	11 (1)	
Patient demographics			
Age, mean (SD)	69.44 (8.75)	68.9 (8.9)	0.10
Gender (%)			
Male	633 (38.2)	477 (36.3)	0.28
Female	1023 (61.8)	838 (63.7)	
Systemic comorbidities (%)			
Diabetes	632 (38.2)	448 (34.1)	0.02
Hypertension	825 (49.8)	788 (59.9)	<0.001
Heart disease	74 (4.6)	82 (6.2)	0.047
Chronic kidney disease	108 (6.5)	69 (5.2)	0.15
Ocular status			
Preoperative BCVA, LogMAR (SD)	0.56 (0.34)	0.58 (0.39)	0.13
Ocular comorbidities (%)			
Diabetic retinopathy	177 (10.7)	129 (9.8)	0.43
Glaucoma	157 (9.5)	139 (10.6)	0.33
Uveitis	4 (0.2)	5 (0.4)	0.49
Pupil <6 mm	4 (0.2)	3 (0.2)	0.94
Lens subluxation	0 (0)	1 (0.1)	0.26
Pseudoexfoliation	8 (0.5)	3 (0.2)	0.26
Prior vitrectomy	1 (0.1)	4 (0.3)	0.11
Ocular biometry (mm)			
Axial length, mean (SD)	23.29 (1.15)	23.36 (1.01)	0.46
Anterior chamber depth, mean (SD)	3.02 (0.41)	3.02 (0.4)	0.60
Nuclear cataract grading† (%)			
Grade 1	209 (12.9)	127 (9.9)	0.01
Grade 2	988 (61.2)	789 (61.4)	
Grade 3	387 (24)	347 (27)	
Grade 4	30 (1.9)	23 (1.8)	

*Data were unavailable in some cases due to incomplete medical records.
†Data were unavailable in some cases due to incomplete medical records and some patients had other types of cataract.
BCVA, best-corrected visual acuity.

Table 2 Comparison of the complications and IOL implantation method

	Trained group	Untrained group	OR (95% CI)	P value
No of operations	1656	1315		
No of cases with the complication* (%)	225 (13.6)	228 (17.3)	0.75 (0.61 to 0.92)	0.005
Posterior capsule rupture	140 (8.5)	136 (10.3)	0.80 (0.62 to 1.02)	0.08
Tearing anterior capsulorrhexis	83 (5.0)	81 (6.2)	0.80 (0.59 to 1.10)	0.17
Zonule dialysis	11 (0.7)	14 (1.1)	0.62 (0.28 to 1.37)	0.23
Retained lens material	0 (0)	15 (1.1)	0.027 (0.002 to 0.455)	<0.001
Other complications	35 (2.1)	37 (2.8)	0.95 (0.59 to 1.51)	0.21
IOL implantation† (%)				
In the bag	1512 (91.8)	1197 (91.1)		0.44
In sulcus	127 (7.7)	104 (7.9)		
Scleral fixation	1 (0.1)	2 (0.2)		
Surgical aphakia	7 (0.4)	11 (0.8)		

*Single or multiple complications may occur in each surgery.
†Data were unavailable in some cases due to incomplete medical records.
IOL, intraocular lens.

rates in resident-performed phacoemulsification.[15–18] Despite diabetes being related with a higher incidence of complications in a previous study, the patients in the trained group who had a higher incidence of diabetes had lower complications.[19] White mature and dense nuclear cataracts were risk factors of posterior capsule rupture, there was no difference between the trained and untrained groups for these types of cataract.[20] In the multivariable regression analysis, only the simulation training and preoperative BCVA were found to be related to the total rate of complications in resident-performed phacoemulsification. Blomquist *et al* also found that a worse preoperative BCVA was correlated with intraoperative vitreous complications in resident-performed phacoemulsification.[21] In contrast, Rutar *et al* did not demonstrate any correlation between preoperative BCVA and total complications.[15]

There were some limitations of this study to note related to it being conducted as a retrospective cohort. We compared different groups of residents from different times, which may have caused a confounding effect and some bias. However, there were no major changes in the surgical equipment and techniques used between the two groups. We reviewed the literature on the risk factors of complications in resident-performed phacoemulsification to identify the known risk factors. In our study, we collected data on the previously known risk factors and conducted multivariable analysis to mitigate the limitation. We considered a prospective study design but decided this may not be suitable for this study because some previous studies have demonstrated the construct validities and benefits of the simulation training. Research on the curriculum design, assessment of training and relationship between performance in simulation and real-life surgery should be further conducted.

In our hospital context, the availability of a simulation training curriculum supplemental to conventional training is highly valuable for residents. The benefits include shortening the learning curve of the residents, allowing the residents to practice their surgical skills in a safe setting, and helping them build their confidence for

Table 3 Subgroup analysis of the posterior capsule rupture rate when separating the two halves of the total cases of the residents

	Posterior capsule rupture	Without posterior capsule rupture	OR (95% CI)	P value
First half of total cases				
Trained group (%)	73 (8.8)	755 (91.2)	0.68 (0.49 to 0.95)	0.02
Untrained group (%)	82 (12.4)	576 (87.6)		
Second half of total cases				
Trained group (%)	67 (8.1)	761 (91.9)	0.98 (0.68 to 1.43)	0.93
Untrained group (%)	54 (8.2)	603 (91.8)		

Table 4 Logistic regression analysis

Variables	Univariable			Multivariable		
	OR	**95% CI**	**P value**	**OR**	**95% CI**	**P value**
Age	1.003	0.99 to 1.01	0.64			
Gender (female)	1.11	0.90 to 1.37	0.33			
Diabetes	1.16	0.94 to 1.42	0.16			
Hypertension	1.04	0.85 to 1.27	0.69			
Heart disease	0.75	0.46 to 1.22	0.25			
Chronic kidney disease	0.91	0.59 to 1.40	0.67			
Preoperative BCVA	1.32	1.09 to 1.59	**0.006**	1.32	1.10 to 1.59	**0.003**
Diabetic retinopathy	1.01	0.72 to 1.40	0.96			
Glaucoma	0.91	0.65 to 1.28	0.59			
Uveitis	2.79	0.70 to 11.20	0.15			
Small pupil (<6 mm)	0.93	0.11 to 7.71	1			
Lens subluxation*	N/A	N/A	1			
Pseudoexfoliation syndrome*	N/A	N/A	0.39			
Prior vitrectomy	1.39	0.16 to 12.46	0.56			
Cataract grading			0.16			
Grade 1	1.39	1.03 to 1.89				
Grade 2	1					
Grade 3	1.11	0.87 to 1.41				
Grade 4	1.39	0.69 to 2.82				
Axial length	1.01	0.93 to 1.11	0.78			
ACD	1.22	0.94 to 1.59	0.13			
Side of operation (left eye)	1.09	0.90 to 1.34	0.38			
Anaesthetic method			**0.045**			0.25
Topical	0.97	0.62 to 1.51				
Subconjunctival	0.59	0.39 to 0.87				
Retrobubar or Peribulbar	1					
General anaesthesia	0.64	0.25 to 1.64				
Simulation training	0.75	0.61 to 0.92	**0.005**	0.75	0.61 to 0.92	**0.005**

Bold values indicate statistical significance.
*OR and 95% CI could not be calculated due to the insufficient number of cases.
BCVA, best-corrected visual acuity.

real-life surgery. The patients also benefit from a reduction in the complication rate when undergoing cataract surgery performed by a simulation-trained resident. In spite of the advantages, the high cost of setting up the equipment and course can be a significant obstacle to the adoption of simulation training. The initial cost of the machine was £130 000 in 2012 and the maintenance with insurance cost is about £30 000 per year. Sharing the simulator and its cost with other teaching centres could be an option to maximise resource utilisation. This idea would allow several residents to access the simulation training and would add benefits to the conventional training. On the other hand, the effects of such training in shortening the residents' learning curve, lowering the complication rate, and improving safety are invaluable.

They should be weighed with the cost in implementation of such simulation training.

CONCLUSION

This study demonstrates that ophthalmic surgical simulation training significantly reduced overall intraoperative complications and posterior capsule rupture in the first half of cases of resident-performed phacoemulsification surgeries. The training improved residents' surgical performance by shifting the learning curve of trainee surgeons.

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