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ORIGINAL RESEARCH

Cataract Surgery Learning Curve: Evaluation of Residents' Surgical Outcomes and Complications Based on Experience*

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ABSTRACT

This study aims to retrospectively evaluate the cataract surgery learning curves and surgical outcomes of residents. Between September 2019 and January 2021, 339 eyes of 301 patients who underwent phacoemulsification surgery by 3 residents were retrospectively examined. The cases were categorized into two groups: the initial six months of training (first six months - first term, n = 83) and during the period when they gained experience (last 6 months - second term, n = 256). Demographic characteristics of the patients, comorbidities, complications, and changes in BCVA were statistically analyzed. Surgical outcomes were compared statistically between the groups. The complication rate was 19.3% in the first term and 6.2% in the second period ($p<0.001$). While the completion rate of all stages of surgery by residents was 66.3% in the first term, this rate increased to 96.9% in the second term ($p<0.001$). Postoperative improvement in BCVA was statistically significant in both terms ($p<0.001$), with mean preoperative and postoperative values of 0.17 ± 0.16 and 0.53 ± 0.34, respectively. Postoperative improvement in BCVA was similar in eyes that developed and did not develop complications ($p = 0.430$). Conversely, BCVA gain in eyes with additional ocular comorbidities was significantly lower than in eyes without ocular disease ($p = 0.015$). The rate of completing surgery without assistance during cataract surgery training increases in proportion to the training period, while the complication rate decreases. Surgical training of residents was found to be reliable for the outcome visual acuity, regardless of the development of complications.

Keywords: Cataract. Surgery. Learning curve. Phacoemulsification. Complication. Education.

Katarakt Cerrahisi Öğrenme Eğrisi: Asistanların Cerrahi Sonuçlarının ve Komplikasyonların Deneyime Göre Değerlendirilmesi

ÖZET

Bu çalışmanın amacı asistanların katarakt cerrahisi öğrenme eğrilerini ve cerrahi sonuçlarını retrospektif olarak değerlendirmektir. Eylül 2019 ile Ocak 2021 tarihleri arasında 3 asistan tarafından fakoemülsifikasyon ameliyatı yapılan 301 hastanın 339 gözü retrospektif olarak incelendi. Olgular asistanların cerrahi eğitime başladıkları dönem (ilk altı ay - ilk dönem, n = 83) ve deneyim kazandıkları dönem (son 6 ay - ikinci dönem, n = 256) iki gruba ayrıldı. Hastaların demografik özellikleri, eşlik eden hastalıkları, ameliyat sırasında ve sonrasında gelişen komplikasyonlar, en iyi düzeltilmiş görme keskinliği kazanımları istatistiksel olarak analiz edildi. Cerrahi sonuçlar gruplar arasında ve ayrıca komplikasyon varlığına göre istatistiksel olarak karşılaştırıldı. Komplikasyon oranı ilk dönemde %19,3, ikinci dönemde %6,2 idi ($p<0,001$). Asistanların ameliyatın tüm aşamalarını tamamlama oranı birinci dönemde %66,3 iken, ikinci dönemde bu oran %96,9'a yükseldi ($p<0,001$). Her iki dönemde de postoperatif EİDGK artışı istatistiksel olarak anlamlı bulunmuştur ($p<0,001$); ortalama preoperatif ve postoperatif değerler sırasıyla 0,17 ± 0,16 ve 0,53 ± 0,34'tür. Komplikasyon gelişen ve gelişmeyen gözlerde EİDGK kazancı benzer bulundu ($p = 0,430$). Öte yandan ek oküler hastalığı olan gözlerde EİDGK kazancı, oküler hastalığı olmayan gözlere göre anlamlı derecede düşük bulundu ($p=0,015$). Katarakt cerrahisi eğitimi sırasında ameliyatı yardımsız tamamlama oranı eğitim süresiyle orantılı olarak artarken komplikasyon oranı azalmaktadır. Asistanların cerrahi eğitiminin, komplikasyon gelişiminden bağımsız olarak, görme keskinliği açısından güvenilir olduğu bulundu.

Anahtar Kelimeler: Katarakt. Cerrahi. Öğrenim eğrisi. Fakoemülsifikasyon. Komplikasyon. Eğitim.

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Phacoemulsification has become the global standard surgery for cataracts worldwide[1]. Competence in phacoemulsification is a fundamental requirement for ophthalmologists. As indicators of effective surgery and training, numerous studies assess visual outcomes, complication rates, and completion rates[2-4].

The Accreditation Council for Graduate Medical Education (ACGME) states that residents must perform a minimum of 86 cataract surgeries as a primary surgeons during their three year specialty training[5]. On the other hand, The Royal College of Ophthalmologists (RCOphth) advises residents to complete at least 350 phacoemulsification during their seven year of specialty training[6]. According to the literature, in order to attain surgical skill and efficacy, 70–80 phacoemulsification cases are needed[7,8]. While there are numerous studies worldwide evaluating the outcomes of phacoemulsification performed by residents, research assessing surgical training in Türkiye remains scarce.

This study aimed to evaluate the surgical outcomes and learning processes of resident doctors in order to assess the effectiveness and reliability of phacoemulsification training. We hypothesized that increased surgical experience would reduce intraoperative complications and improve postoperative visual outcomes, reflecting the progressive development of surgical skills. To assess patient safety, we analyzed the learning curve in our clinic by comparing first and second term cases, with the goal of identifying areas for improvement and providing insights to optimize training methods.

Materials and Methods

In this study, the medical records of patients who underwent phacoemulsification surgery by residents under the supervision of an attending surgeon at the Bursa Uludağ University Hospital's Ophthalmology Clinic between September 2019 and January 2021 were retrospectively examined. Our study was approved by the Bursa Uludağ University Ethics Committee on February 24, 2021, under decision number 2021-4/34, Helsinki Declaration principles were adhered to, and consent was obtained from the patients throughout the study. A total of 339 eyes of 301 patients who were operated on by three residents who completed a 12-month surgical rotation within these dates and had records in their training certificates were included in the study. Two patients who did not have records in residents' training certificates were excluded from the study.

Among the cataracts operated by resident doctors, there were no patients either with luxated/subluxated lenses, iridophacodonesis, open globe injury, keratoplasty, glaucoma surgery, or congenital cataracts.

All patients underwent a complete ophthalmological examination including best-corrected visual acuity (BCVA) Measured using a with Snellen chart. Data collected included cataract type, concomitant systemic and ocular diseases, medication use, history of intravitreal injections, and inadequate pupillary dilation. Prior to surgery, cases were classified as 'simple' or 'difficult' by an experienced specialist according to informal surgical risk factors, such as poor pupillary dilation, shallow anterior chamber, pseudoexfoliation, high myopia, and deep-set eyes, etc. In the initial phase of training, easier cases were preferentially assigned to residents to facilitate the acquisition of basic surgical skills. In the subsequent phase, case allocation was conducted consecutively according to the daily surgical schedule, providing a distribution that approximated random selection. Postoperative follow-ups occurred on day 1, day 10, and at 1 month, including BCVA and autorefraction measurements.

The cases operated on by three resident doctors were divided into two terms: the first six months constituted the first period, and the last six months constituted the second. The residents were named as surgeon 1, surgeon 2, and surgeon 3. Surgeon 1 operated on a total of 101 eyes, surgeon 2 operated on a total of 112 eyes, and surgeon 3 operated on a total of 126 eyes. The completion rates of cases, intraoperative complications, types of complications, steps in which complications occurred, IOL position, postoperative complications, BCVA increase rates, and preoperative cataract surgery risk factors were compared separately and collectively for each surgeon in the first and second terms. Additionally, accompanying anterior and posterior segment pathologies, optic atrophies, and other pathologies causing decreased visual acuity and oculoplastic problems were recorded.

Surgical Training

Before their operating room rotation, residents completed a two-hour (EyeSi) simulator training. The twelve month rotation began with supervised modular steps starting in the second month. Over a six-month period, residents typically participated in 25–30 phacoemulsification cases under the supervision of three attending surgeons. During the final six months, residents who had achieved sufficient proficiency continued to perform the full procedure under supervision.

Statistical Analysis

The normal distribution of the data was examined using the Shapiro-Wilk test. Descriptive statistics were reported as mean and standard deviation for quantitative data, and as frequency and percentage for qualitative data. The Mann-Whitney U test was used to compare two groups when the data did not follow a

normal distribution. For comparing repeated measurements between groups, the percentage change value (percentage change = (final measurement - initial measurement) / initial measurement) was calculated. Additionally, the Wilcoxon Signed-Rank test was used for within-group comparisons. To analyze categorical data, the Pearson Chi-square test, Fisher's Exact test, and Fisher-Freeman-Halton test were used. The significance level was set at α=0.05. The statistical analysis of the data was performed using IBM SPSS 23.0 (IBM Corp. Released 2015. IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.) statistical software package.

Results

A total of 339 eyes from 301 patients who underwent phacoemulsification surgery performed by three resident doctors between September 2019 and January 2021 under the supervision of a consultant were included in the study. The number of cases for surgeon 1, 2, and 3 in the first/second terms were 26/75, 31/81, and 26/100 respectively. The ages of the patients ranged from 14 to 89, with a mean age of 65.45 ± 10.33. (Table I). The average postoperative follow-up period was 2.3 ± 2.5 months (range: 0-14 months, median 1 month). Surgeon 1 operated on a total of 101 eyes, Surgeon 2 operated on a total of 112 eyes, and Surgeon 3 operated on a total of 126 eyes (p>0.05). Among the types of cataracts in the operated eyes, nuclear cataract was the most common with 41.5%.

Table I. Demographic Characteristics

	Surgeon 1	Surgeon 2	Surgeon 3	Total
Age Mean ± SD	64.81 ± 8.34	65.9 ± 9.64	63.8 ± 12.04	65.4 ± 10.33
Women / Man %	46 / 55 45.5 / 54.5	55 / 57 49.1 / 50.9	57 / 69 45.2 / 54.8	158 / 181 46.6 / 54.3
Right / Left %	44 / 57 43.6 / 56.4	59 / 53 52.7 / 47.3	68 / 58 54.0 / 46.0	171 / 168 50.4 / 49.6
Preop VA Mean ± SD	0.17 ± 0.16	0.19 ± 0.19	0.18 ± 0.13	0.18 ± 0.16

SD: Standard deviation, Preop: preoperative, VA: Visual Acuity

Among the patients, 110 (32.4%) had no systemic disease, while 229 (67.6%) had at least one, with diabetes (38.9%) and hypertension (34.5%) being the most common comorbidities. Ocular comorbidities were present in 204 eyes (60.17%). The distribution of these additional diseases is given in Table II. Preoperative evaluation classified 75.8% of cases as difficult. Intravitreal injection history was present in 67 eyes (19.8%), and 43 eyes (12.6%) had poor pupillary dilation. No significant differences were found between the groups or between surgeons in terms of demographic or preoperative characteristics (p > 0.05) (age, side, gender, level, dilation, history of intravitreal injection, preop BCVA or difficulty) and grouped ocular comorbidities (p>0.05).

Table II. Distribution of Ocular Comorbidities

	First term n(%)	Second term n(%)	Total n (%)
Anterior camber - glaucoma	12 (14.5)	32 (12.5)	44 (13)
Retinal disease	35 (42.2)	132 (51.6)	167 (49.3)
Uveitis	-	4 (1.6)	4 (1.2)
Trauma or vitrectomy	-	7 (2.7)	7 (2.1)
Other pathologies that reduce BCVA	1 (1.2)	6 (2.3)	7 (2.1)
Others	1 (1.2)	4 (1.6)	5 (1.5)

BCVA: Best corrected visual acuity, n: case number

Cataract surgery was performed with vitreoretinal surgery due to retinal diseases in 36 eyes (10.6%). Pars plana vitrectomy was performed by a vitreoretinal specialist. Only one of the combined cases was in the first term. Complications occurred in 2 of 36 combined cases (5.6%) and in 30 of 303 phaco-only cases (9.9%) (p=0.554).

The surgical completion rates increased significantly for all residents in the second term: surgeon 1 (from 73.1% to 96%, p = 0.003), surgeon 2 (64.5% to 96.3%, p < 0.001), and surgeon 3 (61.5% to 98%, p < 0.001). Overall, this rate increased from 66.3% to 96.6% (p<0.001). The complication rate was 19.3% in the first term (95% CI: 12.2–29.0) and 6.2% in the second term (95% CI: 3.9–9.9), showing a significant decrease (p<0.001). The overall complication rate was 9.4% (95% CI: 6.8–13.0), showed a decreasing trend with the number of cases (Figure 1). The complication rates for the three surgeons were 5.9% (95% CI: 2.8–12.4), 13.4% (95% CI: 8.3–20.9), and 8.7% (95% CI: 4.9–15.0), respectively, with no statistically significant difference among them (p=0.168).

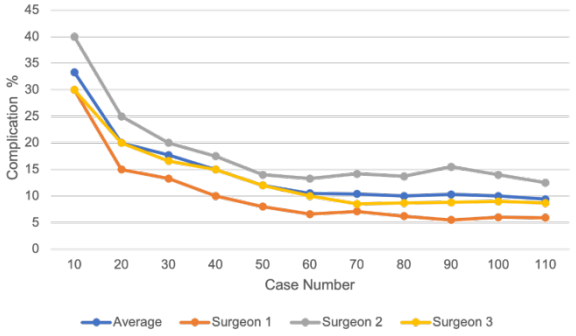


***Figure 1**:*
Complication rates according to progression in the number of cases

Among complicated eyes, 7 (8.5%) were simple and 25 (9.7%) were difficult in terms of preoperative risk factors (p>0.05). The distribution of complication types in terms are shown in Table III. Due to the nucleus drops, type of complication changed significantly according to experience (p<0.001). The overall vitreous loss (VL) rate is 6.2% (Table IV). In addition, a capsular tension ring was placed in 3 cases due to zonular dialysis. Anterior capsule tears occurred in 11 (3.24%) patients.

Table III. Difference in Complication Types Between First-term and Second-term

Complication Type	First term n (%)	Second term n (%)	*p*
PCR	3 (3.6)	7 (2.7)	*0.703*
PCR and VL	8 (9.6)	7 (2.7)	*0.022**
ZD and VL	-	2 (0.7)	*0.545*
Lens Drop	5 (6.0)	-	*0.004**

PCR: Posterior capsule rupture, VL: vitreous loss, ZD: zonular dialysis
Comparisons between groups were performed using Pearson Chi-square test and Fisher-Freeman-Halton exact test where appropriate

Table IV. Distribution of Vitreous Loss in Surgeons'

VL	Surgeon 1 1st/2nd	Surgeon 2 1st/2nd	Surgeon 3 1st/2nd	Total 1st/2nd
n	2 / 2	6 / 4	4 / 3	12 / 9
p	*0.272*	***0.026****	***0.033****	***<0.001****

VL: vitreous loss, n: case number
Comparisons between the first and second terms were performed using Fisher's Exact test

The majority of complications occurred during the phacoemulsification stage (56.3%), followed by the irrigation/aspiration phase (28.1%) (Table V). With increasing surgical experience, the frequency of phacoemulsification-related complications decreased, whereas I/A -related complications showed an increase. However, when the two terms were compared, no statistically significant difference was observed in the stages at which complications occurred (p = 0.399). Vitreous loss occurred in 77.8% of phacoemulsification-related complications, 66.7% of I/A-related, and 40% of IOL placement-related events.

Table V. Distribution of complications according to stages in the first and second periods

Stage	First term n (%)	Second term n (%)	Total n (%)	*p*
Phacoemulsification	11 (68.8)	7 (43.7)	18 (56.3)	*0.285*
Irrigation-aspiration	3 (18.7)	6 (37.6)	9 (28.1)	*0.433*
IOL implantation	2 (12.5)	3 (18.7)	5 (15.6)	*1.000*

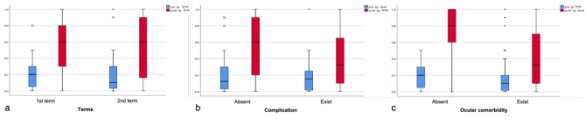
IOL: intraocular lens
Data are presented as n (%). Pearson Chi-square test was used for comparison between groups.

The completion rates of complicated cases without the intervention of the training specialist; 16.6% for Surgeon 1 (n=1), 20% for Surgeon 2 (n=3), 36.3% for Surgeon 3 (n=4), and a total of 25%. Among the three aphakic eyes, one was left aphakic due to high myopia, while complications developed in the remaining two. Sulcus IOL implantation declined from 18.1% to 5.9% between terms (p=0.001).

Secondary surgery was required in ten patients. Corneal incision was sutured in 18 patients. Postoperative complications included diabetic macular edema (n = 22), cystoid macular edema (n = 5), vitreous wick syndrome (n = 1), retained cortex (n = 2), IOL malposition (n = 2), retinal detachment (n = 2), vitreous hemorrhage (n = 3), posterior capsular opacification (n = 3), and glaucoma (n = 1). No cases of endophthalmitis or bullous keratopathy were observed.

Complication rates were 11.3% in eyes with ocular comorbidities versus 6.7% in those without (p = 0.155). Likewise, no significant associations were found between complication rates and systemic disease, glaucoma, retinal pathology, uveitis, trauma, cataract type, poor dilation, or intravitreal injection history (p>0.05).

The mean preoperative BCVA was 0.17 ± 0.16 and postoperative BCVA was 0.53 ± 0.34 (p<0.001). Postoperative BCVA data is available for 327 patients, of whom 204 (62.3%) had visual acuity of 0.5 or higher, and 123 (37.6%) had visual acuity below 0.5. BCVA improved significantly in both terms (both p < 0.001), with no difference between terms (p = 0.201). (Figure 2a) Complicated and uncomplicated cases showed similar BCVA gains (p = 0.430). (Figure 2b) Eyes without ocular comorbidity improved from 0.19 ± 0.14 to 0.72 ± 0.27 (p < 0.001), whereas eyes with comorbidity improved from 0.15 ± 0.17 to 0.40 ± 0.32 (p < 0.001), with a significant difference in gain (p = 0.015). (Figure 2c)



a) Visual acuity improvement in first and second term cases
b) Visual acuity improvement in cases with and without complications
c) Visual acuity improvement in cases with and without ocular disease
(a) Visual acuity significantly improved in both first-term and second-term cases (both p < 0.001, Wilcoxon signed-rank test), with no difference between terms (p = 0.201, Mann–Whitney U test)
(b) No significant difference in visual acuity improvement was observed between cases with (p=0.001) and without (p<0.001) complications (p = 0.430, Mann–Whitney U test).
(c) Visual acuity improvement was significantly lower in cases with ocular comorbidities compared to those without (p < 0.001, Mann–Whitney U test).

***Figure 2**:*
Boxplots showing preoperative and postoperative best corrected visual acuity (BCVA)

Discussion and Conclusion

Ophthalmology residency training programs should ensure that residents develop their competency in phacoemulsification appropriately and guarantee a minimum number of surgeries required to achieve this. In a large-scale survey conducted on residents in the USA in 2013, the number of phacoemulsifications completed during the surgical training period was determined less than 100 for 11%, 101-150 for 47%, 151-200 for 26% and over 200 for 16%.[9] A video-based study published by Balas *et al.*[10] in 2023 identified two phases in the acquisition of surgical skills: basic proficiency typically developed after 80 cases, while surgical mastery began to emerge after 300 cases. In our study, all residents began surgery after their third year residency and exceeded the minimum number of procedures recommended by ACGME.

ACGME reports that specialties should have a wet-lab or surgical simulator[11]. A study comparing the first 25 cases of 12 residents with and without simulator training reported that the use of a simulator reduced case duration and complication rates[12]. The study with the lowest PCR and VL rates (0.66%) in the literature is a pilot study published by Baxter *et al.*[13] from England, in which they prospectively evaluated the training process of 3 residents who received 50 hours of simulator training. We believe that the exceptionally low complication rates observed in this study may, at least in part, be attributed to the extensive 50 hours of simulator practice.

Various approaches exist for introducing residents to phacoemulsification: sequential (stepwise), reverse (from final to initial steps), and modular (performing a single step per surgery)[14,15]. An alternative approach involves performing the entire surgical procedure from start to finish in a single session (one-step method)[16]. The final steps of the procedure are technically less demanding than the initial steps, and reverse training may be advantageous as it reduces the likelihood of surgeon takeover. According to the review by Kaplowitz et al.8, phacoemulsification is the phase with the highest complication rate (53%), as reported in the mean of six studies, and our study supports this finding. Moreover, complications arising toward the end of surgery are typically less vision-threatening than those occurring earlier. Similarly, our study demonstrates that complications during the final stages are associated with a lower risk of VL.

Monitoring complication rates is essential not only to ensure the effectiveness of resident training but also to demonstrate the resident's competency after graduation. In the literature, the PCR and VL rates range from 0.66% to 27.4%[13,20]. Kaplowitz *et al.*[8] conducted a systematic review of 44 studies on resident-performed cataract surgeries and found that PCR rates (with or without VL, as this distinction is often unspecified) exhibited considerable variability, with a mean incidence of 5.71 ± 3.58%. In our study, the overall complication rate was 9.4% and VL rate was 6.4%, aligning with literature. However, endophthalmitis and bullous keratopathy were not observed in our study. Postoperative RD occurred in two patients (0.58%), a rate comparable to a 10-year follow-up study of 4458 resident-performed cases, which reported an RD incidence of 0.76%[21]. An article published by Erdoğan *et al.*[22] from Turkey, documented PCR and nucleus drop rates of 10.6% and 2.7%, respectively, These findings mirrored our results.

Mangan *et al.*[23] from Turkey divided the cases of 2 residents (n=180) into 3 groups according to experience and found that the overall PCR rate was 8.8%; They reported that the highest complication rate (20%) occurred between the residents' 30^(th) and 60^(th) cases (second group). While the rate of expert intervention in the first 30 cases was as high as 75%, this rate decreased in the second group and the rate of unaided cases completed by the assistants was 50%. Similarly, Lee *et al.*[24] reported the case completion rate as 47% in their study, while Dooley and O'Brien[19] reported the case completion rate as 42%. In contrast, our study demonstrated higher independent completion rates — 66.3% for the first 30 cases and 89.4% overall — indicating a more rapid acquisition of surgical proficiency among our residents.

Assessing surgical complications is challenging due to inconsistent definitions and patient-related risk factors. In a randomized study, PCR rates were five times lower when resident cases were assigned using a formal risk classification score.[25] Al-Jindan *et al.*[26] reported lower complication rates in residents' cases classified as simple compared to difficult ones, although no formal scoring system was used. In our study, although complication rates between simple (8.5%) and difficult (9.7%) cases did not differ significantly, the majority of surgeries (75.8%) were considered difficult. Rutar *et al.*[27] and Blomquist *et al.*[28] reported an increase in the complication rate in resident-performed surgeries when challenging factors were present. In our cohort, the lack of a significant difference may be partly attributed to the informal nature of our case classification and the predominance of difficult cases, which could have limited the statistical power to detect subgroup differences.

RCOphth suggests that experiencing various clinical situations (e.g., white cataract, small pupil) allows residents to learn techniques for managing various cases and complications.[6] A survey conducted in the UK found that even after seven years of residency, only 40% of residents feel confident in their ability to cope with VL[29]. Another study reported that only 18%

of residents with 350 completed cases felt comfortable managing VL without supervision[30]. This lack of confidence may be attributed to the limited autonomy provided to residents, particularly when supervisors take over complicated cases, thereby restricting their opportunity to gain independent experience. Consequently, the number of surgeries alone may be insufficient to ensure surgical competence. In this context, Al-Jindan *et al*.[26] reported a 15% resident-led completion rate in complicated cases, whereas our study demonstrated a higher rate of 25%, all of which occurred during the second term when residents had gained more experience. These findings emphasize that, beyond increasing surgical volume, training programs should also ensure that residents are given structured opportunities to actively participate in complex and complicated cases, as such autonomy is crucial for building both technical competence and confidence.

A way to determine visual outcomes for phacoemulsification surgery is to determine the proportion of cases with visual acuity of 20/40 or better. Kaplowitz *et al*.[8], averaging 19 studies, determined that 87.4 ± 5.8% of resident cases had at least 20/40 vision. This rate was 62.3% in our study. The lower rate compared to the literature may be explained by the fact that our institution is a tertiary referral center, where a substantial proportion of patients (60.17%) presented with additional ocular comorbidities (mostly retinal disease 49.3%). These comorbid conditions are frequently associated with relatively poorer visual acuity, which may have contributed to the outcomes observed in our study. The two most important risk factors for poor visual outcome are additional ocular diseases and perioperative complications. Available data show that the most likely cause of not achieving at least 20/40 visual acuity is the presence of an ocular disease[8]. In addition to other studies, our study evaluated postoperative BCVA increase percentages and we observed that there was no statistically significant difference when the visual acuity increases in the groups with and without complications were compared ($p = 0.430$). On the other hand, the increase was significantly lower in the group with ocular disease compared to the group without ocular disease ($p < 0.001$).

To the best of our knowledge, no previous study has specifically examined cataract surgeries combined with pars plana vitrectomy in the context of resident training. Our study is the first to address this issue and demonstrates that incorporating such combined procedures into cataract surgery performed by residents is safe and does not increase the overall complication rate. These findings highlight that including combined cases in the evaluation of the surgical learning curve is both reliable and reflective of real-world clinical practice.

The main limitation of our study is that it was conducted retrospectively and using the file scanning method. In addition, there was no standard for the surgical training structure and supervisor intervention criteria, and no official scoring system was used in preoperative surgical risk assessment. The study duration was relatively short, with a limited number of residents. Also the number of surgical cases varied among residents, and the follow-up period was relatively short (average 2.3 months). Therefore, the classification of the learning phases (novice-experienced) was based on time intervals rather than the exact number of surgeries performed.

In light of these findings, we recommend implementing structured training pathway for phacoemulsification. First, standardize simulator use and define minimum training hours to accelerate skill acquisition and reduce complications. Second, implement a staged curriculum in which residents begin with simpler steps and are initially assigned low-risk cases based on a formal preoperative risk-stratification tool. As residents gain experience, they should should progress to higher-complexity cases and manage complications under direct supervision. This graded-autonomy model will likely to improve the safety and quality of training and producing graduates with greater confidence and operative proficiency.

As residents gain experience, complication rates decrease significantly and complication management improves. While favorable visual outcomes can still be achieved in many cases that develop intraoperative complications, poor final visual acuity appears to be more frequently associated with concomitant ocular diseases. While our findings suggest that exposure to diverse and challenging cases, such as combined surgeries or eyes with risk factors, may support surgical development, further evidence is needed before generalizing this conclusion. Examining surgical outcomes is essential to ensure high-quality education without compromising patient safety. Yet, there is still no standardized phacoemulsification training program at either the national or international level, which highlights the need for unified guidelines. Developing objective performance metrics and implementing structured curricula, supported by large-scale prospective studies, would enable reliable assessment of surgical competency. Standardization and accreditation across centers would further promote consistency, comparability, and overall quality in surgical training.

Researcher Contribution Statement:
Idea and design: Z.Z.G., A.T.Ö.; Data collection and processing: Z.Z.G., A.T.Ö.; Analysis and interpretation of data: Z.Z.G.; Writing of significant parts of the article: Z.Z.G.

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