A Quantitative Assessment of Corneal Endothelium and Transparency following Phacoemulsification in Dense Cataracts

Yonca Asfuroğlu[1], Emine Esra Karaca[2], Mahmut Asfuroğlu[1], Özlem Evren Kemer[2]

ABSTRACT

Objective: To evaluate the impact of phacoemulsification on corneal endothelium and stromal structure in eyes with dense cataracts.

Materials-Methods: In this prospective and comparative study, participants were categorized into two groups based on cataract severity: Group 1 had dense cataracts and Group 2 had moderate cataracts. The best visual acuity, endothelial cell density (ECD), hexagonality (HEX), coefficient of variation (CV), anterior chamber volume (ACV), central corneal thickness (CCT), and corneal densitometry (CD) were evaluated before and 1 month after phacoemulsification. The mean cumulative dissipated energy (CDE), total fluid aspirated (TFA), and effective phacoemulsification time (EPT) were recorded.

Results: One hundred and three eyes (group 1, 50 eyes; group 2, 53 eyes) were included in the study. CDE, TFA, and EPT were significantly higher in group 1 ($p = 0.0001$). At postoperative 1 month, mean endothelial cell loss was 46.5% in dense cataracts and 28.6% in moderate cataracts ($p<0.0001$, 1396±609 cells/mm2 and 1868.7± 551.6 cells/mm2, respectively). The changes in HEX and CCT were significantly greater in dense cataracts after phacoemulsification ($p =0.008$ and $p= 0.0001$, respectively). The change in HEX was positively correlated with TFA in group 1 ($p = 0.03$). Despite these findings, there were no significant differences in the CD values between the two groups.

Conclusion: Dense cataracts undergoing phacoemulsification showed endothelial cell loss and disruptions in HEX. Despite these endothelial changes, CD remained stable postoperatively, suggesting that current phacoemulsification techniques can achieve corneal clarity comparable to that of early stage cataract surgeries in cases with dense cataracts.

Keywords: dense cataract, phacoemulsification, cumulative dissipated energy, total fluid aspirated, endothelial cell loss, corneal densitometry, hexagonality

INTRODUCTION

Corneal endothelium plays a critical role in preserving corneal transparency by functioning as an active pump that facilitates the movement of fluid from the stroma into the anterior chamber.[1] Endothelial cells, which have limited self-renewal capacity and decrease with advancing age, can also be damaged by intraocular surgeries, including phacoemulsification which is the most common method used in cataract surgery worldwide.[2-4]

Although phacoemulsification has long been proven to be the safest method for cataract extraction, risk factors in complicated eyes (e.g., dense cataract, low endothelial cell count, shallow anterior chamber) must be well identified, and necessary precautions must be taken.[5-7] Despite advances in surgical techniques, it has been shown that the number of endothelial cells decrease by 4-20% within one year after phacoemulsification.[8,9] Corneal endothelium may be damaged by factors such as increased ultrasonic energy, prolonged surgical time, and high infusion pres-

1 Ankara Bilkent City Hospital, Department of Ophthalmology, Ankara, Türkiye

2 University of Health Sciences, Ankara Bilkent City Hospital, Department of Ophthalmology, Ankara, Türkiye

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Corresponding author:
Yonca Asfuroğlu
Email: yncatalay@gmail.com

sure, particularly in dense cataracts. Consequently, corneal edema develops and may persist for a prolonged time.[9]

The optical density of the cornea can be evaluated noninvasively using a high-resolution Scheimpflug camera. Corneal densitometry (CD) provides quantitative information on corneal transparency using backward light scattering. Studies have suggested that CD measurements can be used to evaluate corneal transparency and subclinical corneal edema.[10-12]

This study aimed to assess the impact of phacoemulsification on the corneal endothelium and stroma in eyes presenting with dense cataracts. In addition, we investigated the possible correlations between cumulative dissipated energy (CDE), total fluid aspirated (TFA), effective phacoemulsification time (EPT), and changes in corneal parameters in these eyes.

MATERIAL- METHODS

This comparative and prospective study was conducted between August 2023 and March 2024 in accordance with the Helsinki Declaration and it was approved by the University's ethics committee (IRB: E1-233886). Informed consent was obtained from all participants.

The eyes included in the study were divided into two groups: dense cataracts (grade 4 and above) and moderate cataracts (grade 3 and below). A modified Lens Opacities Classification System III (LOCS III) was used to assess cataract density of the cataracts.[13]

Eyes with the following conditions were excluded from the study: diabetes mellitus, ocular surface disease, history of any prior ocular surgery or trauma, pseudoexfoliation, glaucoma, uveitis, high myopia, low endothelial cell count (<1500 cells/mm^2), any coexisting corneal or retinal pathology, and intraoperative complications. Detailed ocular examinations, including best-corrected visual acuity (BCVA), slit-lamp examination, axial length measurement (Lenstar LS 900 Haag-Streit, USA), intraocular pressure (IOP) measurement, dilated fundus examination, and optical coherence tomography (Swept Source-OCT, Triton, Topcon, Japan) were conducted before phacoemulsification. Eyes with dense cataracts in which retinal visualization was inadequate were evaluated using B-scan ultrasonography for possible accompanying retinal pathologies. Corneal endothelial cell density (ECD), coefficient of variation (CV) and hexagonality (HEX) were determined using a noncontact specular microscope (NIDEK CEM 530, USA). After obtaining good alignment, three measurements from the central cornea were obtained using the automatic mode.

Topographic measurements, including anterior chamber volume (ACV), central corneal thickness (CCT), and corneal densitometry (CD) were conducted for all participants using a rotational Scheimpflug device (Pentacam HR; Oculus, Wetzlar, Germany) in a dark room, and images were taken in the standard setting (25 images per scan). CD was segmented into four concentric zones: 0–2 mm, 2–6 mm, 6–10 mm, and 10–12 mm. Furthermore, the cornea was stratified into three distinct layers: the anterior layer (superficial 120 μm), the central layer (located between the anterior and posterior layers), and the posterior layer (innermost 60 μm)[14] All baseline examinations were repeated one month postoperatively by the same technician.

Surgical Technique

Phacoemulsification was performed by the same experienced surgeon under sub-Tenon anesthesia. Following the creation of a 2.2 mm superior clear corneal incision, the anterior lens capsule was stained using trypan blue. Subsequently, an ophthalmic viscosurgical device (OVD) (3% Hyotek, Teknomek) was introduced into the anterior chamber. Following anterior capsulorhexis and hydrodissection, the 'stop and chop' technique was preferred for nuclear division in both groups in a torsional continuous mode (Centurion; Alcon Laboratories, Inc) using the hybrid tip. After the epi-nucleus and cortex removal, an acrylic hydrophobic lens was placed in the bag. Prophylactic intracameral antibiotics were administered, and surgery was completed after stromal hydration.

In the postoperative period, all patients were prescribed topical 0.5% moxifloxacin to be administered four times daily, along with 0.1% dexamethasone applied six times daily and gradually tapered over a four-week period.

Machine settings

The infusion pressure was 36 mmHg. The aspiration flow rate was 32 mL/min, and the vacuum level was 450–600 mmHg. The torsional amplitude in linear mode was adjusted to 30% for moderate cataracts and 60% for dense cata-

racts. CDE, TFA and EPT were recorded from the machine monitor at the end of each case.

Statistics

Data analysis was conducted using IBM SPSS Statistics (version 22.0; IBM Corp., Armonk, NY). The distribution of sample means was assessed using the Kolmogorov-Smirnov test. Continuous data were analyzed by calculating mean ± standard deviation (SD), whereas categorical data were represented as counts and percentages (%). The alterations in variables from the preoperative period to the postoperative period were evaluated between the treatment groups using the Mann-Whitney U test. Pearson's correlation analysis was performed to evaluate the associations between variables. A p-value of less than 0.05 was considered indicative of statistical significance.

RESULTS

A total of 103 eyes from 103 eligible patients (50 patients in Group 1 and 53 patients in Group 2) were included in the study. The demographics and clinical features of the patients with phaco machine settings are shown in Table 1. Noteworthy differences were observed in CDE ($p< 0.0001$), TFA ($p< 0.0001$), and EPT ($p <0.0001$), where group 1 with dense cataracts had markedly higher values than group 2. Table 2 shows the visual acuity, corneal endothelial parameters, and ACV before and after the surgery. Preoperative visual acuity levels were significantly lower in group 1 than in group 2 ($p = 0.0001$). Postoperatively, ECD was markedly lower in group 1 with dense cataracts than in group 2 (Figure 1a, $p<0.0001$, 1396±609 cells/mm^2 and 1868.7± 551.6 cells/mm^2 , respectively). In both groups, postoperative visual acuity, ECD, and ACV were significantly different from the baseline levels ($p< 0.05$). However, when these changes were compared between the two groups, it was found that the HEX and CCT differences (preoperative to postoperative) were significantly higher in group 1 (Table 3, Figure 1, $p =0.008$ and $p= 0.0001$, respectively). When these changes were correlated to CDE, TFA and EPT; it was detected that the change in HEX showed a positive correlation with TFA in group 1 (r: 0.296, p: 0.03).

The preoperative and postoperative CD values of these patients are shown in Supplemental File 1 and 2. No statistically significant differences were observed between the preoperative and postoperative CD values in either group. None of the patients developed clinically significant corneal edema at 1 month postoperatively.

Table 1. *The demographics and clinical features of the patients with phaco machine settings*

Parameters	Group 1 (Dense cataracts) (n: 50)	Group 2 (Moderate cataracts) (n: 53)	p value
Age (years)	71.00 ± 6.53	68.67 ± 8	0.11
Sex (M/F)	26/24	27/26	0.840
AL (mm)	23.44 ± 0.82	23.04 ± 3.04	0.426
Lens Thickness (mm)	4.31 ± 0.31	4.19 ± 0.43	0.158
CDE	25.55 ± 11.23	5.98 ± 3.46	**<0.0001***
EPT (sec)	162.36 ± 58.80	71.04 ± 36.07	**<0.0001***
TFA (ml)	100.32 ± 30.88	68.96 ± 26.54	**<0.0001***

AL : Axial Length, LT : Lens thickness, CDE : Cumulative dissipated energy, EPT : Effective phacoemulsification time, TFA : Total fluid aspirated, *p< 0.05 is statistically significant, Mann-Whitney U test

Table 2. *Visual acuity, corneal endothelial parameters and anterior chamber volume before and after surgery*			
	Group 1(Dense cataracts)	**Group 2(Moderate cataracts)**	**p value**
Preoperative			
VA (logMar)	1.85 ± 0.50	0.57 ± 0.21	**0.0001***
ECD (cells/mm^2)	2612.48 ± 323.68	2617.91 ± 280.55	0.928
CV	32.2 ± 4.62	32.71 ± 5.6	0.624
HEX (%)	66.5 ± 4,9	66.1 ± 5.4	0.719
CCT(µm)	537.74 ± 37.87	550.53 ± 38.29	0.092
ACV (mm^3)	144.38 ± 34.97	140.94 ± 38.85	0.614
Postoperative			
VA (logMar)	0.05 ± 0,08	0.03 ± 0.06	0.274
ECD (cells/mm^2)	1396 ±609	1868.7 ± 551.6	**<0.0001***
CV	30.94 ± 11.01	30.07 ± 7.6	0.646
HEX (%)	62.6 ± 9,54	65.3 ± 6.45	0.091
CCT (µm)	555.7 ± 47	553 ± 39,6	0.792
ACV(mm^3)	176.4 ± 26	172 ± 32	0.508
VA : Visual acuity, ECD : Endothelial cell density, CV : Coefficient Variation, HEX : Hexagonality, CCT : Central corneal thickness, ACV: Anterior chamber volüme, *p< 0.05 is statistically significant, Mann-Whitney U test			

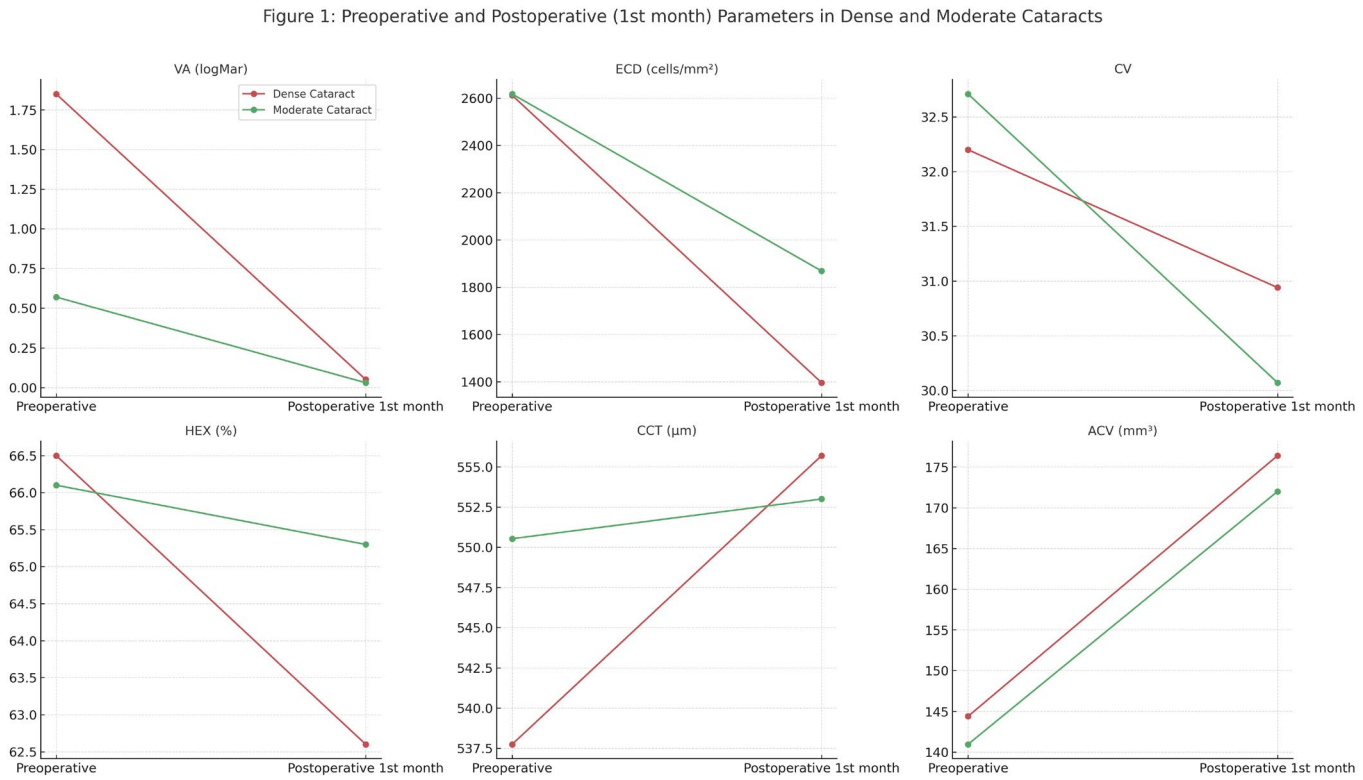

Figure 1: *Preoperative and postoperative (1st month) parameters in dense and moderate cataracts*

Table 3. *Comparison of VA, ECD, CV, HEX, CCT and ACV changes between two groups before and after phacoemulsification*

Change	Group 1 **(Dense cataracts)** p value	Group 2 **(Moderate cataracts)** p value
preVA - poVA	0.0001*	0.0001*
preECD - poECD	0.0001*	0.0001*
preCV - poCV	0.416	0.06
preHEX - poHEX	0.008*	0.401
preCCT - poCCT	0.0001*	0.119
preACV - poACV	0.0001*	0.0001*

Pre : preoperative, Po : postoperative, ECD : Endothelial cell density, CV : Coefficient Variation, HEX : Hexagonality, CCT : Central corneal thickness, ACV : Anterior chamber volüme, *p< 0.05 is statistically significant, Mann-Whitney U test

DISCUSSION

The primary goal of this study was to determine the effect of phacoemulsification on corneal transparency in eyes with dense cataracts during the 1-month postoperative period. In addition to the increased endothelial cell loss, it was also observed that HEX was more impaired in eyes with dense cataracts. However, despite these endothelial changes, the clarity of the cornea does not appear to have been affected in the postoperative period. True regeneration of the corneal endothelium does not occur following surgical injury. A limited compensatory response may take place through the enlargement and migration of the remaining viable endothelial cells to cover the damaged area. However, particularly in eyes with dense cataracts, if phacoemulsification-induced endothelial trauma exceeds a critical threshold, irreversible corneal decompensation and consequent visual deterioration may ensue. In addition, eyes with lower baseline ECD or abnormal endothelial morphology may be more susceptible to intraoperative stress and postoperative endothelial loss. Therefore, preoperative endothelial status could represent an important determinant of postoperative recovery and corneal clarity.[15]

Postoperative studies have reported varying rates of corneal endothelial cell loss, ranging from 17% to 20%, in these eyes.[16-18] In our study, mean endothelial cell loss was 46.5% in dense cataracts and 28.6% in moderate cataracts. This high rate in group 1 may be due to the fact that brunescent cataracts were also not excluded from the study. Endothelial cell loss was also relatively higher in moderate cataracts than in the previous studies.[16-18] This can be attributed to the inclusion of patients with grade 3 cataracts in the moderate cataract group. On the other hand, ECD is not the only parameter that provides information about endothelial health. HEX, which is the percentage of hexagonal cells in the endothelium, should not be below 50%, where intraocular surgeries tend to harm the corneal endothelium.[19] In a study conducted by Beato et al.[17], HEX levels were found to be lower than preoperative values at the one-month postoperative mark in both diabetic and non-diabetic patients following phacoemulsification. In our study, while changes in CV values were not remarkable, we observed that in dense cataracts, HEX was significantly reduced from preoperative levels. A postoperative decrease in HEX indicates morphological stress and loss of cellular uniformity within the corneal endothelium. Such alterations may compromise the barrier and pump functions of endothelial cells, predisposing the cornea to delayed recovery of transparency or, in severe cases, to endothelial decompensation.[18] Therefore, the greater reduction in HEX observed in dense cataracts in our study may reflect higher cumulative surgical stress and reduced endothelial resilience. In addition, we observed that HEX decreased more markedly in eyes with dense cataracts, correlating with TFA during phacoemulsification. This finding may be explained by the increased ultrasound energy and fluid turbulence required for emulsifying harder nuclei, which impose greater mechanical and thermal stress on the corneal endothelium. Such stress can disrupt the cy-

toskeletal integrity, leading to morphological irregularity and a reduction in hexagonal cell pattern. Although endothelial cell count is often at the forefront of postoperative follow-ups in clinical practice, HEX should also be considered when evaluating corneal endothelial health.

Owing to thermal injury and mechanical damage, corneal edema and increased CCT may be observed after phacoemulsification.[9,20] Zeng et al.[20] investigated the effectiveness of phacoemulsification using torsional mode with varying machine settings in cases of dense cataracts. Consistent with our findings, the torsional ultrasound group exhibited increased CCT on postoperative days 1, 7, and 30. Furthermore, our study demonstrated that the postoperative increase in CCT was significantly greater in eyes with dense cataracts compared to those with moderate cataracts. Considering that endothelial cell reduction was more significant after surgery in group 1, the increase in CCT in this group also seems consistent with our findings.

We also aimed to evaluate the extent to which phaco parameters affect the corneal endothelium in eyes with dense cataracts. CDE, TFA, and EPT levels were significantly higher in dense cataracts than in moderate cataracts. Kim et al.[21] conducted a comparative study of torsional versus conventional mode phacoemulsification in moderate and hard cataracts. Similar to our study, in the torsional mode, CDE and EPT were higher in hard cataracts after surgery. While Singh et. Al[7] reported that the greater endothelial cell reduction after phacoemulsification was associated with hard cataracts, age and EPT ; Mathys et al.[22] claimed that the ECD loss was mildly affected by TFA despite a longer EPT and increased phaco power. There are various reports regarding the effects of CDE on endothelial cell loss. Munoz et al.[23] did not find any correlation between endothelial cell loss and CDE levels ; Mahdy et al.[24] suggested that endothelial cell loss was related to CDE. In our study, we did not find a significant correlation between CDE, TFA, EPT, and changes in ECD, CCT, or CV. However, as TFA increased, HEX was more disrupted in dense cataracts than in moderate cataracts. Although it does not seem to correlate with a decrease in ECD, the increased TFA in dense cataracts may affect corneal endothelial pump function by further disrupting the hexagonal shape of these cells.

CD can be used to assess corneal pathologies that cause opacification, even in cases in which the cornea appears transparent on slit-lamp biomicroscopy. Ishikawa et al.[10] used CD to evaluate corneal edema in the first postoperative week after phacoemulsification. They concluded that CD values increased in the early period. However, the postoperative first month results were not included in their study. On the contrary, although CD values remained stable at one month postoperatively, the impact of early corneal edema was not evaluated in our report. In contrast to our findings, Hsieh et al.[25] demonstrated that corneal optical density remained elevated for a period of one month following phaco surgery, particularly at the incision site and within the central cornea (<6mm).

We aimed to determine whether edema persisted subclinically in dense cataracts, even if it was not visible on the slit lamp. At postoperative 1 month, none of the patients developed clinically significant corneal edema. Consistent with this, we observed no significant change in CD in either group after surgery.

Although ECD and HEX changed significantly in dense cataracts compared with moderate cataracts following phacoemulsification, this did not seem to have a clinical impact on corneal stromal clarity in the first post-operative month.

This study had some limitations. First, monitoring changes in corneal parameters in the postoperative first week would have been useful for comparison with the 1st month results. Second, longer follow-up periods are needed for a more accurate assessment of corneal transparency.

To the best of our knowledge, this is the first comparative study to concurrently evaluate corneal endothelial changes and transparency in patients with dense and moderate cataracts.

In conclusion, although ECD is prioritized in daily practice during post-phaco follow-ups, HEX may also be disrupted, particularly in dense cataracts. Despite these endothelial changes, no significant deterioration was detected in the CD postoperatively. Considering that CD reflects corneal transparency, with the current phacoemulsification techniques, it seems possible to achieve corneal clarity comparable to early stage cataract surgeries in cases with dense cataracts.

SUPPLEMENTAL FILE-1

Corneal densitometry (CD) changes after phacoemulsification in dense cataracts, ant : anterior, post : posterior, $p< 0.05$ is statistically significant, (Mann-Whitney U test)

Group 1 (Dense cataracts, CD, mm)	Preoperative	Postoperative 1st month	P value
Ant_0_2	11.03 ± 1.62	11.04 ± 1.38	0.86
Ant_2_6	11.32± 1.60	11.34 ± 1.45	0.94
Ant_6_10	17.21 ± 4.61	17.14 ± 5.15	0.89
Central_0_2	9.91 ± 1.01	10.10 ± 1.69	0.90
Central_2_6	10.20 ± 1.47	10.11 ± 1.36	0.75
Central_6_10	15.78 ± 4.19	14.99 ± 4.22	0.14
Post_0_2	9.15 ± 1.11	9.21 ± 1.39	0.77
Post_2_6	11.02 ± 1.24	10.71 ± 1.06	0.81
Post_6_10	13.45 ± 3.11	12.85 ± 2.78	0.09

SUPPLEMENTAL FILE-2

Corneal densitometry (CD) changes after phacoemulsification in moderate cataracts, ant : anterior, post : posterior, $p< 0.05$ is statistically significant, (Mann-Whitney U test)

Group 2 (Moderate cataracts, CD, mm)	Preoperative	Postoperative 1st month	P value
Ant_0_2	10.52 ± 1.05	10.30 ± 1.00	0.11
Ant_2_6	10.72 ± 1.69	10.93± 2.10	0.05
Ant_6_10	16.16 ± 6.10	16.01 ± 5.69	0.68
Central_0_2	9.61 ± 0.94	9.51 ± 0.89	0.90
Central_2_6	9.65 ± 1.54	9.94 ± 1.33	0.08
Central_6_10	14.39 ± 5.18	14.40 ± 4.58	0.84
Post_0_2	8.78 ± 0.95	8.76 ± 1.01	0.26
Post_2_6	8.80 ± 1.30	9.07 ± 1.15	0.09
Post_6_10	12.24 ± 3.31	12.45 ± 2.86	0.39

Declarations :

Human Ethics and Consent to Participate declaration : This study was conducted in accordance with the Helsinki Declaration. Informed consent was obtained from all participants.

Consent for publication : Yes

Data Availability Statement : The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Conflict of Interest statement : The authors declare that there are no conflicts of interest for this study.

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