Evaluation of Clear Corneal Incision Morphology and Corneal Changes After Coaxial Torsional Phacoemulsification in Soft to Hard Nuclear Cataracts

Mustafa Yaşar[1], Ekrem Çelik[2], Tansu Gönen[3]

ABSTRACT

Purpose: To evaluate the clear corneal incision morphology damage caused by coaxial torsional phacoemulsification due to increase in nuclear cataract density.

Materials and Methods: In this prospective, randomized controlled clinical study, 120 participants presenting with cataracts were divided into six equal groups (nuclear opacity 1 to 6; NO1, NO2, NO3, NO4, NO5, NO6) according to Lens opacity classification system (LOCS) III. Total ultrasound time (UST), phaco time (PT), torsion time (TT), percent of total equivalent phaco power at position 3 (3PTEFG%), cumulative energy use (CDE), and balanced salt solution (BSS) volume measurements were recorded. Postoperative clear corneal incision (CCI) morphology by anterior segment OCT and endothelial cell loss (ECL) were evaluated.

Results: Intraoperative UST, PT, TT, CDE, and 3PTEFG% and BSS data showed statistically significant differences in each group ($P<0.001$). At the postoperative 3rd month, ECL was higher in high-density cataracts as 9.1% in the NO1 group and 53.4% in the NO6 group, and there was a statistically significant difference between all groups ($P<0.001$). Descemet's membrane detachment on postoperative day 1 was statistically significantly higher in the high-density cataract groups (P:0.028).

Conclusion: As the density of nuclear cataracts increases, the energy used, the amount of BSS volume, and corneal damage increase. While damage occurred in all layers in CCI morphology, Descemet's membrane was found to be the structure most affected by the increase in nuclear density in the postoperative early period.

Keywords: Clear corneal incision morphology, Endothelial cell loss, Torsional phacoemulsification.

INTRODUCTION

Phacoemulsification aims to aspirate the crystalline lens with the lowest possible ultrasonic energy without thermal and fluidic damage to the surrounding tissues, complete the surgery through the smallest possible corneal incision, and apply intraocular lens implantation through the same incision. Improved devices and surgical techniques reduce intraoperative and postoperative complications and provide visual rehabilitation in a short time.[1,2]

The heat energy released by the phaco tip's vibration, continuous fluid flow, the turbulence of the anterior chamber fluid, micro air bubbles, surgical instruments, and toxic-free radical formation are the factors that cause endothelial and clear corneal incision (CCI) morphology damage.[3] These damages are more common in high-density nuclear cataracts as the surgical time is longer and more ultrasonic energy is used.[4] In the torsional method widely used in current surgery, especially in high-density nuclear cataracts, the lens is aspirated using less ultrasound energy, and less corneal damage is observed.[3,5,6] In the studies and meta-analyses to date, they have examined the torsional mode efficiency by dividing them into two groups as the moderate and hard nucleus.[7] We can evaluate the effectiveness of a technique by working in 6 different groups in the Lens Opacities Classification System (LOCS) III.[8]

In this study, we evaluated the effects of torsional phacoemulsification surgery intraoperative dynamics on

1- MD, Bursa City Hospital, Department of Ophthalmology, Bursa, Türkiye

2- MD, FEBO, Tekirdag Namik Kemal University, Faculty of Medicine, Department of Ophthalmology, Tekirdag, Türkiye

3- MD, Professor, FICO, Tekirdag Namik Kemal University, Faculty of Medicine, Department of Ophthalmology, Tekirdag, Türkiye

Received: 03.04.2022
Accepted: 11.03.2023

J Glau-Cat 2023; 18: 83-91

DOİ: 10.37844/glau.cat.2023.18.12

Correspondence Address:
Ekrem Çelik
Tekirdağ Namık Kemal University, Faculty of Medicine, Department of Ophthalmology, Suleymanpaşa, Tekirdağ, Türkiye

Phone: +90 505 516 9835
E-mail: ekcelik@gmail.com

corrected distance visual acuity (CDVA), endothelial cell density (ECD), central corneal thickness (CCT), and CCI morphology in six nuclear density groups according to LOCS III.

MATERIALS AND METHODS

This study was a single-center prospective randomized comparative study and comprised 120 patients diagnosed with cataracts. These participants were divided into six groups equally according to LOCS III nuclear opacity grade 1 to 6 (NO1-6). In patients with nuclear opacity 1-3, low visual acuity was associated with cortical and posterior subcapsular opacity. Patients with a central ECD of 1500/mm^2 and above were included in the study. The exclusion criteria were corneal dystrophy, uveitis, glaucoma, retinal diseases, maximally dilated pupil smaller than 7 mm, narrow anterior chamber, pseudoexfoliation, zonular weakness, previous intraocular surgery, and systemic diseases (DM, etc.). The study protocol was approved by the hospital's local ethics committee, and the criteria specified in the Declaration of Helsinki were complied with. After giving detailed information about the purpose of the study and the procedures to be performed, written informed consent was obtained from participants.

Surgical Technique

All surgeries were performed by the same experienced and left-handed surgeon (T.G.) and experienced team. For topical anesthesia, 0.5% proparacaine hydrochloride was instilled three times, 5 minutes apart, 30 minutes before the operation. For endophthalmitis prophylaxis, fornices were cleaned with povidone-iodine solution, left for 3 minutes, and washed with Ringer's lactate. Side port CCIs were performed with a 20 G microvitreoretinal knife at the 1 and 10 o'clock positions in the left eye and the 7 and 11 o'clock positions in the right eye. A cohesive viscoelastic agent (OVD) 1.4% sodium hyaluronate (Healon GV, Abbott Medical Optics, Abbott Park, Illinois, USA) was injected into the anterior chamber. A main clear corneal incision was made with a 2.2 mm disposable slit knife at the 9 o'clock position for the right eye and the 3 o'clock position for the left eye. A 5.5-6 mm diameter continuous curvilinear capsulorhexis (CCC) was created with capsulorhexis forceps. The lens cortex was separated from the lens capsule by hydrodissection, and the lens nucleus was separated from the lens cortex by hydrodelineation. A 0.9 mm, 30° Kelman phaco tip with sleeve (pink micro smooth, Alcon Laboratories Inc, Fort Worth, TX) was inserted into the anterior chamber through a 2.2 mm CCI. Ozil system (IP, Infiniti Vision System, Alcon Laboratories, Inc.) was used for phacoemulsification. Intraoperative parameters: linear torsional amplitude, 100%; dynamic rise, 0; aspiration, 30 ml/min; vacuum, 350 mmHg; bottle height was 110 cm. IP settings activated when the tip lumen is obstructed: longitudinal energy, 95%; vacuum maximum pulse duration, 15 milliseconds; longitudinal/torsional ratio was 1/1. The cortex residues were aspirated with a 20 G bimanual irrigation and aspiration system (I/A) (Alcon Laboratories, Inc.). Anterior chamber and lens capsule filled with 1.4% sodium hyaluronate OVD. The foldable intraocular lens (Tecnis one-piece ZCB0, Advanced Medical Optics-AMO, Santa Ana, USA) was inserted in a disposable plastic cartridge and implanted in the capsule from 2.2 mm CCI. The OVD was removed by bimanual I/A, also cleaning the back of the intraocular lens. Side port leaks were stopped by performing stromal hydration. For the prophylaxis of endophthalmitis, 0.1 cc undiluted moxifloxacin 0.5% ophthalmic solution was injected via side ports into the anterior chamber and the surgery was completed. Balanced salt solution (BSS) (Endosol 500, Advanced Medical Optics-AMO) was used for irrigation fluid. All patients used drops containing steroid (prednisolone acetate 1%) and antibiotic (moxifloxacin 0.5%) postoperatively, and this treatment continued for at least two weeks.

Ophthalmic Evaluation

Detailed ophthalmological examination was performed preoperatively and postoperatively at 1 day, week, month, and 3 months, and and CDVA (measured on Snellen chart converted to LogMAR), intraocular pressure (IOP) (Goldmann Applanation Tonometer), CCT (Ultrasonic Pachymetry 300P, Sonomed, Inc. Lake Success, NY, USA) outcome measures were recorded. The ECD was measured with a noncontact specular microscope (Endothelial Microscope, SP-02® CSO, İtaly) preoperatively, postoperatively first month, and third month. The formula; Endothelial cell loss (%): [(preoperative ECD-postoperative ECD)/preoperative ECD]x100 was used to calculate endothelial cell loss (ECL). The main CCI morphology was imaged by anterior segment optical coherence tomography (AS-OCT) (Cirrus HD-OCT, Carl Zeiss Meditec Inc, Dublin, CA) the first day, week, and month postoperatively. Corneal wound morphological changes on main CCI were evaluated as epithelial misalignment (EpM) (Figure 1A) epithelial gap (EpG) (Figure 1B), endothelial misalignment (EnM) (Figure 2A), endothelial gap (GAP) (Figure 2B), Descemet membrane detachment (DMD) (Figure 3A) and coadaptation loss (CAL) (Figure 3B). At the end of each surgery, the phacoemulsification device screen displays total ultrasound time (UST=total time at position 3 of the phacoemulsification footswitch), phaco time (PT), torsional time (TT), the mean percentage of total equivalent power in position 3 (TEPiP3%), cumulative dissipated energy (CDE=the percentage of average power dissipated during the UST) and BSS (mL) volume data were recorded.

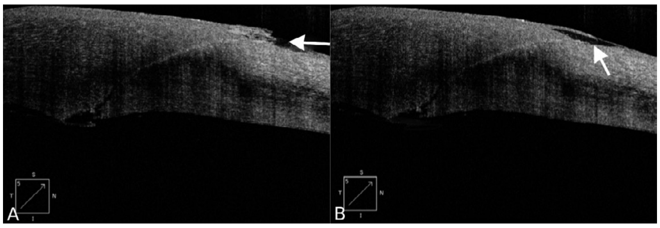

Figure 1. *Epithelial damage in clear corneal incision morphology. **A:** Epithelial misalignment. **B:** Epithelial gap.*

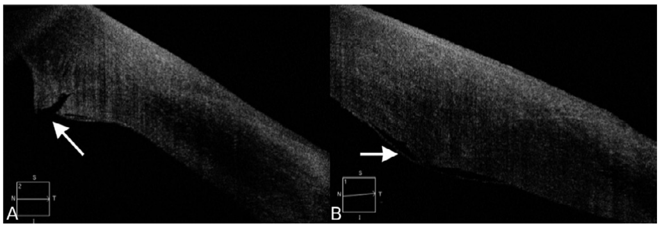

Figure 2. *Endothelial damage in clear corneal incision morphology. **A:** Endothelial misalignment. **B:** Endothelial gap.*

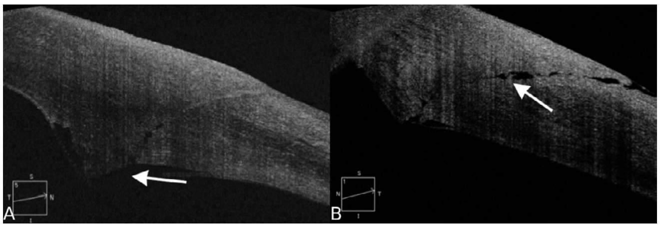

Figure 3. ***A:** Descemet membrane detachment. **B:** Coadaptation loss.*

Statistical Analysis

Statistical analysis was performed using the SPSS program for Windows software (version 26, IBM SPSS Statistics, Chicago, Illinois, USA). The statistical differences in the six groups were compared with the chi-square test and analysis of variance in repeated measures. The relationship between outcome measures was examined by Pearson correlation analysis. P-value $<.05$ was considered statistically significant. The relationship between outcome measures was examined by Pearson correlation analysis. Bonferroni corrected t-test was used for multiple comparisons. $P<.009$ was considered statistically significant in multiple comparisons.

RESULTS

There was no statistically significant difference between the six groups in gender and operated side. The mean age in the NO1 group was lower than in the other groups ($P<0.001$). Intraoperative parameters; UST, PT, TT, CDE, TEPiP3%, and BSS outcome measures differed statistically between groups ($P<0.001$) (Table 1). PT, TT, CDE, and TEPiP3% values were lowest in NO1, highest in NO6; The mean BSS volume was lowest in NO2 and highest in NO6 and showed a statistically significant positive correlation with nuclear cataract density (r: 0.534; $P<0.001$).

The mean CDVA was statistically significantly different at preoperatively and postoperatively one day, week, and month ($P\leq0.009$). A statistically significant difference was observed in the mean CCT on the postoperative 1st day and 1st week between the groups ($P\leq0.008$) (Table 2). There was a positive correlation between the mean CCT and nuclear density on the postoperative 1st day and week ($r\leq0.423$, $P\leq0.002$). CCT was measured in all patients on the postoperative 1st day, week, month, and 3rd month, and the mean values were returned to preoperative values in all groups at the 3rd month. The mean ECD was similar preoperatively and differed statistically at 1 and 3 months postoperatively ($P<0.001$). There was a statistically significant difference in the mean ECL percentage at the 1st and 3rd months postoperatively ($P<0.001$) (Table 2). In contrast, there was a negative correlation between nuclear cataract density and postoperative mean ECD ($r\leq-0.634$, $P<0.001$); found to be a positive correlation with the mean ECL ($r\leq0.634$, $P<0.001$). While the ECL rate was below 10.9% in the NO1 at the third postoperative month, this value was approximately 55% in the NO6. In the NO1, there was a positive correlation between the mean ECL at 1 and 3 months postoperatively, and the UST, PT, and TT results during surgery ($r\geq0.625$, $P\leq0.022$).

AS-OCT images taken for postoperative CCI morphology were statistically similar between the groups on the 1st day, week, and month, in the mean EpM, EpG, and EnM ($P\geq0.161$). The mean EnB was significantly lower in the NO1 at postoperative 1st week ($P=0.010$). While the mean DMD percentage was significantly lower in the NO1 and NO2 groups at postoperative day 1, it increased in line with the nuclear density ($P= 0.028$). While no CAL was observed in the NO1 and NO2 groups at postoperative one week, it was present in the other groups, and there was a statistically significant difference ($P=0.006$) (Table 3).

Table 1: *The subject characteristics and comparison of intraoperative parameters.*

	Groups						
Parameters	**NO1**	**NO2**	**NO3**	**NO4**	**NO5**	**NO6**	**P Value**
Sex, n							0,457
Male	9	11	12	11	6	9	
Female	11	9	8	9	14	11	
Eye, n							0,826
Right	11	9	11	8	10	12	
Left	9	11	9	12	10	8	
Age (year)							<0.001[a]
Mean ± SD	48.5±12.0	58.6±9.6	63.8±10.5	71.4±8.8	70.0±5.9	70.0±.2	
Range	30, 71	40, 78	44, 83	47, 83	61, 81	51, 93	
UST (sec)							
Mean ± SD	8.6±15.5	32.5±15.4	45.5±29.5	37.9±14.6	68.9±28.5	128.6±63.5	<0.001[b]
Range	0, 54	10, 65	2, 149	24, 81	24, 124	68, 296	
Phaco Time (sec)							
Mean ± SD	8.4±15.2	32±15.1	41.6±19.6	36.5±14.3	66.8±27.3	119.6±66.5	<0.001[c]
Range	0, 52	10, 64	2, 88	23, 79	23, 120	3, 282	
CDE							
Mean ± SD	0.7±1.1	4.3±2.8	8.0±4.1	8.8±3.1	16±6.8	31.1±14.1	<0.001[d]
Range	0, 3.3	0.7, 9.7	0, 17.5	3.7, 14.3	6.2, 29.8	16.2, 59.4	
%TEPiP3							
Mean ± SD	6.6±7.8	12.6±5.4	17.2±6.2	23.6±5.4	23.7±3.2	24.2±2.4	<0.001[e]
Range	0, 28.7	2.7, 23	3.3, 28.3	13, 31	14.2, 29.3	19.2, 28.4	
BSS Volume (ml)							
Mean ± SD	39.3±16.0	36.7±13.4	50.5±21.5	41.8±9.5	62.6±20	109.1±60.6	<0.001[f]
Range	20, 77	19, 59	18, 101	31, 59	37, 108	51, 263	

NO: Nuclear opacity; UST: Total ultrasound; TEPiP3%: percentage total equivalent power in position 3, CDE: Cumulative dissipaed energy; BSS: Balanced salt volume

[a] Bonferroni test, NO1-2 P=0.832; NO1-3 P=0.028; NO1-4 P=0.190; **NO1-5 P<0.001; NO1-6 P<0.001;** NO2-3 P=1.000; NO2-4 P=1.000; NO2-5 P=0.032; **NO2-6 P<0.001;** NO3-4 P=1.000; NO3-5 P=0.468; **NO3-6 P<0.001;** NO4-5 P=0.069; **NO4-6 P<0.001; NO5-6 P<0.001.**

[b] Bonferroni test, NO1-2 P=1.000; NO1-3 P=0.242; NO1-4 P=0.308; **NO1-5 P<0.001; NO1-6 P<0.001;** NO2-3 P=1.000; NO2-4 P=1.000; **NO2-5 P=0.001; NO2-6 P<0.001;** NO3-4 P=1.000; NO3-5 P=0.029; **NO3-6 P<0.001;** NO4-5 P=0.021; **NO4-6 P<0.001; NO5-6 P<0.001**.

[c] Bonferroni test, NO1-2 P=0.825; NO1-3 P=0.065; NO1-4 P=0.228; **NO1-5 P<0.001; NO1-6 P<0.001;** NO2-3 P=1.000; NO2-4 P=1.000; NO2-5 P=0.043; **NO2-6 P<0.001;** NO3-4 P=1.000; NO3-5 P=0.281; **NO3-6 P<0.001;** NO4-5 P=0.075; **NO4-6 P<0.001; NO5-6 P<0.001.**

[d] Bonferroni test, NO1-2 P=1.000; NO1-3 P=0.048; NO1-4 P=0.017; **NO1-5 P<0.001; NO1-6 P<0.001;** NO2-3 P=1.000; NO2-4 P=1.000; **NO2-5 P<0.001; NO2-6 P<0.001;** NO3-4 P=1.000; NO3-5 P=0.009; **NO3-6 P<0.001;** NO4-5 P=0.028; **NO4-6 P<0.001; NO5-6 P<0.001.**

[e] Bonferroni test, NO1-2 P=0.011; **NO1-3 P<0.001; NO1-4 P<0.001; NO1-5 P<0.001; NO1-6 P<0.001;** NO2-3 P=0.023; **NO2-4 P<0.001; NO2-5 P<0.001; NO2-6 P<0.001;** NO3-4 P=0.010; NO3-5 P=0.025; NO3-6 P=0.010; NO4-5 P=1.000; NO4-6 P=1.000; NO5-6 P=1.000.

[f] Bonferroni test, NO1-2 P=1.000; NO1-3 P=1.000; NO1-4 P=1.000; NO1-5 P=0.377; **NO1-6 P<0.001;** NO2-3 P=1.000; NO2-4 P=1.000; NO2-5 P=0.199; **NO2-6 P<0.001;** NO3-4 P=1.000; NO3-5 P=1.000; **NO3-6 P<0.001;** NO4-5 P=0.464; **NO4-6 P<0.001; NO5-6 P<0.001.**

Table 2: *Correlation of nuclear opalescence between intraoperative and follow-up parameters.*

	NO	
Intraoperative parameters	**r value**	**p value**
CDE	0.755	<0.001
UST	0.677	<0.001
PT	0.730	<0.001
TT	0.665	<0.001
TEPiP3%	0.722	<0.001
BSS	0.534	<0.001
Follow up parameters		
CCT		
Preoperative	0.112	0.242
Postoperative		
1 day	0.423	<0.001
1 week	0.302	0.002
1 month	-.043	0.660
3 month	0.060	0.556
ECD		
Preoperative	-.090	0.347
Postoperative		
1 month	-.634	<0.001
3 month	-.653	<0.001
ECL		
Postoperative		
1 month	0.634	<0.001
3 month	0.632	<0.001

NO: Nuclear opacity; CDE: Cumulative dissipaed energy; UST: Total ultrasound time; PT: Phaco time; TT: Torsional time; TEPiP3%: percentage total equivalent power in position 3, BSS: Balanced salt volume CCT: Central corneal thickness; ECD: Endothelial cell density; ECL: Endothelial cell loss.

DISCUSSION

In this prospective randomized comparative study, phacoemulsification surgery was performed by the same surgeon using the same OVD, surgical technique, surgical equipment, BSS, and intraocular lens in eyes with nuclear cataracts divided into six stages, using the coaxial torsional method. The effects on intraoperative dynamics, CDVA, endothelial cell density, central corneal thickness, and main corneal incision morphology were evaluated for each nuclear cataract density grade. In this study, corneal changes depending on the energy, time and fluid used appear to be correlated as the nuclear density increases. In coaxial torsional phacoemulsification, damage occurred in all layers in the CCI morphology, while Descemet's membrane was the most affected structure in the early postoperative period.

Studies have shown that as nuclear cataract density increases, intraoperative cumulative energy use, ultrasound time, ultrasound power, and BSS volume use increase.[5,9] It has become possible to apply phacoemulsification using less ultrasound energy, thanks to the developments in devices and tip designs and effective nuclear fragmentation methods.[10,11] In torsional mode, a rotating, oscillating motion at a frequency of 32 kilohertz (kHz) creates a shaving effect without the jackhammer effect. In this way, both the nucleus is not pushed, and the phaco tip moves in all directions, thus breaking the nucleus and causing less frequency movement. The lumen of tip obstruction problem in high-density nuclear cataract surgeries has been solved by this method.[2,10-12]

In our study, which we performed with the coaxial torsional method, the mean total ultrasound time, phaco time, torsional time, CDE, %TEPiP3, and the BSS volume used was significantly higher in eyes with high-density nuclear cataracts. The energy used during phacoemulsification in eyes with low and high nuclear density cataracts was compared and the energy spent, especially in high nuclear density cataracts, increases statistically significantly and exponentially, and this increase is significant but linear in lower grades. In the study of Bencic et al., in which the mean phaco power and mean phaco time were compared according to the nuclear cataract density, it was reported that there was a linear increase in the mean phaco time and power of nuclear cataract density at grade 4 and below, while an exponential increase was observed above grade 4.[8] In the comparison of Ozil IP enhanced software torsional and non-torsional modes of the same device, in mid-nuclear grade cataract surgery with the coaxial microincision method, less average CDE and lower average TEPiP3% data were obtained in the torsional method.[10] Rekas et al. also compared two modes of the same device with the coaxial method according to nuclear density and reported less energy, shorter phaco time, and less fluid use for the torsional mode.[6] It was thought that better tracking of nucleus particles during chopping in the torsional method could be effective in obtaining these results.[13-15]

Kim et al. evaluated the relationship between nuclear cataract density and endothelial cell loss using the coaxial torsional method.[16] In their study, the groups were divided into moderate and hard nuclear cataracts (moderate: NO2 ≤ x ≤ NO4 and hard: NO4 < x ≤ NO5) according to LOCS III and reported endothelial cell loss at the postoperative 1st month as 3.19% and 23.52%, respectively. In another study, Wilczynski et al. used the coaxial method and reported 9.46% endothelial cell loss in the first month postoperatively in grade 2 and below nuclear cataracts classified according to LOCS II.[17] Kurz et al. found endothelial cell loss as 14.1% in grade 4 and below nuclear

Table 3. *Comparison of CDVA, IOP, CCT, ECD, and ECL between groups.*

	Groups												
Parameters	**NO1**		**NO2**		**NO3**		**NO4**		**NO5**		**NO6**		**P Value**
CDVA (logMAR)	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	
Preoperative	0.51±0.31	0.22, 1.30	0.38±0.21	0.22, 1.00	0.71±0.41	0.22, 1.52	0.69±0.70	0.22, 3.00	1.17±0.98	0.30, 3.00	2.17±0.79	0.52, 3.00	<.001[a]
Postoperative													
1 day	0.13±0.12	0.00, 0.39	0.14±0.11	0.00, 0.39	0.41±0.39	0.00, 1.30	0.43±0.26	0.04, 1.00	0.58±0.32	0.15, 1.30	1.13±0.62	0.52, 3.00	<.001[b]
1 week	0.03±0.06	0.00, 0.22	0.02±0.04	0.00, 0.15	0.12±0.15	0.00, 0.39	0.07±0.09	0.00, 0.30	0.16±0.14	0.00, 0.39	0.39±0.32	0.00, 1.30	<.001[c]
1 month	0.04±0.09	0.00, 0.30	0.01±0.02	0.00, 0.09	0.05±0.08	0.00, 0.03	0.02±0.05	0.00, 0.15	0.06±0.10	0.00, 0.30	0.16±0.25	0.00, 1.00	<.009[d]
3 month	0.01±0.04	0.00, 0.15	0.00±0.00	0.00, 0.00	0.02±0.04	0.00, 0.15	0.02±0.04	0.00, 0.15	0.01±0.03	0.00, 0.09	0.09±0.20	0.00, 0.82	0.054
IOP (mmhg)													
Preoperative	13.83±4.11	8.7, 22.0	15.53±3.38	9.0, 22.0	14.79±3.79	9.0, 21.8	13.44±3.42	8.0, 21.0	15.09±5.07	8.0, 26.7	14.35±3.57	8.0, 19.1	0.632
Postoperative													
1 day	14.53±5.81	8.3, 31.0	16.63±6.71	7.6, 32.0	17.74±8.27	7.0, 40.0	14.71±6.11	7.0, 26.0	15.82±7.29	8.0, 40.1	16.50±7.80	8.0, 38.9	0.877
1 week	12.31±4.20	7.0, 22.0	13.14±4.55	8.0, 24.0	11.41±3.39	6.8, 19.8	11.97±3.82	7.0, 19.0	10.83±2.72	6.8, 15.0	10.21±3.02	6.0, 17.0	0.195
1 month	12.53±3.39	7.0, 19.0	14.61±6.78	7.9, 36.0	12.27±4.81	6.8, 28.0	10.77±3.06	7.0, 19.0	11.50±3.34	7.6, 20.0	11.84±2.45	7.0, 16.0	0.143
3 month	11.98±3.41	7.9, 17.0	13.76±3.69	7.6, 19.2	11.93±3.24	7.0, 18.0	11.37±3.06	7.7, 17.0	12.00±3.24	7.9, 18.0	12.26±2.39	7.0, 17.0	0.539
CCT (µm)													
Preoperative	553.1±24.9	502, 585	556.0±42.9	459, 612	550.8±30.2	485, 625	539.1±38.6	452, 632	543.2±38.5	459, 616	546±36.0	477, 615	0.726
Postoperative													
1 day	591.6±36.9	544, 665	621.1±54.6	526, 743	636.7±67.1	520, 781	636.4±53.1	551, 722	647.1±76.0	533, 769	703.2±90.4	533, 781	0.008[e]
1 week	576.6±31.7	528, 633	579.8±43.9	497, 647	594.6±40.4	517, 672	572.4±39.2	497, 658	611.3±58.9	475, 725	623.8±56.3	560, 796	0.005[f]
1 month	567.6±32.0	518, 625	569.7±42.4	489, 624	579.5±31.6	510, 644	552.9±38.6	470, 644	568.0±44.2	465, 639	567.7±41.5	492, 664	0.449
3 month	555.6±20.5	520, 587	558.0±43.4	480, 610	553.9±31.3	486, 623	537.7±41.9	436, 642	546.5±39.9	465, 616	548.9±39.7	480, 626	0.658
ECD (cells/mm2)													
Preoperative	2730±389	2106, 3309	2611±250	1978, 2930	2504±426	1547, 3100	2392±259	2021, 2971	2521±344	2000, 3309	2627±518	1571, 3488	0.145
Postoperative													
1 month	2446±517	1266, 3271	2204±568	992, 2862	1933±473	712, 2878	1584±389	925, 2209	1497±526	796, 2614	1274±466	428, 2087	<0.001[g]
3 month	2486±484	1279, 3261	2162±558	1081, 2820	1965±497	741,2557	1680±365	1024, 2243	1540±512	846, 2749	1305±429	511, 1892	<0.001[h]
ECL													
Postoperative													
1 month	10.8±12.1	0.7, 46.7	15.9±20.1	-10.3, 61.9	21.5±18.3	0.5, 72.1	33.8±15.7	9.4, 62.8	40.5±19.9	6.3, 70.7	55.1±14.6	35.3, 75.6	<0.001[i]
3 month	9.1±11.9	0.7, 46.2	17.6±19.6	-8.9, 58.4	20.3±19.2	0.5, 71.0	29.3±16.3	5.8, 55.8	38.8±18.6	6.9, 68.2	53.4±13.2	35.3, 75.6	<0.001[j]

NO: Nuclear opacity; CDVA: Corrected distance visual acuity; IOP: Intraocular pressure; CCT: Central corneal thickness; ECD: Endothelial cell density; ECL: Endothelial cell loss.

[x] Analysis of variance in repeated measures.

[a] Bonferroni test, NO1-2 P=1.000; NO1-3 P=1.000; NO1-4 P=1.000; NO1-5 P=0.062; **NO1-6 P<0.001;** NO2-3 P=1.000; NO2-4 P=1.000; NO2-5 P=0.010; **NO2-6 P<0.001;** NO3-4 P=1.000; NO3-5 P=0.427; **NO3-6 P<0.001;** NO4-5 P=0.363; **NO4-6 P<0.001; NO5-6 P<0.001.**

[b] Bonferroni test, NO1-2 P=1.000; NO1-3 P=0.447; NO1-4 P=0.300; **NO1-5 P=0.008; NO1-6 P<0.001;** NO2-3 P=0.509; NO2-4 P=0.343; NO2-5 P=0.010; **NO2-6 P<0.001;** NO3-4 P=1.000; NO3-5 P=1.000; **NO3-6 P<0.001;** NO4-5 P=1.000; **NO4-6 P<0.001; NO5-6 P<0.001.**

[c] Bonferroni test, NO1-2 P=1.000; NO1-3 P=1.000; NO1-4 P=1.000; NO1-5 P=0.422; **NO1-6 P<0.001;** NO2-3 P=1.000; NO2-4 P=1.000; NO2-5 P=0.297; **NO2-6 P<0.001;** NO3-4 P=1.000; NO3-5 P=1.000; **NO3-6 P<0.001;** NO4-5 P=1.000; **NO4-6 P<0.001; NO5-6 P<0.001.**

[d] Bonferroni test, NO1-2 P=1.000; NO1-3 P=1.000; NO1-4 P=1.000; NO1-5 P=1.000; NO1-6 P=.159; NO2-3 P=1.000; NO2-4 P=1.000; NO2-5 P=1.000; NO2-6 P=0.013; NO3-4 P=1.000; NO3-5 P=1.000; NO3-6 P=0.118; NO4-5 P=1.000; NO4-6 P=0.019; NO5-6 P=0.290.

[e] Bonferroni test, NO1-2 P=1.000; NO1-3 P=1.000; NO1-4 P=1.000; NO1-5 P=0.770; **NO1-6 P=0.003;** NO2-3 P=1.000; NO2-4 P=1.000; NO2-5 P=1.000; NO2-6 P=0.043; NO3-4 P=1.000; NO3-5 P=1.000; NO3-6 P=0.240; NO4-5 P=1.000; NO4-6 P=.0233; NO5-6 P=0.811.

[f] Bonferroni test, NO1-2 P=1.000; NO1-3 P=1.000; NO1-4 P=1.000; NO1-5 P=0.543; NO1-6 P=0.078; NO2-3 P=1.000; NO2-4 P=1.000; NO2-5 P=0.776; NO2-6 P=0.116; NO3-4 P=1.000; NO3-5 P=1.000; NO3-6 P=0.862; NO4-5 P=0.148; **NO4-6 P=0.013;** NO5-6 P=1.000.

[g] Bonferroni test, NO1-2 P=1.000; NO1-3 P=0.040; **NO1-4 P<0.001; NO1-5 P<0.001; NO1-6 P<0.001;** NO2-3 P=1.000; **NO2-4 P=0.005; NO2-5 P=0.001; NO2-6 P<0.001;** NO3-4 P=0.387; NO3-5 P=0.084; **NO3-6 P=0.001;** NO4-5 P=1.000; NO4-6 P=0.708; NO5-6 P=1.000.

[h] Bonferroni test, NO1-2 P=0.956; NO1-3 P=0.026; **NO1-4 P<0.001; NO1-5 P<0.001; NO1-6 P<0.001;** NO2-3 P=1.000; NO2-4 P=0.054; **NO2-5 P=0.003; NO2-6 P<0.001;** NO3-4 P=0.904; NO3-5 P=0.083; **NO3-6 P<0.001;** NO4-5 P=1.000; NO4-6 P=0.207; NO5-6 P=1.000.

[i] Bonferroni test, NO1-2 P=1.000; NO1-3 P=1.000; **NO1-4 P=0.004; NO1-5 P<0.001; NO1-6 P<0.001;** NO2-3 P=1.000; NO2-4 P=0.062; **NO2-5 P=0.002; NO2-6 P<0.001;** NO3-4 P=0.473; NO3-5 P=0.016; **NO3-6 P<0.001;** NO4-5 P=1.000; NO4-6 P=0.009; NO5-6 P=0.252.

[j] Bonferroni test, NO1-2 P=1.000; NO1-3 P=1.000; NO1-4 P=0.025; **NO1-5 P<0.001; NO1-6 P<0.001;** NO2-3 P=1.000; NO2-4 P=0.815; NO2-5 P=0.010; **NO2-6 P<0.001;** NO3-4 P=1.000; NO3-5 P=0.018; **NO3-6 P<0.001;** NO4-5 P=1.000; **NO4-6 P=0.001;** NO5-6 P=0.227.

Table 4: *Correlation between endothelial cell loss and intraoperative phaco parameters*

	Groups											
Parameters	**NO1**		**NO2**		**NO3**		**NO4**		**NO5**		**NO6**	
CDE	1 month	3 month	1 month	3 month	1 month	3 month	1 month	3 month	1 month	3 month	1 month	3 month
r value	0.489	0.501	0.470	0.455	-.101	-.116	-.099	-.099	0.335	0.330	-.028	-.017
p value	0.090	0.081	0.090	0.102	0.681	0.635	0.686	0.687	0.161	0.168	0.920	0.953
UST												
r value	0.668	0.675	0.268	0.254	0.174	.040	-.013	0.121	0.156	0.171	-.031	-.038
p value	0.013	0.011	0.355	0.380	0.477	0.870	0.959	0.620	0.524	0.485	0.913	0.892
Phaco Time												
r value	0.625	0.640	0.015	0.018	-.055	-.068	0.259	0.396	0.237	0.232	-.199	-.148
p value	0.022	0.018	0.961	0.951	0.823	0.783	0.284	0.093	0.330	0.340	0.477	0.599
TT												
r value	0.669	0.676	0.270	0.257	0.140	0.050	-.017	0.117	0.161	0.175	-.025	-.034
p value	0.012	0.011	0.350	0.376	0.569	0.839	0.946	0.634	0.511	0.474	0.930	0.904
TEPiP3%												
r value	-.295	-.282	0.462	0.452	-.246	-.153	0.026	-.233	0.343	0.294	0.023	0.101
p value	0.329	0.350	0.096	0.104	0.311	0.531	0.915	0.337	0.151	0.221	0.936	0.720
BSS Volume (ml)												
r value	0.059	0.144	0.448	0.435	0.383	0.276	0.201	0.301	0.194	0.184	-.025	-.062
p value	0.848	0.639	0.108	0.120	0.106	0.252	0.410	0.211	0.427	0.450	0.930	0.827

NO: Nuclear opacity; UST: Total ultrasound; TT: Torsional time; TEPiP3%: percentage total equivalent power in position 3, CDE: Cumulative dissipaed energy; BSS: Balanced salt volume

cataract densities according to LOCS III using the coaxial pulse-mode longitudinal method.[18] In our study, the mean ECL with low (NO1) and high (NO6) nuclear density cataracts was 10.8% and 55.1% at postoperative 1st month, and 9.1% and 53.4% at three months, respectively. There was a significant positive correlation between nuclear density and the mean ECL at one month and three months postoperatively. In addition, there was a significant positive correlation between the mean ECL and UST, PT, and TT in low nuclear density cataracts at one month and three months postoperatively.

Among the main factors causing postoperative corneal edema are the ECD, nuclear cataract density, heat generation during surgery, and BSS volume used.[19,20] In our study, it was observed that CCT increasing is less in low nuclear density cataracts, while it increased more in high-density cataracts in the postoperative 1st day and week. In the postoperative 3rd month, preoperative CCT values were restored and the mean CDVA improved to a similar degree in the groups with the effect of the improvement in CCT values. Due to the effect of corneal edema on CDVA results, postoperative 1st day, week, and month results statistically differed between groups.[19]

While developing phacoemulsification methods, it is also aimed to reduce the heat released during surgery. Sudden and prolonged temperature increases in the corneal tissue affect the CCI morphology.[21-23] In eyes with high-density nuclear cataracts, this heat due to prolonged energy use increases local corneal edema and CCI damage. Combined with mechanical trauma and stromal hydration, it causes increased loss of coadaptation in the CCI region.[24] Coaptation loss was more common in eyes with high-density cataracts at postoperative 1st week.

EnG and EnM are endothelial closure problems caused by delayed healing of corneal edema.[25] Xia et al. reported that EnG formation was significantly higher in cases with high postoperative corneal thickness.[4] In our study, EnG differed significantly between the groups at postoperative 1st week and was more common in eyes with high-density nuclear cataracts. The epithelial opening also increases the risk of endophthalmitis as it disrupts the epithelial barrier mechanism.[1,24] In this study, epithelial healing developed rapidly, and epithelial space and alignment were not observed on the postoperative 1st-day imaging.

DMD is caused by the separation of the corneal lamellar stroma and Descemet's membrane, which have different

Table 5: *The comparison of clear corneal incision morphological changes.*

	Groups						
Parameters n (%)	**NO1**	**NO2**	**NO3**	**NO4**	**NO5**	**NO6**	**P Value**
EnM							
1. day	9 (45)	8 (40)	10 (50)	11 (55)	9 (45)	11 (55)	0.917
1. week	9 (45)	9 (45)	3 (15)	8 (40)	9 (45)	10 (50)	0.247
1. month	7 (35)	10 (50)	4 (20)	7 (35)	8 (40)	12 (60)	0.161
EnG							
1. day	17 (85)	16 (80)	16 (80)	16 (80)	16 (80)	17 (85)	0.994
1. week	4 (20)	8 (40)	13 (65)	14 (70)	13 (65)	12 (60)	0.010
1. month	2 (10)	0 (0)	3 (15)	1 (5)	1 (5)	0 (0)	0.417
DMD							
1. day	4 (20)	4 (20)	9 (45)	10 (50)	11 (55)	12 (60)	0.028
1. week	3 (15)	2 (10)	7 (35)	5 (25)	7 (35)	10 (50)	0.063
1. month	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (5)	1.000
EpM							
1. day	2 (10)	2 (10)	2 (10)	1 (5)	0 (0)	0 (0)	0.555
1. week	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	
1. month	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	
EpG							
1. day	2 (10)	2 (10)	4 (20)	4 (20)	2 (10)	4 (20)	0.818
1. week	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	
1. month	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	
CAL							
1. day	6 (30)	11 (55)	9 (45)	9 (45)	13 (65)	7 (35)	0.270
1. week	0 (0)	0 (0)	4 (20)	3 (15)	7 (35)	3 (15)	0.006
1. month	0 (0)	0 (0)	0 (0)	2 (10)	0 (0)	0 (0)	0.160

NO: Nuclear opacity; EnM = Endothelial misalignment; EnG = Endothelial gap; DMD = Descemet membrane detechmant; EpM = Epithelial misalignment; EpG = Epithelial gap; CAL = Coadaption loss.

physical properties. Intraocular lens implantation, high-density nucleus, and surgical instruments are the main causes of mechanical trauma that leading cause of DMD. In the literature, DMD detected in a slit-lamp examination is significantly lower than that detected by AS-OCT. The incidence of DMD after surgery with AS-OCT is 50%.[1,2,4] In our study, while more DMD was observed in the high-density cataract groups on the first day, it persisted in one patient in the NO6 group at the postoperative 1st month.

One of the limitations of this study is the insufficient dispersive feature of the OVD we used. This may be one of the reasons for the excessive corneal endothelial cell loss and CCI damages. Changes in CCI morphology were imaged for the first time at the 24th hour. The CCI changes in epithelial gap and misalignment could not be adequately measured because epithelial healing was also completed on the postoperative first day. Earlier measurement is required to observe a difference. This study claimed the efficacy of torsional software in hard cataracts but could not make this difference strongly. While determining the nuclear density groups, a homogeneous distribution in age could not be achieved and a higher mean age was observed in hard cataracts. Failure to perform age-matched groups may cause aging, which has an effect on corneal changes, to affect the results. Unfortunately, there is no literature regarding comparisons with other methods using this six-group of lens opacities classification system.

In conclusion, in the coaxial torsional method, we applied in soft to hard nuclear cataracts using the six stages of standardized classification system LOCS III, the amount of energy used and the balanced salt solution consumed increase in correlation as the nuclear cataract density increases and endothelial cell loss increases with the effect of these factors. In line with this correlation, as nuclear cataract density increased, the most prominent structural change in CCI morphology emerged as Descemet's membrane detachment in the early postoperative period.

Conflict of interest: The authors declare no conflict of interest.

Financial Disclosure: No author has a financial or proprietary interest in any material or method mentioned.

Ethical committee: Local Ethics Committee of Tekirdag Namik Kemal University Hospital (2013.84.07.03)

Funding: None.

Acknowledgements: The authors thank Professor Afsun Şahin MD., from the Koç University Research Center for Translational Medicine, for checking and reviewing our manuscript.

Declaration of not being published before: We declare that this article has not been published elsewhere and was not submitted for simultaneous publication elsewhere.

REFERENCES

1. Can I, Bayhan HA, Celik H, et al. Anterior segment optical coherence tomography evaluation and comparison of main clear corneal incisions in microcoaxial and biaxial cataract surgery. J Cataract Refract Surg. 2011;37:490-500.
2. Gonen T, Sever O, Horozoglu F, et al. Endothelial cell loss: Biaxial small-incision torsional phacoemulsification versus biaxial small-incision longitudinal phacoemulsification. J Cataract Refract Surg. 2012;38:1918-24.
3. Hayashi K, Hayashi H, Nakao F, et al. Risk factors for corneal endothelial injury during phacoemulsification. J Cataract Refract Surg. 1996;22:1079-84.
4. Xia Y, Liu X, Luo L, et al. Early changes in clear cornea incision after phacoemulsification: an anterior segment optical coherence tomography study. Acta Ophthalmol. 2009;87:764-8.
5. Liu Y, Zeng M, Liu X, et al. Torsional mode versus conventional ultrasound mode phacoemulsification: randomized comparative clinical study. J Cataract Refract Surg. 2007;33:287-92.
6. Rekas M, Montés-Micó R, Krix-Jachym K, et al. Comparison of torsional and longitudinal modes using phacoemulsification parameters. J Cataract Refract Surg. 2009;35:1719-24.
7. Leon P, Umari I, Mangogna A, et al. An evaluation of intraoperative and postoperative outcomes of torsional mode versus longitudinal ultrasound mode phacoemulsification: a Meta-analysis. Int J Ophthalmol. 2016;9:890-7.
8. Bencić G, Zorić-Geber M, Sarić D, et al. Clinical importance of the lens opacities classification system III (LOCS III) in phacoemulsification. Coll Antropol. 2005;29:91-4.
9. Bozkurt E, Bayraktar S, Yazgan S, et al. Comparison of conventional and torsional mode (OZil) phacoemulsification: randomized prospective clinical study. Eur J Ophthalmol. 2009;19:984-9.
10. Ratnarajan G, Packard R, Ward M. Combined occlusion-triggered longitudinal and torsional phacoemulsification during coaxial microincision cataract surgery: effect on 30-degree mini-flared tip behavior. J Cataract Refract Surg. 2011;37:825-9.
11. Tognetto D, Cecchini P, Leon P, et al. Stroke dynamics and frequency of 3 phacoemulsification machines. J Cataract Refract Surg. 2012;38:333-42.
12. Cionni RJ, Crandall AS, Felsted D. Length and frequency of intraoperative occlusive events with new torsional phacoemulsification software. J Cataract Refract Surg. 2011;37:1785-90.
13. Davison JA, Chylack LT. Clinical application of the lens opacities classification system III in the performance of phacoemulsification. J Cataract Refract Surg. 2003;29:138-45.
14. Kim EK, Cristol SM, Kang SJ, et al. Viscoelastic protection from endothelial damage by air bubbles. J Cataract Refract Surg. 2002;28:1047-53.
15. Cameron MD, Poyer JF, Aust SD. Identification of free radicals produced during phacoemulsification. J Cataract Refract Surg. 2001;27:463-70.
16. Kim DH, Wee WR, Lee JH, et al. The comparison between torsional and conventional mode phacoemulsification in moderate and hard cataracts. Korean J Ophthalmol. 2010;24:336-40.
17. Wilczynski M, Supady E, Loba P, et al. Comparison of early corneal endothelial cell loss after coaxial phacoemulsification through 1.8 mm microincision and bimanual phacoemulsification through 1.7 mm microincision. J Cataract Refract Surg. 2009;35:1570-4.
18. Kurz S, Krummenauer F, Gabriel P, et al. Biaxial microincision versus coaxial small-incision clear cornea cataract surgery. Ophthalmology. 2006;113:1818-26.
19. Li YJ, Kim HJ, Joo CK. Early changes in corneal edema following torsional phacoemulsification using anterior segment optical coherence tomography and Scheimpflug photography. Jpn J Ophthalmol. 2011;55:196-204.
20. Lundberg B, Jonsson M, Behndig A. Postoperative corneal swelling correlates strongly to corneal endothelial cell loss after phacoemulsification cataract surgery. Am J Ophthalmol. 2005;139:1035-41.
21. Jun B, Berdahl JP, Kim T. Thermal study of longitudinal and torsional ultrasound phacoemulsification: tracking the temperature of the corneal surface, incision, and handpiece. J Cataract Refract Surg. 2010;36:832-7.
22. Han YK, Miller KM. Heat production: Longitudinal versus torsional phacoemulsification. J Cataract Refract Surg. 2009;35:1799-805.
23. Chen X, Ji Y, Lu Y. Comparison of clear corneal incision injuries between torsional and conventional phacoemulsification. Graefes Arch Clin Exp Ophthalmol. 2013;251:2147-54.
24. Calladine D, Tanner V. Optical coherence tomography of the effects of stromal hydration on clear corneal incision architecture. J Cataract Refract Surg. 2009;35:1367-71.
25. Bolz M, Sacu S, Drexler W, et al. Local corneal thickness changes after small-incision cataract surgery. J Cataract Refract Surg. 2006;32:1667-71.