Corneal endothelial cell loss during phacoemulsification: Bevel-up versus bevel-down phaco tip

Amir Faramarzi, MD, Mohammad Ali Javadi, MD, Farid Karimian, MD, Mohammad Reza Jafarinasab, MD, Alireza Baradaran-Rafii, MD, Fariba Jafari, MD, Mehdi Yaseri, MS

PURPOSE: To compare corneal endothelial cell loss during cataract extraction by phacoemulsification with 2 different phaco-tip positions.

SETTING: Ophthalmic Research Center and Department of Ophthalmology, Labbafinejad Medical Center, Shahid Beheshti Medical University, Tehran, Iran.

DESIGN: Randomized clinical trial.

METHODS: Eyes scheduled for cataract extraction were randomly assigned stop-and-chop phacoemulsification with the phaco tip in the conventional bevel-up position or with the phaco tip in the bevel-down position. During surgery, the effective phacoemulsification time (EPT) was recorded. Preoperative endothelial cell parameters were compared with measurements taken 3 months postoperatively.

RESULTS: Each group comprised 30 eyes (30 patients). There were no statistically significant differences in age, sex, anterior chamber depth, axial length, or EPT between the 2 groups. The mean preoperative endothelial cell density (ECD) was 2544 cells/mm^2 $\pm$ 64 (SD) in the bevel-up group and 2471 $\pm$ 59 cells/mm^2 in the bevel-down group (P=.610). Postoperatively, both groups had a significant decrease in ECD. The mean endothelial cell loss was 5.9% in the bevel-up group and 13.6% in the bevel-down group (P=.012). The percentage of hexagonal cells and coefficient of variation in cell size were not different between the 2 groups preoperatively or postoperatively; however, after surgery, there was a significant decrease in the percentage of hexagonal cells in both groups.

CONCLUSION: Corneal endothelial cell loss during phacoemulsification was significantly higher when the phaco tip was in the bevel-down position than in the conventional bevel-up position.

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The loss of corneal endothelial cells during phacoemulsification remains a serious concern. If the loss is severe enough, it can cause corneal decompensation. Endothelial cell damage can be influenced by several preoperative and intraoperative parameters. Preoperative parameters include older age,[1] small pupil diameter,[1] firmness of the nucleus,[1] and shorter axial length (AL).[1,2] Intraoperative parameters include the incision size and design,[3,4] phacoemulsification time,[1,2,5,6] phacoemulsification technique,[6,7] and type of ophthalmic viscosurgical device (OVD) used.[8] Several mechanisms have been proposed for endothelial cell damage during phacoemulsification; these include mechanical contact with nuclear fragments, irrigation flow, turbulence and movement of fluids, direct trauma caused by instruments or lens fragments, and formation of cavitation bubbles.[9,10] Because lowering ultrasound (US) delivery into the eye may reduce the risk for endothelial cell loss during phacoemulsification, power modulation systems were designed to provide effective lens removal at lower levels of phaco power and US energy.[11]

Keeping the US energy far from the endothelium can theoretically decrease the amount of damage to endothelial cells. Also, there is a theory that the directionality of the microcavitation bubbles produced during

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the backstroke of the phaco tip is coordinated with the needle's bevel angle[12]; therefore, with a 30-degree or 45-degree phaco tip in the bevel-up position, the direction of the microbubble propagation is against (perpendicular to) the corneal endothelial cells.[13] According to this theory, holding the phaco tip in the bevel-down position directs the US energy posteriorly, far from the endothelial cells.

This study evaluated the effect of the phaco-tip bevel position on endothelial cell density (ECD) during phacoemulsification. To our knowledge, it is the first study to consider this subject. The corneal endothelial cell count performed preoperatively and postoperatively can serve as a useful indicator to estimate the level of corneal endothelial cell damage during phacoemulsification; therefore, we used specular microscopy to determine the effect of the phaco-tip bevel position on these cells.

PATIENTS AND METHODS

This prospective randomized clinical trial comprised eyes with senile cataract that had phacoemulsification cataract surgery at Labbafinejad Medical Center between January 2010 and August 2010. The Medical Ethics Committee of the Ophthalmic Research Center, Shahid Beheshti Medical University, approved the study protocol. All patients provided written informed consent.

The inclusion criterion was moderate lens opacity. Nuclear hardness was evaluated clinically at the slitlamp according to the color of the nucleus based in the Lens Opacities Classification System III.[14] The exclusion criteria were a history of significant ocular trauma or intraocular surgery, corneal pathology, pseudoexfoliation syndrome, intraocular inflammation, a preoperative endothelial cell count less than 1800 cells/mm^2, a preoperative fully dilated pupil smaller than 6.0 mm, glaucoma, diabetes mellitus, surgical complications (anterior or posterior capsule tear), and postoperative inflammation.

In all cases, a complete preoperative ocular examination was performed including uncorrected distance visual acuity (UDVA), corrected distance visual acuity (CDVA), slitlamp evaluation, Goldmann applanation tonometry, posterior pole evaluation with a noncontact 90.0 diopter lens, and indirect ophthalmoscopy. The AL and anterior chamber depth (ACD) were measured by ultrasonic A-scan (US-800, Nidek International). The ECD, percentage of hexagonal cells, variation in endothelial cell size (coefficient of variation [CV]), and central corneal thickness (CCT) were measured using a noncontact specular microscope (EM-3000, Tomey) at the corneal center. Specular images of more than 60 cells were analyzed. Specular microscopy was performed preoperatively and 3 months postoperatively.

Surgical Technique

The same surgeon (A.F.) performed all operations using topical anesthesia of tetracaine 1.0% eyedrops. Two limbal stab incisions were made, after which the anterior chamber was filled with hydroxypropyl methylcellulose 2%. A capsulorhexis 5.0 to 5.5 mm in diameter was created with a bent-tip 27-gauge insulin needle. After a 2.8 mm temporal clear corneal incision was made, hydrodissection and hydrodelineation of the nucleus were performed.

Phacoemulsification of the nucleus was performed using the stop-and-chop technique with a 30-degree 20-gauge phaco needle. Patients were randomly divided into 2 groups. In 50% of eyes, the phaco tip was held in the bevel-down position (bevel-down group) and in the other 50% in the bevel-up position (bevel-up group) whenever the phaco tip was introduced into the anterior chamber. In both groups, the phaco probe was used to sculpt a central groove to nearly three quarters of the thickness of the nucleus. Then, the phaco probe and the second instrument were used to crack the posterior plate of the nucleus in half by moving the 2 instruments in opposite directions. The phaco tip was run through each heminucleus separately, breaking each into smaller fragments with a Nagahara chopper. The pieces were then emulsified.

In all cases, after the nucleus was completely emulsified, irrigation/aspiration of cortical material was performed with a Simcoe cannula. Next, a foldable hydrophobic acrylic intraocular lens (Acrysof SA60AT, Alcon Surgical) was implanted in the capsular bag using an injector system (Monarch II, cartridge C). Finally, the anterior chamber was irrigated, the OVD was removed, the wounds were secured by stromal hydration, and the eye was patched.

Phaco Machine Parameters

All operations were performed with a Sovereign phaco machine and WhiteStar technology (Advanced Medical Optics, Inc.). During the sculpting stage, vacuum was 50 mm Hg, the aspiration flow rate was 25 cc/min, and linear continuous mode of US with 60% power was used. During the chopping stage, the parameters were changed to a vacuum of 300 mm Hg (threshold 200 mm Hg) and an aspiration flow rate of 40 mm Hg and microburst US mode with power of 30% was used. The bottle heights were 75 cm and 100 cm above the patient's head during the sculpting stage and chopping stage, respectively. The parameters evaluated intraoperatively included phaco time (seconds), mean phaco power (%), and effective phaco time (EPT) (seconds). The EPT was the product of phaco time and phaco power (EPT = phaco power × phaco time).

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From the Ophthalmic Research Center and Department of Ophthalmology (Faramarzi, Javadi, Karimian, Jafarinasab, Baradaran-Rafii, Jafari), Labbafinejad Medical Center, Shahid Beheshti Medical University, and the Department of Epidemiology and Biostatics (Yaseri), School of Public Health, Tehran University of Medical Sciences, Tehran, Iran.

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Corresponding author: Amir Faramarzi, MD, Ophthalmic Research Center, Ophthalmology Department, Labbafinejad Medical Center, Pasdaran Avenue Boostan 9 Street, Tehran 1666694516, Iran. E-mail: amirfaramarzy@yahoo.com.

Postoperative Evaluation

All patients followed a regimen of topical chloramphenicol 4 times a day for 1 week and topical betamethasone 0.1% 6 times a day for the first week, after which it was gradually tapered. All patients were examined postoperatively at 1 and 7 days and 1 and 3 months. The last examination at 3 months included UDVA, CDVA, slitlamp biomicroscopy, Goldmann applanation tonometry, fundoscopy, and specular microscopy.

Statistical Analysis

The sample size was calculated with a significance level (α) of 0.05, power of 90%, standard deviation (SD) of change equal to 15%, and a clinically important difference of 10% of endothelial cell loss. The normality of data distribution was tested using the Kolmogorov-Smirnov test. Data were recorded as the mean ± SD, median (range), frequency, and percentage. To evaluate differences in demographic and clinical characteristics between groups, the chi-square test was used for categorical variables and *t* tests for continuous variables. Preoperative versus postoperative changes in endothelial cell variables within groups were analyzed using paired *t* tests. A *P* value less than 0.05 was considered statistically significant. Associations between endothelial cell loss and patients' variables were evaluated using Spearman correlation coefficients. Statistical analyses were performed using SPSS statistical software (version 17.0, SPSS, Inc.).

RESULTS

Sixty eyes of 60 patients (30 eyes in each group) were included in this study. Table 1 shows the baseline demographic and clinical data of the patients in each group. There were no statistically significant differences between the groups in age, sex, ACD, AL, and lens hardness. The mean EPT was 17.6 ± 7.3 seconds in the bevel-up group and 18.2 ± 14.2 seconds in the bevel-down group ($P=.8$). Also, there were no statistically significant between-group differences in preoperative CCT or endothelial cell characteristics, including ECD, percentage of hexagonality, and CV.

Table 2 shows the preoperative and postoperative endothelial cell parameters by group. Postoperatively, both groups had a significant decrease in endothelial cells. However, the mean percentage of endothelial cell loss was statistically significantly higher in the bevel-down group than in the bevel-up group. There was a statistically significant decrease in the percentage of hexagonal cells after surgery in the bevel-up group and the bevel-down group ($P=.002$ and $P=.016$, respectively). However, there was no significant change postoperatively in the CV or CCT in either group (Figure 1).

Table 3 shows the correlations between endothelial cell loss and the demographic or clinical characteristics of the patients. In both groups, there were no significant correlations between endothelial cell loss and age, ACD, or AL. Endothelial cell loss had a positive correlation with EPT in the bevel-down group ($r = 0.626$, $P<.001$) but not in the bevel-up group ($r = 0.049$, $P=.797$) (Figure 2). Also, multiple linear regression analysis showed that EPT was an independent predictor for endothelial cell loss in the bevel-down group ($P=.042$). There were no statistically significant differences in postoperative UDVA, CDVA, or intraocular pressure between the groups during the follow-up period. There were no cases of persistent corneal edema at the end of follow-up in either group.

Table 1. Preoperative and intraoperative patient parameters.

Parameter	Bevel		*P* Value
	Up (n = 30)	Down (n = 30)	
Mean Age ± SD	69.3 ± 7.9	68.1 ± 7.6	.566
Sex, n (%)			1.0
Male	19 (63.3)	19 (63.3)	
Female	11 (36.7)	11 (36.7)	
Eye, n (%)			.606
Right	16 (53.3)	14 (46.7)	
Left	14 (46.7)	16 (53.3)	
Mean AL (mm) ± SD	23.2 ± 0.7	22.9 ± 0.8	0.244
Mean ACD (mm) ± SD	3.0 ± 0.3	3.1 ± 0.4	0.277
Mean ECD (cells/mm^2) ± SD	2544 ± 299	2471 ± 284	0.336
Mean EPT (seconds) ± SD	17.6 ± 7.3	18.2 ± 14.2	0.838

ACD= anterior chamber depth; AL= axial length; ECD= endothelial cell density; EPT= effective phaco time

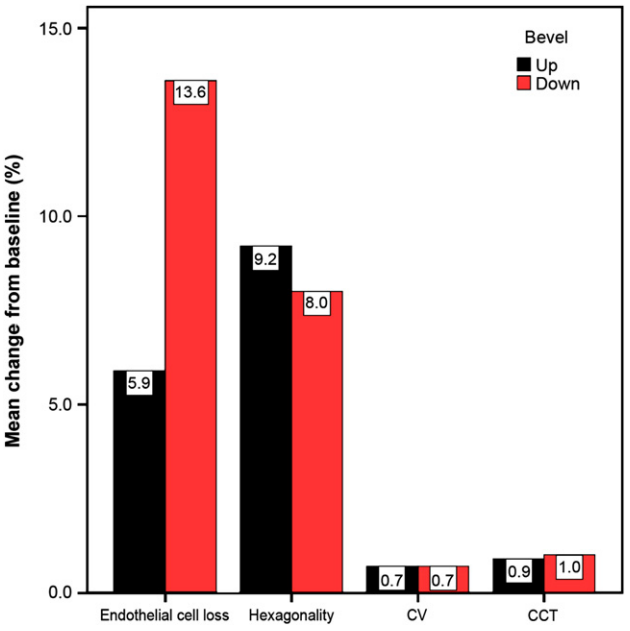

Figure 1. Mean postoperative changes of corneal endothelial cell parameters and CCT from baseline by group (CCT = central corneal thickness; CV= coefficient of variation).

Table 2. Preoperative and postoperative endothelial cell parameters by group.

Parameter	Bevel		Difference		
	Up	Down	Mean	95% CI	*P* Value*
ECD (cells/mm^2)					
Mean preop ± SD	2544 ± 299	2471 ± 284	73	−78, 224	.336
Mean postop ± SD	2388 ± 268	2139 ± 480	249	48, 450	.016
Mean change ± SD	156 ± 150	332 ± 363	−176	−351, −1	.017
Change %					
Mean ± SD	5.9 ± 5.8	13.6 ± 15.2	−7.7	−13.6, 1.75	.012
Median	6	11	—	—	—
Range	−4, 20	−13, 49	—	—	—
P value†	<.001	<.001	—	—	—
Hexagonal cells (%)					
Mean preop ± SD	51 ± 5.9	50.8 ± 5.5	0.2	−2.7, 3.1	.879
Mean postop ± SD	45.7 ± 4.2	46.2 ± 9.7	−0.5	−4.6, 3.4	.796
Mean change ± SD	5.3 ± 6.9	4.5 ± 10.8	0.8	−3.9, 5.5	.734
Change %					
Mean ± SD	9.2 ± 13.3	8 ± 21.9	1.2	−8.2, 10.6	.798
Median	8	3	—	—	—
Range	−15, 32	−31, 71	—	—	—
P value†	.002	.016	—	—	—

CI = confidence interval; ECD= endothelial cell density
*Based on *t* test
†Based on paired *t* test

DISCUSSION

In the present study, we compared the corneal endothelial cell damage created during phacoemulsification cataract surgery with 2 phaco-needle positions: bevel up and bevel down. To our knowledge, no published study has considered the consequences of phaco-needle bevel position on corneal endothelial cells during phacoemulsification. Various preoperative and intraoperative factors have been mentioned as causes of corneal endothelial cell damage during phacoemulsification; among them, longer phaco time is the most significant.[2] In our study, all known risk factors for endothelial cell damage during cataract surgery, including the patient's age, nuclear firmness, incision size and position, ACD, lens thickness, AL, phacoemulsification parameters and techniques, were the same; the only difference between the 2

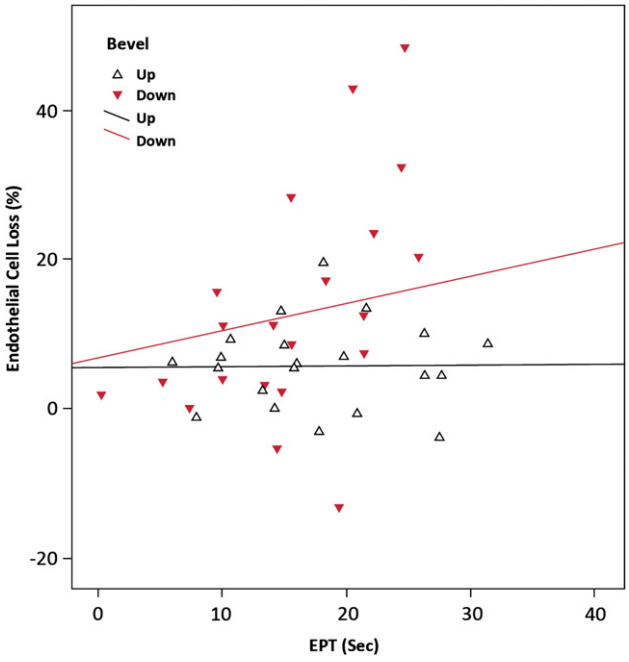

Figure 2. Correlations between endothelial cell loss and EPT by group (EPT = effective phaco time).

Table 3. Correlations between endothelial cell loss (%) and preoperative and intraoperative factors.

Parameter	Endothelial Cell Loss (%)			
	Bevel Up		Bevel Down	
	r Value*	*P* Value	*r* Value*	*P* Value
Age	−0.207	.272	0.338	.068
AL	−0.301	.106	−0.341	.065
ACD	−0.097	.610	0.074	.698
EPT	0.049	.797	0.626	<.001

ACD = anterior chamber depth; AL = axial length; EPT = effective phaco time
*Spearman correlation

groups was in the position of the phaco needle. We found that phacoemulsification with the phaco needle in the bevel-down position caused more endothelial cell loss than phacoemulsification with the phaco needle in the bevel-up position.

Several theories of the mechanism of US phacoemulsification cataract extraction have been proposed; these include direct action of the vibrating phaco needle against the cataractous lens, termed the jackhammer effect, and the indirect cavitational effects of microbubbles, which produce brief instances of heat and pressure.[15] Cavitation occurs most in close proximity to the tip of the phaco needle, and cavitation bubbles have been observed and recorded during the backstroke of the phaco tip only.[16] These bubbles are suspected of being an important factor in corneal endothelial cell damage during phacoemulsification.[10,17] When the phaco tip is in the bevel-up position, it seems as though the jackhammer effect is more efficient because the sharp point of the phaco tip strikes the lens tissue first; however, with the phaco tip in the bevel-down position, the sharp point of the phaco tip is active only when the phaco tip is completely engaged in the lens tissue.

If the phaco tip is introduced to the deeper part of the nucleus with the phaco tip in the bevel-down position, the surface of the nucleus and the bevel of the phaco tip are not parallel to each other and complete occlusion is impossible until deep penetration of the needle through the lens tissue occurs. Therefore, the surgeon must place the phaco tip closer to the surface of the lens for better occlusion during heminucleus chopping and emulsification of the particles. Thus, phacoemulsification occurs closer to endothelial cells and causes more damage to these cells. In phacoemulsification with the phaco needle in the bevel-up position, the phaco tip can be positioned deeply and parallel to the lens tissue, with stable occlusion far from the endothelial cells. The increase in temperature in the anterior chamber during phacoemulsification is a well-known and potentially relevant factor in corneal endothelial cell damage.[18] A single US pulse can increase the temperature by 0.8°C when close to the phaco tip.[19] In the bevel-up technique, the phaco tip, and therefore the source of heat, are farther from the endothelial cells than in the bevel-down technique, and this decreases the chance of endothelial cell damage.

Another explanation for our finding of greater endothelial cell loss during bevel-down phacoemulsification may be the limited surgeon experience with this unusual technique. However, the surgeon in our study had performed many phacoemulsification surgeries with the tip in the bevel-down position before the study and had sufficient experience with the technique. Also, the EPT was equal in the 2 groups; therefore, higher amounts of US energy were not used with the bevel-down technique. All other steps of the phacoemulsification surgery were the same in both groups, and there were no differences in surgical techniques and phaco parameters except the position of the phaco tip.

In our study, there was no correlation between postoperative endothelial cell loss, change in hexagonality, and CV of the endothelial cells with age, ACD, or AL in either group. However, in the bevel-down group, we found a positive correlation between endothelial cell loss and EPT. This correlation was not seen in the bevel-up group. This discrepancy may be due to the above-mentioned point that phacoemulsification occurs closer to the endothelial cells in the bevel-down technique; therefore, the endothelial cells are more vulnerable to the released US energy with this technique. In the bevel-up group, phacoemulsification of the nucleus occurred farther from the endothelial cells and damage to these cells was less dependent on the amount of consumed US energy. This result supports the belief that the most important factor in endothelial cell damage during phacoemulsification is the distance between the vibrating phaco tip and the endothelial cells.

In a study by Walkow et al.,[2] a risk factor for endothelial cell loss during phacoemulsification was a short AL. A possible explanation could be the greater mean distance between the phaco tip and the cornea in longer eyes. According to this study, an important risk factor for endothelial cell loss during phacoemulsification was the short distance between the phaco tip and the endothelial cells. This contrasts with a study by O'Brien et al.,[20] which did not find a correlation between AL and the rate of endothelial cell loss. The enhanced anterior chamber stability with the 2.75 mm incision and the associated reduced wound leakage may have protected the corneal endothelium. Also, neither of the 2 studies found a significant correlation between endothelial cell loss and ACD, which might have been expected. A possible explanation could be the deepening of the anterior chamber intraoperatively, especially with tighter wounds.

The mean percentages of endothelial cell loss in our study in the bevel-up and bevel-down groups 3 months after surgery were approximately 6% and 14%, respectively. A mean percentage of endothelial cell loss of 4.7% to 11.0% has been reported 3 months after phacoemulsification with the stop-and-chop technique.[5,6,9,12,13] Therefore, even with the bevel-down technique, our results are acceptable.

In a study by Alió et al.,[21] phacoemulsification in the anterior chamber was as safe as endocapsular phacoemulsification using the stop-and-chop technique.

However, the mean endothelial cell loss was about 11% in both groups, nearly the same as the endothelial cell loss in the bevel-down group in our study. The differences in mean US time and mean US power between groups were not statistically significant; however, the calculated EPT with the stop-and-chop technique was greater than when phacoemulsification was performed in the anterior chamber. Therefore, because phacoemulsification in the anterior chamber with less EPT caused damage to the endothelial cells similar to that of phacoemulsification in the bag with greater EPT, we believe that decreasing the distance between the phaco tip and the endothelial cells is an important factor in inducing endothelial cell damage.

In conclusion, our study found that the mean percentage of endothelial cell loss in phacoemulsification using the stop-and-chop technique with the phaco tip in the bevel-down position was nearly twice what it was when the phaco tip was in the bevel-up position. This result is probably due to the emulsification of the nucleus that takes place in the vicinity of the endothelial cells when the phaco tip is in the bevel-down position. Better occlusion of the phaco tip with superficial parts of the nucleus in the bevel-down position and fear of posterior capsule damage may force placement of the phaco tip nearer to the posterior surface of the cornea, leading to endothelial cell damage. Therefore, we do not recommend emulsifying a cataractous lens with the phaco tip in the bevel-down position.

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First author:
Amir Faramarzi, MD

Ophthalmic Research Center and Department of Ophthalmology, Labbafinejad Medical Center, Shahid Beheshti Medical University, Tehran, Iran