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Comparative Analysis of Pre- and Post-Operative Central Corneal Thickness and Corneal Endothelial Cell Density in Uneventful Phacoemulsification: A Cross-Sectional Study

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ABSTRACT

Background: Phacoemulsification is the gold standard surgical technique for cataract extraction. Despite technical refinements, the procedure is associated with measurable loss of corneal endothelial cells and transient increases in Central Corneal Thickness (CCT). Understanding the magnitude and predictors of these changes is essential for optimizing surgical outcomes.

Aim: To compare pre- and post-operative CCT and corneal Endothelial Cell Density (ECD) in patients undergoing uneventful phacoemulsification, and to correlate these parameters with phacoemulsification power and duration.

Methods: This comparative cross-sectional study enrolled 100 patients with senile nuclear sclerosis grade II–III cataract at a tertiary care centre in Indore, India (September 2022–March 2024). All patients underwent phacoemulsification with the divide-and-conquer technique and Posterior Chamber Intraocular Lens (PCIOL) implantation by a single surgeon. Preoperative and one-month postoperative assessments included ECD, Coefficient of Variation (CV), polymegathism, and CCT measured using non-contact specular microscopy (Tomey EM-4000) and ultrasound pachymetry (PACSCAN-300), respectively. Intraoperative phacoemulsification power and duration were recorded. Statistical analysis was performed using the paired t-test and Spearman's rank correlation (SPSS v22).

Results: The mean patient age was 61.93 ± 9.50 years (range: 42–82 years). Mean preoperative ECD was 2428.59 ± 337.39 cells/mm², which decreased significantly to 2174.99 ± 417.74 cells/mm² postoperatively (10.44% reduction; $p < 0.001$). Mean CCT increased significantly from 508.68 ± 34.82 µm to 525.21 ± 40.41 µm (3.24% increase; $p < 0.001$). CV increased from 39.15 ± 6.13% to 41.96 ± 8.51% ($p = 0.001$) and polymegathism from 43.80 ± 6.96% to 45.78 ± 6.30% ($p = 0.014$). A statistically significant positive correlation was found between phacoemulsification power and endothelial cell loss (rho = 0.267; $p = 0.007$). No significant correlations were identified between phacoemulsification duration and any corneal parameter ($p > 0.05$).

Conclusion: Uneventful phacoemulsification with standardized technique produces statistically significant but clinically modest changes in corneal endothelial parameters and CCT at one month. Higher phacoemulsification power correlates significantly with greater endothelial cell loss, underscoring the importance of energy-minimizing surgical strategies. Postoperative corneal changes appear transient, with expected recovery over subsequent months.

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Introduction

Cataract remains the leading cause of preventable blindness globally and surgical management is the only option [1]. Phacoemulsification is the gold standard for cataract surgery owing to its small self-sealing incision (2–3 mm), reduced surgically induced astigmatism, rapid visual rehabilitation, and superior clinical outcomes compared to Conventional Extracapsular Cataract Extraction (ECCE) and manual small-incision cataract surgery (MSICS) [2-5].

Despite its recognized safety profile, phacoemulsification is not entirely without risk to intraocular structures. Ultrasonic energy, irrigation-aspiration-induced fluid turbulence, mechanical trauma from lens fragments, and photothermal effects, all contribute to iatrogenic Endothelial Cell Loss (ECL) [6-8].

Surviving endothelial cells compensate through migration, enlargement, and morphological polymegathism adaptive changes that ultimately reduce the functional reserve of the endothelial pump [9]. Endothelial Cell Density (ECD) is clinically significant because progressive decline can precipitate corneal decompensation. When ECD falls below a critical threshold of 450–800 cells/mm², the pump-leak mechanism fails, resulting

in stromal oedema, bullous keratopathy, and irreversible loss of corneal transparency [10]. Published literature reports ECL of 5–20% in the first one to three months following uncomplicated phacoemulsification, a range influenced by nucleus hardness, phacoemulsification technique, cumulative dissipated energy, anterior chamber depth, and surgeon experience [11-13]. Central Corneal Thickness (CCT) measured by ultrasound pachymetry serves as an indirect indicator of endothelial functional integrity. Postoperative corneal oedema transiently increases CCT; its normalization over weeks reflects endothelial recovery. Specular microscopy additionally quantifies cellular morphology through the coefficient of variation (CV) of cell size and the proportion of hexagonal cells (polymegathism), offering insight into the degree of endothelial stress and healing [14].

While several studies have evaluated endothelial cell changes following phacoemulsification, comparative data from the Indian subcontinent—where nuclear sclerotic cataracts predominate and often present at a more advanced grade—remain limited. Furthermore, few studies have simultaneously correlated both phacoemulsification power and duration with multiple endothelial morphometric parameters under standardized single-surgeon, single-technique conditions, which minimizes confounding surgical variables.

The present study was designed to prospectively compare pre- and post-operative CCT and corneal ECD in patients undergoing uneventful phacoemulsification with Posterior Chamber Intraocular Lens (PCIOL) implantation, performed by a single surgeon using the divide-and-conquer nucleofractis technique, and to correlate these changes with intraoperatively recorded phacoemulsification power and duration.

Materials and Methods

Study Design and Setting

This was a comparative cross-sectional study conducted between September 2022 and March 2024 at the Department of Ophthalmology, Sri Aurobindo Medical College and PG Institute (SAMC & PGI), Indore, India—a tertiary care centre. Ethical clearance was obtained from the Institutional Ethics Committee, and written informed consent was secured from all participants prior to enrolment. The study adhered to the tenets of the Declaration of Helsinki.

Sample Size and Patient Selection

One hundred consecutive patients with senile immature cataract (nuclear sclerosis grade II–III by the Lens Opacities Classification System III) who were scheduled for phacoemulsification with PCIOL implantation were enrolled over the 18-month study period.

- **Inclusion Criteria:** (1) senile immature cataract with nuclear sclerosis grade II or III; (2) normal intraocular pressure (IOP); (3) adequate pupil dilatation (8–9 mm); (4) willingness to undergo phacoemulsification with PCIOL by the same surgeon using the same technique; (5) either sex.
- **Exclusion Criteria:** (1) non-consenting patients; (2) coexisting ocular morbidities other than cataract (e.g., glaucoma, corneal disease, uveitis); (3) intraoperative complications; (4) history of ocular trauma; (5) prior ocular surgery.

Preoperative Assessment

All patients underwent a comprehensive preoperative evaluation including uncorrected and best-corrected visual acuity (UCVA/BCVA), auto-refractometry, subjective refraction, non-contact tonometry, slit-lamp biomicroscopy, dilated fundus examination, biometry, and syringing. Cataract grading was performed using the LOCS III system. Systemic workup included complete blood count, erythrocyte sedimentation rate, serum urea and creatinine, random blood sugar, HIV, HBsAg, and electrocardiogram.

Corneal endothelial parameters ECD (cells/mm²), CV (%), and polymegathism (6A, %) were measured using a non-contact specular microscope (Tomey EM-4000, SN 217409). CCT was measured by ultrasound pachymetry (PACSCAN-300; Sonomed). All measurements were obtained within one week prior to surgery.

Surgical Technique

All surgeries were performed under topical anaesthesia by a single experienced surgeon using a standardized phacoemulsification technique: temporal clear corneal incision (2.8 mm), continuous curvilinear capsulorhexis (5–5.5 mm), hydrodissection, phacoemulsification by the divide-and-conquer nucleofractis method, irrigation-aspiration of cortical remnants, and implantation of a foldable PCIOL in the bag. Dispersive viscoelastic was used for endothelial protection. Phacoemulsification power (energy, Pe) and duration (total ultrasound time, Pt) were recorded intraoperatively for each case.

Postoperative Assessment

Patients were reviewed at one month postoperatively. At this visit, ECD, CV, and polymegathism were reassessed using specular microscopy, and CCT was remeasured by pachymetry under identical conditions.

Statistical Analysis

Data were entered into Microsoft Excel and analysed using SPSS version 22. Normality was assessed with the one-sample Kolmogorov–Smirnov test. Descriptive statistics (mean ± standard deviation) were computed for all continuous variables. The paired t-test was used to compare pre- and post-operative values. Spearman's rank correlation (rho) was applied to assess associations between phacoemulsification parameters and corneal outcomes. A p-value < 0.05 was considered statistically significant.

Results

Demographic Profile

The study enrolled 100 patients (53 females, 47 males) with a mean age of 61.93 ± 9.50 years (range: 42–82 years). The majority of patients (69%) belonged to the 51–70-year age group. The mean age did not differ significantly between females (61.92 ± 10.40 years) and males (61.94 ± 8.48 years; $p = 0.995$). Cataract distribution: NS2 (54%), NS3 (20%), NS1–2 (13%), NS2–3 (11%), and NS3–4 (2%). Demographic data are summarised in Table 1.

Table 1: Demographic and Clinical Profile of Study Participants (N = 100)

Parameter	Category / Value	n (%) or Mean ± SD
Age group	40–50 years	13 (13.0%)
	51–60 years	33 (33.0%)
	61–70 years	36 (36.0%)
	71–80 years	16 (16.0%)
	>80 years	2 (2.0%)
Mean age (years)	Overall	61.93 ± 9.50
Sex	Female	53 (53.0%)
	Male	47 (47.0%)
Cataract grade (NS)	NS1–2	13 (13.0%)
	NS2	54 (54.0%)
	NS2–3	11 (11.0%)
	NS3	20 (20.0%)
	NS3–4	2 (2.0%)

NS = Nuclear Sclerosis Grade (Lens Opacities Classification System III).

Endothelial Cell Density

Mean preoperative ECD was 2428.59 ± 337.39 cells/mm², which decreased significantly to 2174.99 ± 417.74 cells/mm² at one month postoperatively, representing a mean reduction of 10.44% ($p < 0.001$). All changes are summarised in Table 2.

Coefficient of Variation

Mean preoperative CV was 39.15 ± 6.13%, which increased significantly to 41.96 ± 8.51% postoperatively (increase of 6.57%; $p = 0.001$), indicating greater heterogeneity in endothelial cell size following surgical stress.

Polymegathism

Mean preoperative polymegathism (6A) was 43.80 ± 6.96%, increasing significantly to 45.78 ± 6.30% at one month (increase of 4.34%; $p = 0.014$), reflecting increased variability in cell surface area.

Central Corneal Thickness

Mean preoperative CCT was 508.68 ± 34.82 µm, which increased significantly to 525.21 ± 40.41 µm postoperatively (increase of 3.24%; $p < 0.001$), consistent with transient postoperative corneal oedema.

Table 2: Comparison of Pre- and Post-Operative Corneal Parameters (N = 100)

Parameter	Pre-op (Mean ± SD)	Post-op (Mean ± SD)	Change (%)	p-value
ECD (cells/mm²)	2428.59 ± 337.39	2174.99 ± 417.74	−10.44%	< 0.001*
CV (%)	39.15 ± 6.13	41.96 ± 8.51	+6.57%	0.001*
Polymegathism (%)	43.80 ± 6.96	45.78 ± 6.30	+4.34%	0.014*
CCT (µm)	508.68 ± 34.82	525.21 ± 40.41	+3.24%	< 0.001*

ECD = Endothelial Cell Density; CV = Coefficient of Variation; CCT = Central Corneal Thickness. * statistically significant (paired t-test, $p < 0.05$).

Phacoemulsification Parameters

The mean phacoemulsification power (energy, Pe) was 19.65 ± 5.75%, and mean ultrasound duration was 1.54 ± 0.87 minutes (Table 3).

Table 3: Mean Intraoperative Phacoemulsification Parameters (N = 100)

Parameter	Mean ± SD
Phacoemulsification power (Pe, %)	19.65 ± 5.75
Ultrasound duration (Pt, minutes)	1.54 ± 0.87

Correlations with Phacoemulsification Power

A statistically significant positive correlation was observed between phacoemulsification power and ECL (rho = 0.267; $p = 0.007$), indicating that higher energy use was associated with greater endothelial cell loss. Correlations between phaco power and changes in CV (rho = −0.097; $p = 0.336$), polymegathism (rho = 0.087; $p = 0.392$), and CCT (rho = −0.099; $p = 0.326$) were not statistically significant (Table 4).

Correlations with Phacoemulsification Duration

No statistically significant correlations were identified between phacoemulsification duration and ECL (rho = −0.020; p = 0.841), change in CV (rho = 0.058; p = 0.564), polymegathism (rho = 0.180; p = 0.073), or CCT (rho = −0.159; p = 0.115) (Table 4).

Correlations between Endothelial Parameters and CCT Change

No significant correlations were found between ECL and change in CCT (rho = −0.141; p = 0.163), change in CV and CCT (rho = 0.153; p = 0.127), or change in polymegathism and CCT (rho = 0.110; p = 0.277) (Table 4).

Table 4: Spearman's Rank Correlations between Intraoperative Parameters, Endothelial Changes, and CCT (N = 100)

Correlation Pair	Spearman's rho	p-value	Significance
ECL vs. Phaco power	0.267	0.007	Significant*
ΔCV vs. Phaco power	−0.097	0.336	NS
ΔPolymegathism vs. Phaco power	0.087	0.392	NS
ΔCCT vs. Phaco power	−0.099	0.326	NS
ECL vs. Phaco duration	−0.020	0.841	NS
ΔCV vs. Phaco duration	0.058	0.564	NS
ΔPolymegathism vs. Phaco duration	0.180	0.073	NS
ΔCCT vs. Phaco duration	−0.159	0.115	NS
ECL vs. ΔCCT	−0.141	0.163	NS
ΔCV vs. ΔCCT	0.153	0.127	NS
ΔPolymegathism vs. ΔCCT	0.110	0.277	NS

ECL = Endothelial Cell Loss (Preoperative Minus Postoperative ECD); ΔCV = Change in Coefficient of Variation; ΔCCT = Change in Central Corneal Thickness; NS = Not Significant. * $p < 0.05$.

Discussion

This study prospectively evaluated corneal endothelial parameters and CCT before and one month after uneventful phacoemulsification in 100 patients with nuclear sclerosis grade II–III cataract. The consistent single-surgeon, single-technique design minimised confounding surgical variables, affording a reliable assessment of phacoemulsification-induced corneal changes.

Demographic Characteristics

The mean patient age of 61.93 ± 9.50 years and a slight female predominance (53%) observed in the present study are consistent with reported epidemiological patterns of age-related cataract in India [15]. Deshpande et al. reported a mean age of 62.18 years in a comparable cohort, while Ianchulev et al. and Lee et al. found slightly higher mean ages of 70.2 ± 8.2 and 67.96 ± 7.17 years, respectively, in Western populations [16,17]. similarly reported female preponderance in their series [18,19].

Endothelial Cell Density

The 10.44% reduction in ECD observed at one month aligns closely with the range of 5–20% reported in the literature [20]. Ianchulev et al. demonstrated a 10% ECL at three months in a multicentre randomised trial, which stabilised thereafter, suggesting that the maximum cell loss occurs in the early postoperative period [16]. Reported 11.4% ECL in a double-blind randomised trial, documented a significant decline from 2376.6 ± 104.6 to 2173.5 ± 110.35 cells/mm² at 14 weeks [21,22]. In contrast, found a non-significant reduction in ECD at six months following iris-fixated lens implantation and demonstrated insignificant ECD changes with a longer follow-up in post-keratoplasty eyes [23]. The relatively conservative ECL in the present series likely reflects the graded nuclear sclerosis (predominantly NS2) and the standardised surgical approach with judicious use of dispersive viscoelastic, consistent with the endothelial protection principles of minimising ultrasound proximity to the endothelium, maintaining stable fluidics, and preserving normal IOP [24].

Coefficient of Variation and Polymegathism

The significant postoperative increases in CV (6.57%) and polymegathism (4.34%) indicate that surgical stress induced cellular enlargement and shape variation among surviving endothelial cells—morphological hallmarks of compensatory healing [9]. These findings accord with the observation that ECL triggers migration and pleomorphism of adjacent cells to maintain a continuous endothelial sheet [23-25]. In contrast, reported non-significant changes in CV at six months, a discrepancy likely attributable to differences in follow-up duration, since cellular morphology may stabilise as regenerative compensation progresses. Ataş et al. corroborated a significant increase in polymegathism correlating with ECL and phaco power [26]. to our knowledge, the direct correlation between CV and CCT change, and between polymegathism and CCT change, has not been previously reported; neither correlation was significant in the present study, suggesting that morphological cellular stress does not independently drive stromal oedema.

Central Corneal Thickness

The 3.24% increase in CCT at one month postoperatively reflects transient corneal oedema secondary to endothelial pump compromise and the inflammatory milieu of the early postoperative period. Published series confirm that CCT increases markedly on postoperative day one and returns progressively to preoperative baseline by four to eight weeks. Kumar et al. reported a CCT rise from 530.29 ± 11.34 µm preoperatively to 596.03 ± 16.64 µm on day one, normalising by six weeks [27]. documented a peak CCT of 626.39 µm on postoperative day one, returning to 553.80 µm by one week [28]. Similarly observed that CCT of 606.04 ± 6 µm on day one returned to the preoperative value of 550.3 ± 4 µm by postoperative day 30 [29]. the comparatively modest CCT elevation in the present study at one month suggests that most of the early oedematous change had already undergone partial resolution at the time of assessment, and complete normalisation would be expected with continued follow-up.

Phacoemulsification Power and Duration

A statistically significant, albeit weak, positive correlation was found between phacoemulsification power and ECL (rho = 0.267; p = 0.007). This supports the established principle that ultrasound energy delivered in proximity to the corneal endothelium generates heat, cavitation, and hydroxyl free radicals that directly damage endothelial cells [6]. Ataş et al. reported a significant positive correlation between ECL and mean phacoemulsification power (p = 0.007 corroborated this in their double-blind trial [21-26]. No significant correlations were observed between phaco power and changes in CV, polymegathism, or CCT, indicating that energy-mediated cell loss does not independently translate to detectable morphological or thickness changes at the group level within the observed range of powers.

Phacoemulsification duration (mean 1.54 ± 0.87 minutes) showed no significant correlation with any corneal parameter in the

present study. This contrasts with findings by Mahdy et al., who identified a significant positive correlation between ECL and phacoemulsification duration in a series with a notably longer mean operative time of 11.76 minutes, and by Walkow et al., who reported phacoemulsification time as the most significant determinant of ECL [30,31]. The shorter operative duration in the present cohort, reflecting predominantly soft-to-moderate nuclear grades, likely explains the absence of a duration-ECL correlation. Cumulative Ultrasound Time (CUT) may supersede power alone as a predictor of ECL when operative times are prolonged.

Correlation between ECL and CCT

No significant correlation was demonstrated between the degree of ECL and the change in CCT (rho = −0.141; p = 0.163) [32]. This is consistent with the findings of who reported that CCT normalises by 3–12 months regardless of the degree of ECL, provided that residual ECD exceeds a physiological compensatory threshold. Kohlhaas et al. similarly found no significant ECL–CCT correlation despite documenting 18–27% ECL and 9–12% corneal thickening at 12 months [10]. These observations suggest that within the range of moderate ECL encountered in routine phacoemulsification, the residual endothelial reserve is sufficient to restore normal corneal hydration without clinically significant long-term CCT elevation.

Clinical Implications

The present study reinforces the concept that phacoemulsification power—rather than duration alone—is a primary modifiable determinant of endothelial cell loss in patients with moderate nuclear sclerosis undergoing short-duration procedures. Surgical strategies that minimise ultrasound energy, such as pre-chop techniques, torsional phacoemulsification, burst and pulse modes, and generous use of dispersive viscoelastic, are therefore clinically important in preserving the corneal endothelium, particularly in patients with pre-existing reduced ECD, corneal dystrophies, or other risk factors for endothelial decompensation. Specular microscopy and ultrasound pachymetry are valuable complementary tools for preoperative risk stratification and postoperative monitoring [33-35].

Conclusion

Uneventful phacoemulsification with standardised divide-and-conquer nucleofractis and PCIOL implantation, performed by a single surgeon, produces statistically significant but clinically modest and largely transient changes in corneal endothelial parameters and CCT at one month postoperatively. Mean endothelial cell density declined by 10.44%, with corresponding increases in CV (6.57%) and polymegathism (4.34%), while CCT increased by 3.24%. Higher phacoemulsification power was significantly correlated with greater endothelial cell loss, whereas phacoemulsification duration did not emerge as a significant predictor within the range observed. No significant relationship was identified between ECL and CCT change, suggesting that residual endothelial reserve is sufficient for corneal hydration homeostasis in uncomplicated cases. These findings highlight the importance of energy-minimising surgical techniques and careful patient selection in preserving the corneal endothelium and optimising long-term visual outcomes following cataract surgery.

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