Section: Ophthalmology

Original Research Article

COMPARISON OF EFFECTIVE PHACOEMULSIFICATION TIME AND CORNEAL ENDOTHELIAL CELL LOSS FOLLOWING PHACOEMULSIFICATION USING THREE DIFFERENT ULTRASOUND FREQUENCIES

Nisha Bharti[1], Esha[2], Shipra Sharda[3], PK Malik[4]

[1]Assistant Professor, Department of Ophthalmology, Kalyan Singh Government Medical College Bulandshahr Uttar Pradesh, India.
[2]Assistant Professor, Department of Ophthalmology, NCR Medical College, Meerut, India.
[3]Assistant Professor, Department of Ophthalmology, Chacha Nehru Bal Chikitsalaya, New Delhi, India.
[4]Professor, Dr Ram Manohar Lohia Hospital, New Delhi

Received : 12/05/2026
Received in revised form : 03/07/2026
Accepted : 18/07/2026

Keywords:
Cataract, Phacoemulsification, Ultrasound frequency, Corneal endothelium, Endothelial cell density, Effective phacoemulsification time.

Corresponding Author:
Dr. Nisha Bharti,
Email: drnisha008@gmail.com

DOI: 10.47009/jamp.2026.8.4.232

Source of Support: Nil,
Conflict of Interest: None declared

Int J Acad Med Pharm
2026; 8 (4); 1383-1388

ABSTRACT

Background: To compare the effective Phacoemulsification time and endothelial cell Loss using three different ultrasound frequencies of the same machine for phacoemulsification of senile cataract LOCS III grade 4.0 to 6.9. **Materials and Methods:** A prospective comparative study was conducted on 165 eyes of 165 patients with age-related cataract undergoing uncomplicated phacoemulsification. Patients were equally allocated into three groups (55 eyes each) according to the ultrasound frequency used during surgery (53 kHz, 42 kHz, and 28 kHz). Baseline demographic characteristics, cataract grade (LOCS III), preoperative best-corrected visual acuity (BCVA), and endothelial cell density (ECD) were recorded. Effective phacoemulsification time (EPT) was documented intraoperatively. Postoperative BCVA and ECD were evaluated at 1 week, 1 month, 3 months, 6 months, 9 months, and 12 months. Percentage endothelial cell loss was also compared among the three groups. **Results:** A total of 165 eyes were included in the study, with 91 (55.2%) males and 74 (44.8%) females. Gender distribution was comparable among the three groups. The mean cataract grade (LOCS III) was 5.80 ± 0.78, 5.47 ± 0.80, and 5.45 ± 0.99 in the 53 kHz, 42 kHz, and 28 kHz groups, respectively, with no significant overall difference ($p = 0.073$), although cataracts were significantly denser in the 53 kHz group than the 42 kHz group ($p = 0.033$). Preoperative BCVA (LogMAR) was comparable among the groups (0.71 ± 0.20, 0.72 ± 0.20, and 0.74 ± 0.20, respectively; $p = 0.593$). Mean preoperative endothelial cell density was 2364.95 ± 389.16, 2355.20 ± 347.21, and 2261.67 ± 324.14 cells/mm² in the three groups, respectively ($p = 0.244$). Mean EPT followed the order 28 kHz > 53 kHz > 42 kHz. In the subgroup with LOCS III grade >5.5, mean EPT was 4.71 ± 2.25 s, 3.76 ± 1.34 s, and 7.04 ± 2.40 s in the 53 kHz, 42 kHz, and 28 kHz groups, respectively ($p = 0.0003$). Endothelial cell density decreased significantly from baseline in all groups throughout follow-up; however, no statistically significant intergroup difference was observed at any postoperative visit. At 12 months, mean ECD was 2142.00 ± 243.69, 2114.74 ± 235.82, and 2147.26 ± 195.22 cells/mm², respectively ($p = 0.721$). Percentage endothelial cell loss was comparable at 1 week and 1 month but differed significantly during later follow-up, with the 42 kHz group demonstrating the greatest endothelial cell loss and the 28 kHz group the least. **Conclusion:** Phacoemulsification using higher ultrasound frequencies (42 kHz and 53 kHz) resulted in significantly shorter effective phacoemulsification time compared with 28 kHz, particularly in harder cataracts. Although postoperative endothelial cell density was comparable among the three groups throughout the 12-month follow-up, the 28 kHz group demonstrated the lowest percentage endothelial cell loss during long-term follow-up. These findings indicate that higher ultrasound frequencies enhance surgical efficiency by reducing effective phacoemulsification time without compromising corneal endothelial cell preservation, supporting their safe and effective use in the management of hard senile cataracts.

INTRODUCTION

Cataract is the leading cause of reversible blindness worldwide and remains a major public health challenge, particularly in developing countries. With increasing life expectancy, the burden of age-related cataract continues to rise, making cataract surgery one of the most commonly performed ophthalmic procedures. Phacoemulsification with foldable intraocular lens implantation has become the gold standard for cataract extraction because of its smaller incision size, rapid visual rehabilitation, reduced surgically induced astigmatism, and excellent postoperative outcomes.[1]

Despite continuous advances in phacoemulsification technology, preservation of the corneal endothelium remains an important concern. The corneal endothelium is a single layer of hexagonal cells responsible for maintaining corneal deturgescence and transparency. Since these cells possess minimal regenerative capacity, excessive intraoperative endothelial cell loss may result in persistent corneal edema and, in severe cases, irreversible corneal decompensation.[2]

Endothelial damage during phacoemulsification is multifactorial and depends on cataract density, cumulative ultrasound energy, effective phacoemulsification time (EPT), irrigation fluid turbulence, anterior chamber stability, surgical technique, and the distance between the phaco tip and corneal endothelium. Among these factors, ultrasound energy delivery plays a major role in determining endothelial safety.[3]

Modern phacoemulsification systems operate at different ultrasound frequencies to optimize nuclear emulsification while minimizing thermal and mechanical injury to the corneal endothelium. Lower ultrasound frequencies may improve cutting efficiency and reduce ultrasound energy delivered to the anterior chamber, thereby potentially decreasing endothelial cell loss. However, evidence comparing endothelial outcomes among different ultrasound frequencies remains limited.

The present prospective comparative study was therefore undertaken to evaluate postoperative corneal endothelial cell density following phacoemulsification performed using three different ultrasound frequencies (53 kHz, 42 kHz, and 28 kHz). In addition, the study assessed the influence of effective phacoemulsification time on endothelial cell loss and postoperative visual outcomes over a one-year follow-up period.

MATERIALS AND METHODS

Study Design: This prospective randomized control trial study was conducted in the Department of Ophthalmology, PGIMER and Dr. Ram Manohar Lohia Hospital, New Delhi, after obtaining approval from the Institutional Ethics Committee. The study adhered to the tenets of the Declaration of Helsinki, and written informed consent was obtained from all participants before enrolment.

Study Population

A total of 165 eyes of 165 patients with age-related senile cataract were enrolled between (study period). Patients were randomized into three equal groups (55 eyes each) according to the ultrasound frequency used during phacoemulsification:

Group A: 53 kHz

Group B: 42 kHz

Group C: 28 kHz

Patients were randomly distributed by an independent observer using envelope technique into three groups. Only one eye per patient was included in the study.

Inclusion Criteria

Patients aged ≥40 years with age-related senile cataract having LOCS III nuclear opalescence grades 4.0–6.9, scheduled for phacoemulsification with posterior chamber intraocular lens implantation, and willing to participate in the study were included.

Exclusion Criteria

Patients with previous intraocular surgery, corneal pathology affecting endothelial cell count, glaucoma, pseudoexfoliation syndrome, uveitis, traumatic or complicated cataract, mature or hypermature cataract, retinal pathology affecting visual prognosis, poorly dilating pupils (<6 mm), or intraoperative complications such as posterior capsular rupture, zonular dialysis, dropped nucleus, or conversion to extracapsular cataract extraction were excluded.

Preoperative Evaluation

All patients underwent a comprehensive ophthalmic examination that included:

Best-corrected visual acuity (BCVA) using Snellen's chart and converted to LogMAR for statistical analysis.

Slit-lamp biomicroscopy.

Cataract grading using the Lens Opacities Classification System III (LOCS III).

Dilated fundus examination whenever media clarity permitted.

Keratometry and axial length measurement for intraocular lens power calculation.

Non-contact specular microscopy for measurement of preoperative corneal endothelial cell density (ECD).

Surgical Technique

All surgeries were performed by a single experienced cataract surgeon using the same phacoemulsification platform; Megatron S4 (Geuder, Heidelberg, Germany). The operating surgeon was blinded about the frequency of handpiece used in each case. Ultrasound power was preset to 40% in all cases and vacuum 400mm Hg on cool flash mode. A standardized surgical technique was followed in all patients. Following a 2.8-mm clear corneal incision and continuous curvilinear capsulorhexis, hydrodissection and hydrodelineation were performed. Nuclear emulsification was carried out using the assigned ultrasound frequency (53 kHz, 42 kHz, or 28 kHz), while all other machine settings remained unchanged. Cortical aspiration was followed by implantation of a foldable posterior chamber intraocular lens within the capsular bag.

The effective phacoemulsification time (EPT) was recorded automatically by the phacoemulsification system for each surgery.

Postoperative Evaluation

Patients were examined at 1 week, 1 month, 3 months, 6 months, 9 months, and 12 months after surgery.

At each follow-up visit, the following parameters were evaluated:

Best-corrected visual acuity (BCVA)

Slit-lamp examination

Corneal endothelial cell density (ECD) using non-contact specular microscopy

Statistical Analysis

Categorical variables were presented in number and percentage (%) and continuous variables were presented as mean ± SD and median. Normality of data was tested by Kolmogorov-Smirnov test. If the normality was rejected then non parametric test was used.

Statistical tests were applied as follows-

1. Quantitative variables were compared using Independent T test/Mann-Whitney Test (as the data sets were not normally distributed) between the two groups and ANOVA/Kruskal Wallis test between three groups.

2. Qualitative variables were correlated using Chi-Square test.

A p value of <0.05 was considered statistically significant.

The data was entered in MS EXCEL spreadsheet and analysis was done using Statistical Package for Social Sciences (SPSS) version 21.0.

RESULTS

A total of 165 eyes of 165 patients were included in the study, with 55 eyes in each group.

Baseline Characteristics

The study included 91 (55.2%) males and 74 (44.8%) females. There was no significant difference in gender distribution among the three ultrasound frequency groups (p = 0.845). All three groups were comparable in terms of age. [Figure 1a and 1b].

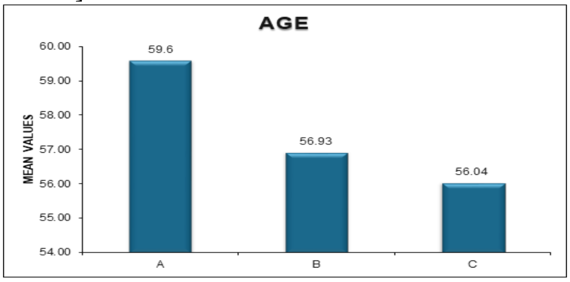

Figure 1a: Age distribution among three groups

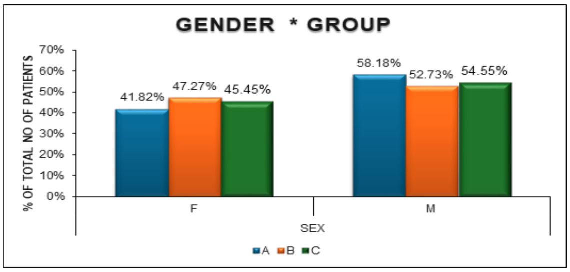

Figure 1b: Baseline demographic characteristics.

The mean cataract grade (LOCS III) was 5.80 ± 0.78 in the 53 kHz group, 5.47 ± 0.80 in the 42 kHz group, and 5.45 ± 0.99 in the 28 kHz group. Although the overall difference was not statistically significant (p = 0.073), post hoc analysis demonstrated significantly denser cataracts in the 53 kHz group compared with the 42 kHz group (p = 0.033). No significant differences were observed between the remaining pairwise comparisons. [Figure 2]

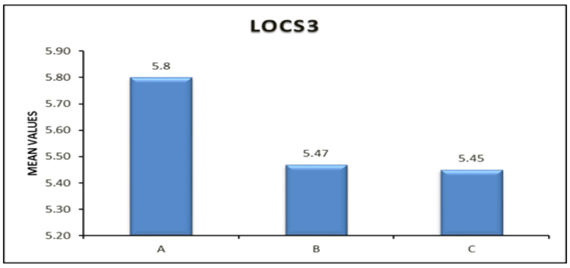

Figure 2: LOCS III grading between groups A, B and C

Preoperative BCVA (LogMAR) was comparable among the three groups (0.71 ± 0.20, 0.72 ± 0.20, and 0.74 ± 0.20 for the 53 kHz, 42 kHz, and 28 kHz groups, respectively; p = 0.593). [Figure 3]

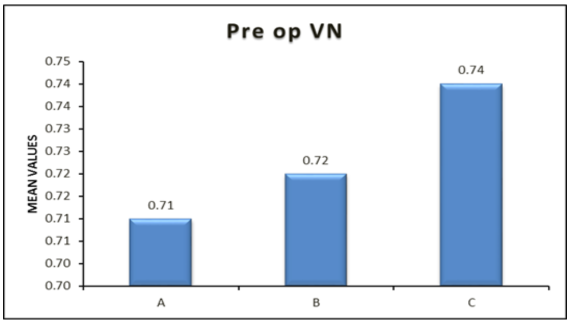

Figure 3: Pre-op comparison of visual acuity parameter between the three groups.

Similarly, mean preoperative endothelial cell density (ECD) did not differ significantly among the groups, measuring 2364.95 ± 389.16 cells/mm², 2355.20 ± 347.21 cells/mm², and 2261.67 ± 324.14 cells/mm² in the 53 kHz, 42 kHz, and 28 kHz groups, respectively (p =0.244).

Effective Phacoemulsification Time

Mean± SD of Effective Phaco Time was 3.48 ± 2.34 in group A, 2.92 ± 1.25 in group B and 4.26 ± 2.81

in group C. Group C had highest EPT among the three groups. However p value =0.128 showed that difference in EPT was not significant between all three groups. But on intergroup analysis difference in EPT was found to be statistically significant between group B and C (p=0.044) implying that EPT was lesser in group B with 42 KHz frequency than group C with 28 KHz frequency. Group A and B had comparable EPT (p=0.548).

Table 1

EPT(seconds)	A	B	C	P VALUE	A VS B	A VS C	B VS C
Mean ± SD	3.48 ± 2.34	2.92 ± 1.25	4.26 ± 2.81	0.128	0.548	0.188	0.044

The mean effective phacoemulsification time (EPT) differed among the three ultrasound frequency groups, with the 42 kHz group demonstrating the shortest EPT, followed by the 53 kHz group, whereas the 28 kHz group required the longest EPT. [Figure 4]

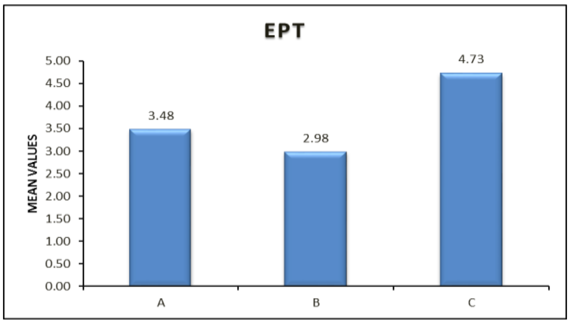

Figure 4: Effective phacoemulsification time according to ultrasound frequency groups A, B and C.

Subgroup analysis in eyes with LOCS III grade >5.5 included 28, 20, 19 patients in group A, B and C respectively. The mean EPT was 4.71 ± 2.25 seconds in the 53 kHz group, 3.76 ± 1.34 seconds in the 42 kHz group, and 7.04 ± 2.40 seconds in the 28 kHz group, demonstrating a statistically significant difference among the groups (p = 0.0003). Pairwise comparison showed significantly lower EPT in the 42 kHz group compared with the 28 kHz group. [Figure 5]

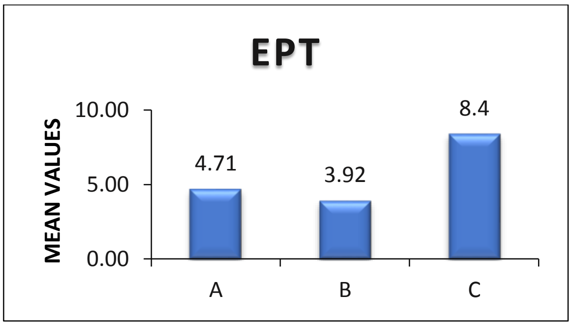

Figure 5: Subgroup analysis of effective phacoemulsification time in eyes with LOCS III grade >5.5.

Table 2

EPT				0.0003	0.180	0.010	<.0001
Sample size	28	20	19				
Mean ± Stdev	4.71 ± 2.25	3.76 ± 1.34	7.04 ± 2.4				

Table 3

BCVA	A	B	C	P value	A vs. B	A vs. C	B vs. C
Sample size	55	55	55				
PRE OP	0.71 ± 0.2	0.72 ± 0.2	0.74 ± 0.2	0.593	0.720	0.321	0.503
1 WEEK	0.4 ± 0.42	0.34 ± 0.21	0.39 ± 0.22	0.468	0.634	0.488	0.211
1 MONTH	0.28 ± 0.21	0.28 ± 0.2	0.34 ± 0.22	0.252	0.780	0.202	0.121

Subgroup analysis of LOCS III >5.5 shows that group A had lesser EPT in comparison to C and group B had lesser EPT than group C.

Postoperative Best-corrected Visual Acuity

Best-corrected visual acuity improved significantly following phacoemulsification in all three groups. However, postoperative BCVA was comparable between the groups at all follow-up visits, with no statistically significant intergroup differences. [Figure 6]

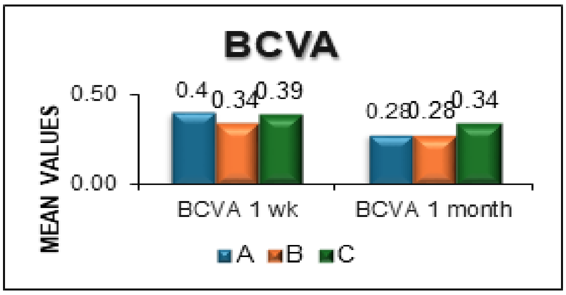

Figure 6: Post -op visual acuity comparison between the three groups.

The table shows post -op vision was comparable between the three groups

ISSN (O): 2687-5365; ISSN (P): 2753-6556

Endothelial Cell Density

Postoperative endothelial cell density decreased significantly from baseline in all three groups following phacoemulsification. However, comparison of absolute postoperative ECD between the three ultrasound frequency groups showed no statistically significant differences at any follow-up visit.

At 1 week, mean ECD was 2101.13 ± 413.14 cells/mm², 2212.91 ± 292.18 cells/mm², and 2131.96 ± 217.80 cells/mm² in the 53 kHz, 42 kHz, and 28 kHz groups, respectively ($p = 0.167$).

At 1 month, mean ECD measured 2119.42 ± 273.94 cells/mm², 2143.05 ± 232.82 cells/mm², and 2111.33 ± 212.08 cells/mm², respectively ($p = 0.733$).

At 3 months, mean ECD was 2122.46 ± 244.53 cells/mm², 2077.67 ± 194.78 cells/mm², and 2098.44 ± 183.54 cells/mm², respectively ($p = 0.534$).

At 6 months, corresponding values were 2116.78 ± 260.54 cells/mm², 2096.93 ± 203.51 cells/mm², and 2110.58 ± 187.10 cells/mm², respectively ($p = 0.889$).

At 9 months, mean ECD was 2133.18 ± 248.18 cells/mm², 2095.09 ± 210.93 cells/mm², and 2130.44 ± 189.34 cells/mm², respectively ($p = 0.593$).

At the final 12-month follow-up, mean ECD was 2142.00 ± 243.69 cells/mm² in the 53 kHz group, 2114.74 ± 235.82 cells/mm² in the 42 kHz group, and 2147.26 ± 195.22 cells/mm² in the 28 kHz group, with no statistically significant intergroup difference ($p = 0.721$). [Figure 7]

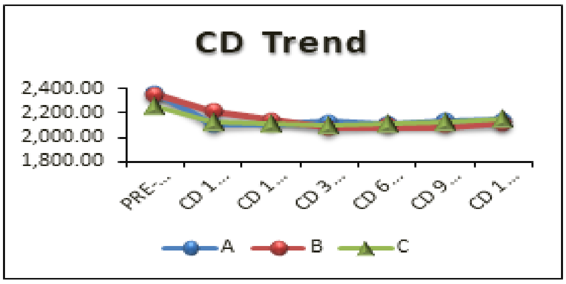

Figure 7: Mean postoperative endothelial cell density (cells/mm²) during 12-month follow-up

Table 4

(CD)	A	B	C	P VALUE	A VS B	A VS C	B VS C
PREOP	2364.95 ± 389.16	2355.2 ± 347.21	2261.67 ± 324.14	0.244	0.890	0.133	0.147
1 WK	2101.13 ± 413.14	2212.91 ± 292.18	2131.96 ± 217.8	0.167	0.105	0.626	0.102
1 MONTH	2119.42 ± 273.94	2143.05 ± 232.82	2111.33 ± 212.08	0.733	0.627	0.863	0.457
3 MONTH	2122.46 ± 244.53	2077.67 ± 194.78	2098.44 ± 183.54	0.534	0.290	0.561	0.566
6 MONTHS	2116.78 ± 260.54	2096.93 ± 203.51	2110.58 ± 187.1	0.889	0.657	0.886	0.715
9 MONTHS	2133.18 ± 248.18	2095.09 ± 210.93	2130.44 ± 189.34	0.593	0.388	0.948	0.357
12 MONTHS	2142 ± 243.69	2114.74 ± 235.82	2147.26 ± 195.22	0.721	0.552	0.901	0.433

Endothelial cell densities during all follow up visits were comparable in all three groups but there was overall decrease in CD in all three groups from baseline.CD were seen to be highest in group A followed by C then B.

DISCUSSION

The present prospective randomized comparative study evaluated the effect of three ultrasound frequencies (53 kHz, 42 kHz, and 28 kHz) on effective phacoemulsification time (EPT) and corneal endothelial cell density (ECD) following phacoemulsification. The study demonstrated that while ultrasound frequency significantly influenced surgical efficiency, postoperative endothelial cell density remained comparable among the three groups throughout the 12-month follow-up.

The baseline characteristics of the three groups were comparable with respect to gender distribution, cataract grade, preoperative best-corrected visual acuity, and endothelial cell density. This ensured that postoperative differences were primarily attributable to the ultrasound frequency rather than preoperative variations.

Effective phacoemulsification time is an important indicator of ultrasound energy utilization during cataract surgery. Although the overall trend demonstrated shorter EPT with the 42 kHz frequency, the difference became particularly evident in eyes with denser cataracts. In the subgroup with LOCS III nuclear opalescence grade >5.5, the mean EPT was significantly lower with 42 kHz (3.76 ± 1.34 seconds) compared with 53 kHz (4.71 ± 2.25 seconds) and 28 kHz (7.04 ± 2.40 seconds) ($p = 0.0003$). These findings suggest that increasing ultrasound frequency improves emulsification efficiency in harder nuclei.

Our findings are consistent with those reported by Dewan et al, who demonstrated that higher ultrasound frequencies significantly reduced effective phacoemulsification time while maintaining satisfactory endothelial safety.[5] In a subsequent randomized controlled trial comparing three ultrasound frequencies, the authors similarly reported superior surgical efficiency with intermediate and higher frequencies, particularly in denser cataracts.[6]

Despite significant differences in effective phacoemulsification time, postoperative endothelial cell density was comparable among the three groups throughout the study period. Endothelial cell density decreased following surgery in all groups, reflecting the expected endothelial trauma associated with phacoemulsification. However, no statistically significant intergroup differences were observed at any postoperative visit up to one year. These findings indicate that all three ultrasound frequencies provide comparable endothelial safety when phacoemulsification is performed using a standardized surgical technique.

These observations are in agreement with Walkow et al., who reported that endothelial cell loss following phacoemulsification is influenced by multiple factors, including cataract density, ultrasound exposure, irrigation turbulence, and surgical manipulation rather than ultrasound energy alone.[3] Similarly, Hayashi et al. Demonstrated that endothelial cell loss increases with increasing nuclear hardness because denser cataracts require greater ultrasound exposure for emulsification.[4]

Although absolute postoperative endothelial cell density remained similar among the three groups, percentage endothelial cell loss demonstrated significant differences during later follow-up. The 28 kHz group exhibited the least percentage endothelial cell loss, whereas the 42 kHz group showed the greatest endothelial cell loss during long-term follow-up. The reason for this observation remains uncertain and may be related to differences in ultrasound wave characteristics, cavitation dynamics, or fluidics rather than ultrasound frequency alone. Further studies are required to evaluate these mechanisms.

The strengths of the present study include its prospective randomized design, standardized surgical protocol, surgeries performed by a single experienced surgeon, equal allocation of patients into the three groups, and long-term follow-up extending to one year. These factors minimized inter-surgeon variability and enabled a comprehensive assessment of postoperative endothelial changes. The study has certain limitations. It was conducted at a single tertiary care centre with a relatively modest sample size. Furthermore, only uncomplicated age-related cataracts were included; therefore, the findings may not be directly applicable to eyes with pseudoexfoliation syndrome, corneal endothelial disorders, traumatic cataracts, or other complex clinical situations. Subgroups did not have uniform number and grade of cataracts making the analysis less standardised. Future multicentre studies involving larger populations and longer follow-up are needed to validate these findings and further define the optimal ultrasound frequency for different grades of cataract.

CONCLUSION

Phacoemulsification using different ultrasound frequencies demonstrated differences in effective phacoemulsification time, with the 42 kHz frequency achieving the shortest EPT in eyes with denser cataracts (LOCS III >5.5) (3.76 ± 1.34 seconds) compared with the 53 kHz (4.71 ± 2.25 seconds) and 28 kHz (7.04 ± 2.40 seconds) groups, a difference that was statistically significant ($p = 0.0003$). The postoperative endothelial cell density remained comparable among the three groups throughout the 12-month follow-up. Although percentage endothelial cell loss differed during long-term follow-up, all three ultrasound frequencies demonstrated satisfactory endothelial safety. Based on these findings, higher ultrasound frequencies, particularly 42 kHz, may be preferred for the management of denser cataracts to improve surgical efficiency without compromising corneal endothelial preservation.

REFERENCES

1. Foster A, Resnikoff S. The impact of Vision 2020 on global blindness. Eye (Lond). 2005;19(10):1133–1135.
2. Bourne WM. Biology of the corneal endothelium in health and disease. Eye (Lond). 2003;17(8):912–918.
3. Walkow T, Anders N, Klebe S. Endothelial cell loss after phacoemulsification: relation to preoperative and intraoperative parameters. J Cataract Refract Surg. 2000;26(5):727–732.
4. Hayashi K, Hayashi H, Nakao F, Hayashi F. Corneal endothelial cell loss after phacoemulsification in relation to nucleus hardness. J Cataract Refract Surg. 1996;22(6):699–703.
5. Dewan T, Malik PK, Kumari R. Comparison of effective phacoemulsification time and corneal endothelial cell loss using 2 ultrasound frequencies. J Cataract Refract Surg. 2019;45(9):1285-93.
6. Dewan T, Malik PK, Tomar P. Comparison of effective phacoemulsification time and corneal endothelial cell loss using three different ultrasound frequencies: A randomized controlled trial. Indian J Ophthalmol. 2022;70(4):1180-85.

ISSN (O): 2687-5365; ISSN (P): 2753-6556