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ORIGINAL RESEARCH

Comparative Safety and Energy Efficiency of Two Phaco Power Modulation Strategies in Diabetic Patients Undergoing Phacoemulsification

Sindy Boru Sembiring[1,2], Gusbakti Rusip[1], Ermi Girsang[1], Gede Pardianto[1,2]

[1]Universitas Prima Indonesia, Medan, North Sumatra, Indonesia; [2]Sabang Merauke Eye Centre, Medan, North Sumatra, Indonesia

Correspondence: Gusbakti Rusip, Universitas Prima Indonesia, Medan, North Sumatra, Indonesia, Email gusbakti@unprimdn.ac.id

Purpose: Given the reduced endothelial reserve and impaired pump function in diabetic corneas, optimizing phaco power modulation (PPM) may reduce intraoperative energy exposure and enhance corneal protection during phacoemulsification. This study aimed to compare the safety and energy efficiency of two PPM in diabetic patients undergoing phacoemulsification.

Patients and Methods: Forty eyes of 40 diabetic patients with immature cataracts and no diabetic retinopathy were enrolled, requiring optical biometry–examinable cataracts (OBEC) and adequate preoperative imaging quality. Phacoemulsification was performed using a phaco-chop technique with a Venturi-based system. Patients were assigned to PPM 1 (30% power, 30% pulse, 70% duty cycle) or PPM 2 (50% power, 70% pulse, 50% duty cycle). Absolute phaco time (APT), effective phaco time (EPT), visual acuity, and central corneal thickness (CCT) were assessed preoperatively and up to 1 month postoperatively.

Results: PPM 1 resulted in significantly lower APT compared with PPM 2 (49.6 vs 71.1 s; p = 0.007), while EPT did not differ significantly. Both groups showed significant visual improvement, with mean visual acuity improving to LogMAR 0.08 (PPM 1) and 0.18 (PPM 2) at 1 month, without a significant intergroup difference. CCT increased transiently on postoperative day 1 (to 595.7 µm in PPM 1 and 568.4 µm in PPM 2) and returned to near-baseline values by 1 month in both groups.

Conclusion: Both PPM configurations were safe and effective in diabetic eyes, producing comparable visual improvement and reversible postoperative corneal thickening, supporting the use of either PPM in diabetic cataract surgery. Although PPM 1 achieved significantly lower APT, EPT and corneal recovery were similar between groups, indicating greater ultrasound efficiency without compromising corneal safety. Interpretation of these findings is limited by the small sample size, inclusion of only OBEC, and the use of CCT as an indirect surrogate of endothelial function.

Keywords: absolute phaco time, effective phaco time, diabetes mellitus, central corneal thickness, anterior segment optical coherence tomography

Introduction

Cataract remains the leading cause of blindness worldwide and the second most common cause of visual impairment after refractive errors. Globally, an estimated 36 million people are blind, with more than 12 million cases attributed to cataract. Its incidence increases with age, and the number of affected individuals is projected to reach 40 million by 2025.[1] In Indonesia, the 2013 National Health Survey reported that cataract accounts for 81.2% of all blindness, representing 1.8 million cases with an annual incidence of 0.1%.[2] The standard treatment for cataract is surgical removal of the opaque lens followed by intraocular lens implantation (IOL). Phacoemulsification is currently the preferred technique because of its superior safety profile and visual outcomes.[3] However, the procedure may generate thermal and mechanical stress on intraocular tissues, particularly the corneal endothelium, which is crucial for maintaining corneal transparency. As a result, endothelial cell loss can occur after phacoemulsification or similar procedures and may be more pronounced in patients with preexisting endothelial vulnerability, such as those with diabetes mellitus (DM).[4]

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Patients with diabetes have a two- to fivefold higher risk of developing cataract compared to non-diabetic individuals, with prevalence reaching 60% by the age of 65. Besides accelerating cataract formation, DM affects all corneal layers through oxidative stress, decreased Na^+/K^+–ATPase activity, and accumulation of advanced glycation end-products (AGEs). These processes reduce endothelial cell density, promote corneal edema, and diminish endothelial functional reserve, making diabetic corneas more susceptible to surgical stress.[5,6] Consequently, diabetic corneas are more prone to ultrasonic energy–induced injury during phacoemulsification.

Although previous studies have evaluated the impact of ultrasonic energy on corneal parameters, direct comparisons between different phaco power modulation (PPM) strategies in diabetic patients remain limited. PPM involves adjusting the ultrasonic power output during surgery to optimize energy delivery while minimizing collateral damage to surrounding ocular structures, particularly the cornea. In diabetic patients, who often present with lower endothelial cell density, thicker corneas, and slower regenerative capacity, PPM plays a key role in minimizing intraoperative stress and promoting postoperative recovery.[7–9] Therefore, this study aims to compare two PPM strategies and evaluate their impact on postoperative corneal safety, as reflected by changes in central corneal thickness, while also assessing intraoperative energy efficiency parameters in diabetic patients undergoing phacoemulsification.

Materials and Methods

This was a pre–post quasi-experimental study using anterior segment optical coherence tomography (AS-OCT) to monitor corneal structural and numerical cellular changes in diabetic patients undergoing cataract surgery. The study was conducted at SMEC Eye Hospital, Medan, Indonesia, between March and July 2025. Ethical approval was obtained from the Institutional Review Board of SMEC Eye Hospital, and all participants provided written informed consent in accordance with the Declaration of Helsinki.

The study enrolled patients with type 2 DM and immature senile cataract, without diabetic retinopathy or diabetic macular edema. Only cataracts that could still be evaluated by optical biometry were included, corresponding to the Optical Biometry Examinable Cataract (OBEC) classification.[10] In this classification, OBEC indicates lenses with sufficient optical transparency to allow optical biometry evaluation, even when the visual acuity is poor. Mature, hypermature, or very dense cataracts that prevented reliable measurement were excluded from the study.

Eligible participants were aged 40–80 years and had been previously diagnosed with diabetes mellitus by an internist according to the American Diabetes Association (ADA) criteria, including HbA1c $\geq$ 6.5%, and were receiving standard medical therapy.[11] HbA1c measurements were not repeated on the day of surgery, as in our clinical setting this test is routinely performed at approximately 3-month intervals rather than during immediate preoperative evaluation.

Additional inclusion criteria required intraocular pressure (IOP) $\leq$ 20 mmHg and the ability to undergo anterior segment optical coherence tomography (AS-OCT) assessment.

Exclusion criteria comprised significant ocular comorbidities, intraoperative pupil diameter $<$ 5 mm, surgical duration $>$ 15 minutes, and intraoperative complications such as posterior capsular rupture or vitreous prolapse. Postoperative exclusions included corneal edema or infection precluding AS-OCT assessment, IOP $>$ 20 mmHg at follow-up, progressive diabetic retinopathy or diabetic macular edema during follow-up, and patient withdrawal. Figure 1 illustrates the flow of participants from enrollment to study completion, including all reasons for exclusion.

Eligible participants were assigned to either PPM 1 or PPM 2 in a 1:1 allocation using a predefined sequence prepared by a staff member who was not involved in outcome assessment. Allocation was implemented sequentially at the time of enrolment using an alternating assignment approach to maintain balanced group sizes throughout recruitment. To minimize performance bias, the operating surgeon was not involved in group allocation during patient selection and enrolment. The assigned PPM setting was applied only when the patient entered the operating room, at which point the phacoemulsification system parameters were configured according to the allocated group. Both groups used pulse-mode ultrasound delivery: PPM 1 was set at Power 30%, Pulse 30%, and Duty Cycle 70%, whereas PPM 2 was set at Power 50%, Pulse 70%, and Duty Cycle 50%.

The sample size was calculated based on a previous study by Morikubo et al, which reported a mean central corneal thickness of 544.0 μm with a standard deviation of 37.2 μm in diabetic eyes undergoing cataract surgery.[12] Using this standard deviation and assuming a clinically meaningful difference of 30 μm, with an alpha level of 0.05 and 80%

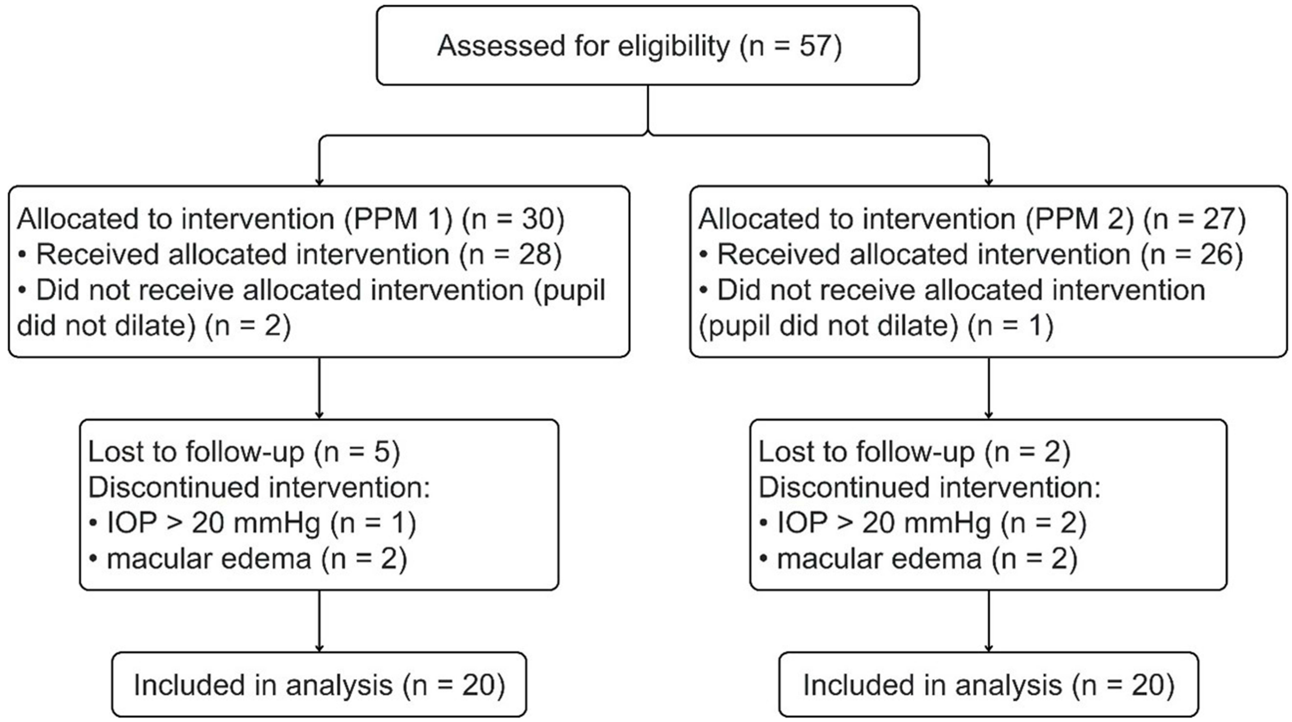

Figure 1 Flow of the participants throughout the study.

statistical power, the minimum required sample size was determined to be 16 patients per group. To account for a potential 20% drop-out rate, we enrolled 20 patients per group.

Preoperative evaluation included detailed anamnesis, random blood glucose and blood pressure measurements, best corrected visual acuity (BCVA) testing with a chart projector at 6 meters, objective and subjective refraction using a NIDEK ARK-1 non-contact autorefractometer (NIDEK Co., Ltd., ARK-1, Gamagori, Aichi, Japan) and trial lenses (Shin-Nippon Biomedical Laboratories, Ltd., Trial Lens Set, Tokyo, Tokyo, Japan), and IOP measurement using the NIDEK NT-530 non-contact tonometer (NIDEK Co., Ltd., NT-530, Gamagori, Aichi, Japan). NIDEK SL-1800 slit-lamp biomicroscope (NIDEK Co., Ltd., SL-1800, Gamagori, Aichi, Japan) and Keeler indirect ophthalmoscope, 20D/90D lenses (Keeler Ltd., Indirect Ophthalmoscope, Windsor, Berkshire, UK) were performed for anterior and posterior segment evaluation. Corneal morphology and central corneal thickness (CCT) were measured using AS-OCT (NIDEK Co., Ltd., RS-3000, Gamagori, Aichi, Japan). CCT was used as an indirect surrogate marker of endothelial functional response. Direct endothelial cell density (ECD) measurement using specular microscopy was not performed in this study/ was not available in our institution at the time of the study. Macular OCT imaging was performed to exclude diabetic macular involvement. Keratometry and axial length were assessed using optical biometry (NIDEK Co., Ltd., AL-Scan, Gamagori, Aichi, Japan).

All surgeries were performed by a single experienced cataract surgeon using the phaco-chop technique with bimanual irrigation–aspiration and hydroimplantation of a foldable hydrophilic aspheric IOL. A venturi-based phacoemulsification system (Bausch & Lomb Inc., Stellaris, Rochester, NY, USA) was used for all procedures to ensure uniformity. The maximum vacuum was set at 400 mmHg with linear control, and the aspiration flow rate was maintained at up to 40 mL/min. The infusion bottle height was kept at approximately 80–120 cm above the patient's eye level to maintain anterior chamber stability and adequate intraocular pressure during the procedure. The system automatically recorded Absolute Phaco Time (APT), Effective Phaco Time (EPT), and total surgical time. Any intraoperative complications were documented.

Postoperative examinations were conducted at 1 day, 1 week, and 1 month after surgery. At each follow-up, assessments included BCVA (converted to LogMAR), IOP measurement, slit-lamp evaluation, fundus examination,

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and AS-OCT imaging. Corneal thickness and structural integrity were analyzed numerically from AS-OCT cross-sectional images. For the postoperative dataset, eyes were excluded only when macular OCT revealed macular edema.

All collected data were reviewed for completeness and accuracy and then analyzed using statistical software (IBM Corp., SPSS Statistics version 25.0, Armonk, NY, USA). Continuous variables such as CCT, IOP, visual acuity, and phacoemulsification parameters (APT, EPT) were expressed as mean ± standard deviation (SD). Normality of data distribution was assessed using the Shapiro–Wilk test. For normally distributed variables, independent t-tests were used to compare intergroup differences between PPM 1 and PPM 2, and paired t-tests were applied for pre- and postoperative comparisons within each group. For variables that did not meet normality assumptions, non-parametric alternatives (Mann–Whitney *U*-test for intergroup comparisons and Wilcoxon signed-rank test for within-group pre–post comparisons) were used. A p-value < 0.05 was considered statistically significant. The primary outcome was the change in CCT as measured by AS-OCT. Secondary outcomes included improvements in visual acuity and intraoperative phacoemulsification efficiency parameters.

Results

Patient Population

Preoperative characteristics for both groups are presented in Table 1. There were no statistically significant differences between groups at baseline for age, blood pressure, blood glucose, preoperative visual acuity, preoperative IOP, and preoperative CCT (all p > 0.05). This confirmed baseline comparability of the two groups. All eyes met the OBEC criteria, ensuring adequate preoperative imaging quality in both groups.

Intraoperative Phacoemulsification Parameters

Intraoperative ultrasound parameters are shown in Table 2. The PPM 1 group demonstrated significantly lower APT compared with the PPM 2 group (p = 0.007), whereas EPT did not differ significantly between the two modulations (p = 0.168). No major intraoperative complications occurred in either group, and all surgeries were completed uneventfully with the standardized phaco-chop technique using a Venturi system.

Visual Acuity Outcomes

Within-group comparisons revealed a significant improvement in visual acuity at all postoperative time points in both groups (all $p < 0.001$) (Table 3). Visual acuity improved markedly from preoperative measurements to day 1, with continued gains at week 1 and month 1. Between-group comparison of postoperative visual acuity demonstrated no statistically significant difference at day 1 ($p = 0.658$) or week 1 ($p = 0.708$). At month 1, the PPM 1 group showed a trend toward better visual acuity; however, this difference did not reach statistical significance ($p = 0.054$).

Table 1 Preoperative Characteristics

Characteristics	PPM 1 (n = 20)	PPM 2 (n = 20)	Total (n = 40)	P value
Age	64.10 ± 9.75 (48–78)	62.85 ± 6.08 (51–72)	63.48 ± 8.05 (48–78)	0.630
Systolic blood pressure	146.15 ± 28.04 (110–195)	143.10 ± 22.08 (118–188)	144.63 ± 24.96 (110–195)	0.892
Diastolic blood pressure	78.75 ± 11.06 (64–110)	80.25 ± 13.45 (61–108)	79.50 ± 12.18 (61–110)	0.705
Random Blood glucose	211.50 ± 96.04 (92–393)	196.80 ± 84.38 (75–369)	204.15 ± 89.54 (75–393)	0.610
Preoperative visual acuity	1.23 ± 0.53 (0.54–1.85)	1.03 ± 0.42 (0.54–1.85)	1.13 ± 0.48 (0.54–1.85)	0.307
Preoperative IOP	15.00 ± 2.69 (10–20)	16.10 ± 2.93 (11–20)	15.55 ± 2.83 (10–20)	0.229
Preoperative CCT	538.50 ± 41.10 (465–629)	521.75 ± 32.45 (465–588)	530.13 ± 37.52 (465–629)	0.161

Table 2 Phaco Time Duration

	PPM 1 (n = 20)	PPM 2 (n = 20)	P value
Absolute Phaco time	49.58 ± 15.52 (24.09–74.02)	71.08 ± 26.41 (31.08–148.02)	0.007
Effective Phaco time	7.99 ± 4.39 (3.03–17.04)	10.90 ± 9.03 (2.04–44.00)	0.168

Table 3 Change in Visual Acuity

	Mean ± SD	Min–Max	Mean ± SD	Min–Max	P value
PPM 1	Preoperative Visual Acuity		Postoperative 1 Day		< 0.001
	1.28 ± 0.53	0.54–1.85	0.41 ± 0.18	0.10–1.00	
			Postoperative 1 Week		< 0.001
			0.22 ± 0.13	0.00–0.48	
			Postoperative 1 Month		< 0.001
			0.08 ± 0.10	0.00–0.40	
PPM 2	Preoperative Visual Acuity		Postoperative 1 Day		< 0.001
	1.03 ± 0.42	0.54–1.85	0.38 ± 0.19	0.00–0.69	
			Postoperative 1 Week		< 0.001
			0.24 ± 0.19	0.00–0.69	
			Postoperative 1 Month		< 0.001
			0.18 ± 0.17	0.00–0.60	

Corneal Thickness Changes

Changes in CCT are summarized in Table 4. Both groups exhibited a significant increase in CCT on postoperative day 1 and week 1 relative to baseline (all $p < 0.001$), consistent with transient postoperative corneal edema. By month 1, CCT had largely returned to preoperative values in both groups, and the differences compared with baseline were no longer statistically significant *(p = 0.294 for PPM 1; p = 0.234 for PPM 2)*.

Table 4 Change in Corneal Thickness

	Time Point	Mean ± SD	P value*
PPM 1	Preoperative	538.50 ± 41.10	–
	Postoperative 1 Day	595.65 ± 53.21	<0.001
	Postoperative 1 Week	558.60 ± 52.13	<0.001
	Postoperative 1 Month	541.65 ± 46.07	0.294
PPM 2	Preoperative	521.75 ± 32.45	–
	Postoperative 1 Day	568.40 ± 43.85	<0.001
	Postoperative 1 Week	536.35 ± 35.23	<0.001
	Postoperative 1 Month	525.45 ± 33.32	0.234

Notes: *P-values represent paired comparisons between each postoperative time point and the preoperative baseline within the same group.

Between-group comparison, demonstrated no significant differences in CCT at day 1 *($p = 0.074$)*, week 1 *($p = 0.122$)*, or month 1 *($p = 0.210$)*. Although the PPM 1 group exhibited numerically higher CCT values during the early postoperative period, these differences were small and not statistically meaningful. Overall, both PPM produced a similar profile of reversible postoperative corneal thickening.

Discussion

Phacoemulsification is a cataract removal technique that uses rapid ultrasonic-frequency movements of a piezoelectric-driven phaco tip to mechanically break up the lens, rather than actual sound or acoustic waves.[13] Total ultrasound exposure can be quantified through APT, representing the cumulative activation time, and EPT, defined as APT multiplied by the mean phaco power to reflect the equivalent duration at 100% continuous output.[14]

In this study, PPM 1 demonstrated a significantly lower APT than PPM 2, whereas EPT remained similar between groups. Theoretically, lowering pulses per second (PPS) improves emulsification efficiency by creating longer intervals between pulses, allowing sufficient time for vacuum to draw nuclear fragments toward the phaco tip and keep them engaged. When the pause between pulses is adequate, the fragments are less likely to repulse or “bounce,” resulting in a more stable engagement that facilitates more effective breakdown of the nucleus. This enhanced stability makes the procedure faster and indirectly reduces APT.[8,13]

Previous studies have similarly shown that reducing PPS alone—while keeping power and duty cycle constant—can decrease both APT and EPT.[15] In our study, the reduction in APT aligns with this theoretical expectation. However, EPT did not differ between groups. This is likely because the average phaco power actually used in both groups was low and nearly identical, approximately 16% in this study, meaning that the difference in maximum power settings (30% in PPM 1 vs. 50% in PPM 2) did not translate into meaningful differences in real power delivery. Moreover, because average phaco power reflects the interaction between power and duty cycle, the differing duty cycle settings may have contributed to the uniformity in EPT. These factors explain why EPT remained unchanged and why our findings differ from earlier studies that controlled power and duty cycle more strictly. Additionally, this study altered all three parameters simultaneously (power, PPS, and duty cycle), creating compensatory effects that likely preserved EPT despite the significant reduction in APT. However, it is important to emphasize that our study involved only immature cataracts. In mature (hard) cataracts, higher PPS has been shown to result in lower EPT and better endothelial preservation compared with lower PPS settings.[16,17]

A previous study in which the mean phaco power was similar between groups found that a lower APT effectively reduced the overall duration of ultrasound activation, thereby limiting cumulative mechanical and thermal load on the cornea.[18] In contrast, another study where mean phaco power differed substantially between groups showed that even with a low APT, higher phaco power produced greater postoperative corneal edema and poorer visual acuity outcomes. Together, these findings emphasize that corneal safety depends on minimizing both phaco time and power.[19]

The significantly lower APT in PPM 1—while maintaining similar EPT and comparable postoperative CCT—indicates that PPM 1 functions as an ultrasound-sparing setting that delivers equivalent safety with reduced cumulative energy exposure. At the same time, both PPM maintained similar EPT values and demonstrated equally good energy efficiency, showing that emulsification performance was preserved across both configurations.

Significant improvement in visual acuity from preoperative to all postoperative time points was observed in both groups. This aligns with the expected physiological mechanism: removal of the opaque crystalline lens and implantation of a clear IOL restores optical clarity and enhances retinal illumination. Rapid recovery in diabetic patients is further supported by modern phaco techniques—together with the optimized PPM used in this study—which help reduce surgical trauma and postoperative inflammation.[20]

Previous studies similarly demonstrated early improvements in visual acuity after phacoemulsification, with significant gains detectable as early as the first postoperative day and stabilizing over subsequent weeks.[21,22] The consistent visual improvement observed in both groups suggests that differences in pulse structure and power modulation did not adversely affect early or intermediate recovery.

Both groups exhibited significant increases in CCT at day 1 and week 1, followed by near-complete return to baseline by month 1. This profile reflects transient stromal edema due to temporary endothelial pump impairment and barrier dysfunction caused by mechanical stress from phacoemulsification.[23,24]

When comparing the percentage change in CCT from baseline, the postoperative response observed in this study was highly consistent with patterns previously reported in diabetic eyes. In earlier work, CCT increased by approximately 10% in diabetic patients on postoperative day 1 (compared with ~6% in non-diabetic eyes). In our study, the CCT increase on day 1 was ~11% in PPM 1 and ~9% in PPM 2, both closely matching the typical diabetic response reported previously.[25]

However, by week 1 the profile in our study more closely resembled that of non-diabetic eyes rather than diabetic eyes. Prior studies reported a week-1 increase of ~8% in diabetic eyes, contrasted with only ~3% in non-diabetic eyes. In this study, the CCT increase had already declined to ~4% in PPM 1 and ~3% in PPM 2, indicating a substantially faster resolution of edema than normally expected in diabetic corneas. This suggests that both PPM used in this study may effectively mitigate the prolonged edema typically associated with diabetes.[25]

By month 1, CCT returned almost completely to baseline in both groups, with only ~0.6% (PPM 1) and ~0.7% (PPM 2) thickening. These values were not only lower than those reported for diabetic eyes in previous studies (~7% at month 1), but were also better than the typical non-diabetic response, which still demonstrated ~2% residual thickening at one month.[25] Other work evaluating diabetic eyes has similarly reported month 1 thickening of approximately ~1.6%, further underscoring that the month-1 recovery achieved in this study was more complete.[12] Notably, earlier studies showed that diabetic eyes could still exhibit ~3% thickening even by month 3, underscoring the prolonged recovery typically observed in this population.[25]

Taken together, the markedly faster normalization of CCT in both PPM highlights the safety and efficiency of these PPM strategies. Importantly, the corneal recovery profile in diabetic eyes in this study not only matched non-diabetic benchmarks but in some cases surpassed them, supporting the suitability of these for use in diabetic patients who are generally more vulnerable to postoperative corneal compromise.[23]

In addition, this study was conducted in a heterogeneous diabetic population in which individual clinical factors may influence corneal endothelial vulnerability. However, baseline demographic and clinical characteristics were comparable between the two PPM groups (all $p > 0.05$), reducing the likelihood of intergroup confounding. The findings should therefore be interpreted as reflecting the comparative performance of the two PPM settings within a diabetic cataract population rather than the influence of specific patient characteristics.

No significant differences in CCT between PPM 1 and PPM 2 were observed at any postoperative interval. However, although PPM 1 demonstrated a lower APT, the postoperative day-1 CCT was numerically higher than in PPM 2. This finding may appear counterintuitive if a direct linear relationship between ultrasound exposure and corneal edema is assumed. In practice, early postoperative CCT is influenced by multiple perioperative factors beyond ultrasound energy alone, including baseline inter-individual endothelial functional reserve, intraoperative irrigation load, wound hydration, transient intraocular pressure fluctuations, and measurement variability related to tear film and immediate postoperative corneal hydration. Therefore, APT/EPT and early postoperative CCT do not necessarily correlate in a strictly proportional manner. Importantly, CCT in both groups demonstrated rapid recovery toward baseline by one month, and intergroup comparisons did not indicate increased corneal stress attributable to either PPM setting.

Study Limitations

This study has several limitations. First, the sample size was relatively small (n=40). Although adequately powered for statistical comparison, the limited number of subjects restricts generalizability of the findings. Second, the study included only cataracts that were assessable by optical biometry–examinable cataract (OBEC), which predominantly represent immature or moderate cataracts. Cataract density was therefore used primarily as an inclusion criterion, and correlation analysis between cataract density and phaco time parameters was not performed. Consequently, the findings may not fully extend to more advanced or dense cataracts. Previous studies suggest that increasing cataract hardness is theoretically associated with greater ultrasound energy requirements during phacoemulsification, which may contribute

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to variability in phaco time across cases.[15] Further studies including denser cataracts would help broaden the spectrum of lens opacities evaluated.

Third, endothelial health was not assessed using direct ECD measurements. It is important to acknowledge that CCT reflects the functional consequence of endothelial stress rather than direct endothelial cell loss. Although increases in CCT are widely used as a clinical indicator of transient endothelial dysfunction after phacoemulsification, they cannot substitute for direct endothelial cell density measurements. Therefore, our findings should be interpreted as reflecting postoperative corneal functional response rather than definitive cellular-level changes. Future studies incorporating specular microscopy, including endothelial cell density and morphological assessment, would provide a more direct evaluation of endothelial changes.

Finally, the present study was designed as a comparison within a diabetic population, focusing on the relative performance of two PPM strategies in this clinically vulnerable group. A non-diabetic control cohort was therefore not included. Although the inclusion of such a group could provide additional insight into diabetes-related corneal responses, this was beyond the predefined objective of the current study.

Conclusion

This study aimed to compare the safety and energy efficiency of two phaco power modulation (PPM) strategies in diabetic patients undergoing phacoemulsification. Both PPM settings resulted in significant postoperative improvement in visual acuity and demonstrated comparable corneal safety profiles in diabetic eyes, as reflected by the rapid and near-complete normalization of central corneal thickness (CCT), with no significant differences between groups.

While overall corneal recovery and visual outcomes were similar, PPM 1 achieved a significantly lower absolute phaco time (APT) while maintaining comparable effective phaco time (EPT), suggesting a more ultrasound-efficient configuration without evidence of increased corneal stress. Collectively, these findings indicate that both PPM 1 and PPM 2 are clinically acceptable options for diabetic patients undergoing phacoemulsification, with PPM 1 offering potential advantages in terms of reduced cumulative energy exposure.

Abbreviations

PPM, phaco power modulation; OBEC, optical biometry–examinable cataracts; APT, absolute phaco time; EPT, effective phaco time; CCT, central corneal thickness; LogMAR, logarithm of the minimum angle of resolution; IOL, intraocular lens; DM, diabetes mellitus; AGEs, advanced glycation end-products; AS-OCT, anterior segment optical coherence tomography; ADA, American Diabetes Association; IOP, intraocular pressure; BCVA, best corrected visual acuity; OCT, optical coherence tomography; SD, standard deviation; PPS, pulses per second. ECD, endothelial cell density.

Data Sharing Statement

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Ethics Approval and Informed Consent

This study was conducted in accordance with the principles of the Declaration of Helsinki. Ethical approval was obtained from the SMEC Hospital Research Ethical Review Committee (Approval No. EA00000692) and the Health Research Ethics Committee (Komite Etik Penelitian Kesehatan, KPEK) of Universitas Prima Indonesia, registered under KEPPKN Registration No. 1271012S (Ethical Clearance Letter No. 131/KEPK/UNPRI/III/2025). Written informed consent was obtained from all participants prior to enrollment.

Consent for Publication

Not applicable, as this manuscript does not include any identifiable personal data or images of participants.

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Disclosure

The authors declare that they have no conflicts of interest related to this study.

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