Acta Scientific Ophthalmology (ISSN: 2582-3191)

Volume 8 Issue 7 July 2025

Research Article

Comparison of Different Phacoemulsification Modes of Nuclear Disassembly (Continuous, Pulse and Burst) in Terms of Post-Operative Visual Outcomes in Cataract Surgery

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Received: June 05, 2025

Published: June 27, 2025

Abstract

Objective: To compare different phacoemulsification modes of nuclear disassembly (continuous, pulse and burst) in terms of post-operative visual outcomes

Methodology: A total of 450 patients diagnosed with cataract who underwent phacoemulsification surgery were enrolled in this study. Patients were randomly assigned to three groups which were divided on the basis of phacoemulsification mode used for nuclear disassembly. Group A patients were operated in continuous mode, Group B in pulse mode and Group C in burst mode. These three groups were subsequently compared using appropriate statistical tests in terms of intraoperative parameters of phacoemulsification and post-operative visual outcomes.

Results: The mean age of presentation was 61.17 years. The mean effective phacoemulsification time (seconds) in Group A was 8.82 ± 11.86 seconds, Group B was 5.77 ± 6.71 seconds and in Group C was 6.68 ± 8.70 seconds. The mean ultrasound power (Watt) used in Group A was 18.68 ± 2.06 W, Group B was 18.73 ± 1.79 W, and Group C was 19.04 ± 1.82 W. The mean cumulative dissipated energy (Joules) in Group A was 179.70 ± 259.23 J, in Group B was 116.35 ± 144.85 J and in Group C was 137.29 ± 190.97 J. There was a statistically significant improvement seen in post-operative Uncorrected Visual Acuity (UCVA) as compared to pre-operative UCVA in 82% subjects in Group A, 82% in Group B and 84.66% in Group C (Wilcoxon signed rank test, $p < 0.0001$). On post-operative day (POD) 7, Best Corrected Visual Acuity (BCVA) of 6/9 or better was achieved in 75.33% subjects of Group B, and 72% subjects of Group A as well as Group C. It improved to 82.67%, 91.33% and 84% in Group A, B and C respectively on POD180. The mean pre-operative and post-operative astigmatism was -0.94 ± 0.84 and -0.98 ± 0.91 respectively. The mean intra-ocular pressure on POD7 in Group A was 17.41 ± 2.45, in Group B was 17.32 ± 2.58 and in Group C was 17.97 ± 2.35. Corneal oedema on POD1 was present in 26% cases of Group A, 19.333% cases of Group B and 21.33% cases of Group C.

Conclusion: To achieve better visual outcomes the two most important factors during phacoemulsification surgery i.e. total energy dissipated into the eye and time it takes to emulsify the nucleus (Effective phaco time) should be kept at minimum which can be achieved with phaco power-modulation.

Keywords: Cataract; Phacoemulsification; Phaco Power Modulation

Introduction

Cataract is the most prevalent and treatable cause of visual impairment and blindness globally [1]. Age-related cataracts, also known as senile cataracts, are the most common type in adults, typically developing between the ages of 45 and 50 [2]. Various factors such as genetic, biochemical, socioeconomic, and environmental play a role in cataract formation [3]. According to four-part severity scale, cataract can be divided based on severity of opacity: Early Immature Senile cataract (grade 1), Immature Senile cataract (grade 2), Mature senile cataract (grade 3), and Hyper mature senile cataract (grade 4) [4]. Only treatment available for cataract is its surgical removal [5]. The revolution in cataract surgery came when Kelman introduced phacoemulsification to the world of ophthalmology. It boasted of the smallest incision till date, which was self-sealing as well as allowed implantation of the IOL through that small incision itself [6,7]. In phacoemulsification, the nucleus is broken with oscillatory movements achieved at the phaco tip using ultrasonic power produced using specialised piezoelectric crystals. The broken nucleus is then aspirated [8-11]. Ultrasound power modulations have vividly increased the efficiency of ultrasound energy dissipated into the surrounding tissues and have reduced the amount of heat production, hence reducing the risk of thermal damage resulting in excellent postoperative outcomes [12]. There are three modes of phacoemulsification, namely: Continuous mode, Pulse mode and Burst mode. The main difference lies in the duration for which phaco power is delivered into the eye in one cycle [13].

In continuous mode, there is continuous delivery of ultrasound energy where power steadily increases until full excursion is attained [14].

Figure 1

In pulse mode each pulse is followed by same amount of pause time resulting in fifty percent reduction in delivery of phaco power [15].

Figure 2

In burst mode the frequency of the bursts rises as the foot pedal is depressed, but the length stays constant [16].

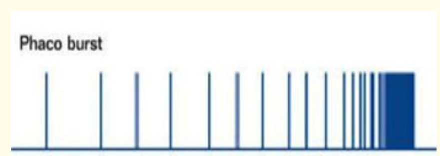

Figure 3

In this study we have compared different modes of phacoemulsification in terms of their post-operative visual outcomes.

Materials and Methods

A total of 450 patients who were diagnosed with cataract and underwent phacoemulsification surgery in Department of Ophthalmology of Rajindra Hospital, Government Medical College, Patiala were included in this study. Ethical approval was taken from the institute's ethical committee. Informed written consent was taken from the subjects after explaining the type and purpose of study and need for follow up. Patients were randomized into three groups on the basis of mode of phacoemulsification used-Group A -Continuous mode, Group B -Pulse mode and Group C -Burst mode. On the basis of nucleus hardness, cataract was subdivided into Grade 1, Grade 2, Grade 3 and Grade 4. Patients with prior intraocular surgery; secondary causes of cataract like corticosteroids, trauma, drugs; any systemic illness, retinal detachment, diabetic retinopathy, age related macular degeneration, uveitis, glaucoma, corneal opacity, pseudo exfoliation syndrome, degenerative myopia, subluxated or luxated lens were excluded from the study. Pre-operatively Uncorrected Visual Acuity (UCVA), Best Corrected Visual Acuity (BCVA) with Snellen's chart, Intra-ocular Pressure (IOP) measurement with Non-Contact Tonometer (NCT), direct and distant direct Ophthalmoscopy, slit-lamp biomicroscopy examination, Fundus examination using Indirect Ophthalmoscopy, A scan for biometry, and routine pre-operative blood investigations were done. The patients were given topical antibiotic cover pre-operatively.

Surgical technique

The surgery was performed under local anaesthesia (facial block and peribulbar block). After properly cleaning and draping the eye with povidone-iodine 10%, the side ports were made using 15-degree side port blade, followed by main port incision with 2.8 mm keratome blade. Air was injected followed by trypan blue dye to stain the anterior lens capsule. Dye was cleared using basic salt solution, then dispersive ophthalmic viscosurgical device was injected to fill the anterior chamber. Capsulorrhexis of 5 mm diameter was made using 26-gauge cystitome needle followed by hydrodissection and hydrodelineation of lens. Nucleus was disassembled using phacoemulsification. The phacoemulsification machine which we have used in this study is Faros phacoemulsification device/Anterior segment model (Oertli Instrumente AG, Berneck, Switzerland). The following parameters were noted for each case: Phaco Mode, Ultrasound Power (USP), Vacuum limit, Aspiration Flow Rate (AFR), Effective Phaco Time (EPT), and Cumulative Dissipated Energy (CDE). Phacoemulsification modes used were Continuous mode for Group A, Pulse mode for Group B and Burst mode for Group C. Amount of phaco power to be used in each case was decided based on the grade of nuclear hardness ranging from Grade 1 to 4, with maximum USP being 55%. AFR between 35-45 ml/min was used and range of vacuum used was 350-450 mmHg. EPT was noted at the end of nucleus disassembly in each case which represented the time for which phacoemulsification power was on, and it was calculated in seconds. CDE was calculated afterwards using the equation = EPT X USP, and it represented the total energy that dissipated during the surgery. Then aspiration of cortex was done using automated bimanual irrigation and aspiration cannula (I/A). In case of uncomplicated procedure, foldable posterior chamber intraocular lens (PC IOL) was placed in the capsular bag. The remaining viscoelastic substance was removed using bimanual I/A. Ports were hydrated, anterior chamber was formed with air, antibiotic-steroid combination was injected subconjunctivally and the case was closed. Patients were given topical antibiotic-steroid combination postoperatively which was tapered weekly over a course of 6 weeks. Patients were reviewed on post-operative day (POD) 1 and slit lamp examination was performed to look for any corneal oedema, anterior chamber reaction, and IOL placement and centration. Subsequent follow up visits were done on POD 7, POD 30, POD 90, and POD 180, which included assessment of UCVA, BCVA (using Snellen's chart); IOP (using NCT); and keratometry using autorefractometer.

Statistical analysis

Mean (Standard Deviation) and frequency (percentage) were given for continuous and categorical variables. Post Hoc Tukey test, paired t-test and chi- square test was done for comparison of proportions. Kruskal Wallis test and Wilcoxon signed rank test was used to compare pre- and post-operative visual acuity. A p value below 0.05 was considered significant.

Results

Demographic profile

A total of 450 patients were enrolled in this study. Nuclear disassembly in Group A was done using continuous mode, in Group B using pulse mode and in Group C using burst mode. There were 150 subjects in each group. Overall mean age of presentation was 61.17 years. The age was statistically comparable in all the three groups (p = 0.923, ANOVA test). Out of 450 cataract patients,47.6% were females and 52.4% were males with no gender predilection (p = 0.285, chi-square test). 48% of the total eyes involved were right eyes and 52% were left eyes and there was no eye predilection (p = 0.423, chi-square test). Distribution of cases in different grades of nuclear sclerosis in three groups was as follows - in Group A, there were 25.33%, 34.67%, 25.33%, and 14.67% patients in Grade 1, 2, 3 and 4 respectively; in Group B there were 25.33%, 36%, 25.33%, and 13.33% patients in Grade 1, 2, 3 and 4 respectively; and in Group C there were 22.67%, 40.67%, 24%, and 12.67% patients in Grade 1, 2, 3 and 4 respectively. There was no statistically significant difference between the groups in terms of nucleus hardness (p = 0.974, Kruskal Wallis test).

Analysis of intraoperative phacoemulsification parameters

The mean EPT (seconds) in Group A was 8.82 ± 11.86, Group B was 5.77 ± 6.71 and in Group C was 6.68 ± 8.70. The mean EPT in Group A was statistically significantly higher as compared to Group B (p = 0.013, Tukey post hoc test) but there was no significant difference between Group A and C (p = 0.117, Tukey post hoc test) and between Group B and C (p = 0.675, Tukey post hoc test). Upon analysis of EPT in different grades of nuclear sclerosis, there was no significant difference between Group A, B and C in grade 1 (p = 0.755, Tukey post hoc test). In Grade 2, there was statistically significantly more EPT in Group A as compared to Group B (p = 0.005, Tukey post hoc test) but there was no significant difference between Group A and C (p = 0.062, Tukey post hoc test) as well as in Group B and C (p = 0.574, Tukey post hoc test). In Grade 3, there was statistically significantly more EPT in Group A as compared to Group B (p = 0.001, Tukey post hoc test) and Group C (p = 0.014, Tukey post hoc test) however there was no significant difference between Group B and Group C (p = 0.406, Tukey post hoc test) and in Grade 4 there was significantly more EPT in Group A as compared to Group B (p = 0.012) but there was no significant difference between Group A and B (p = 0.245) as well as in Group B and C(p = 0.406) according to Tukey Post-Hoc test.

Grade	Group A	Group B	Group C	p value	p value (Tukey Post-Hoc Test)		
					A vs B	A vs C	B vs C
1. EPT (seconds)							
Grade 1	0.73 ± 0.62	0.64 ± 0.59	0.66 ± 0.47	0.755 (F = 0.282) (NS)	0.748 (NS)	0.862 (NS)	1.000 (NS)
Grade 2	4.24 ± 1.92	3.22 ± 1.48	3.53 ± 1.56	0.006 (F = 5.318) (S)	0.005 (S)	0.062 (NS)	0.574 (NS)
Grade 3	10.13 ± 3.62	6.95 ± 2.71	7.93 ± 3.49	0.001 (F = 9.260) (HS)	0.001 (HS)	0.014 (S)	0.406 (NS)
Grade 4	31.34 ± 16.16	20.15 ± 6.39	25.17 ± 11.32	0.016 (F = 4.474) (S)	0.012 (S)	0.245 (NS)	0.406 (NS)
2. CDE (Joules)							
Grade 1	12.27 ± 10.34	10.57 ± 9.68	11.34 ± 7.96	0.733 (F = 0.312) (NS)	0.711 (NS)	0.908 (NS)	0.936 (NS)
Grade 2	76.15 ± 34.53	58.74 ± 26.34	66.10 ± 28.61	0.012 (F = 5.520) (S)	0.009 (S)	0.179 (NS)	0.388 (NS)
Grade 3	196.93 ± 69.07	137.62 ± 54.10	155.99 ± 65.82	0.001 (F = 8.736) (HS)	0.001 (HS)	0.017 (S)	0.427 (NS)
Grade 4	683.85 ± 348.20	432.49 ± 137.11	555.81 ± 240.60	0.011 (F = 4.872) (S)	0.008 (S)	0.268 (NS)	0.310 (NS)

Table 2: Analysis of EPT and CDE in different grades of nuclear sclerosis in the three groups.

The mean USP (Watt) used in Group A was 18.68 ± 2.06, Group B was 18.73 ± 1.79, and Group C was 19.04 ± 1.82, however, the difference in mean ultrasound power used in three groups was not statistically significant (p = 0.207, ANOVA test). The mean CDE (Joules) in Group A was 179.70 ± 259.23, in Group B was 116.35 ± 144.85 and in Group C was 137.27 ± 190.97. According to Tukey Post-Hoc test, the CDE was statistically significantly more in Group A as compared to Group B (p = 0.020) but there was no statistical significance was noted between Group A and C (p = 0.170) as well as in Group B and C (p = 0.647). On comparing CDE in different grades of nuclear sclerosis, in Grade 1 there was no statistically significant difference between Group A, B and C (p = 0.733, ANOVA test). In Grade 2 there was statistically significantly more CDE in Group A as compared to Group B (p = 0.009, Tukey post hoc test) but there was no statistically significant difference between Group A and C (p = 0.179, Tukey post hoc test) as well as in Group B and C (p = 0.388, Tukey post hoc test). In Grade 3 there was statistically significantly more CDE in Group A as compared to Group B (p = 0.001, Tukey post hoc test) and Group C (p = 0.017, Tukey post hoc test) however there was no statistically significant difference between Group B and Group C (p = 0.427, Tukey post hoc test). In Grade 4 there was statistically significantly more CDE in Group A as compared to Group B (p = 0.008, Tukey post hoc test) but there was no significant difference between Group A and C (p = 0.268, Tukey post hoc test) as well as in Group B and C(p = 0.310, Tukey post hoc test).

Visual outcome analysis

Visual acuity (VA) measurements were taken pre-operatively and post-operatively on day 7, 30,90 and 180 using Snellen's chart.

There was a statistically significant improvement seen in post-operative UCVA as compared to pre-operative UCVA in 82% subjects in Group A, 82% in Group B and 84.66% in Group C (Wilcoxon signed rank test, p < 0.00001). On comparison of percentage of subjects who achieved UCVA of 6/9 or better on POD7, POD30, POD60 and POD180, no statistically significant difference was noted (p > 0.05, Kruskal Wallis test).On comparison of percentage of subjects who achieved BCVA of 6/9 or better on POD7, POD30, POD60 and POD180, no statistically significant difference was noted (p > 0.05, Kruskal Wallis test). However statistically significant difference (p = 0.013, Kruskal Wallis test) was noted on POD14 where 80% subjects in Group A, 91.33% subjects in Group B and 81.33% subjects in Group C achieved BCVA of 6/9 or better. BCVA achieved post-operatively in different grades of nuclear sclerosis was statistically comparable in three groups. (p > 0.05, Kruskal Wallis test). Best Corrected Near Visual Acuity (BCNVA) ofN6 was achieved by 86.67% patients in Group A, 83.33% patients in Group B and 84.67% patients in Group C which was statistically comparable in all the three groups (p > 0.05, Kruskal Wallis test).

Post-operative corneal oedema on was more in Group A (26%) followed by Group C (21.33%) then Group B (19.33%) but the difference was not statistically significant (p = 0.363, chi-square test). Mean IOP on POD 7 in Group A was 17.41 ± 2.45, in Group B was 17.32 ± 2.58 and in Group C was 17.97 ± 2.35. According to ANOVA test, there was no statistically significant difference in mean IOP values amongst the three groups (p = 0.134). Similarly, non-statistically significant results were obtained for IOP on the subsequent follow up days (p > 0.05, ANOVA test). The mean pre-operative and post-operative astigmatism (K_1-K_2; K_1 = flatter axis K_2 = steeper axis) in 450 cases was -0.94 ± 0.84 and -0.98 ± 0.91 respectively. On comparison, no statistically significant difference was observed between the two (p = 0.278, paired t-test).

In eyes where we were able to follow up the patients for long term, posterior segment complication of cystoid macular oedema was documented in 2 eyes, one from Group A and one from Group C. It was managed by administering thrice daily nepafenac 0.1% w/v eye drops. No incidence of retinal detachment was reported in any case.

A. BCVA analysis between three groups						
			Group A	Group B	Group C	P value (Kruskal Wallis test)
Post-operative BCVA 6/9 or better		POD7	72%	75.33%	72%	0.627 (NS)
POD30		82.67%	91.33%	83.33%	0.055 (NS)	
POD90		82.67%	91.33%	84%	0.063 (NS)	
POD180		82.67%	91.33%	84%	0.063 (NS)	
B. BCVA analysis in different grades of nuclear sclerosis in three groups						P value (Kruskal Wallis test)
Post-operative BCVA 6/9 or better	Grade 1	POD7	24%	25.33%	20.67%	0.193 (NS)
		POD180	24.67%	25.33%	22%	0.581 (NS)
	Grade 2	POD7	30.67%	28.67%	34.67%	0.341 (NS)
		POD180	33.33%	32.67%	34%	0.228 (NS)
	Grade 3	POD7	13.33%	15.33%	14%	0.773 (NS)
		POD180	18.67%	22%	19.33%	0.353 (NS)
	Grade 4	POD7	4%	6%	2.6%	0.057 (NS)
		POD180	6%	11.33%	7.33%	0.126 (NS)

Table 3: Visual Acuity analysis post-operatively.

Discussion

Only available management for cataract is surgical removal. Cataract surgery is one of the most common procedures done worldwide [17]. Amongst various cataract surgeries, phacoemulsification has become much more popular because advancements in techniques and equipment have increased the safety and efficiency of the procedure [6]. Less energy is delivered in phacoemulsification after adoption of nucleus disassembly strategies of phaco chop and divide and conquer [18]. Phaco-power modulation is another factor that has dramatically improved postoperative outcomes after phacoemulsification surgery. The main aim of phaco-power modulation is to disassemble the hardest of the nuclei with the least time and minimum energy possible which ultimately minimises its heat conversion and thermal damage. In this study, although not statistically significant, burst mode delivered more Ultra Sound Power (USP) as compared to pulse and continuous mode. Similarly, in a study conducted by Ozkurt YB., *et al*. [8] and Badoza D., *et al*. [16] statistically significantly higher ultrasound power was documented in burst mode as compared to other modes. In our study, the mean Effective Phacoemulsification Time was significantly longer in continuous mode as compared to pulse mode but there was no difference between continuous and burst mode as well as pulse and burst mode. If we compared the overall values then mean EPT was shorter in pulse mode as compared to the other two groups. Similar to our findings Baykara M., *et al*. [19] reported more surgical time in burst mode as compared to pulse mode. However contrary to this Ozkurt YB., *et al*. [8] and Badoza D., *et al*. [16] documented significantly shorter EPT in burst mode as compared to other modes. On comparing Cumulative Dissipated Energy (CDE) there was statistically more CDE in continuous mode as compared to other two modes, there was no statistically significant difference between pulse and burst mode, however, the least CDE was in pulse mode. Similar results were observed by Yang WJ., *et al*. [20] who compared CDE in conventional continuous mode and torsional-burst mode and they concluded that the CDE in continuous mode was significantly greater than the burst mode. By using same formula Ozkurt YB., *et al*. [8] calculated effective ultrasound time and Badoza D., *et al*. [16] calculated RUSE (Relative Ultra Sound Energy), however, the values were least in burst mode as compared to other modes. After comparing EPT and CDE in different grades of nuclear sclerosis we came to the conclusion that as the grade of nuclear sclerosis increases the EPT and CDE also increase i.e. harder the nuclei more time and energy is required for nuclear disassembly during phacoemulsification in all the three groups. On comparing the three groups we observed that in hard cataracts more time and energy was consumed in continuous mode as compared to other two modes, however no such difference was documented for softer cataracts. Hence by using phaco-power modulation, we can reduce EPT as well as CDE of phacoemulsification surgery. Based on above discussion it can be concluded that regardless of grade of nuclear sclerosis pulse is the most energy and time efficient mode.

BCVA improved over time in each group. Postoperative BCVA was found to be better in pulse mode followed by burst mode followed by continuous mode but there was no statistically significant difference amongst the three groups on each follow up day. In a study conducted by Ozkurt YB., *et al*. [8] VA measurements were significantly lower for burst mode as compared to continuous and pulse mode on post-operative day 1 and day 7, however, VA on month 1 and month 3 did not differ significantly amongst three groups. This finding is similar to our current study. Contrary to this, in a study conducted by Badoza D., *et al*. [16] compared pulse and burst mode by determining the post operative VA on day 1, 4 and 7. The mean VA on day 1 was higher in burst mode as compared to pulse mode but difference in these modes was not significant. There was no significant difference between them on postoperative day 4 and 7. In our study, final visual rehabilitation was better in pulse mode followed by burst mode then followed by continuous mode. Also, the BCVA stabilised earliest in pulse mode as compared to other modes.

Our study had more Corneal oedema in continuous mode followed by burst mode and then by pulse mode. In a study conducted by Ozkurt YB., *et al*. [8] found significantly more corneal oedema in burst mode where as Badoza D., *et al*. [16] documented higher incidence of corneal oedema in pulse mode. In our study corneal oedema was least in pulse mode which corresponds to mean EPT and mean CDE which were also minimum in pulse mode as mentioned earlier. We believe, this is why we observed better VA and earliest visual rehabilitation in pulse mode as compared to burst and continuous mode. From these findings we can also understand that in order to reduce postoperative corneal oedema and achieve clear corneas we must keep phacoemulsification time and cumulative dissipated energy to the minimum. This can only be achieved by phacoemulsification power-modulation.

Conclusion

From our study it can be fairly concluded that to achieve better visual outcomes the two most important factors during phacoemulsification surgery are the total energy dissipated into the eye and the time it takes to emulsify the nucleus (phaco time). These two factors are the function of power-modulation capability of new generation phaco machines. So, power-modulation becomes necessary in order to achieve clear corneas postoperatively and ultimately a good visual outcome. Based on the results in our study, when it comes to softer cataracts (Nuclear sclerosis - Grade 1 to 2), all the three modes work efficiently as there is no difference in time and energy consumed. However, in harder cataracts (Nuclear sclerosis Grade 3 to 4), continuous mode utilises significantly higher energy and takes more time so should not be preferred in those cases. Ultimately, phaco power-modulation is a tool which when used in adjunction with one's surgical skills can help a surgeon further refine his/her surgical outcomes.

Conflict of Interest

None.

Funding Source

None.

Ethics Statement

The study was approved by institutional Ethics Committee and Review Board.

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