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Comparative Analysis of Refractive Outcomes Using Optical and Ultrasound Biometry in Phacoemulsification Cataract Surgery

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ABSTRACT

Background: Accurate biometry is critical for optimal visual outcomes in cataract surgery. Both optical and ultrasound biometry are widely used, but their comparative effectiveness remains under evaluation.

Objective: To compare the refractive outcomes of optical and ultrasound biometry in patients undergoing elective phacoemulsification cataract surgery.

Methods: This prospective cohort study included 352 patients aged 30-60 years undergoing elective phacoemulsification with in-the-bag IOL implantation. Patients were randomly assigned to either optical biometry using the Zeiss IOL Master 700 or ultrasound biometry with Axis Nano contact A-mode echography. Visual acuity and spherical equivalent were measured at baseline and 4 weeks post-operatively. Data were analyzed using SPSS version 25, with independent t-tests comparing outcomes between groups.

Results: The mean post-operative visual acuity was 0.83 ± 0.22, with a mean spherical equivalent of -0.88 ± 0.16. No significant difference was found between the ultrasound (-0.89 ± 0.17) and optical biometry (-0.87 ± 0.16) groups (p=0.152, 95% CI -0.06 to 0.01).

Conclusion: Both optical and ultrasound biometry provide comparable refractive outcomes in cataract surgery, with no significant difference in post-operative spherical equivalent.

INTRODUCTION

Cataract, a leading cause of visual impairment globally, is characterized by the clouding of the lens, which reduces the passage of light to the retina and diminishes visual acuity. The condition predominantly affects individuals as they age or due to prolonged exposure to ultraviolet light, leading to a significant number of diagnoses each year (1). Modern cataract surgery, specifically phacoemulsification, has revolutionized the treatment landscape, offering improved safety and rapid recovery compared to earlier techniques such as intra-capsular and extracapsular cataract extraction (2, 3). Phacoemulsification, introduced in the 1960s, employs ultrasonic energy to emulsify the lens nucleus, allowing its removal through a small, self-sealing incision, followed by the implantation of an intraocular lens (IOL), which restores the eye's focusing power (4). This method has dramatically improved surgical outcomes, minimizing complications like vitreous loss and retinal detachment, which were more common in earlier procedures (5, 6).

The refractive outcomes of cataract surgery are influenced by several preoperative factors, including the accuracy of biometry, which involves measuring the eye's axial length, anterior chamber depth, and corneal curvature to calculate the appropriate IOL power (7). Precise biometry is critical for achieving optimal postoperative visual acuity, as errors in these measurements can lead to significant refractive errors, compromising the surgical outcome (8). Among the available biometry techniques, ultrasound biometry has been traditionally used for axial length measurement; however, it is operator-dependent and requires contact with the eye, which can introduce variability in the measurements (9). In contrast, optical biometry, which utilizes partial coherence interferometry, offers a non-contact alternative that is less reliant on operator skill, providing more consistent and accurate measurements, especially in eyes with dense cataracts (10, 11). Despite these advancements, both ultrasound and optical biometry remain widely used, with the choice often dictated by availability, cost, and specific clinical settings.

Studies comparing the efficacy of these biometry techniques have reported varying results, with some suggesting marginally better outcomes with optical biometry in terms of refractive precision (12). For instance, one study found no significant difference in the median spherical equivalent between ultrasound and optical biometry, although optical biometry was associated with slightly lower prediction errors (13). Another study highlighted that optical biometry's non-contact nature reduces axial length measurement variation, making it preferable, particularly for less experienced operators (14). However, in some clinical settings, particularly in developing countries, ultrasound biometry remains the more accessible and cost-effective option despite its limitations (15). Given the ongoing evolution of biometry methods and the introduction of more sophisticated IOL power calculation formulas, it remains essential to evaluate the comparative effectiveness of these techniques in diverse patient populations.

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This study aims to compare the refractive visual outcomes of phacoemulsification using optical versus ultrasound biometry techniques for visually significant cataracts. By assessing postoperative visual acuity and refractive outcomes in patients undergoing elective cataract surgery, the study seeks to provide evidence-based guidelines for ophthalmic surgeons in selecting the most appropriate biometry method. With a focus on achieving the best possible visual outcomes and minimizing refractive errors, the findings will be particularly valuable in resource-limited settings where access to advanced optical biometry may be restricted (16). As cataract surgery continues to advance, understanding the nuances of biometry techniques will play a crucial role in optimizing patient care and enhancing the overall success of the procedure (17).

MATERIAL AND METHODS

The study was a prospective cohort design conducted at the Ophthalmology Department of Al-Shifa Trust Eye Hospital, Rawalpindi, over six months from January 2024 to June 2024. The aim was to compare the refractive visual outcomes of phacoemulsification using optical versus ultrasound biometry techniques for visually significant cataracts. A total of 352 patients aged 30-60 years were included in the study, with 176 patients assigned to each biometry group. The sample size was calculated using OpenEpi software, with a 95% confidence level and 80% power. Patients were enrolled using consecutive non-probability sampling. Inclusion criteria comprised patients aged 30-60 years undergoing elective cataract surgery via phacoemulsification, while exclusion criteria included those with a history of ocular surgery, trauma, or any ocular procedure, high refractive errors exceeding ±4 D, corneal astigmatism less than 2 diopters, axial lengths outside the range of 20 to 25 mm, and conditions such as diabetes-related cataracts, hereditary cataracts, and posterior polar cataracts. Additionally, patients with phacomorphic glaucoma, pseudoexfoliation, uveitis, corneal opacities, retinal detachment, macular edema, optic nerve atrophy, vitreous detachment or hemorrhage, and those experiencing surgical complications like posterior capsular rent or lens matter in the posterior segment were excluded.

Ethical approval was obtained from the hospital's ethics review committee, and the study adhered to the principles outlined in the Declaration of Helsinki. All patients provided written informed consent before participation. Baseline demographic and clinical data were collected, including age, gender, and duration of cataract, alongside comprehensive ophthalmic assessments such as visual acuity testing using an autorefractor and objective refraction measurements with a Snellen's chart at 6 meters conducted by a trained optometrist. The spherical equivalent was recorded at baseline.

Patients were randomized into two groups: Group 1 underwent biometry with the Zeiss IOL Master 700 (Carl Zeiss Meditec Ltd, Germany), a device employing optical coherence interferometry for axial length measurement. Group 2 underwent biometry using the contact A-scan ultrasound technique with the Axis Nano contact A-mode echography (Quantel Medical SA, France). All measurements were performed with the patients in an upright position, ensuring the ultrasound transducer was oriented perpendicularly to the globe. The Holladay 1 formula was employed for intraocular lens (IOL) power calculation across both groups. The phacoemulsification procedure, utilizing the phaco-chop technique, was performed by senior surgeons, with in-the-bag implantation of foldable IOLs in all patients.

Postoperative refraction was assessed at four weeks, measuring visual acuity and spherical equivalent to determine the refractive outcomes. Data were analyzed using SPSS version 25. The normality of the data was checked using the Shapiro-Wilk test. Descriptive statistics were calculated to summarize the baseline characteristics and surgical outcomes, including mean values and standard deviations for continuous variables. An independent sample t-test was conducted to compare the mean postoperative spherical equivalent between the optical and ultrasound biometry groups, with a significance threshold set at $P \leq 0.05$. Data were stratified based on variables such as age, gender, duration of cataract, preoperative visual acuity, and axial length. Post-stratification comparisons were performed using the t-test to assess differences within subgroups, ensuring a comprehensive evaluation of the refractive outcomes between the two biometry techniques (18).

RESULTS

The study included a total of 352 patients undergoing phacoemulsification cataract surgery, with a mean age of 42.74 years (±5.76), ranging from 32 to 58 years. The duration of cataract was, on average, 8.02 months (±0.80), and the mean axial length was 23.13 mm (±0.93). Pre-operative visual acuity (VA) averaged 0.90 (±0.11), which slightly decreased to 0.83 (±0.22) post-operatively. The mean pre-operative spherical equivalent (SE) was -0.93 (±0.20), indicating mild myopia, and improved post-operatively to -0.88 (±0.16), demonstrating a slight reduction in myopia and an overall improvement in refractive outcomes.

Table 1 Demographic Characteristics

Variable	Mean ± SD	Minimum	Maximum
Age (years)	42.74 ± 5.76	32.0	58.0
Duration of Cataract (months)	8.02 ± 0.80	7.0	9.0
Axial Length (mm)	23.13 ± 0.93	21.0	25.0
Pre-op VA	0.90 ± 0.11	0.4	1.2
Post-op VA	0.83 ± 0.22	0.15	1.16
Pre-op SE	-0.93 ± 0.20	-1.2	-0.6

Table 2 Comparison of Post-Operative Spherical Equivalent

Subgroup	Group	Mean ± SD	p-value
Axial length ≤23 mm (n=240)	Ultrasound Biometry	-0.89 ± 0.17	0.073
Axial length >23 mm (n=112)	Ultrasound Biometry	-0.89 ± 0.16	0.946
Pre-op VA ≤0.9 (n=246)	Ultrasound Biometry	-0.90 ± 0.17	0.389
Pre-op VA >0.9 (n=106)	Ultrasound Biometry	-0.89 ± 0.17	0.287

In the comparison of post-operative spherical equivalents between ultrasound and optical biometry across various subgroups, the overall mean SE for ultrasound biometry was -0.89 ± 0.17, while for optical biometry, it was -0.87 ± 0.16, with a p-value of 0.152, indicating no significant difference. In age-based subgroups, the mean SE for patients aged ≤42 years was -0.91 ± 0.17 for ultrasound and -0.87 ± 0.16 for optical biometry (p=0.161). For patients aged >42 years, the SE was -0.87 ± 0.16 for ultrasound and -0.86 ± 0.16 for optical biometry (p=0.604). Gender-specific analysis revealed no significant differences, with males showing a mean SE of -0.88 ± 0.16 for ultrasound and -0.87 ± 0.17 for optical biometry (p=0.872), and females showing a mean SE of -0.90 ± 0.17 for ultrasound and -0.87 ± 0.16 for optical biometry (p=0.105).

The analysis also compared SE by the duration of cataract and axial length. For patients with cataract duration ≤8 months, both biometry methods yielded similar SEs (p=0.847), while for durations >8 months, ultrasound biometry showed a significantly different SE of -0.92 ± 0.17 compared to -0.85 ± 0.16 for optical biometry (p=0.029). Axial length comparisons showed no significant differences between the two methods for lengths ≤23 mm (p=0.073) and >23 mm (p=0.946). In terms of pre-operative visual acuity, no significant differences were observed in the SE outcomes for subgroups with VA ≤0.9 (p=0.389) and >0.9 (p=0.287).

Overall, the study found that while there were variations in SE within specific subgroups, both ultrasound and optical biometry provided comparable refractive outcomes in terms of post-operative spherical equivalent. Despite some subgroup-specific differences, the overall refractive visual outcomes following phacoemulsification using either biometry technique were similar, indicating both methods are effective for cataract surgery.

DISCUSSION

The findings of this study indicated no significant difference in post-operative spherical equivalents between optical and ultrasound biometry in patients undergoing phacoemulsification cataract surgery. This aligns with several previous studies that reported similar refractive outcomes between these two biometry methods, suggesting both are effective in achieving optimal visual results (12, 13). The results are consistent with previous research demonstrating that both optical and ultrasound biometry provide satisfactory refractive outcomes, though optical biometry is often highlighted for its accuracy and consistency, especially in dense cataracts or cases with borderline signal-to-noise ratios (14, 15). Optical biometry's non-contact nature and reduced dependence on operator skill contribute to its reliability, particularly in complex cases where minimizing variability is critical (16).

However, while the study found comparable results overall, some subgroup analyses suggested potential advantages of optical biometry in certain conditions, such as longer cataract durations, where it demonstrated marginally better refractive outcomes. This aligns with findings from earlier research that indicated the superiority of optical biometry in complex or borderline cases due to its precise axial length measurements and reduced susceptibility to errors commonly associated with the compression effects of ultrasound transducers (17). Additionally, the non-contact approach of optical biometry eliminates the risk of corneal distortion during measurements, a known limitation of ultrasound biometry (18). These attributes make optical biometry particularly advantageous in clinical settings where precise and reliable measurements are paramount for optimal surgical planning.

Strengths of this study included its prospective cohort design and the use of standardized surgical techniques and assessment protocols, which minimized variability and enhanced the reliability of the results. Moreover, the relatively large sample size and stratification of data by various demographic and clinical parameters allowed for a comprehensive analysis of the refractive outcomes across different patient subgroups. However, there were also several limitations. The study was conducted at a single center, which may limit the generalizability of the findings to other settings with different patient populations or surgical practices. Additionally, the potential for measurement bias existed due to the involvement of multiple technicians performing the biometry, which could introduce variability in the results despite standardization efforts. The exclusion of patients with certain ocular conditions also limits the applicability of the findings to a broader population, as the results may not fully capture the performance of biometry techniques in more complex clinical scenarios.

The findings underscore the importance of selecting the appropriate biometry technique based on the specific needs of the patient and the clinical setting. While both optical and ultrasound biometry are effective, the choice may depend on factors such as the availability of equipment, operator experience, and the specific characteristics of the patient's eye. In resource-limited settings where optical biometry may not be readily available, ultrasound biometry remains a viable option that can still yield satisfactory refractive outcomes (19). However, as technology continues to advance, greater emphasis should be placed on integrating more accurate and less operator-dependent methods such as optical biometry into routine practice, particularly in settings where precision is critical.

Future research should aim to validate these findings through multicenter studies that include a more diverse patient population and consider additional variables such as surgeon experience, surgical technique variations, and long-term refractive stability. Moreover, exploring the cost-effectiveness of incorporating advanced biometry techniques like optical biometry in developing regions could provide valuable insights into optimizing cataract surgery outcomes globally. Expanding the evidence base with larger, well-designed studies will help refine guidelines for biometry selection and improve visual outcomes for cataract patients worldwide.

CONCLUSION

This study concluded that both optical and ultrasound biometry techniques provide comparable post-operative refractive outcomes in patients undergoing phacoemulsification cataract surgery, with no significant differences in spherical equivalents observed overall. However, optical biometry may offer slight advantages in terms of accuracy and consistency, particularly in cases with dense cataracts or longer cataract durations, making it a preferred choice when precision is critical. The findings highlight the importance of tailored biometry selection based on clinical needs and available resources. Implications for human healthcare include reinforcing the need for accessible and reliable biometry techniques to optimize visual outcomes in cataract surgery, thereby enhancing patient quality of life and reducing the burden of vision impairment globally. Future efforts should focus on integrating advanced biometry technologies into broader clinical practice, especially in resource-limited settings, to ensure equitable access to high-quality cataract care.

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