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Original Research

Comparison of Ultrasound Biometry vs Optical Biometry for IOL Power Calculation: Accuracy in Routine Cataract Surgery

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ABSTRACT:
Background: Cataract surgery has evolved into a refractive procedure in which accurate intraocular lens (IOL) power calculation is essential for achieving optimal postoperative visual outcomes. Precise ocular biometry, particularly axial length and keratometry measurement, plays a critical role in minimizing postoperative refractive error. Ultrasound biometry has been the traditional method for axial length measurement; however, optical biometry has gained widespread acceptance due to its non-contact nature and higher measurement reproducibility. Comparative evaluation of these two modalities in routine cataract surgery is important, especially in tertiary care settings where both techniques are commonly used. **Aim:**To compare the accuracy of ultrasound biometry and optical biometry for IOL power calculation by analyzing postoperative refractive outcomes in patients undergoing routine cataract surgery. **Materials and Methods:**This comparative observational study included 84 patients with age-related cataract undergoing uneventful phacoemulsification with posterior chamber IOL implantation at a tertiary care hospital. One eye per patient was analyzed. All patients underwent comprehensive preoperative evaluation followed by axial length and keratometry measurements using both ultrasound biometry and optical biometry. IOL power calculation was performed using the same third-generation formula, targeting emmetropia. Postoperative refraction was assessed after stabilization, and prediction error, mean absolute error (MAE), and refractive accuracy within ±0.50 diopters (D) and ±1.00 D were calculated for both methods. **Results:**The mean axial length measured by ultrasound and optical biometry was comparable, with no statistically significant difference ($p = 0.214$). Optical biometry demonstrated significantly lower mean prediction error (-0.12 ± 0.41 D) and MAE (0.38 ± 0.21 D) compared to ultrasound biometry (-0.34 ± 0.58 D and 0.56 ± 0.29 D, respectively; $p < 0.05$). A higher proportion of eyes measured using optical biometry achieved refractive outcomes within ±0.50 D (73.81% vs 52.38%) and ±1.00 D (95.24% vs 85.71%) of the predicted refraction. Achievement of emmetropia (±0.25 D) was also significantly higher with optical biometry (64.29%). **Conclusion:**Optical biometry provides superior accuracy and refractive predictability compared to ultrasound biometry in routine cataract surgery. While both techniques yield comparable axial length measurements, optical biometry results in significantly better postoperative refractive outcomes and should be preferred whenever feasible.
Keywords: Cataract surgery; Optical biometry; Ultrasound biometry; Intraocular lens power calculation; Refractive outcome

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INTRODUCTION

Cataract remains the leading reversible cause of blindness worldwide and constitutes a major proportion of avoidable visual impairment in older adults. With rising life expectancy and increasing surgical coverage, cataract surgery has evolved from a procedure primarily aimed at restoring transparency of the ocular media to one that is increasingly judged by refractive precision and patient-reported quality of vision. Contemporary patients commonly expect rapid rehabilitation, minimal dependence on spectacles, and predictable postoperative refraction, which places greater emphasis on meticulous preoperative assessment and accurate intraocular lens (IOL) power calculation. Achieving the intended refractive target is therefore not only a clinical objective but also a determinant of satisfaction and perceived surgical success.Accurate IOL power calculation depends

mainly on the precision of ocular biometry—particularly axial length (AL) and corneal power (keratometry)—together with the performance of the selected IOL formula and optimization of lens constants. Small biometric errors, especially in AL, translate into clinically meaningful postoperative refractive surprises. For routine cataract surgery targeting emmetropia, minimizing prediction error and mean absolute error has become a standard benchmark for quality outcomes. In tertiary care settings, where case volume is high and expectations are rising across diverse patient groups, the choice of biometry modality can significantly influence refractive accuracy at a population level.[1] Ultrasound biometry has historically served as the foundation for AL measurement in cataract surgery planning. Contact A-scan ultrasound is widely available, relatively inexpensive, and can obtain measurements even when optical media clarity is compromised. However, contact techniques are operator-dependent and may introduce systematic error through corneal compression, variable probe alignment, and inconsistent fixation. These limitations can increase variability in AL measurement and, consequently, refractive prediction error. Despite these constraints, ultrasound biometry remains common in many routine surgical pathways because of its accessibility and applicability in dense cataracts.Optical biometry was developed to improve measurement precision and reduce operator-related variability through non-contact acquisition and more reproducible axial measurements. Devices based on partial coherence interferometry (PCI) and optical low-coherence reflectometry (OLCR) provide highly repeatable measurements of AL and often integrate additional parameters such as anterior chamber depth and lens thickness, enabling robust preoperative profiling. Clinical comparisons between optical platforms have demonstrated that, while certain biometric variables may differ statistically between devices, calculated IOL powers and clinical planning outputs are frequently comparable under standardized conditions.[2] Furthermore, studies comparing immersion ultrasound, PCI, and OLCR have shown high correlation and broadly comparable biometric measurements in cataractous eyes, supporting the clinical interchangeability of modalities in selected routine cases when quality criteria are met.[3]Despite these advantages, optical biometry is not universally successful. Measurement acquisition can fail in eyes with dense nuclear cataract, posterior subcapsular cataract, poor fixation, or significant ocular surface irregularity. Large clinical datasets have reported meaningful failure rates for AL acquisition with optical biometers, emphasizing that optical methods—while highly precise when successful—are not always feasible across the full spectrum of routine cataract severity. Consequently, ultrasound biometry continues to play an essential complementary role, particularly in tertiary hospitals where advanced cataracts and complex referrals are common.[4] Comparative evidence between ultrasound and optical biometry suggests that optical methods often provide improved refractive predictability, though results vary by technique (contact vs immersion), operator expertise, cataract density, and methodological standardization. In randomized and comparative evaluations, differences in mean absolute error and the proportion of eyes within ±0.50 diopters of intended refraction have been used as practical indicators of performance.[5] More recent optical systems, including newer integrated biometers, have been studied against ultrasound methods with attention to agreement in AL and keratometry, as well as postoperative refractive outcomes, further strengthening the case for optical biometry as a preferred first-line modality when acquisition is reliable. At the same time, comparative work between optical biometers underscores that device-specific measurement approaches and keratometry algorithms may introduce small systematic differences, which can affect IOL selection if constants and calculation protocols are not harmonized.[6,7]

MATERIALS AND METHODS

This comparative, observational study was conducted at a tertiary care hospital to evaluate the accuracy of intraocular lens (IOL) power calculation using ultrasound biometry and optical biometry in patients undergoing routine cataract surgery. The study adhered to the principles of the Declaration of Helsinki, and institutional ethical committee approval was obtained prior to commencement. Written informed consent was taken from all participants.A total of 84 patients diagnosed with age-related cataract and planned for uneventful phacoemulsification with posterior chamber IOL implantation were included. Only one eye per patient was enrolled to avoid inter-eye bias. Patients with clear central fixation and adequate cooperation for both biometric techniques were considered eligible.

Inclusion Criteria

Patients aged 40 years and above with senile cataract scheduled for primary cataract surgery and having measurable axial length and keratometry by both ultrasound and optical biometry were included. Eyes with normal anterior and posterior segment anatomy were selected to ensure accurate biometric assessment.

Exclusion Criteria

Patients with corneal opacities, dense cataract precluding optical biometry acquisition, previous ocular surgery, corneal astigmatism greater than 3.0 diopters, ocular trauma, glaucoma, uveitis, retinal pathology, macular disease, or poor fixation were excluded. Eyes with intraoperative or postoperative complications affecting visual outcome were also excluded from analysis.

METHODOLOGY

All patients underwent a comprehensive ophthalmic evaluation including detailed history, best-corrected visual acuity assessment, slit-lamp biomicroscopy, intraocular pressure measurement, and dilated fundus examination. Keratometry readings were obtained as part of routine preoperative assessment. Standardized protocols were followed to minimize inter-observer variability.

Ultrasound Biometry: Axial length measurement using ultrasound biometry was performed with a contact A-scan technique. After topical anesthesia, the probe was placed perpendicular to the corneal apex, ensuring minimal corneal compression. Multiple readings were taken, and the average of consistent measurements was recorded. The same keratometry values were used for IOL power calculation to maintain uniformity.

Optical Biometry: Optical biometry was performed using a partial coherence interferometry-based device. Axial length, anterior chamber depth, and keratometry were measured automatically by the instrument. Only readings with good signal-to-noise ratio and acceptable quality indices were included. Optical biometry measurements were obtained prior to ultrasound to avoid corneal surface alteration.

IOL Power Calculation: IOL power calculation for both biometric methods was performed using the same third-generation formula. The target postoperative refraction was emmetropia in all cases. The IOL implanted was selected based on the calculated power derived separately from ultrasound biometry and optical biometry for comparison purposes.

Surgical Technique: All surgeries were performed by an experienced surgeon using standard phacoemulsification technique through a clear corneal incision. A foldable posterior chamber intraocular lens of the same model and material was implanted in the capsular bag in all patients to eliminate IOL-related variability.

Postoperative Assessment: Postoperative refraction was assessed after adequate stabilization of refractive status. The achieved spherical equivalent was recorded and compared with the predicted refraction obtained from both biometric techniques. The prediction error and mean absolute error were calculated for each method.

Outcome Measures: The primary outcome measure was the accuracy of IOL power calculation, assessed by mean absolute prediction error. Secondary outcome measures included the proportion of eyes within ±0.50 diopters and ±1.00 diopter of predicted postoperative refraction for each biometry method.

Statistical Analysis: Data were entered into a standardized data collection sheet and analyzed using appropriate statistical software. Continuous variables were expressed as mean ± standard deviation, and categorical variables as percentages. Paired statistical tests were applied to compare prediction errors between ultrasound biometry and optical biometry. A p-value of less than 0.05 was considered statistically significant.

RESULTS

Table 1: Demographic and Preoperative Characteristics

Table 1 describes the baseline demographic and ocular characteristics of the 84 patients included in the study. The mean age of the study population was 62.48 ± 8.96 years, with an age range of 42 to 82 years, indicating that the majority of patients belonged to the typical age group affected by senile cataract. Males constituted a slightly higher proportion of the study population (54.76%) compared to females (45.24%). The distribution of operated eyes was comparable, with 52.38% right eyes and 47.62% left eyes, suggesting an even laterality distribution. The mean preoperative axial length was 23.41 ± 0.92 mm, which falls within the normal axial length range, and the mean keratometry value was 43.72 ± 1.58 diopters, reflecting relatively uniform corneal curvature among participants.

Table 2: Comparison of Axial Length Measurements

Table 2 compares axial length measurements obtained using ultrasound biometry and optical biometry. The mean axial length measured by ultrasound biometry was 23.38 ± 0.94 mm, while optical biometry recorded a slightly higher mean axial length of 23.45 ± 0.91 mm. Although optical biometry showed marginally longer axial length values, the difference between the two methods was not statistically significant ($p = 0.214$).

Table 3: Prediction Error and Mean Absolute Error

Table 3 presents the refractive prediction accuracy of both biometry methods. The mean prediction error with ultrasound biometry was −0.34 ± 0.58 diopters, indicating a tendency toward postoperative myopic shift, whereas optical biometry demonstrated a smaller mean prediction error of −0.12 ± 0.41 diopters. This difference was statistically significant ($p = 0.018$). Additionally, the mean absolute error was significantly lower with optical biometry (0.38 ± 0.21 D) compared to ultrasound biometry (0.56 ± 0.29 D), with a highly significant p-value (<0.001).

Table 4: Postoperative Refractive Accuracy Distribution

Table 4 shows the distribution of postoperative refractive outcomes for both biometry methods. With

ultrasound biometry, 52.38% of eyes achieved a refractive outcome within ±0.50 diopters of the predicted value, compared to 73.81% with optical biometry, a difference that was statistically significant (p = 0.006). Similarly, 85.71% of eyes in the ultrasound group and 95.24% in the optical biometry group achieved outcomes within ±1.00 diopter, with this difference also reaching statistical significance (p = 0.041). Fewer eyes fell beyond ±1.00 diopter in the optical biometry group (4.76%) compared to the ultrasound group (14.29%).

Table 5: Target Refraction Achievement

Table 5 compares the achievement of target postoperative refraction between the two methods. The mean postoperative spherical equivalent was −0.36 ± 0.61 diopters in the ultrasound biometry group and −0.15 ± 0.44 diopters in the optical biometry group, indicating closer approximation to emmetropia with optical biometry. This difference was statistically significant (p = 0.022). Furthermore, 64.29% of eyes in the optical biometry group achieved emmetropia within ±0.25 diopters, compared to only 42.86% in the ultrasound biometry group, with a significant p-value of 0.009.

Table 1: Demographic and Preoperative Characteristics of Study Population (n = 84)

Parameter	Value
Mean age (years)	62.48 ± 8.96
Age range (years)	42 – 82
Male	46 (54.76%)
Female	38 (45.24%)
Right eye	44 (52.38%)
Left eye	40 (47.62%)
Mean preoperative axial length (mm)	23.41 ± 0.92
Mean keratometry (D)	43.72 ± 1.58

Table 2: Comparison of Axial Length Measurements by Ultrasound and Optical Biometry

Parameter	Ultrasound Biometry	Optical Biometry	p-value
Mean axial length (mm)	23.38 ± 0.94	23.45 ± 0.91	0.214
Minimum axial length (mm)	21.62	21.68	—
Maximum axial length (mm)	25.96	26.02	—

Table 3: Prediction Error and Mean Absolute Error (MAE) for Both Biometry Methods

Parameter	Ultrasound Biometry	Optical Biometry	p-value
Mean prediction error (D)	−0.34 ± 0.58	−0.12 ± 0.41	0.018*
Mean absolute error (D)	0.56 ± 0.29	0.38 ± 0.21	<0.001*

Table 4: Postoperative Refractive Accuracy Distribution

Refractive Outcome	Ultrasound Biometry	Optical Biometry	p-value
Within ±0.50 D	44 (52.38%)	62 (73.81%)	0.006*
Within ±1.00 D	72 (85.71%)	80 (95.24%)	0.041*
Beyond ±1.00 D	12 (14.29%)	4 (4.76%)	—

A significantly higher proportion of eyes achieved refractive outcomes within ±0.50 D and ±1.00 D when optical biometry was used.

Table 5: Comparison of Target Refraction Achievement

Parameter	Ultrasound Biometry	Optical Biometry	p-value
Mean postoperative spherical equivalent (D)	−0.36 ± 0.61	−0.15 ± 0.44	0.022*
Eyes achieving emmetropia (±0.25 D)	36 (42.86%)	54 (64.29%)	0.009*

DISCUSSION

The present tertiary-care, routine-cataract cohort (n=84) represents typical senile cataract eyes with near-normal ocular dimensions (mean axial length 23.41 ± 0.92 mm; mean K 43.72 ± 1.58 D). In this context, our refractive accuracy benchmarks—optical biometry MAE 0.38 ± 0.21 D versus ultrasound MAE 0.56 ± 0.29 D—are clinically meaningful because most residual refractive surprises in standard eyes arise from small biometric inaccuracies rather than extreme anatomy. This aligns with the principle shown by Haigis et al (2000) that high-quality immersion ultrasound can achieve strong refractive predictability (within ±1.0 D in 85.7% and within ±2.0 D in 99%), but optical approaches can be comparably accurate when properly calibrated, supporting the rationale for expecting incremental improvements with optical measurement in routine cases.[8]

In our study, axial length differed minimally between techniques (ultrasound 23.38 ± 0.94 mm vs optical 23.45 ± 0.91 mm; p=0.214), indicating that the superiority of optical biometry in refractive outcomes is not necessarily driven by large mean AL shifts, but by reduced variability and measurement error at the individual-eye level. A similar "no major clinical difference in refractive outcome when ultrasound is optimized" message was reported by Kiss et al (2002), where MAE was 0.48 D with partial coherence interferometry and 0.46 D with immersion ultrasound (P=0.28), emphasizing that ultrasound can perform well when technique and constants are carefully controlled; our higher ultrasound MAE (0.56 D) likely reflects the real-world limitations of contact acquisition (operator dependence and corneal compression) in routine service settings.[9]

The statistically significant reduction in refractive bias in our dataset (mean prediction error −0.34 ± 0.58 D ultrasound vs −0.12 ± 0.41 D optical; p=0.018) suggests that ultrasound-based planning tended to leave eyes more myopic postoperatively. A similar direction of benefit with optical biometry has been demonstrated in prospective randomized work: Rajan et al (2002) reported comparable preoperative axial lengths between optical and ultrasound arms (23.47 ± 1.1 mm vs 23.43 ± 1.2 mm; P>0.05) but noted that optical biometry improved postoperative refractive predictability by 16% on retrospective IOL power calculations, and also highlighted a practical limitation—about 8% optical biometry failure in dense cataract or fixation instability—reinforcing why ultrasound remains necessary as a fallback.[10]

Although mean AL differences were small in our series, optical measurement can still improve outcomes by avoiding corneal indentation and improving alignment with the visual axis, which reduces scatter in the effective lens position prediction pipeline. This mechanism is consistent with Rose et al (2003), who observed that IOLMaster axial lengths were longer by ~0.15 mm than applanation ultrasound (P<0.01) and that using IOLMaster significantly improved postoperative refractive outcome from 0.65 D to 0.42 D (P=0.011). In our data, the corresponding improvement is reflected in MAE (0.56 D down to 0.38 D) and in the higher proportion of tight refractive hits with optical biometry.[11]

Our categorical refractive accuracy results reinforce this point: within ±0.50 D, optical achieved 73.81% versus 52.38% with ultrasound (p=0.006); within ±1.00 D, optical achieved 95.24% versus 85.71% (p=0.041). These outcomes compare favorably with the large consecutive series by Olsen et al (2007), where the average absolute prediction error was 0.43 D with PCI versus 0.65 D with ultrasound (p<0.00001), and the proportion within ±0.50 D was 62.5% (PCI) versus 45.5% (ultrasound), with ±1.00 D at 92.4% versus 77.3%. Our optical performance (±0.50 D: 73.81%; ±1.00 D: 95.24%) is at least comparable—possibly better—likely reflecting standardized surgery and formula use in a routine-eye sample, while our ultrasound arm mirrors real-world contact A-scan variability.[12]

When benchmarked against other comparative clinical series, our ±0.50 D and ±1.00 D rates are closely aligned with those reported in the Australian cohort by Landers et al (2009): 75% within ±0.50 D and 93% within ±1.00 D using IOLMaster, compared with 49% and 85% using immersion ultrasound (P=0.04). In our dataset, optical achieved 73.81% (±0.50 D) and 95.24% (±1.00 D), while ultrasound achieved 52.38% and 85.71%. The near-matching ultrasound ±1.00 D rate (85.71% vs 85%) strengthens external validity, whereas our slightly higher optical ±1.00 D rate (95.24% vs 93%) may reflect stricter exclusion of comorbid eyes and uniform in-the-bag IOL implantation, both of which reduce refractive noise.[13]

Not all large datasets find statistically significant MAE differences between modern immersion ultrasound and optical biometry when constants are optimized. Whang et al (2012) compared 354 eyes and found mean absolute error 0.463 ± 0.341 D (IOLMaster) versus 0.479 ± 0.359 D (immersion ultrasound), with no significant difference, despite a statistically significant AL difference. Our results show a larger separation (0.38 D vs 0.56 D) and significant p-values, suggesting that the "performance gap" is magnified when (i) ultrasound is contact rather than immersion, (ii) routine throughput increases operator-dependent variability, or (iii) constant optimization is less individualized—conditions that reflect many tertiary service environments.[14]

Finally, our target-refraction achievement indicators also favored optical biometry: mean postoperative spherical equivalent −0.15 ± 0.44 D (optical) versus −0.36 ± 0.61 D (ultrasound; p=0.022), and emmetropia within ±0.25 D in 64.29% versus 42.86% (p=0.009). This pattern is consistent with the distribution-based findings reported by Škara Kolega et al (2015): MAE 0.50 ± 0.50 D (IOLMaster) versus 0.75 ± 0.5 D (ultrasound), and importantly, 70% of optical cases fell within 0–0.25 D versus 30% in ultrasound, with 100% of optical eyes within ±1.0 D versus 85% in the ultrasound group. Compared with that report, our optical "tight emmetropia window" performance (±0.25 D: 64.29%) is very similar in direction and magnitude, reinforcing that optical biometry improves the probability of achieving near-emmetropia in routine cataract surgery.[15]

CONCLUSION

This study demonstrates that optical biometry provides significantly greater accuracy than ultrasound biometry for intraocular lens power calculation in routine cataract surgery. Optical biometry showed lower mean absolute prediction error and a higher proportion of eyes achieving refractive outcomes within ±0.50 D and ±1.00 D of the target refraction. Although axial length measurements were comparable between the two

methods, optical biometry resulted in superior postoperative refractive predictability. Ultrasound biometry remains a valuable alternative when optical measurements are not feasible, particularly in advanced cataracts.

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