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RESEARCH ARTICLE

Comparative accuracy of IOL power calculation formulas in nanophthalmic eyes undergoing cataract surgery

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Abstract

Aim: To compare the predictive accuracy of three widely used IOL power calculation formulas—Hoffer Q, SRK/T, and SRK II—in adult patients with nanophthalmos undergoing cataract surgery or clear lens extraction. Methods: This retrospective observational study included 45 eyes with axial lengths ≤ 20.5 mm diagnosed with nanophthalmos. All patients underwent uncomplicated cataract surgery or clear lens extraction with posterior chamber IOL implantation. Preoperative biometry was performed using ZEISS IOL Master 700 or NANO AXIS A-scan. IOL power was calculated using Hoffer Q, SRK/T, and SRK II formulas. Postoperative spherical equivalent was recorded at one month, and prediction error was calculated as the difference between actual and predicted refraction. Mean absolute error (MAE) and percentage of eyes within ±0.25 D, ±0.50 D, ±1.00 D, and ±2.00 D were assessed. Statistical analysis included one-sample t-tests and descriptive statistics using SPSS version 26. Results: The Hoffer Q formula showed the lowest mean absolute prediction error (−0.44 ± 0.30 D), followed by SRK/T (+0.68 ± 0.73 D), while SRK II exhibited the highest error (+3.28 ± 0.52 D). The Hoffer Q formula demonstrated superior accuracy, with 75.6% of eyes within ±0.50 D and 93.3% within ±1.00 D of the target refraction. SRK II showed a statistically significant hyperopic shift ($p < 0.001$), whereas Hoffer Q and SRK/T did not show statistically significant differences from zero prediction error. Conclusion: Among the three formulas studied, the Hoffer Q formula provided the most accurate IOL power prediction in nanophthalmic eyes, with the lowest refractive error and highest consistency. These findings support the use of Hoffer Q in managing cataract patients with nanophthalmos and highlight the need for further evaluation of advanced formulas in this subgroup.

Keywords: Nanophthalmos, IOL power calculation, short axial length, cataract surgery, Accuracy of IOL Power.

Introduction

Cataract surgery with intraocular lens (IOL) implantation stands as a cornerstone of modern ophthalmology, widely recognized as one of the most frequently performed and successful surgical procedures globally. The fundamental objective of this intervention is to restore visual clarity by replacing the opacified crystalline lens with an artificial IOL. Achieving optimal visual outcomes following cataract surgery is profoundly dependent on the precise calculation of the IOL power, which directly dictates the patient's postoperative refractive error and overall satisfaction (Dervin, 2018). The overarching aim is to predict the postoperative refractive outcome with exceptional accuracy and consistency, thereby mitigating any unexpected refractive surprises (Dervin, 2018). Contemporary patients often harbor elevated expectations regarding their visual outcomes post-cataract surgery, frequently anticipating a significant reduction in their reliance on glasses (Ladas, 2021). Conversely, even minor inaccuracies in IOL power calculation can culminate in substantial refractive errors, leading to patient dissatisfaction and potentially necessitating additional interventions such as IOL exchange, piggyback IOLs, or laser refractive surgery (Dervin, 2018). While IOL power calculation has achieved remarkable refinement for eyes with average axial lengths (ALs), considerable challenges persist for eyes situated at the extremes of the AL spectrum, encompassing both very long myopic

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eyes and very short hyperopic eyes (Blehm, 2024). These atypical ocular biometries often deviate from the underlying assumptions embedded within many conventional IOL formulas. Nanophthalmos, a rare and intricate developmental ocular disorder, represents a particularly demanding subset of short eyes. It is distinguished by an abnormally diminutive ocular globe coupled with unique anatomical constraints, which inherently complicates accurate IOL power prediction and elevates the risk of surgical complications (Rajendrababu, 2022). A critical aspect of this challenge is that even a slight error in axial length measurement in a small eye can translate into a disproportionately larger refractive error postoperatively (Rajendrababu, 2022). This highlights the heightened sensitivity of IOL power calculations in nanophthalmic eyes, where the margin for measurement imprecision is dramatically reduced, necessitating the use of the most advanced and precise biometry techniques available. The consequence of even seemingly minor inaccuracies can be clinically significant refractive surprises, directly impacting patient satisfaction and potentially requiring further interventions. Moreover, achieving optimal visual outcomes in challenging eyes like nanophthalmos extends beyond merely selecting the "best" IOL formula. Success is contingent upon the meticulous optimization of the entire pre- and intra-operative workflow, encompassing various interconnected factors. This necessitates a comprehensive, systemic approach rather than a singular focus on formula selection. Nanophthalmos, derived from the Greek word "nano" meaning dwarf, is a rare genetic disorder characterized by a congenitally small eye resulting from compromised ocular growth (O'Grady, 1971). It is considered a severe form of microphthalmia, where the eye, despite its reduced size, typically retains preserved functionality and organization (Fernández-Vigo, 2023). The structural peculiarities of nanophthalmic eyes are central to understanding the challenges they pose. A critical anatomical feature is the disorganized and thickened sclera, attributed to abnormal collagen fibrils and elevated levels of fibronectin. This leads to reduced scleral permeability and inelasticity, which impairs vortex venous drainage and transcleral protein flux (Carricondo, 2018). These scleral abnormalities are not merely isolated findings but are pivotal in the pathogenesis of associated complications, fundamentally contributing to a high-pressure, low-drainage environment within the eye. The disproportionately large lens within a small ocular globe results in a crowded anterior segment, characterized by iris convexity, a shallow anterior chamber, and narrow angles (Sarıcaoğlu, 2020). This anatomical crowding is a key factor predisposing patients to various anterior segment pathologies. Furthermore, patients with nanophthalmos are prone to various posterior segment findings, including cystoid macular edema, retinal and choroidal folds, a crowded optic disc, sclerochoroidal thickening, pigmentary retinal dystrophy, optic disc drusen, foveoschisis, and retinal cysts (Rajendrababu, 2022). Clinically, nanophthalmic eyes often appear small, sunken, and deep-set within the orbit, with narrow palpebral fissures (Rajendrababu, 2022). The fundamental principle underpinning IOL power calculation is the accurate prediction of the Effective Lens Position (ELP). ELP is defined as the effective distance between the anterior surface of the cornea and the principal plane of the intraocular lens after it has been implanted and stabilized within the eye, assuming the IOL is infinitely thin (Sarıcaoğlu, 2020). Crucially, ELP is the only parameter in IOL power calculation that cannot be directly measured preoperatively (Sarıcaoğlu, 2020). Its accurate prediction is therefore the primary limiting factor for achieving precise postoperative refractive outcomes, even when axial length and corneal power can be measured with high precision (Sarıcaoğlu, 2020).

Given the unique anatomical characteristics and refractive challenges posed by nanophthalmic eyes, achieving accurate intraocular lens power prediction remains a significant clinical hurdle. Although several studies have compared various IOL power calculation formulas in eyes with short axial lengths, there remains a notable paucity of targeted research specifically addressing the refractive predictability of these formulas in nanophthalmos. Moreover, many existing studies emphasize visual acuity outcomes rather than focusing on precise refractive accuracy, which is critically important for minimizing postoperative surprises in this high-risk subgroup. Therefore, this study was undertaken to directly compare the predictive accuracy of three commonly used IOL formulas—Hoffer Q, SRK/T, and SRK II—in nanophthalmic eyes undergoing cataract surgery or clear lens extraction. By evaluating mean prediction errors and assessing the proportion of eyes achieving refractive outcomes within clinically acceptable ranges, this research aims to provide evidence-based guidance for optimizing IOL selection and improving refractive outcomes in this uniquely challenging population (Table 1).

Methodology

This study was a retrospective, observational analysis aimed at comparing the accuracy of intraocular lens (IOL) power calculation formulas in patients with nanophthalmic eyes who underwent cataract surgery or clear lens extraction. The study followed the tenets of the Declaration of Helsinki ethical approval for this study was obtained from the institutional review board of GD Goenka University (Ref: GO/OPT/2023/15). The study included patients aged 18 years and older who were diagnosed with nanophthalmos. The diagnostic criteria for nanophthalmos included an axial length (AL) of 20.5 mm or less, high hyperopia of +8.00 diopters or greater, and a shallow anterior chamber depth

(ACD). All patients had undergone uncomplicated cataract surgery or clear lens extraction with posterior chamber IOL implantation and had both complete preoperative biometry and postoperative refraction data available. Patients were included only if they had a minimum follow-up of one month after surgery, with stable postoperative refractive outcomes. Patients were excluded from the study if they had a history of previous intraocular surgery, experienced intraoperative or postoperative complications (such as posterior capsular rupture or cystoid macular edema), or had preexisting ocular pathologies that could affect refractive outcomes, such as keratoconus, corneal endothelial dystrophy, macular degeneration, or other retinal disorders. Incomplete follow-up data or missing measurements also led to exclusion from the study. All patients underwent a detailed preoperative ophthalmological examination. This included measurement of best corrected visual acuity (BCVA) using Snellen charts, slit-lamp biomicroscopy, intraocular pressure assessment with Goldmann applanation tonometry, and fundus evaluation. Axial length and anterior chamber depth were measured using either the ZEISS IOL Master 700 optical biometer or the NANO AXIS A-scan ultrasound biometer, depending on the clinical case. In manual biometry cases, immersion ultrasound technique was used to ensure greater accuracy. Corneal power (keratometry readings) was measured using manual keratometry (Bausch & Lomb) or automatically through the ZEISS IOL Master.

In each case, the IOL power was calculated using three different formulas: Hoffer Q, SRK/T, and SRK II. The lens constants used in these formulas were based on optimized values as provided by the biometry software or manufacturer recommendations. The target postoperative refraction was typically emmetropia or mild hyperopia ranging from +0.75 diopters to +3.00 diopters, depending on individual patient needs and surgical plans. All surgeries were performed using a standard technique of phacoemulsification or clear lens extraction under local anesthesia. A foldable posterior chamber intraocular lens was implanted in the capsular bag in all patients. All procedures were conducted by experienced cataract surgeons following a uniform surgical protocol. Postoperative refraction was recorded one month after surgery to ensure that the refractive outcomes had stabilized. The spherical equivalent (SE) of the final refraction was documented for each eye. The prediction error for each IOL calculation formula was determined by subtracting the predicted refraction (calculated preoperatively) from the actual postoperative spherical equivalent. The absolute value of this error was also calculated to determine the mean absolute error (MAE) for each formula. The primary outcome measure of the study was the mean absolute prediction error (MAE) for each formula. Secondary outcomes included the percentage of eyes with a prediction error within ±0.25 diopters, ±0.50 diopters, ±1.00 diopters, and ±2.00 diopters of the target refraction. The study also evaluated whether each formula showed a directional bias toward myopic or hyperopic outcomes. All statistical analyses were performed using SPSS software version 26. Descriptive statistics, including means and standard deviations, were calculated for continuous variables. A one-sample t-test was used to determine whether the mean prediction error for each formula was significantly different from zero, which would indicate a bias in prediction. A p-value less than 0.05 was considered statistically significant (Table 2 and Figure 1).

Results

A total of forty-five eyes from adult patients diagnosed with nanophthalmos were included in the study. All patients had undergone either cataract surgery or clear lens extraction with posterior chamber intraocular lens implantation. The axial lengths of the included eyes ranged from 16.0 mm to 20.5 mm, consistent with the diagnostic criteria for nanophthalmos. Postoperatively, all eyes achieved a best corrected visual acuity (BCVA) of 6/18 or better, confirming favorable visual outcomes.

To assess the accuracy of IOL power prediction, the postoperative spherical equivalent (SE) was compared to the predicted refraction obtained using three IOL calculation formulas: Hoffer Q, SRK/T, and SRK II. The mean absolute prediction error for the Hoffer Q formula was −0.44 ± 0.30 diopters, indicating a slight myopic bias. The SRK/T formula had a mean prediction error of +0.68 ± 0.73 diopters, suggesting a mild hyperopic tendency. In contrast, the SRK II formula exhibited a significantly larger mean prediction error of +3.28 ± 0.52 diopters, indicating a strong hyperopic shift and poor prediction accuracy. Statistical analysis was conducted using a one-sample t-test to determine whether the mean prediction errors differed significantly from zero. The SRK II formula showed a highly significant deviation from zero, with a t-value of 6.242 and a p-value less than 0.001. The 95% confidence interval for this error ranged from +2.23 to +4.35 diopters, confirming a significant and consistent hyperopic outcome. The SRK/T formula did not show a statistically significant difference from zero, with a t-value of 0.935, a p-value of 0.355, and a confidence interval ranging from −0.79 to +2.16 diopters. Similarly, the Hoffer Q formula did not yield a statistically significant error, with a t-value of −1.465, a p-value of 0.150, and a confidence interval between −1.06 and +0.17 diopters. In addition to analyzing mean prediction errors, the study evaluated the percentage of eyes that achieved refractive outcomes within specific error ranges. The Hoffer Q formula provided the most accurate results, with 48.9% of eyes falling within ±0.25 diopters, 75.6% within ±0.50 diopters, 93.3% within ±1.00 diopters, and 100% within ±2.00 diopters of the predicted refraction. The SRK/T formula achieved slightly lower accuracy, with 26.7% of eyes within ±0.25 diopters, 51.1% within ±0.50

Table 1: One-sample t-test comparing the prediction errors of three IOL power calculation formulas (Hoffer Q, SRK/T, and SRK II) against zero. The test evaluates whether the mean prediction error significantly deviates from perfect prediction (i.e., no error). SRK II showed a statistically significant hyperopic prediction error (p < 0.001), while Hoffer Q and SRK/T did not show statistically significant deviations.

	Test Value = 0						
	t	*df*	*Sig. (2-tailed)*	*Mean Difference*	*95% Confidence Interval of the Difference*		*Error*
					Lower	*Upper*	
Diff_SRK2	6.242	44	0.000	3.28889	2.2271	4.3507	1.06182443718692
Diff_SRKT	0.935	44	0.355	0.68333	-0.7889	2.1555	1.47219961187021
Diff_HofferQ	-1.465	44	0.150	-0.44444	-1.0559	0.1670	0.61141894486910

diopters, 84.4% within ±1.00 diopters, and 97.8% within ±2.00 diopters. In contrast, the SRK II formula performed poorly, with only 4.4% of eyes within ±0.25 diopters, 8.9% within ±0.50 diopters, 17.8% within ±1.00 diopters, and 35.6% within ±2.00 diopters of predicted values.

Overall, the Hoffer Q formula demonstrated the highest predictive accuracy among the three formulas tested. It consistently delivered results that were closest to the target refraction and showed minimal directional bias. The SRK/T formula showed moderate accuracy, while the SRK II formula was found to be significantly less reliable and demonstrated a strong tendency toward hyperopic errors in nanophthalmic eyes.

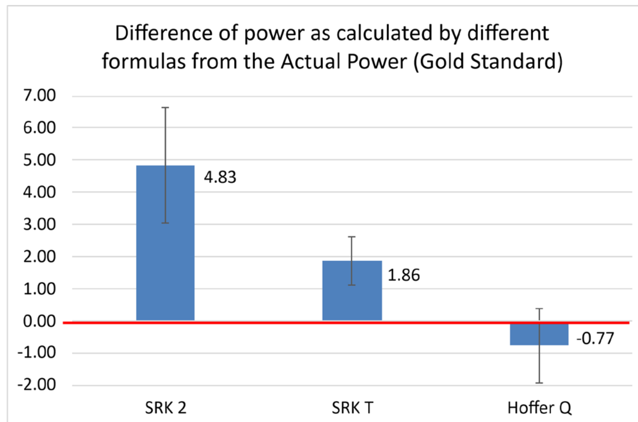

Figure 1: Bar graph showing the mean difference between IOL power calculated by SRK II, SRK/T, and Hoffer Q formulas compared to the actual power (Gold Standard) in nanophthalmic eyes. SRK II significantly overestimated the IOL power, resulting in the highest positive deviation (mean difference = +4.83 D), while Hoffer Q slightly underestimated the power (mean difference = –0.77 D). Error bars represent the standard deviation, and the red line denotes zero error (perfect prediction)

Discussion

It is widely acknowledged that IOL power calculation in short eyes, commonly defined as eyes with an axial length (AL) less than 22 mm, is inherently less accurate and more problematic than in eyes with normal or long Als (Wang, 2018). This reduced accuracy presents significant challenges for cataract surgeons aiming for precise refractive outcomes. Studies evaluating IOL formulas, many of which were primarily developed and validated for adult eyes with average biometry, consistently show varying and often larger prediction errors when applied to pediatric cases, which frequently involve shorter axial lengths (Rathod, 2025). The unique anatomical characteristics of short eyes, coupled with the necessity for high-power IOLs, are key contributors to the difficulties in achieving precise refractive predictions (Wang, 2018). Historically, errors in IOL power calculation were attributed to several factors: incorrect AL measurement (54% of inaccuracies), imprecise postoperative Anterior Chamber Depth (ACD) estimation (38%), and inaccuracies in corneal power evaluation (8%) (Wang, 2018). While biometry has improved, ELP prediction remains a challenge. Refractive outcomes following cataract surgery in nanophthalmic eyes are notoriously unpredictable. Many eyes in this population fail to achieve a postoperative refraction within 1 diopter (D) of the target, indicating a significant

Table 2: One-sample statistics showing the mean difference in predicted IOL power compared to the actual power (Gold Standard) for three IOL calculation formulas: SRK II, SRK/T, and Hoffer Q. The SRK II and SRK/T formulas showed statistically significant overestimation of IOL power (p < 0.001), while the Hoffer Q formula did not show a significant difference (p = 0.180). The standard error and overall error indicate the variability of prediction for each formula.

One-Sample Statistics						*Sig. (2-tailed)*	
		N	*Mean*	*Std. Deviation*	*Std. Error Mean*		*Error*
Diff_SRK2	SRK 2	24	4.8333	4.24627	0.86677	0.000	1.79
Diff_SRKT	SRK T	24	1.8646	1.78913	0.36520	0.000	0.76
Diff_HofferQ	Hoffer Q	24	-0.7708	2.73158	0.55758	0.180	1.15

Table 3: Comparative Statistical Performance of Hoffer Q, SRK/T, and SRK II in Short Eyes (Mean Absolute Error, Percentage within ±0.5 D)

Formula	*Mean Absolute Error (MAE) (D)*	*Percentage within ±0.5 D (%)*	*Axial Length Range (mm)*	*Source Citation*
Hoffer Q	0.59 ± 0.26 (vs SRK-T)	Not specified	< 22	1
Hoffer Q	0.510 (overall MAE)	Not explicitly stated	< 22	9
Hoffer Q	0.533 (worst performer)	Not explicitly stated	< 22.0	15
Hoffer Q	0.39 ± 0.38 (vs BUII)	75.0% (vs BUII)	< 22.0	16
SRK/T	0.78 ± 0.18 (vs Hoffer Q)	Not specified	< 22	1
SRK/T	0.555 (overall MAE)	Not explicitly stated	< 22	9
SRK/T	Not specified, but advised against	Not specified, but advised against	< 22.0	15
SRK II	1.146 (overall MAE)	Not explicitly stated	< 22	9

challenge in achieving emmetropia or desired refractive outcomes (Lai, 2024). A major contributing factor to this unpredictability is the requirement for very high-powered IOLs, which are frequently needed in nanophthalmic eyes. These IOLs often exceed +40 D and can sometimes reach powers greater than +70D (Lai, 2024). High-power IOLs inherently possess certain downsides, including a wider manufacturing tolerance (which can be as much as ±1 D from the stated power) and an increased inaccuracy in the effective lens position (ELP) prediction, further exacerbating the refractive unpredictability (Lai, 2024). Overall, lens surgery in extremely short eyes, while generally considered safe, is described as "rather imprecise," with nanophthalmic eyes specifically showing "compromised outcomes" in terms of refractive predictability (Hammer, 2025). The Hoffer Q formula has historically been widely recommended for IOL power calculation in short eyes (defined as axial length < 22 mm) by various ophthalmic guidelines, including those from the Royal College of Ophthalmology (Dervin, 2018). A comparative study evaluating Hoffer Q against SRK-T in eyes with an AL < 22 mm reported that Hoffer Q demonstrated superior performance, yielding a mean predictive error of 0.59 ± 0.26 D, which was statistically significantly lower than SRK-T's 0.78 ± 0.18 D ($p < 0.0001$) (Dervin, 2018). A meta-analysis published in 2016, which included studies up to October 2016, indicated that the Haigis formula was statistically superior to Hoffer Q in short eyes, with a mean difference in Mean Absolute Error (MAE) of -0.07 D (p=0.003) (Wang,2018). Some studies have noted that Hoffer Q tends to produce a slight myopic refractive prediction error, approximately -0.22 D (Gokce, 2017).

SRK/T is recognized as a third-generation IOL power calculation formula, building upon earlier empirical models (Siddiqui, 2017). In the aforementioned comparative study of Hoffer Q versus SRK-T for eyes with AL < 22 mm, SRK-T demonstrated a higher mean predictive error of 0.78 ± 0.18 D, indicating that it performed less accurately than Hoffer Q in this short axial length cohort.[1] The 2016 meta-analysis also found that Haigis was statistically superior to SRK/T in short eyes, with a mean difference in MAE of -0.07 D (p=0.009) (Wang, 2018). SRK II is classified as a second-generation IOL power calculation formula, an empirical modification of the original SRK formula (Siddiqui, 2017). The 2016 meta-analysis consistently showed that Haigis was statistically superior to SRK II in short eyes, with a substantial mean difference in MAE of -0.41 D (p=0.01) (Wang, 2018). Furthermore, the largest MAE difference observed in that meta-analysis was between Holladay 2 and SRK II (0.65 D), reinforcing SRK II's comparatively poor performance (Wang, 2018).

Table 3 clearly illustrates that, among the three specified formulas, Hoffer Q generally exhibits better performance than SRK/T and SRK II in eyes with short axial lengths, aligning with historical clinical recommendations. However, a critical observation emerges from the conflicting data regarding Hoffer Q's performance, particularly the recent ARVO abstract (Sandhu, 2023) which labels it as the "worst performer" for short AL eyes. This contradiction highlights the evolving understanding and potential variability in formula performance across different cohorts and study designs, suggesting that while Hoffer Q has been a traditional choice, newer formulas may offer superior accuracy.

Conclusion

This study sought to address the clinical gap by evaluating and comparing the refractive prediction accuracy of three widely used IOL power calculation formulas—Hoffer Q, SRK/T, and SRK II—in a cohort of adult nanophthalmic eyes undergoing cataract surgery or clear lens extraction. Our analysis revealed that the Hoffer Q formula outperformed the other two, providing the lowest mean absolute refractive error and the highest percentage of eyes within ±0.50 D and ±1.00 D of the targeted postoperative refraction. This suggests that Hoffer Q is more robust and reliable for use in eyes with short axial lengths, likely due to its ability to better estimate the effective lens position (ELP), which is critical in these anatomically atypical eyes. The SRK/T formula showed moderate predictive accuracy, with a slight tendency toward hyperopic outcomes, but without reaching statistical significance. In contrast, the SRK II formula demonstrated the poorest performance, significantly overestimating IOL power and resulting in a consistent hyperopic shift. This suggests that older, second-generation formulas like SRK II may be inadequate for eyes with highly abnormal anatomy, such as nanophthalmos, and should be avoided in such cases.

These findings reinforce the importance of formula selection tailored to ocular anatomy and highlight the need for continuous refinement of IOL calculation methods in challenging eyes. While the Hoffer Q formula remains a strong candidate for short eyes, especially nanophthalmic eyes, future research should also consider evaluating newer generation formulas—such as the Barrett Universal II, Holladay II, and AI-based formulas—which may offer improved accuracy and consistency. Additionally, further prospective studies with larger sample sizes and longer follow-up durations are warranted to validate these findings and assess their long-term clinical relevance. In conclusion, for nanophthalmic eyes undergoing cataract or clear lens surgery, the Hoffer Q formula currently provides the most reliable refractive outcomes among the formulas studied. However, surgeons must continue to exercise clinical judgment, use the most precise biometry techniques available, and stay informed about emerging technologies to optimize surgical planning and postoperative satisfaction in this high-risk population.

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