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Kane Formula

Jack X Kane

The Kane formula was created in 2017 using a large database of cases (~30,000) to develop the underlying algorithm. The formula is based on theoretical optics and incorporates both regression and artificial intelligence components to further refine its predictions. The formula was created using high-performance cloud-based computing (a way to leverage the power of the cloud to create a virtual supercomputer capable of performing many decades worth of calculations in a few days). Variables used in the formula are axial length, keratometry, anterior chamber depth, lens thickness, central corneal thickness, and patient biological sex. Lens thickness and central corneal thickness are optional variables as these are not available on all biometry platforms. The formula is available for use free of charge at www.iolformula.com.

Since its inception, the formula has consistently been shown to be the most accurate in a variety of studies and subgroups of eyes. The first paper to assess the formula was a single-surgeon study of 846 patients using a single IOL type, which demonstrated that it was more accurate than the Hill-RBF 2.0, Barrett Universal 2, Olsen, Holladay 2, Haigis, Hoffer Q, Holladay 1, and SRK/T formulas [1].

The improved accuracy compared to other modern formulas was further established in an update to the landmark paper by Melles et al. in *Ophthalmology* [2]. This paper—the largest to date on IOL power calculation—studied 18,501 eyes of 18,501 patients assessing the performance of the Barrett Universal 2, Olsen, Haigis, Holladay 2, Holladay 1, and Hoffer Q and found that the Barrett Universal 2 formula was the most accurate. The update to this paper [3] included four additional formulas that were not available for the original study (Kane, Olsen 4-factor, EVO, and Hill-RBF 2.0) and assessed their accuracy using the same dataset as the original paper. This update showed a new leader, with the Kane formula, demonstrating the highest percentage of eyes within ± 0.25, ± 0.50,± 0.75, and± 1.00 D and the lowest standard deviation, mean absolute error, and median absolute error for both the SN60WF and SA60AT IOLs. It was the most accurate formula for short, medium, medium long, and extremely long axial length eyes. In this study, the formula outperformed the long-established best formula for short eyes—with 34.2% reduction in the mean absolute error compared with the Hoffer Q—and the best formula for long eyes—with a 33.3% reduction in the mean absolute error compared to the SRK/T. Compared with the Barrett, which was the best performing in the original study, the reduction in mean absolute error was 12.5% in the short axial

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J. X. Kane (✉)
Northern Health Ophthalmology Unit,
Melbourne, Australia

J. Aramberri et al. (eds.), *Intraocular Lens Calculations*, Essentials in Ophthalmology,
https://doi.org/10.1007/978-3-031-50666-6_46

length group and 7.4% in the long axial length group.

Another major study from the NHS of 10,930 patients published in the *Journal of Cataract and Refractive Surgery* also demonstrated the improved accuracy of the Kane formula compared to the Hill-RBF 2.0, Olsen, Barrett, Haigis, Hoffer Q, Holladay 1, Holladay 2, and SRK/T. This study also showed the formula to be the most accurate in both short and long axial length eyes and for each IOL type included in the study [4]. This confirmed the finding of the Melles et al. study [3] with the superior performance of the formula across the entire axial length spectrum. These two studies are the largest published to date by a significant margin, and their findings were unequivocally in favor of using the Kane formula.

A review article [5] was published in *Ophthalmology* in 2020 looking at every IOL power formula study over the past 10 years. This study assessed 68 papers on IOL power calculation identifying 36 unique formulas that had been studied (not including obsolete formulas such as SRKII) over the preceding 10 years. The paper showed that despite only being created in 2017, the overall weight of evidence over the previous 10 years demonstrated that the Kane formula (see Fig. 46.1) was the most accurate over the entire axial length and in both the short eye (≤22.0 mm) and long eye (≥26.0 mm) subgroups. The study demonstrated the tendency of new formulas to have a single paper that shows their excellent results, which were either never studied again or failed to replicate their success with subsequent independent papers, which highlights the need to proceed with caution before adapting a new IOL formula.

Since this review paper, many additional studies have continued to demonstrate the excellent performance of the Kane formula in a variety of different subgroups including short axial length and long axial length, in a variety of anterior chamber depth (ACD) and lens thickness (LT) subgroups and with a variety of different devices.

Short axial length eyes are the most difficult to predict because the high IOL powers inserted lead to the exquisite sensitivity of the effective lens position to any errors in prediction. A JCRS paper [6] of 182 patients having an IOL power of

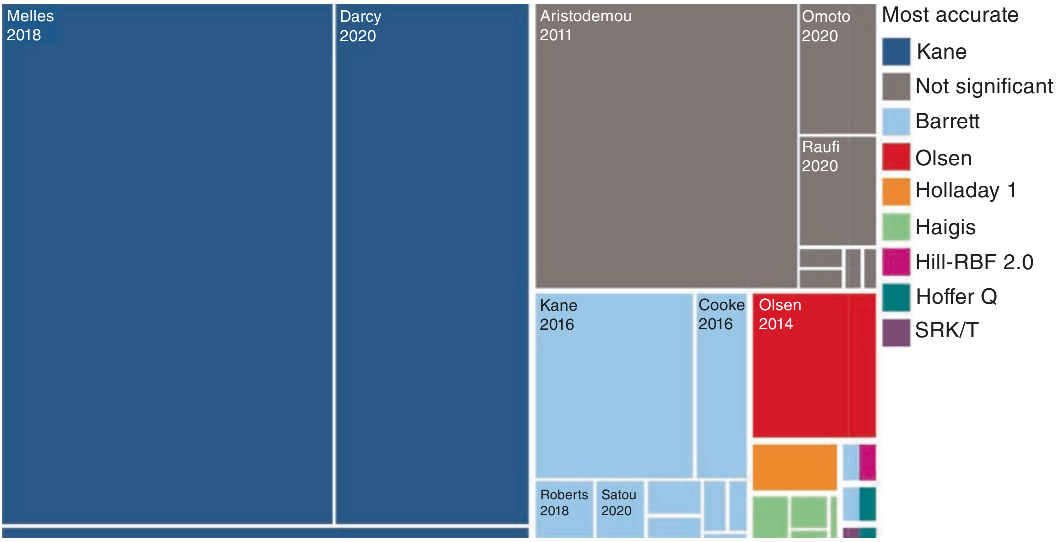

Fig. 46.1 Treemap of studies that assessed the entire axial length spectrum summarizing the most accurate formula. Each separate box represents a different study, the color of the box represents the most accurate formula for that study, and the relative size of the box represents the size of the study. (Adapted from Kane and Chang [5] with permission)

≥30 diopters inserted (utilizing a database of 28,349 eyes) demonstrated that the Kane formula had the highest percentage of eyes within ± 0.50 D compared to the other studied formulas (EVO 2.0, Barrett, Hill-RBF 2.0, Olsen, and conventional formulas). The improvement was an additional 22.0% of eyes within ± 0.50 D compared to the Barrett formula. Other studies have confirmed these findings with a study of 150 short eyes (axial length ≤ 21.5 mm or IOL power ≥ 28.5) demonstrating that the Kane formula was the equal most accurate formula [7] and another paper with 241 eyes with an axial length ≤ 22.0 mm showed again that it was the equal most accurate formula [8].

In long axial length eyes, the findings of the review have been further confirmed by two additional papers [9, 10], which both demonstrated that the Kane formula had the most accurate results compared to all other studied formulas including the Barrett, EVO, and Hill-RBF 2.0 in eyes with axial length ≥ 26.0 mm. In extreme myopia (axial length ≥ 30.0 mm), the benefit of the Kane formula over the others was even more significant.

An interesting study [11] looking at the performance of formulas based on ACD and LT subgroups demonstrated no significant bias of the formula in any of the nine ACD and LT subgroups. In this study of 628 patients, the Kane formula had the highest percentage of patients within ± 0.50 D. Another study [12], on a new formula (the VRF-G) by the creator of the VRF-G, demonstrated that the Kane formula had the lowest mean absolute error and standard deviation of the prediction error compared with all 12 other formulas in the 828 patients studied.

The findings of the review have been replicated with multiple different devices including ANTERION [13] (Heidelberg) where the formula had the highest percentage of eyes within ± 0.50 D, on the Lenstar (Haag-Streit) where it had the highest percentage of eyes within ± 0.50 D, [14] and on the IOLMaster 700 (Zeiss) where in 410 patients it had the highest percentage of eyes within ± 0.50 D and the lowest mean absolute error and standard deviation of the prediction error [15].

Additionally, it has been shown to be accurate in other specific populations including post-vitrectomy eyes where it was the only formula to not have a systematic bias [16] and in the aged population where it had the equal highest percentage of eyes within ± 0.50 D [17].

The formula performs well across the entire axial length range, in short and long eyes, in all combinations of anterior chamber depth and lens thickness, and in other studied populations. The use of the formula may free ophthalmologists from the outdated practice of using a variety of formulas depending on the axial length of the patient.

Toric Formula

The Kane toric formula uses an algorithm incorporating regression, theoretical optics, and artificial intelligence techniques to calculate the total corneal astigmatism. It then applies an ELP-based approach to calculate the residual astigmatism for a particular eye and IOL power combination.

In the largest study on toric IOL formula accuracy published in *Ophthalmology* [18], the Kane toric formula was shown to be more accurate than all currently available toric formulas (Barrett, Abulafia-Koch, Holladay 2 with total SIA, EVO 2.0, and Næser-Savini). The formula resulted in a higher percentage of eyes within ± 0.50 D of the astigmatic prediction error with 5.7% more compared to the next best-performing formula (the Barrett toric formula) and 12.7% compared to the worst-performing formula in the study (the Holladay 2 toric formula with total SIA). The Kane toric formula performed the best for with-the-rule, against-the-rule, and oblique astigmatism cases (Fig. 46.2).

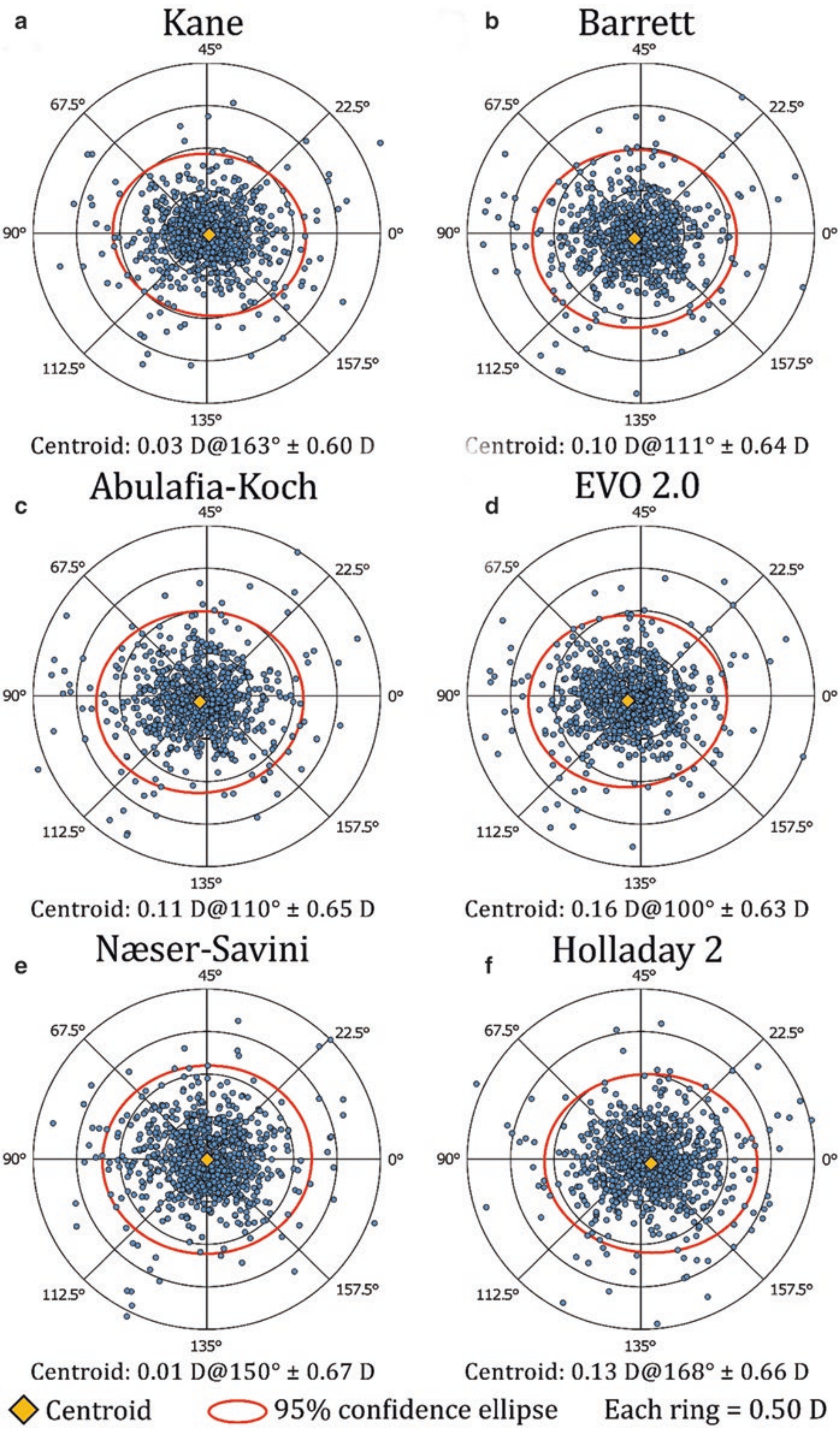

Fig. 46.2 Double-angle plots of the prediction error for each of the formulas assessed (A-F) using the postoperative keratometry and the actual measured IOL axis. The centroids and SDs for each formula are also shown. Adapted from Kane and Connell [18] with permission

Keratoconus Formula

The Kane keratoconus formula is a purely theoretical modification of the original Kane formula. It uses a modified corneal power, derived from anterior corneal radii of curvature, that better represents the true anterior/posterior ratio in keratoconic eyes. The formula also minimizes the effect of corneal power on the ELP calculation to enable more accurate predictions. The variables used in the formula are identical to those in the original formula, and the formula works with standard biometric devices. The same A-constant that is used for a particular IOL for non-keratoconic patients should be used.

This formula was first presented at the 15th IPC meeting in Napa with an article in *Ophthalmology* in 2020 [19]. This article described the largest study of keratoconus patients. In 146 eyes of 146 patients who had IOLMaster biometry, it was found that the Kane keratoconus formula had the best results. It achieved 8.3% more patients within ± 0.50 D than the SRK/T and 7.1% more within ± 0.50 D than the Barrett in mild keratoconus. In moderate keratoconus, it demonstrated an additional 5.4% within ± 0.50 D compared to the Barrett and 13.5% compared to the SRK/T. In severe keratoconus (where average keratometry was ≥53 D), it achieved 20% more within ± 0.50 D compared with the Barrett and 12% more than the SRK/T and had 32% more within ± 1.00 D compared with the Barrett and 28% more than the SRK/T. Another study [20] that included eight eyes with an average keratometry reading over 48 D showed the improved performance of the Kane keratoconus formula compared with the original Kane formula. Comparing the Kane versus the Kane keratoconus formula in these eyes showed a reduction in the mean absolute error from 1.54 D for the original Kane formula to 0.54 D for the Kane keratoconus formula and change from a high hyperopic prediction error + 1.11 D to a low myopic prediction error − 0.15 D.

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