ARTICLE

Accuracy of 8 intraocular lens calculation formulas in relation to anterior chamber depth in patients with normal axial lengths

Sabite Emine Gökce, MD, Ildamaris Montes De Oca, MD, David L. Cooke, MD, Li Wang, MD, PhD, Douglas D. Koch, MD, Zaina Al-Mohtaseb, MD

Purpose: To determine the effect of anterior chamber depth (ACD) on the accuracy of 8 intraocular lens calculation formulas in patients with normal axial lengths (ALs).

Setting: Baylor College of Medicine, Alkek Eye center, Houston, Texas, USA.

Design: Retrospective case series.

Methods: Patients having cataract surgery with ALs between 22.0 mm and 25.0 mm were divided into 3 groups based on their preoperative ACD measurement. The mean prediction errors, mean absolute errors (MAEs), and median absolute errors for each group were calculated.

Results: For the ACD of 3.0 mm or less group and the ACD of 3.5 mm or more group, the Barrett Universal II, Holladay 2, Haigis, and Olsen ray-tracing formulas had mean prediction error values that were not significantly different from zero. For the ACD of 3.01 to 3.49 mm group, all formulas had mean prediction error values that were not significantly different from zero. For the ACD of 3.0 mm or less group, the Barrett Universal II formula had a smaller median absolute error than the Haigis, Hoffer Q, and Olsen optical low-coherence reflectometry (OLCR) (Lenstar) formulas and a smaller MAE than the Hoffer Q, Hill-RBF, and Olsen OLCR ($P < .05$). In the ACD of 3.5 mm or more group, the Barrett MAE was smaller than the Hoffer Q ($P < .05$); however, there were no significant differences between median absolute errors.

Conclusion: In eyes with normal ALs, taking preoperative ACD values into consideration might improve refractive outcomes.

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Cataract surgery is one of the most commonly performed surgical procedures worldwide. Despite advances in modern intraocular lens (IOL) power calculations, the inability to accurately predict pseudophakic anterior chamber depth (ACD) and hence, postoperative effective lens position (ELP) remains a major obstacle to accurate calculations. Modern formulas aim to increase their accuracy by using an improved ACD algorithm to predict pseudophakic ACD. It has been previously shown that errors in the prediction of postoperative ACD might account for 20% to 40% of the total refractive prediction error of an otherwise perfect IOL calculation formula.[1]

As described in a recent editorial,[2] IOL calculation formulas are best classified by functional category and by the biometric variables that they use to calculate IOL power, with the primary categories being vergence, ray tracing, and artificial intelligence–based vergence, and ray-tracing formulas directly calculate the estimated ELP whereas artificial intelligence–based formulas select IOL power without directly predicting the ELP.

Two-variable vergence formulas (Holladay 1,[3] Hoffer Q,[4] and SRK/T[5]) use axial length (AL) and corneal power to calculated ELP. The ACD is used in ELP calculation by (1) vergence formulas that use 3 or more variables, (2) ray tracing, and (3) a new artificial intelligence–based formula (Hill radial basis function [RBF][A]). The Haigis formula[6] is unique in that it uses ACD but does not use corneal power to calculate ELP. Other variables used in ELP calculation are lens thickness (Holladay 2,[7] Barrett

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From the Cullen Eye Institute (Gökce, Montes De Oca, Wang, Koch, Al-Mohtaseb), Baylor College of Medicine, Houston, Texas, and the Great Lakes Eye Care (Cooke), Saint Joseph and the Department of Neurology and Ophthalmology (Cooke), Michigan State University, College of Osteopathic Medicine, East Lansing, Michigan, USA; the Department of Ophthalmology, Dünya Göz Hospital (Gökce), Ankara, Turkey.

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Corresponding author: Zaina Al-Mohtaseb, MD, Cullen Eye Institute, Baylor College of Medicine, 6565 Fannin NC 205, Houston, Texas 77030, USA. E-mail: zaina1225@gmail.com.

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Table 1. Descriptive data of patients in the 3 ACD subgroups.

Parameter	ACD (mm)	Lens Thickness (mm)	AL (mm)	Age (Y)
Group 1 (ACD ≤3.0 mm, n = 102)				
Mean ± SD	2.76 ± 0.18	4.69 ± 0.41	23.62 ± 0.53	74 ± 7.3
Range	2.21, 3.0	3.78, 5.61	22.28, 24.97	55, 93
Group 2 (ACD 3.01 mm–3.49 mm, n = 85)				
Mean ± SD	3.24 ± 0.14	4.38 ± 0.36	23.77 ± 0.61	73 ± 6.8
Range	3.01, 3.49	3.62, 5.32	22.85, 24.98	53, 90
Group 3 (ACD ≥3.5 mm, n = 83)				
Mean ± SD	3.72 ± 0.20	4.04 ± 0.41	23.94 ± 0.52	69 ± 9.7
Range	3.50, 4.28	3.14, 4.83	23.04, 24.99	33, 83

ACD = anterior chamber depth; AL = axial length

Universal II,[B] and Olsen ray tracing[8]) and corneal diameter (Holladay 2[7] and Barrett Universal II[B]).

As Holladay et al.[9] first described for a given AL, there can be wide variability in ACD. They classified eyes in 9 categories according to the AL (short, normal, and long) and ACD (shallow, normal, and deep). The purpose of the current study was to determine, for eyes with normal ALs, the effect of ACD on the accuracy of 8 IOL calculation formulas.

PATIENTS AND METHODS

A retrospective chart review was performed to identify patients who had uncomplicated cataract surgery with IOL implantation from July 2012 to January 2016 at Baylor College of Medicine, Alkek Eye Center, Houston, Texas, USA. Institutional Review Board Approval (Baylor College of Medicine) was obtained. Inclusion criteria were AL between 22.0 mm and 25.0 mm as measured by optical biometry, available corneal power (keratometry [K]), ACD, and manifest refraction at least 3 weeks after surgery with corrected vision 20/30 or better. Patients who had additional surgical procedures at the time of cataract surgery (including corneal relaxing incisions), previous intraocular surgery or refractive surgery, any corneal pathology, or intraoperative complications were excluded.

Axial length, K value, and ACD were measured with optical low-coherence reflectometry (OLCR) (Lenstar LS-900, Haag-Streit AG). All eyes had phacoemulsification surgery under topical anesthesia with a 2.4 mm temporal clear corneal incision. All eyes were implanted with either a Tecnis ZCB00 or ZCT IOL (both Johnson & Johnson Vision Care, Inc.) with an optimized A constant of 119.48.

The effect of ACD on refractive outcomes and accuracy of IOL formulas after routine cataract surgery were evaluated in 270 eyes with normal ALs (22.0 to 25.0 mm). Patients were divided into 3 groups based on their preoperative ACD measurements of 3.0 mm or less, 3.01 mm to 3.49 mm, and 3.5 mm or more.

Outcomes of 3 categories of formulas in the study were evaluated as follows: (1) 5 vergence formulas: Holladay 1[3] and Hoffer Q[4] formulas (2-variable), Haigis formula[6] (3-variable), Barrett Universal II formula[B] (5-variable), and Holladay 2 formula[7] (7-variable), (2) the Olsen ray-tracing purchased version[C] (Phacooptics) and Olsen OLCR formulas,[10] and (3) the Hill-RBF,[A] which uses the artificial intelligence–based radial basis function to find relationships not otherwise evident in theoretical approaches.[D] The Lenstar software was used to calculate the IOL power by the Holladay 1,[3] Hoffer Q,[4] Haigis,[6] Barrett Universal II,[B] and Olsen OLCR[10] formulas. The Olsen OLCR formula uses preoperative lens thickness and ACD

Table 2. Refractive prediction errors, MAE, and median absolute error produced by each formula.

	Formula			
Parameter	Barrett	Haigis	Hoffer Q	H1
Group 1 (ACD ≤3.0 mm, n = 102)				
Mean RPE (D) ± SD	0.00 ± 0.32	0.00 ± 0.39	−0.20* ± 0.41	−0.14* ± 0.36
Range−1.0, 0.88	−1.07, 0.77	−1.30, 0.55	−1.17, 0.59	−1.0, 0.76
MAE (D) ± SD	0.24 ± 0.20	0.32 ± 0.22	0.36 ± 0.28	0.30 ± 0.24
MedAE	0.18	0.30	0.30	0.23
Group 2 (ACD 3.0 mm–3.5 mm, n = 85)				
Mean RPE (D) ± SD	−0.01 ± 0.36	0.02 ± 0.38	0.03 ± 0.37	0.02 ± 0.36
Range	−1.13, 0.81	−1.32, 1.18	−1.22, 1.09	−1.08, 0.86
MAE ± SD	0.29 ± 0.21	0.30 ± 0.23	0.32 ± 0.20	0.29 ± 0.20
MedAE	0.25	0.25	0.29	0.28
Group 3 (ACD ≥3.5 mm, n = 83)				
Mean RPE (D) ± SD	0.01 ± 0.30	−0.02 ± 0.35	0.21* ± 0.33	0.15* ± 0.30
Range	−0.67, 0.83	−0.93, 0.75	−0.68, 1.15	−0.50, 0.87
MAE ± SD	0.24 ± 0.18	0.28 ± 0.20	0.32 ± 0.23	0.27 ± 0.19
MedAE	0.21	0.26	0.32	0.26

ACD = anterior chamber depth; H1 = Holladay 1; H2 W/Ref = Holladay 2 calculated with refraction values; H2 No Ref = Holladay 2 calculated without refraction values; MAE = mean absolute error; MedAE = median absolute error; OLCR = optical low-coherence reflectometry; PV = ray-tracing purchased version; RBF = radial basis function; RPE = refractive prediction errors
*Significantly different from zero