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ORIGINAL PAPER

Comparison of formulas and methods for high myopia patients requiring intraocular lens powers less than six diopters

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Abstract

Purpose To determine the best method to minimize postoperative hyperopia and achieve mild myopia in patients requiring low-powered (<6.00 D) MN60MA intraocular lenses (IOLs).

Methods This retrospective non-comparative case series consists of 32 eyes (20 patients). Postoperative spherical equivalent (SE) refractions were compared using four methods: standard formulas with varying target refractions (Haigis −1.00 D, Hoffer Q −1.75 D, Holladay 1 −1.50 D and SRK/T −1.00 and −1.25 D), axial length adjustment methods for standard formulas targeted for both plano and −0.50 D, Barrett Universal II formula and the Haigis formula using separate constants for plus and minus IOLs (Haigis +/−). SE (mean, standard deviation, median, range), median absolute error (MedAE), prediction errors, percentage SE less than 0.25 D and greater than −1.00 D, percentage SE within ±0.50 and ±1.00 D of the targeted refraction were calculated.

Results All methods and formulas gave acceptable mean SE refractions ranging from −0.04 to −0.68 D. The Barrett Universal II, Haigis +/−, standard Haigis formula targeted for −1.00 D and the Holladay 1 formula targeted for −1.50 D met stricter criteria of final SE between 0.25 and −1.00 D in 94–100% of eyes and MedAE between 0.37 and 0.51 D. Other methods had more myopic or hyperopic outliers.

Conclusions For these eyes with high myopia, the Barrett Universal II, Haigis +/−, standard Haigis targeted for −1.00 D and the standard Holladay 1 targeted for −1.50 D formulas produce the best results exceeding established benchmark criteria and minimizing hyperopic surprises.

Keywords Cataract surgery · High myopia · Intraocular lens calculation · Low-powered intraocular lens

Introduction

Avoiding postoperative hyperopia in patients with extreme high myopia who require intraocular lens (IOL) powers less than six diopters is still a major problem for most modern formulas [1–9]. Several studies have compared standard third-generation formulas and found most lacking in precision [1, 4, 6, 7, 9–12]. The current study retrospectively analyzed a large cohort of high myopia patients implanted with low positive- or negative-powered MN60MA IOLs (Alcon, Fort Worth, TX, USA) and compared final refractive results among four separate methods recommended in previous reports: empirically using third-generation formulas targeting

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different amounts of myopia [2, 3, 7, 13], using third-generation formulas with the Wang–Koch axial length adjustment and varying the target refraction [6, 9], applying the Barrett Universal II formula [9] and calculating the Haigis formula with separately adjusted *a*0 constants for positive and negative lenses, respectively, [8, 14] to see which method works best for this select group of patients.

Patients and methods

The study was performed with the approval of the Virginia Mason Medical Center (VMMC) Institutional Review Board (IRB)/Ethics Committee and in accordance with the U.S. Health Insurance Portability and Accountability Act and adhered to the tenets of the Declaration of Helsinki guidelines for human research. Thirty-two eyes (15 right) from 20 patients (mean age 62 years, range 47–74 years: 10 male) receiving MN60MA posterior chamber IOLs ranging from −3.00 to +5.00 D for routine cataract surgery at the VMMC, Seattle, Washington from August 2009 to March 2016 were included in this study. Eight negative lenses (five −1.00 D, two −2.00 D, one −3.00 D), 21 positive lenses (two 1.00 D, two 2.00 D, eight 3.00 D, four 4.00 D, five 5.00 D) and 3 zero-powered lenses were implanted in the capsular bag. Ten eyes received single limbal relaxing incisions at the time of surgery. Scleral frown incisions (2.65 mm) and phacoemulsification with the Alcon Infiniti or Centurion machines were used in all patients. Axial lengths (mean 30.31 mm, range 28.12–33.16 mm; signal-to-noise ratio >2 in all but one eye which had a SNR 1.9) and anterior chamber depths (ACD) were measured with partial coherence interferometry (IOLMaster, Carl Zeiss Meditec, Inc. v. 5.02). Keratometry values were measured with a manual calibrated office keratometer (Haag-Streit, Bern, Switzerland). Two patients had previous cornea transplants with all sutures removed prior to cataract surgery, one patient had a failed filter bleb and one had a previous scleral buckle. Twelve eyes had final postoperative best spectacle corrected distance visual acuity (BSCVA) of 20/15, 16 had BSCVA of 20/20 and two eyes each had BSCVA of 20/25 and 20/30, respectively, measured at least 1 month after uncomplicated surgery (range 4–313 months, median 8 months).

Initial IOL power measurements for third-generation formulas used the following constants: (Haigis: *a*0: 0.229, *a*1 0.011, *a*2 0.205; Holladay 1: 1.73, Hoffer Q: 5.49, SRK/T A constant: 118.9). The following data points were collected for each eye:

1. Standard third-generation formulas (Haigis, Hoffer Q, Holladay 1 and SRK/T) were retrospectively set for different target values to minimize hyperopic results using the internal software of an immersion A-scan instrument (Accutome, Inc., Malvern, PA): Haigis formula: −1.00 D, Hoffer Q; −1.75 D, Holladay 1 formula; −1.50 D and the SRK/T formula; −1.00 and −1.25 D [15–18].
2. Axial length (AL) adjustments for all equations followed the recommendations previously published and each equation used these adjustments with the target refraction set to zero using the internal software of the Accutome immersion A-scan instrument [6]. Due to high numbers of hyperopic results with this method, all equations were then separately targeted for −0.50 D.
   (a) Haigis: 0.9621 × IOLM AL + 0.6763
   (b) Hoffer Q: 0.8776 × IOLM AL +2.9269
   (c) Holladay 1: 0.8814 × IOLM AL + 2.8701
   (d) SRK/T: 0.8981 × IOLM AL + 2.5637
3. Barrett Universal II formula (www.apacrs.org/barrett_universal2/) [19]. Constants recommended in the online software were used: $A = 119.2$, lens factor 1.99. The IOL value that gave a low myopic (−0.25 to −0.75 D) result was chosen as the preferred lens. Unadjusted axial length from the IOLMaster was used with the refraction target set for plano for all eyes.
4. Haigis formula (Haigis +/−) using optimized constants for both positive and negative low-powered IOLs (User Group for Laser Interference Biometry (ULIB) online table (available at http://ocusoft.de/ulib/c1.htm; accessed December 1, 2015): positive-powered lens: *a*0 5.78, *a*1 0.40, *a*2 0.10; negative-powered lens: *a*0 −4.22, *a*1 0.40, *a*2 0.10. The calculations for this formula were performed on the IOLMaster with the target refraction set for plano for all eyes [8, 14].

Since the MN60MA intraocular lens is only available in 1.00 D steps in the range −5.00 to +5.00 D, in order to minimize the risk of postoperative hyperopia,

the IOL chosen was the next highest value for data sets 1 and 2 above as shown in the following examples:

(a) If formula shows −2.00 to −1.01 D, −1.00 D is chosen
(b) If formula shows +2.00 to +2.99 D, +3.00 D is chosen

The surgical goal was mild myopia around −0.50 D in 32 eyes. For some eyes, the Barrett Universal II and Haigis +/− formulas predicted two possible lens power choices for mild myopia, e.g., 1.00 D lens for −0.10 D result and a 2.00 D lens for a −0.73 D result. The chosen lens was the one predicting a final refraction closer to −0.50 D.

If a specific formula method recommended a different lens power than the one actually implanted, the expected final spherical equivalent (SE) was back-calculated by either adding to or subtracting from the actual calculated SE the difference in expected final refraction between the two IOLs using the value of 0.64 D change in spherical equivalent per diopter difference. This value represents the mean change in SE per diopter for this group of eyes and is similar to previously published methods [20].

Most studies will report percentages of eyes within ±0.50 D of the intended surgical result. This seemed inappropriate for this group of patients since these IOLs only come in 1.00 D and not 0.50 D steps. Instead, the percentages of eyes for each formula falling within the final postoperative range −1.00 to 0.25 D are reported since this would achieve an excellent postoperative result in such extremely myopic patients. Due to the method of choosing the IOL power for each formula outlined above, this study could not calculate refractive prediction errors in the standard way for data sets 1 and 2 since the chosen IOL was rounded up to the next highest whole number [21]. However, for the two equations specifically designed for low-powered IOLs which gave predictions for whole numbered IOLs (Barrett Universal II and Haigis +/−), the refractive prediction errors (PE) were calculated as the difference between the predicted refraction and the actual final measured spherical equivalent refraction [8, 14, 19] A negative PE indicates a hyperopic refractive outcome. In addition, the mean, standard deviation (SD), median, range of postoperative final spherical equivalent refractions, median absolute error (MedAE), the percentage left >0.25 D hyperopic or less than −1.00 D myopic for the recommended IOL and the percentage of eyes within ±0.50 and ±1.00 D of the targeted final refractive error are also reported. The MedAE was calculated by converting all negative SE to positive and calculating the median value to determine clinical efficacy.

Results

Table 1 summarizes the data for all 32 eyes. The mean spherical equivalent ranged from −0.34 to −0.68 D for all four third-generation formulas with varying target refractions which were chosen to minimize hyperopic results. Changing the target from −1.00 to −1.25 D for the SRK/T formula reduced the number of hyperopic refractions to one eye (0.64 D) but increased the number of myopic results in 6 eyes (range −1.14 to −1.40 D) with a doubling of the mean refraction to −0.68 D. Using AL adjustments targeting for a plano result decreased the mean numerical error range (−0.04 to −0.28 D); however, many eyes were left hyperopic (range 0.13–0.64 D). Targeting −0.50 D with AL adjustments minimized or eliminated hyperopic results while leading to several SE results between −1.00 and −1.65 D and increasing the mean refractive range by −0.50 D (range −0.46 to −0.80 D). The Barrett and Haigis +/− formulas had mean SE of −0.36 and −0.34 D, respectively. The all important percentage of eyes within the final refractive range of 0.25 to −1.00 D was 100% with the Barrett Universal II and the Haigis +/− formulas, 97% with the Holladay 1 formula targeted for −1.50 D and 94% with the standard Haigis formula targeted for −1.00 D. Benchmark studies have shown that in routine cataract surgery 71% of eyes are within ±0.50 D and 93–94% within ±1.00 D of target refraction [22, 23]. Figure 1 displays the percentage of eyes within these ranges with the target refractive goal of −0.50 D. Only the AL-adjusted Hoffer Q, Holladay 1 and SRK/T formulas targeted for plano refraction did not meet these criteria.

Table 2 summarizes the same data looking only at the 8 eyes that had minus-powered lenses placed at surgery. The major finding was the lack of any outlier eyes using the Barrett Universal II and Haigis +/− formulas and only one eye with residual myopia less than −1.00 D (−1.28 D) and no hyperopic outliers using the standard Haigis formula targeted for

Table 1 Mean, standard deviation, range, median absolute error and outliers for all formulas and methods

Formula	Mean ± SD	Range	Median	MedAE	≤0.25≥ –1.00 D (%)	Myopic outliers	Hyperopic outliers
Haigis −1.0	−0.54 ± 0.37	0.13 to −1.28	−0.51	0.51	30/32 (94)	−1.15, −1.28	
SRK/T −1.25	−0.68 ± 0.43	0.64 to −1.40	−0.69	0.69	25/32 (78)	−1.14, −1.14, −1.15, −1.15, −1.28, −1.40	0.64
SRK/T −1.00	−0.34 ± 0.37	0.64 to −1.00	−0.45	0.50	30/32 (94)		0.39, 0.64
Holladay 1 −1.50	−0.44 ± 0.33	0.13 to −1.28	−0.50	0.50	31/32 (97)	−1.28	
Hoffer Q −1.75	−0.52 ± 0.41	0.64 to −1.28	−0.50	0.51	28/32 (88)	−1.15, −1.28, −1.28	0.64
Haigis ALadj	−0.28 ± 0.43	0.64 to −1.28	−0.25	0.38	28/32 (88)	−1.28	0.27, 0.50, 0.64
Haigis ALadj −0.50	−0.80 ± 0.39	0 to −1.65	−0.83	0.83	24/32 (75)	−1.14, −1.15, −1.16, −1.28, −1.28, −1.28, −1.37, −1.65	
SRK/T ALadj	−0.10 ± 0.40	0.64 to −1.00	0	0.25	27/32 (84)		0.27, 0.39, 0.50, 0.55, 0.64
SRK/T ALadj −0.50	−0.66 ± 0.39	0 to −1.65	−0.64	0.64	27/32 (84)	−1.15, −1.28, −1.28, −1.28, −1.65	
Holladay 1 ALadj	−0.12 ± 0.43	0.64 to −1.00	−0.12	0.32	26/32 (81)		0.27, 0.39, 0.50, 0.64, 0.64, 0.64
Holladay 1 ALadj −0.50	−0.62 ± 0.41	0.13 to −1.65	−0.64	0.64	28/32 (88)	−1.15, −1.28, −1.28, −1.65	
Hoffer Q ALadj	−0.04 ± 0.40	0.64 to −1.00	0.14	0.25	23/32 (72)		0.27, 0.27, 0.39. 0.39, 0.50, 0.55, 0.64, 0.64, 0.64
Hoffer Q ALadj −0.50	−0.46 ± 0.48	0.64 to −1.65	−0.50	0.50	27/32 (84)	−1.15, −1.28, −1.65	0.50, 0.64
Barrett Universal II	−0.36 ± 0.28	0.13 to −1.00	−0.38	0.38	32/32 (100)		
Haigis +/−	−0.34 ± 0.28	0.14 to −0.77	−0.37	0.37	32/32 (100)		

Numbers adjacent to formula name indicate target refractions used for each formula to aim for final spherical equivalent goal of −0.50 D

SD standard deviation, *MedAE* median absolute error, *ALadj* axial length adjusted, *Haigis +/−* Haigis formula with separate *a*0 constants for plus/minus lenses

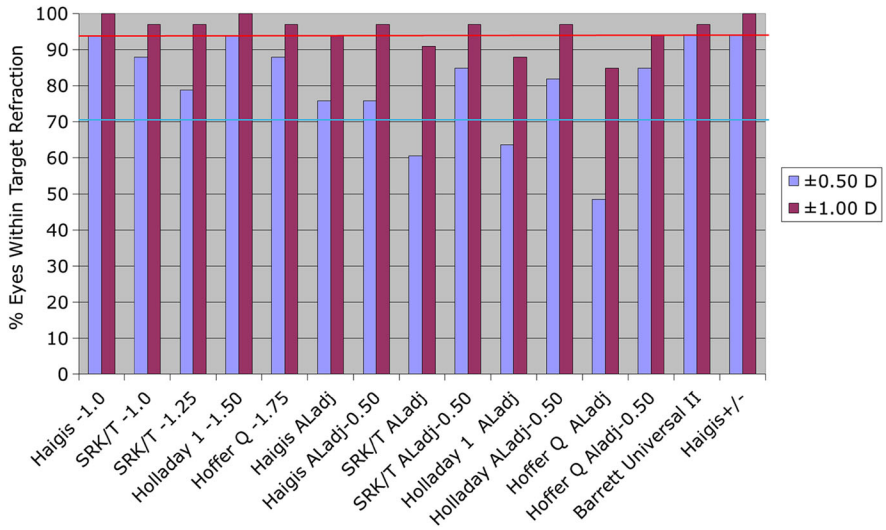

Fig. 1 Percentage of eyes within ±0.50 D and ±1.00 D of targeted spherical equivalent for all formulas and methods. *ALadj* axial length adjusted, *Haigis +/−* Haigis formula with separate *a*0 constants for plus/minus lenses. Numbers adjacent to formula name indicate target refractions used for each formula to achieve mild myopia. *Blue line* and *red line* represent benchmark criteria for ±0.50 and ±1.00 D from targeted final spherical equivalent, respectively

−1.00 D and Holladay 1 formula targeted for −1.50 D.

Table 3 summarizes the PE for the Barrett Universal II and Haigis +/− formulas. Both formulas gave similar results showing small degrees of residual hyperopic PE (0.19 and 0.21 D, respectively).

Discussion

The aim of this paper was to determine the best way to use published formulas to obtain excellent clinical results in this select group of highly myopic patients. Since these lenses only come in one diopter steps, choosing a lens that is off by one diopter from the ideal lens will lead to a final spherical equivalent that is either 0.64 D too myopic or hyperopic. Aiming for mild myopia helps to minimize any unacceptable hyperopic results, and reporting the percentage of eyes within −1.00 to 0.25 D final spherical equivalent is a meaningful clinical number.

Most studies have shown that using routine lens constants in standard third-generation formulas and aiming for emmetropia produce hyperopic surprises in this group of patients [1, 4–6, 9–12]. Many authors suggest aiming for myopia to avoid this problem; however, the exact amounts of targeting for myopia to achieve end results closer to emmetropia have not been precisely tested [2, 3, 6, 9]. This study highlights the different target refractions for the common third-generation IOL formulas (Haigis −1.00 D, Hoffer Q −1.75 D, Holladay 1 –1.50 D, SRK/T −1.00/−1.25 D) that can be used to minimize hyperopia and meet benchmark standards.

Adjusted AL regression equations were developed by Wang and Koch who theorized that because optical biometry assigns a single index of refraction for all measurements in eyes of any length, longer eyes with a higher proportion of vitreous will have artificially longer AL readings [6]. AL-adjusted methods either targeted for plano or −0.50 D results create either higher numbers of hyperopic or myopic SE results, respectively; however, aiming for −0.50 D does meet the benchmark criteria of ±0.50 D in at least 71% of eyes and ±1.00 D in 93–94% of eyes [22, 23].

Negative-powered IOLs pose unique refractive problems. The MN60MA lens is a meniscus IOL having its concave sides facing the cornea. The principle planes for plus powers lie posterior to the IOL and for minus powers anterior to the IOL [14] Since the principle plane is related to the effective lens position which itself is related to IOL formula constants, Haigis stresses that plus and minus IOLs need different IOL constants [14] The Barrett Universal II formula, which relates ACD to axial length and keratometry, is a theoretical formula based on

Table 2 Negative-powered intraocular lens subset: mean, standard deviation, range, median absolute error and outliers for all formulas and methods

Formula	Mean ± SD	Range	Median	MedAE	≤0.25≥ −1.00 D (%)	Myopic outliers	Hyperopic outliers
Haigis −1.0	−0.64 ± 0.42	0 to −1.28	−0.64	0.64	7/8 (88)	−1.28	
SRK/T −1.25	−0.40 ± 0.58	0.64 to −1.28	−0.40	0.52	6/8 (75)	−1.28	0.64
SRK/T −1.00	−0.08 ± 0.48	0.64 to −0.64	−0.13	0.39	6/8 (75)		0.39, 0.64
Holladay 1 −1.50	−0.48 ± 0.44	0 to −1.28	−0.40	0.40	7/8 (88)	−1.28	
Hoffer Q −1.75	−0.40 ± 0.58	0.64 to −1.28	−0.40	0.52	6/8 (75)	−1.28	0.64
Haigis ALadj	−0.32 ± 0.47	0.64 to −0.89	−0.40	0.52	7/8 (88)		0.64
Haigis ALadj −0.50	−0.88 ± 0.41	0 to −1.28	−0.96	0.96	6/8 (75)	−1.28, −1.28	
SRK/T ALadj	0.00 ± 0.47	0.64 to −0.64	0.12	0.32	6/8 (75)		0.39, 0.64
SRK/T ALadj −0.50	−0.64 ± 0.47	0 to −1.28	−0.52	0.52	6/8 (75)	−1.28, −1.28	
Holladay 1 ALadj	−0.16 ± 0.47	0.64 to −0.64	−0.32	0.40	6/8 (75)		0.39, 0.64
Holladay 1 ALadj −0.50	−0.72 ± 0.48	0.00 to −1.28	−0.77	0.77	6/8 (75)	−1.28, −1.28	
Hoffer Q ALadj	0.08 ± 0.40	0.64 to −0.64	0.12	0.25	6/8 (75)		0.39, 0.64
Hoffer Q ALadj −0.50	−0.32 ± 0.47	0.64 to −0.89	−0.40	0.52	7/8 (88)		0.64
Barrett Universal II	−0.32 ± 0.25	0.00 to −0.64	−0.32	0.32	8/8 (100)		
Haigis +/−	−0.32 ± 0.25	0.00 to −0.64	−0.32	0.32	8/8 (100)		

Numbers adjacent to formula name indicate target refractions used for each formula to aim for final spherical equivalent goal of −0.50 D

SD standard deviation, *MedAE* median absolute error, *ALadj* axial length adjusted, *Haigis +/−* Haigis formula with separate *a*0 constants for plus/minus lenses

Table 3 Prediction errors for Barrett Universal II and Haigis +/− formulas

Formula	Mean ± SD	Range	Median	MedAE
Barrett Universal II	−0.19 ± 0.30	0.38 to −0.91	−0.19	0.26
Haigis +/−	−0.21 ± 0.36	0.46 to −1.16	−0.18	0.23

SD standard deviation, *MedAE* median absolute error, *Haigis +/−* Haigis formula with separate aO constants for plus/minus lenses

Gaussian thick lens optical principles that also takes into account the principle planes of refraction and lens thickness [19]. Theoretically, using plus IOL constants for minus lenses would produce hyperopic results by choosing a too strong minus lens, and this error would increase with increased axial length [14]. In fact, this problem has been documented in other studies [1–3, 8, 10, 12]. Results improved when separate lens constants were used in other reports [8, 11, 24]. The current study confirms excellent final refractive results using the Bartlett Universal II and Haigis +/− formulas in patients requiring negative-powered IOLs.

The current study confirms one but not all of the conclusions from a recently published study which recommended AL adjustment with both the Haigis and Holladay 1 formulas along with the Barrett Universal II formula to meet benchmark criteria in patients requiring these low diopters IOLs [9]. The current study also confirms some of the recommendations from Warren Hill's website (http://www.doctor-hill.com/iol-main/extreme_axial_myopia.htm (assessed 2/6/16) which no longer advises targeting moderate amounts of myopia and suggests using the Haigis +/− formula, Barrett Universal II formula and adjusted optical biometry axial length methods of Wang and Koch for these highly myopic eyes.

There are several limitations in this study. Although this report has one of the largest groups of eyes receiving low-powered IOLs, data from only 32 eyes from a single surgeon were analyzed retrospectively.

Since a Lenstar (Haag-Streit AG, Koeniz, Switzerland) was not available, the Olsen formula (Phacooptics, Aarhus, Denmark) was not tested. The Holladay 2 formula (Holladay IOL Consultant Software & Surgical Outcomes Assessment, Bellaire, TX) was also not tested. Bilateral eyes of twelve patients were included which increased the number of study eyes although including only one eye in intraocular lens formula studies has been recommended [21]. There are a small number of patients in any surgeon's practice requiring these low diopter IOLs which is why the IOL constants could not be personally optimized [9]. Myopic target refractions for the standard third-generation formulas proposed in this study to minimize hyperopic SE would need to be validated in the future with another patient cohort. It is possible that intraoperative aberrometry using either the Bartlett Universal II or Haigis +/− formulas could also give similar results, but this technology was not tested at this time.

In conclusion, the simplest method in choosing the proper low-powered MN60MA IOL for highly myopic eyes is to use the Barrett Universal II formula which can be accessed via the Internet and the Haigis +/− formula programmed into the IOLMaster. Aiming for mild myopia minimizes the small amounts of hyperopic prediction errors associated with both formulas. Excellent results exceeding benchmark criteria can also be achieved using the standard Haigis formula targeted for −1.00 D and the Holladay 1 formula targeted for −1.50 D and placing the next highest IOL power in the eye. All these methods minimize postoperative hyperopic surprises.

Compliance with ethical standards

Conflict of interest The author declares that he has no conflict of interest. The author certifies that he has no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Retrospective study: For this type of study, formal consent is not required.

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