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Accuracy of new and standard intraocular lens power calculations formulae in Saudi pediatric patients

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Abstract:

PURPOSE: The purpose of this study is to compare the accuracy of new generation formulas to standard formulas for intraocular lens (IOL) power calculations in pediatric patients.

SUBJECTS AND METHODS: This retrospective case series compared the postoperative refractions to the predicted refractions after lensectomy and IOL implantation in pediatric patients. Four new generation formulas (Haigis, Holladay II, Olsen, and Barrett Universal II) were compared to four standard formulas (Holladay I, Hoffer Q, SRK/T, and SRKII) 4. The absolute prediction error (APE) was calculated as the absolute difference between the actual postoperative spherical equivalent and predicted spherical equivalent). The Friedman test was used to evaluate the difference between formulas. $P < 0.05$ was statistically significant.

RESULTS: The study sample was comprised 44 eyes from 29 patients (20 males and 9 females) with median age at surgery of 2.85 years (2.04–6.14 years). The Holladay I and II, Barrett Universal II, SRK/T, SRKII, Olsen, and Hoffer Q formulas had comparable median APE (MedAPE) of 1.32 D (0.51–2.11 D), 1.34 D (0.82–1.94 D), 1.28 D (0.73–1.85 D), 1.26 D (0.60–2.08 D), 1.16 D (0.54–1.16 D), 1.34 D (0.80–1.98 D), and 1.27 D (0.63–2.08 D), respectively ($P = 1.0$). The Haigis formula had the statistically highest MedAPE of 2.00 D (1.27–3.04 D) ($P < 0.001$). More than 70% of eyes were within ± 2.0 D for the Holladay I and II, Barrett Universal II, SRK/T, SRKII, Olsen, and Hoffer Q formulas. Fifty percent of eyes were within ± 2.0 D for the Haigis formula.

CONCLUSION: New generation IOL formulas do not outperform standard IOL formulas in predicting postoperative refraction for pediatric patients.

Keywords:

Children, intraocular lens formula, intraocular lens power, pediatric, prediction error

Introduction

Recently, significant research has focused on intraocular lens (IOLs) power calculation in pediatric patients. The standard IOL calculation formulas current used are the Hoffer Q,^[1] Holladay I,^[2] SRK/T,^[3] and SRK II.^[4,5] However, the selection of IOL power calculation formula in pediatric patients remains controversial. There are three approaches in the literature to address IOL power calculations for pediatric patients.

The first approach compared standard formulas in pediatric patients regarding prediction error. This approach advised the use of Hoffer Q,^[6] SRK/T^[7,8] and SRK II^[9,10] for IOL power calculations in pediatric patients. Hence, these studies did not agree on a single formula for use in pediatric patients. Moreover, some of these comparisons were not statistically significant. The second approach was to correct for hyperopic or myopic shift in the formula. However, these studies did not document the magnitude of hyperopia that should be targeted.^[11] The third approach was to transition to new generation formulas

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such as Holladay II, Haigis, Olsen, and Barrett Universal II. New generation formulas use more predictors and more accurate theoretic models to predict the effective lens position. Hence, better prediction of postoperative refractive error is expected.^[12]

The purpose of this study is to compare the accuracy of standard and new generation IOLs power calculation formulas in pediatric patients. Many studies have compared new and standard formulas in adults.^[13] However, to the best of my knowledge, this the first study to compare the accuracy of new and standard IOL power calculations formulas in pediatric patients.

Subjects and Methods

This retrospective case review included pediatric patients who underwent lensectomy with IOL implantation for congenital/developmental cataract at tertiary eye hospital between December 2003 and October 2016. At the time of surgery, informed consent and surgical counseling were completed for all cases. This study adhered to the tenets of the declaration of Helsinki. Only eyes that had uneventful surgery were included. Patients with ocular pathology other than congenital/developmental cataract were excluded from the study.

Data were collected on age at surgery, axial length (AL), anterior chamber depth (ACD), lens thickness (LT), average keratometry (K), implanted IOL power, IOL model, the A-constant, 1 month postoperative cycloplegic refraction. Contact ultrasound A-scan (Scan-1000; Ophthalmic Technology International, Toronto, Canada) was used to measure the AL, ACD, and LT. K was measured by the ARK-30 Auto-Keratometer/Refractor (NIDEK Co. Ltd., Gamgauri, Japan). These measurements were performed in operating room under general anesthesia at the same time of surgery. All patients received lensectomy together with primary posterior capsulotomy, anterior vitrectomy and posterior chamber IOL implantation within the capsular bag. For patients 7 years or younger, the target refraction (Diopter) was calculated as 7 minus patient age. The target refraction was set to make the eye hyperopic to compensate for the myopic shift that would occur due to elongation of the eye as the child ages. All biometry measurements and cycloplegic refractions were performed by four experienced optometrists.

The lens constants (A constant for SRK/T, pACD for Hoffer Q, and SF for Holladay I) were back-calculated so the prediction error was zero, that is the formula provided by its author with lens constant is the dependent variable was used with actual postoperative refraction used as target refraction. These group-optimized constants were then entered in SRK/T, Hoffer Q, and Holladay

I and II. The SRK/T optimized A constant was entered in the Barrett Universal II and Olsen formulas. The optimized SF was converted to a0 and entered in the Haigis formula, the a1 and a2 constants for the Haigis formulas, were kept at their default values of 0.40 and 0.10, respectively. Optimized ultrasonic IOL constants were used in the IOL power calculations. Barrett Universal II is available as an online formula (http://www.apacrs.org/barrett_universal2/). Holladay I and II, SRK/T, Hoffer Q were available from Holladay IOL Consultant (v2017, 0225, USA). SRKII and Haigis were programmed in excel sheets (v 2013, Microsoft, USA). The Olsen formula was performed via PhacoOptics software (v. 1.10.100.2031, IOL Innovations ApS, Aarhus, Denmark).

The numerical prediction error (NPE) was calculated as the difference between the actual postoperative spherical equivalent (ASE) and predicted spherical equivalent. Thus, a positive NPE indicates a refractive outcome that was more hyperopic than predicted or a hyperopic shift. The absolute prediction error (APE) was calculated as the absolute value of NPE. The percent of eyes ± 0.50 D, ± 1.00 D, and ± 2.0 D were calculated for all formulas.

The Friedman test was performed to show difference among formulas. A series of Wilcoxon signed rank tests were performed to show difference between pairs of formulas. $P < 0.05$ was considered statistically significant. Statistical analysis was executed with statistical package for the social sciences (SPSS, v. 22; IBM Corp., NY, USA).

Results

This retrospective case series comprised 44 eyes from 29 patients (20 males and 9 females). The median age at surgery was 2.85 years (2.04–6.14 years). Table 1 presents a summary of biometry and refraction. The mean values of ACD, LT, and K were within normal limits except for the short AL [Table 1]. The IOLs that were implanted include, SN60WF (23 cases), MA60AC (8 cases), SA60AT (9 cases), (Alcon Laboratories, Inc., Fort Worth, TX); Rayner 620H (3 cases), (Rayner Intraocular Lenses Limited, Worthing, UK); and Corneal CP65T (1 case).

Table 2 summarize the mean and median of NPE and APE for all formulas. The NPE was negative for all formulas indicating that the refractive outcome was more myopic than predicted. The SRKII had no outliers and had the smallest NPE and deviation ($P > 0.05$). Figure 1 shows numerical prediction error for new and standard intraocular lens power calculation formulas. Friedman test for difference in APE among formulas was statistically significant ($P < 0.001$). Series of Wilcoxon signed-ranks test for difference in APE between pairs of formulas shows that no statistical differences exist between formulas except the Haigis formula which had

Table 1: Biometry and refraction

Parameter	Minimum	Maximum	Median	Mean±SD
Axial length (mm)	17.99	24.13	21.68	21.87±1.47
ACD (mm)	2.22	4.45	3.64	3.57±0.52
Lens thickness (mm)	2.56	5.45	3.67	3.73±0.89
Keratometry (D)	40.50	53.50	44.16	44.47±2.67
Implanted IOLP (D)	13.50	30.00	21.50	21.16±3.79
ASE (D)	-1.13	8.50	2.38	3.47±2.87

ACD=Anterior chamber depth, IOLP=Intraocular lens power, ASE=Actual postoperative spherical equivalent, SD=Standard deviation

Table 2: Numerical and absolute prediction errors of standard and new generation intraocular lens power calculations formulas

Formula	Numerical prediction error (D), mean±SD	Absolute prediction error (D)		
		Mean±SD	Median	IQR
SRKII	-0.23±1.53	1.26±0.88	1.16	0.54-1.16
SRK/T	-0.28±1.73	1.43±1.09	1.26	0.60-2.08
Hoffer Q	-0.45±1.81	1.48±1.11	1.27	0.63-2.08
Barrett Universal II	-0.56±1.77	1.49±1.08	1.28	0.73-1.85
Holladay I	-0.25±1.79	1.43±0.99	1.32	0.51-2.11
Holladay II	-0.46±1.82	1.52±1.08	1.34	0.82-1.94
Olsen	-0.66±1.86	1.58±1.16	1.34	0.80-1.98
Haigis	-1.70±2.01	2.23±1.39	2.00	1.27-3.04

SD=Standard deviation, IQR=Interquartile range, D=Diopter

Table 3: Percentage of eyes with numerical prediction error

Formula	Percentage of eyes within numerical prediction error indicated		
	±0.50 D (%)	±1.0 D (%)	±2.0 D (%)
Holladay II	15.9	31.8	79.5
Barrett Universal II	13.6	38.6	77.3
SRKII	20.5	43.2	75.0
SRK/T	15.9	38.6	75.0
Olsen	11.4	31.8	75.0
Holladay I	25.0	36.4	72.7
Hoffer Q	22.7	36.4	72.7
Haigis	6.8	15.9	50.0

APE higher than other formulas ($P < 0.001$). Table 3 summarizes the proportion of eyes with NPE of ± 0.50 D, ± 1.00 D, and ± 2.00 D. The Haigis formula had only 50% of eyes within ± 2.0 D. The remaining formulas had $>70\%$ of eyes within ± 2.0 D.

To evaluate the limitations of formulas, NPE was plotted against AL, K, ACD, and LT, which are the most important predictors of ELP and consequently NPE. Figure 2 shows that formulas produce a myopic shift of -0.5 to -1.0 D for eyes with normal AL (22 mm to 25 mm) but vary within ± 2 D for short eyes (19–21 mm). The Holladay II was within ± 1 D over the entire range of AL. Figure 3 shows that the formulas vary within ± 2 D in eye with normal K values (43–46 D) and mild steeping (47–53 D). Figure 4 shows that the formulas produce a myopic shift of -0.5 to -1.0 D in eyes with

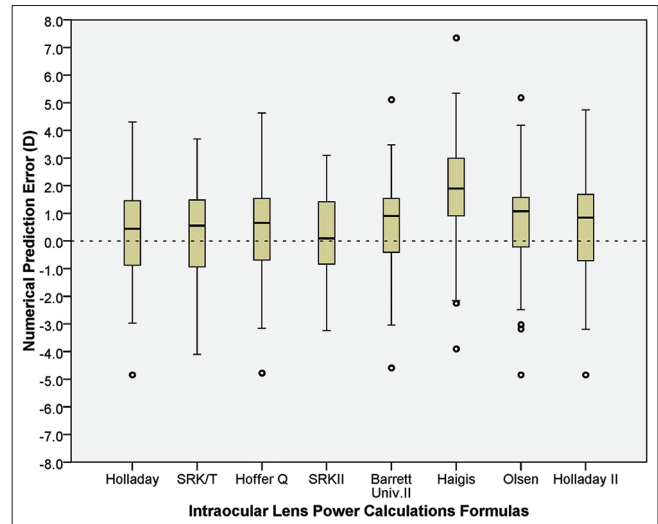


Figure 1: Numerical prediction error for standard and new generation intraocular lens power calculation formulas

normal ACD (3.5–4.5 mm) but vary roughly within ± 1.00 D in short eyes (19–21 mm). Figure 5 indicates that the formulas vary roughly within ± 1.00 D over the entire range of LT (3–5.50 mm). The NPE for the Haigis was an exception for all predictors and roughly varied within ± 3.0 D over the entire range. Figure 6 shows that formulas vary within ± 2 D in the IOL range of IOL power used (18–24 D) and vary $> \pm 2$ D outside this range.

Discussion

IOL power calculations in pediatric patients differ from adults in two aspects. First, the AL, ACD, LT, and K can differ. In this study, the ACD, LT, and K were within normal values but the AL was short. Second, the target refraction is selected to be more hyperopic in pediatric patients than in adults. These two factors could render standard IOL formulas inaccurate in pediatric patients. All formulas showed a myopic shift (mean NPE is negative) in this study. This is consistent with other studies that compare formulas in short eyes.^[14] The myopic shift indicates a more hyperopic target refraction is required for IOL implantation in pediatric patients. In addition, there is a need to develop IOLs formula specific for pediatric patients. SRKII had the lowest prediction error but was not statistically significant [Table 2]. The Holladay II had the highest percent of eyes (79.5%) within ± 2.0 D prediction error [Table 3]. However, the percentages of eyes with NPE within ± 0.50 D, and ± 1.00 D for each formula were below the adult benchmark standard of 85% of eyes with NPE ± 1.0 D and 55% of eyes with NPE ± 0.50 D.^[15] Our outcomes indicate that the NPE of formulas was roughly within ± 1.00 D for the entire ranges of LT and ACD and within ± 2.00 D over the entire ranges of AL and K [Figures 2-5]. These observations indicate that NPE may be more sensitive

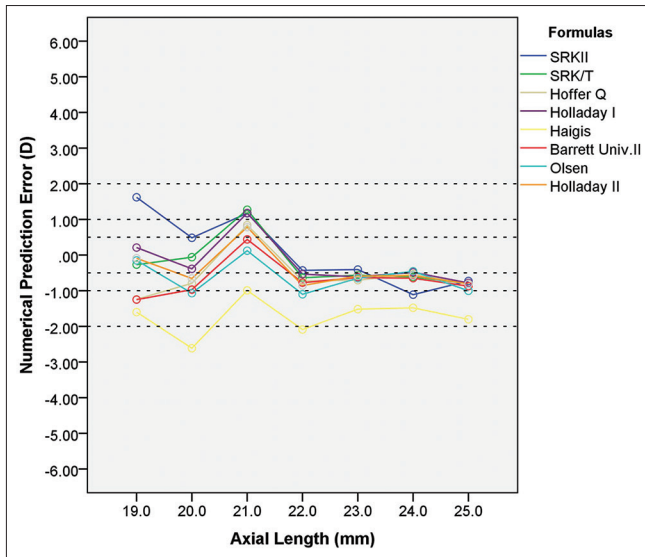


Figure 2: Numerical prediction error versus axial length

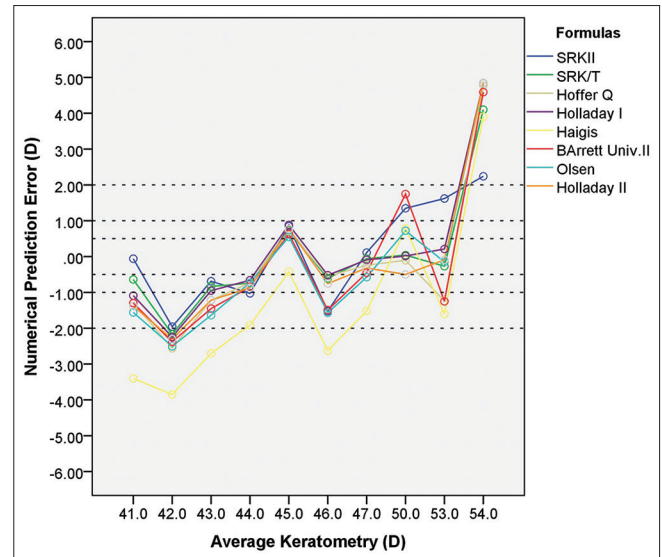


Figure 3: Numerical prediction error versus average keratometry

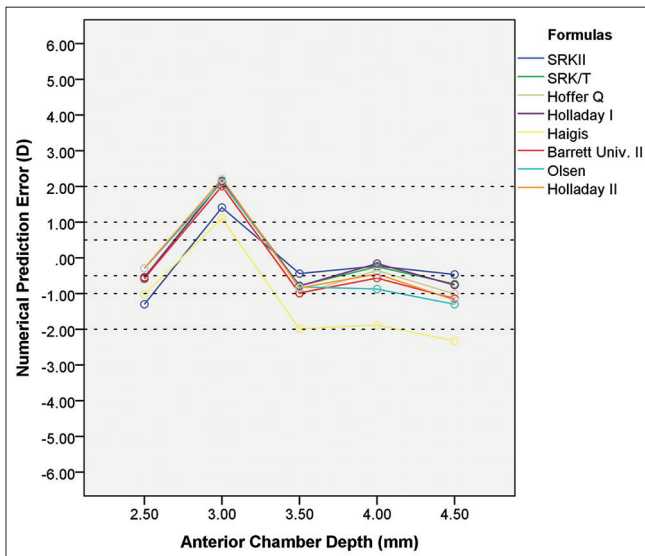


Figure 4: Numerical prediction error versus anterior chamber depth

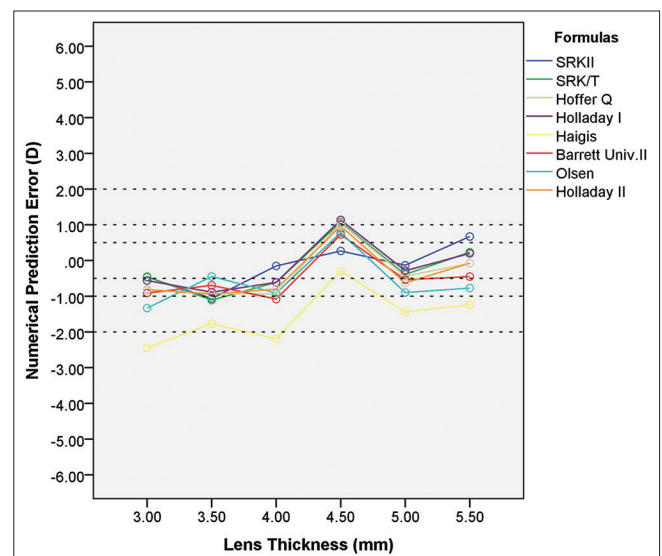


Figure 5: Numerical prediction error versus lens thickness

to AL and K than ACD and LT. The IOL formulas in the current study had a minimum NPE in the IOL power range of 18–24 D. This outcome concurs with Melles *et al.*, who reported a minimum NPE within the same range of IOL power.^[12]

Recommendations in the literature vary on the use of IOL formulas for pediatric patients. Nihalani and VanderVeen found that Hoffer Q was the most predictable formula.^[6] However, Vasavada *et al.* and O’Gallagher *et al.* recommended the SRK/T because it was the most accurate formula in pediatric patients.^[7,8] We found that the SRKII had the lowest prediction error. Similarly, Kekunnaya *et al.* and Joshi *et al.* reported that SRKII was the most predictable formula in pediatric patients.^[9,10] Alternately, Andreo *et al.* showed that

theoretical formulas did not outperform a regression formula.^[16]

New generation formulas include more predictors compared to standard formulas. For example, the Holladay II formula uses AL, average K, ACD, white-to-white WTW, LT, age, and preoperative refraction. The Olsen formula uses AL, ACD, K, LT, central corneal thickness, and age. The Haigis formula uses AL, ACD, and K. The Barrett Universal II formula uses AL, K, LT, ACD, and WTW. In addition, new generation formulas use different predictors to calculate the ELP such as the C-constant in the Olsen formula,^[17] use of ACD and AL in the Haigis formula^[18] or use of lens factor in Barrett Universal II. Once optimized, these predictors could make the formulas more

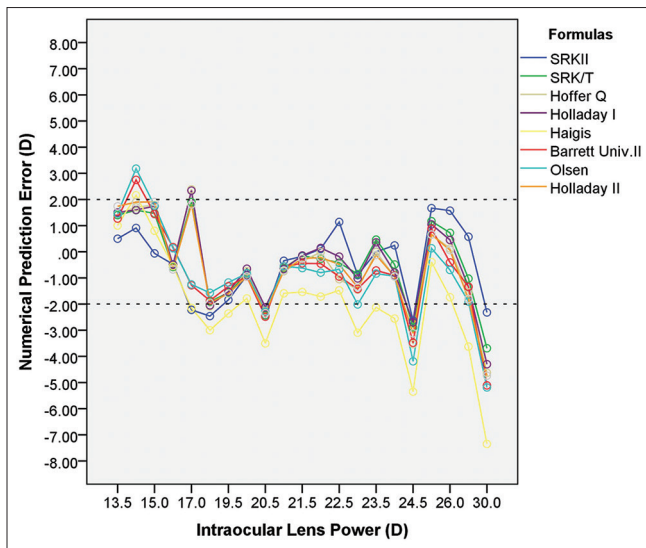


Figure 6: Numerical prediction error versus intraocular lens power

accurate. Optimization of the IOL constants is required before comparing formulas. Optimization of constants results in lower NPE and APE compared to using the manufacturer's constants.^[7] Furthermore, the new formulas use more accurate theoretical methods in their calculations. Formulas of Haigis, Holladay II, Barrett Universal II follow the vergence formula, i.e., $U + P = V$ where U is the vergence of an object, P is the power of the lens, and V is the vergence of the image. Unlike vergence formulas, Olsen is the only formula that uses ray tracing to calculate lens power. In this method, three rays emanating from an object are traced: a parallel ray, a ray through the center of the optical system of the eye, and a ray through the focal point of the optical system of the eye. Hence, this formula requires the index of refraction, lens configuration, i.e., front and back power of the IOL. The Olsen formula also uses ACD and LT to predict ELP. However, AL and K could be included to the improve accuracy. Haigis proposed the concept that the ELP of the IOL is a curve dependent on AL and ACD instead of a constant value. The Barrett Universal II, also a thick lens formula, takes into consideration the IOL principle planes and a lens factor to calculate ACD.^[19] There is no published literature on the variables used in the Holladay II formula.

Trivedi *et al.* and Vasavada *et al.* found that Holladay II had with least prediction error even in absence of a preoperative refraction, as is often the case for pediatric patients.^[7,20] However, the comparisons were not statistically significant. Melles *et al.* compared standard and new generation formulas in adults and found that the Barrett Universal II was the optimal formula with least APE ($P < 0.01$) and had the lowest standard deviation for the NPE.^[12] Cooke and Cooke ranked formulas for short eyes as follows: Olsen, Haigis,

Holladay I, SRK/T, and Hoffer Q; however, they did not report any statistically significant differences.^[21] In this study, the new generation formulas did not outperform the standard formulas. Excluding Haigis, these comparisons were not statistically significant; despite the fact that standard formulas use only two parameters (AL and K). In the current study, the Haigis formula had a significantly higher APE than other formulas ($P < 0.001$). However, we did not follow Haigis's recommendation to optimize the constants using regression analysis but instead, we converted an optimized SF for the a0 constant. This could explain the higher NPE and APE generated by the Haigis formula compared to the other formulas. The ELP in the Haigis formula is adjusted for AL through a2 constant. This could reduce the NPE in the extreme ranges of AL. Cooke and Cooke showed that Holladay II performed better when the preoperative refraction was excluded.^[22] Hence, Holladay II was used here without preoperative refraction. In our study, cataract often precluded a refraction.

There are some limitations to this study. The small sample size may hinder definitive conclusions on the use one formula for pediatric patients. In addition, the absence of WTW and preoperative refraction does affect the accuracy of some formulas. However, refraction was not possible due to presence of cataract. Another study limitation was the use of ultrasound A-scan compared to immersion A-scan or optical biometry. Nakhli reported that measurement of AL differed significantly in short eyes between A-scan and optical biometry.^[23] However, optical biometry device available was not suitable for very young patients and immersion A-scan was avoided fearing spillage of water at the site of surgery. In addition, variation in data due to use of ultrasound a-scan will affect prediction error similarly; hence, their comparisons will not be affected. This study follows Hoffer *et al.* proposal to use 1-month postoperative refraction and optimized lens constants.^[24] Nonetheless, it differs in use of ultrasonic biometry instead of optical biometry and the lack of postoperative corrected distance visual acuity of 6/12. However, optical biometry and visual acuity were not possible in this study of pediatric patients.

In summary, this study found that there is no significant difference between the new generation and standard IOL power calculation formulas in pediatric patients. Development of a new regression or theoretical formulas specific for pediatric IOL implantation with more measurements and optimized coefficients is recommended for future studies.

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Conflicts of interest

The authors declare that there are no conflicts of interests of this paper.

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