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A Comparison of Optical Biometers Used in Children for Myopia Control

Ein Vergleich zwischen optischen Biometern im Einsatz bei Kindern zur Überwachung der Myopieprogression

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Key words

myopia, axial length, children, biometry, refractive error, progressive myopia

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ABSTRACT

Purpose To assess the reproducibility (i.e., inter-device reliability) of the biometers Topcon MYAH, Oculus Myopia Master, and Haag-Streit Lenstar LS900 with the Carl Zeiss IOLMaster 700 and the intra-subject repeatability in myopic children in order to reliably detect axial growth for myopia management.

Methods Twenty-two myopic children (11.1 ± 2.4 yr) with a spherical equivalent of − 3.53 ± 2.35 D were examined with each of the biometers to assess axial length (AL) and corneal parameters (steepK, flatK, meanK, vectors J0, J45), and16 of these children agreed to a second round of measurements. Reproducibility of the first measurements between the IOLMaster and every other biometer was assessed employing a Bland-Altman approach and paired Student's t-test. Repeatability was assessed as intra-subject standard deviation and was used to estimate the minimum time interval required between two AL measurements to reliably detect axial growth of an eye of at least 0.1 mm/year.

Results Repeatability for AL measurements was as follows: IOLMaster: 0.05 mm, Myopia Master: 0.06 mm, Myah: 0.06 mm, Lenstar: 0.04 mm; the respective minimal time interval for axial growth assessment in myopia management was estimated as 5.6, 6.6, 6.7, and 5.0 months, respectively. Best reproducibility of the AL measurement was found between IOLMaster and Lenstar [95% Limits of Agreement (LoA) for reproducibility − 0.06 to 0.02]. As regards to the measured means, Lenstar gave measures of AL that were longer than with the IOLMaster by 0.02 mm ($p < 0.001$). Myopia Master measures of meanK were significantly lower (by 0.21 D with $p < 0.001$) than the values from the IOLMaster. As for J0, all biometers deviated significantly from IOLMaster measurements ($p < 0.05$).

Conclusion Generally good agreement was observed between all the biometers. When assessing myopia progression in children, a time frame of at least 6 months between the AL measurements is advisable in order to reliably determine any deviation from a normal growth pattern.

ZUSAMMENFASSUNG

Ziel der Arbeit Beurteilung der Reproduzierbarkeit (Zuverlässigkeit zwischen den Geräten) der Biometer Topcon MYAH, Oculus Myopia Master und Haag-Streit Lenstar LS900 mit dem Carl Zeiss IOLMaster 700 und der Wiederholbarkeit der Messergebnisse innerhalb einer Testperson, um zuverlässig ein Augenlängenwachstum im Myopiemanagement zu erkennen.

Methodik 22 kurzsichtige Kinder (11,1 ± 2,4 Jahre) mit einem sphärischen Äquivalent von − 3,53 ± 2,35 dpt wurden mit den verschiedenen Biometern untersucht, um die Achslänge und die Hornhautparameter (steepK, flatK, meanK, Vektoren J0, J45) zu bestimmen. 16 dieser Kinder stimmten einer 2. Messung an den Geräten zu. Die Reproduzierbarkeit der ersten Messungen zwischen dem IOLMaster und jedem anderen Biometer wurde mittels Bland-Altman-Analyse und gepaarten t-Tests bewertet. Die Wiederholbarkeit wurde als Standardabweichung innerhalb einer Testperson bestimmt, damit das minimale Zeitintervall errechnet werden kann, welches zwischen 2 Achslängenmessungen liegen sollte, um ein Augenlängenwachstum von mindestens 0,1 mm/Jahr zu erkennen.

Ergebnisse Die Wiederholbarkeit der Achslängenmessungen beträgt: IOLMaster: 0,05 mm, Myopia Master: 0,06 mm, Myah: 0,06 mm, Lenstar: 0,04 mm; das jeweilige minimale Zeitintervall für die Beurteilung eines Augenlängenwachstums von 0,1 mm/Jahr im Myopiemanagement bei Kindern wurde auf 5,6, 6,6, 6,7 bzw. 5,0 Monate geschätzt. Die beste Reproduzierbarkeit der Achslängenmessung zeigte sich zwischen IOLMaster und Lenstar [95% Übereinstimmungsbereich bei − 0,06 bis 0,02 mm]. Im Mittel misst der Lenstar eine um 0,02 mm länger Achslänge ($p < 0{,}001$) und der Myopia Master eine um 0,21 dpt geringere Hornhautbrechkraft ($p < 0{,}001$) als der IOLMaster. Für J0 wichen alle Biometer signifikant von den IOLMaster-Messungen ab ($p < 0.05$).

Schlussfolgerung Es wurde eine gute Übereinstimmung zwischen den Biometern festgestellt. Bei der Beurteilung der Myopieprogression bei Kindern ist ein Zeitraum von mindestens 6 Monaten zwischen den Achslängenmessungen ratsam, um eine Abweichung von einem physiologischen Augenlängenwachstum sicher erkennen zu können.

Introduction

Biometer devices for the assessment of eye biometry have a longstanding use in the power calculation for intraocular lenses in mostly middle-aged or elderly patients who undergo cataract surgery or refractive lens exchange [1, 2]. More recently, biometers have become important tools for ophthalmologists that focus on myopia control management in children and adolescents [3, 4]. For myopia control management, it is important to detect any deviation from a normal growth pattern in a child's eye as early and as safely as possible and to start the appropriate treatment.

Myopia can be triggered by behavioral and environmental factors [5]. It usually first develops in childhood between the ages 5 and 10 [6] (often called school myopia). It is contemplated that every child's eye that has a normal growth pattern of a developing eye will eventually approach the state of emmetropia in adulthood. Any axial length (AL) growth that is in excess of this normal growth will cause axial myopia and, if not reduced to normal, lead to the condition of progressive myopia [7]. Treatment options that have been proven to be effective by randomized clinical trials (RCTs) are low-dose atropine [8] and vision aids such as multifocal contact lenses [9], orthokeratology lenses [10], and spectacle lenses having included lens segments [11, 12]. Myopia control management uses the therapeutic tools with the aim to decrease an eye's excessive axial growth to approach at a growth rate that corresponds to the growth of children of the same age who become or stay emmetropic [3, 4, 13]. Thus, one essential element for proper myopia control management is the assessment of AL growth rate [14] through the measurement of AL (mm) at two points of time. The AL growth rate is then calculated at the time of the second measurement and referenced to a 1-year period to give numbers in mm growth per year (mm/yr). For a good assessment of AL growth, the availability of a reliable and stable AL measurement is key.

With the introduction of new biometers that are specifically designed for AL measurement in myopia management [Myopia Master, Oculus Optikgeräte, Wetzlar, Germany; by partial coherence interferometry (PCI), Myah, Topcon, Tokyo, Japan; by optical low-coherence interferometry (OLCI), and novel software tools for myopia management on the Lenstar LS900 (Haag-Streit), Koeniz, Switzerland; by optical low-coherence reflectometry (OLCR)], the measurement of AL in children is about to become the key method for optometrists and ophthalmologists who are dedicated to myopia management [15, 16]. Any optical biometry holds the advantage that it is independent of pupil size and accommodation, as an AL measurement can be performed before and after cycloplegia, leading to the same results [17]. Yet, the IOLMaster 700 [Carl Zeiss Meditec, Oberkochen, Germany; by swept-source optic coherence tomography (SS-OCT)] remains the standard instrument for biometry for ophthalmologists concerned with cataract surgery or refractive surgery. One problem may arise from the fact that there are different biometers around, which even employ different technologies of biometry. Children who are about to enter myopia management are sometimes called for a second opinion by a different optometrist or ophthalmologist who may then employ a different optical biometer. It is thus important to know whether there is a good agreement between the different types of biometers. Pedersen and colleagues [18] have looked at this before but tested adult subjects instead of children. Furthermore, as the assessment of the axial growth rate becomes more important, it is important to know the minimum time interval between two measurements to calculate the current axial growth rate, giving a minimum axial growth to be reliably detected. Repeated measurements on the same subject will inevitably vary

▶ **Table 1** Mean values and SD of the repeated measurements performed with all biometers.

	Parameter	n	1st Measurement (Mean ± SD)	2nd Measurement (Mean ± SD)	P value
IOLMaster 700	AL (mm)	32	24.58 ± 1.15	24.58 ± 1.15	0.77
	meanK (D)	31	43.79 ± 1.50	43.81 ± 1.45	0.36
	J0 (D)	31	0.53 ± 0.48	0.54 ± 0.47	0.64
	J45 (D)	31	0 ± 0.23	0.01 ± 0.24	0.62
Myopia Master	AL (mm)	25	24.61 ± 1.10	24.61 ± 1.11	0.60
	meanK (D)	26	43.11 ± 1.20	43.14 ± 1.29	0.72
	J0 (D)	26	0.33 ± 0.25	0.33 ± 0.30	0.75
	J45 (D)	26	0.05 ± 0.13	0.05 ± 0.16	0.94
Myah	AL (mm)	30	24.44 ± 1.18	24.44 ± 1.18	0.95
	meanK (D)	27	43.60 ± 1.52	43.58 ± 1.54	0.48
	J0 (D)	27	0.55 ± 0.48	0.54 ± 0.46	0.74
	J45 (D)	27	0 ± 0.20	− 0.02 ± 0.19	0.33
Lenstar	AL (mm)	29	24.56 ± 1.13	24.56 ± 1.13	0.30
	meanK (D)	28	43.55 ± 1.48	43.55 ± 1.47	0.95
	J0 (D)	28	0.54 ± 0.45	0.54 ± 0.45	0.99
	J45 (D)	29	− 0.01 ± 0.21	0 ± 0.21	0.86

around the true value because of the measurement error. On the assumption that the standard deviation (SD) between repeated measurements is the same for all subjects [19], we can measure the size of the measurement error for repeated measurements, i.e., the intra-subject SD or repeatability.

The present work thus aimed to analyze the repeatability and reproducibility of biometric data obtained with the IOLMaster 700, Myopia Master, Myah, and Lenstar LS900.

Methods

This retrospective analysis included a total of 44 eyes of 22 myopic children who were scheduled for a routine ophthalmological examination at our clinic between June 2022 and August 2022. To assess the repeatability of the biometers, a subset of 16 subjects who agreed to a second measurement on at least one of the biometers was used. Patients with ocular pathologies other than refractive and/or axial myopia were excluded in this evaluation.

Instruments and measurements

The AL (in mm), steepK, flatK, and meanK values (each in D) were obtained using IOLMaster, Lenstar, Myopia Master, and Myah. To minimize inter-operator variation, all measurements were performed by the same optometrist (A. M.) in a dim lit (15 lx) room. The measurements were performed at all the biometers, IOLMaster, Myopia Master, Myah, and Lenstar, before the full ophthalmic exam. Both eyes of each subject were included in the evaluation and the biometric measurements of each eye were considered as independent. All eyes (n = 44) were measured with the IOLMaster at least once. This biometer was chosen as the reference for the comparison and to assess reproducibility (see ▶ **Table 1**). For both, the first and second measurement, the order of biometers was randomized.

Analysis of the data

Data analysis was performed using Python (Python Software Foundation, Wilmington, DE, USA). For reproducibility of the measurements (i.e., inter-device reliability), the graphical method described by Bland and Altman was adopted [20]. To measure the size of the measurement error of each biometer in our young cohort, we calculated the intra-subject SD based on the two consecutive AL measurements for each child. To assess repeatability, the difference between two (consecutive) measurements for the same subject and the true AL is expected to be less than SQR(2)*1.96*SD or 2.77*SD for 95% of pairs of observations (intra-subject repeatability) [19]. We calculated the minimum interval of time that should lie between two AL measurements based on the respective intra-subject repeatability found for each biometer. A paired Student's t-test was used to compare the first and the second measurement of meanK, J0, J45, and AL and to compare the first measurements of the Myopia Master, Myah, and Lenstar with the IOLMaster.

Corneal power *K* for the steep (steepK) and flat (flatK) corneal radius R was calculated using the following equation:

$$K = \frac{n' - n}{R}$$

where n' is the refractive index of the cornea of 1.332 and n is the refractive index of air with 1.

▸ **Table 2** Overview of the intra-subject SD, intra-subject repeatability (2.77*SD), and the calculated time interval required between two axial length measurements for different axial growth rates to be reliably detectable.

Device	SD [mm] (95% CI)	Repeatability (2.77*SD) [mm] (95% CI)	Measurement interval required to reliably detect axial growth [months]			
			0.05 mm/yr (95% CI)	0.1 mm/yr (95% CI)	0.2 mm/yr (95% CI)	0.3 mm/yr (95% CI)
IOLMaster 700	0.02 (0.01–0.02)	0.05 (0.03–0.06)	11.3 (7.4–15.2)	5.6 (3.7–7.6)	2.8 (1.8–3.8)	1.9 (1.2–2.5)
Myopia Master	0.02 (0.01–0.03)	0.06 (0.03–0.08)	13.2 (8.0–18.4)	6.6 (4.0–9.2)	3.3 (2.0–4.6)	2.2 (1.3–3.1)
Myah	0.02 (0.01–0.03)	0.06 (0.04–0.08)	13.4 (8.6–18.2)	6.7 (3.6–9.1)	3.3 (2.1–4.5)	2.2 (1.4–3.0)
Lenstar	0.02 (0.01–0.02)	0.04 (0.03–0.06)	10.0 (6.4–13.7)	5.0 (3.2–6.8)	2.5 (1.6–3.4)	1.7 (1.1–2.3)

For the vectorial analysis, the corneal astigmatism was converted from the cylindrical notation to power vector notation by applying a Fourier transformation using the following equations [21]:

$$J_0 = -\frac{C}{2} \times \cos(2\alpha)$$

$$J_{45} = -\frac{C}{2} \times \sin(2\alpha)$$

where C is the negative cylindrical power calculated from steepK and flatK values and α is the cylindrical axis. J0 refers to cylinder power set at orthogonally 90° and 180° meridians, representing Cartesian astigmatism. Positive values of J0 indicate a greater refractive power and increased curvature along the vertical meridian than along the horizontal. J45 refers to a cross-cylinder set at 45° and 135°, representing oblique astigmatism.

Ethics

This study was conducted with the approval of the Ethics Committee of the University Hospital Jena (No.: 2019/1520) in accordance with national law and under the tenets of the Declaration of Helsinki in its latest revision. Informed consent was obtained from all participating children and both their parents.

Results

The 22 myopic children had a mean age of 11.28 ± 2.4 yr [95% confidence interval (CI) 10.28 to 12.29 yr]; their mean spherical equivalent (SE) was − 3.53 ± 2.36 D (95% CI − 4.52 to − 2.55 D).

Repeatability of the biometers

▸ **Table 1** gives an overview of the first and second measurements for the corresponding parameters collected (AL, meanK, J0, J45), where *n* gives the number of eyes, as not all eyes were measured twice with each biometer. Paired Student t-test did not show any significant difference between the measurements.

The intra-subject repeatability of AL measurements and the minimum time interval that should lie between two consecutive AL measurements with the according 95% (CI) for different requirements of reliability, i.e., detection limits, are given in ▸ **Table 2**.

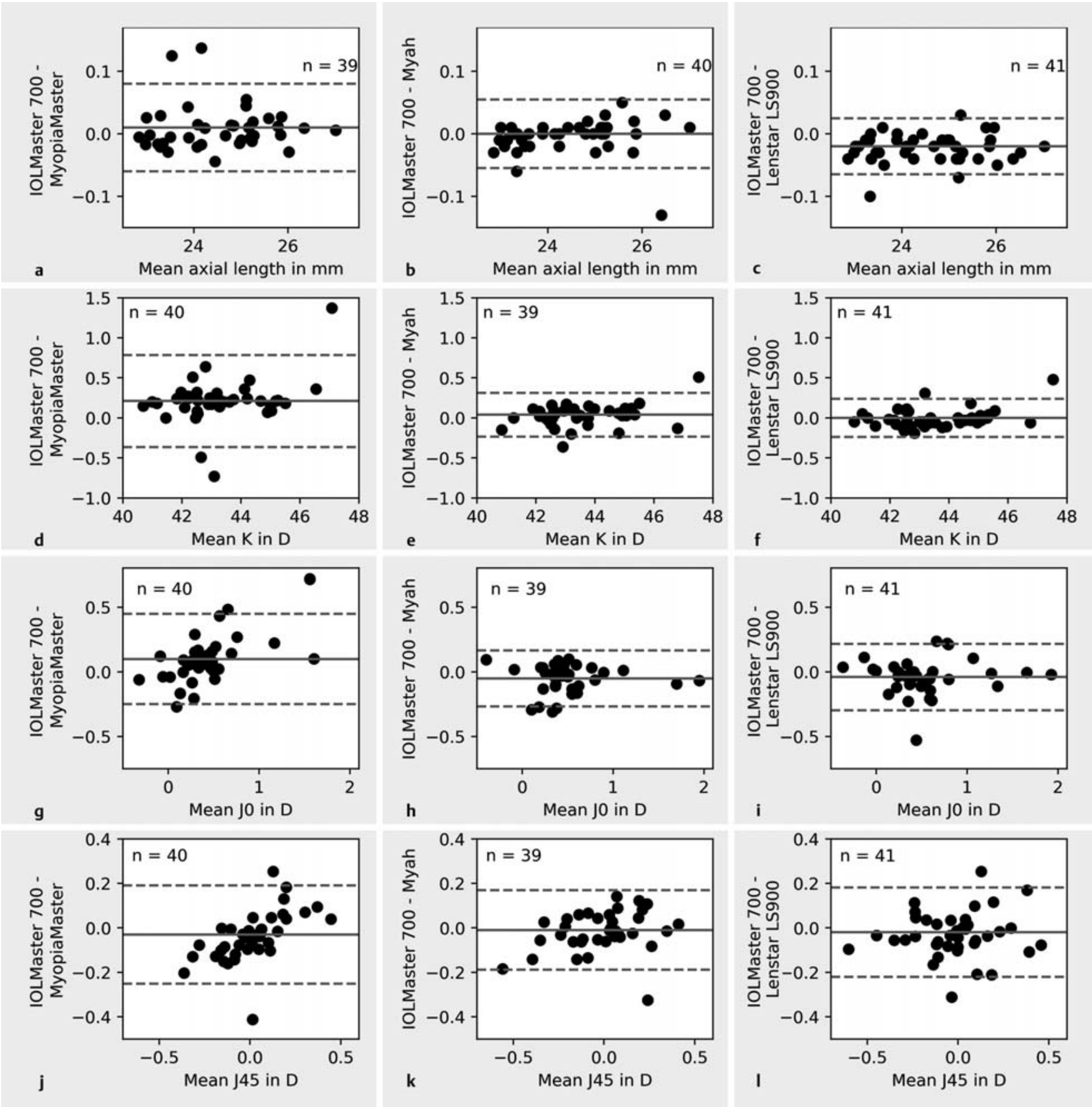
▸ **Table 3** Comparison of all eyes measured with all devices and the corresponding result of the paired Student's t-test with the values of the IOLMaster 700.

AL [mm]	n	Mean	SD	P value
IOLMaster 700	35	24.54	1.12	–
Myopia Master		24.52	1.11	n. s.
Myah		24.54	1.12	n. s.
Lenstar LS900		24.56	1.12	***
meanK [D]				
IOLMaster 700	33	43.47	1.55	–
Myopia Master		43.26	1.44	***
Myah		43.44	1.49	n. s.
Lenstar LS900		43.48	1.50	n. s.
J0 [D]				
IOLMaster 700	33	0.47	0.43	–
Myopia Master		0.38	0.33	**
Myah		0.52	0.44	*
Lenstar LS900		0.53	0.43	*
J45 [D]				
IOLMaster 700	33	− 0.02	0.21	–
Myopia Master		0.01	0.14	n. s.
Myah		− 0.01	0.19	n. s.
Lenstar LS900		− 0.01	0.21	n. s.

n. s.: not significant, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

Reproducibility of the biometers

▸ **Table 3** gives an overview of the measured parameters of all eyes that were measured at least once with all of the biometers.



▶ **Fig. 1** Bland-Altman plots of AL (**a – c**), meanK (**d – f**), J0 (**g – i**), and J45 (**j – l**) for Myopia Master, Myah, and LenstarLS900 with the IOLMaster 700. The solid line represents the mean difference and dashed lines, the lower and upper and limits of agreement from − 1.96 SD to + 1.96 SD, with values shown in ▶ **Table 4**.

Regarding the AL measurement, Myopia Master and Myah were in close agreement with the IOLMaster, except for Lenstar, which significantly deviated from the IOLMaster by 0.02 mm ($p < 0.001$). In the assessment of corneal power (meanK), only Myopia Master deviated from the IOLMaster by 0.21 D (95% CI: − 0.36 D to 0.78 D), on average ($p < 0.001$). The vector assessments (J0, J45) did not deviate from each other to a clinically relevant degree, i.e., differences were less than 0.10 D.

▶ **Fig. 1** shows the Bland-Altman plots for reproducibility of the Myopia Master, Myah, and Lenstar, with the IOLMaster as the reference, for AL, meanK, J0, and J45, with the respective mean difference and limits of agreement (LoA) shown in ▶ **Table 4**.

Discussion

To monitor myopia progression in young children and adolescents, it is well established to assess the refractive status of the

▶ **Table 4** Mean difference and limits of agreement 9FG90ROCFfrom − 1.96 SD to + 1.96 SD for Bland-Altman plots in ▶ **Fig. 1**.

	IOLMaster 700 and Myopia Master Mean (1.96*SD)	**IOLMaster 700 and Myah Mean (1.96*SD)**	**IOLMaster 700 and Lenstar LS900 Mean (1.96*SD)**
AL [mm]	0.01 (− 0.06/0.08)	0 (− 0.05/0.05)	− 0.02 (− 0.06/0.02)
meanK [D]	0.21 (− 0.36/0.78)	0.04 (− 0.23/0.31)	0 (− 0.24/0.24)
J0 [D]	0.10 (− 0.25/0.45)	− 0.05 (− 0.27/0.17)	− 0.04 (− 0.30/0.22)
J4 [D]	− 0.03 (− 0.25/0.19)	− 0.01 (− 0.19/0.17)	− 0.02 (− 0.22/0.18)

eye. Recently, the biometric measurement of the AL of the eye and the corneal curvature became the more important means [14]. Biometric and refractive measures taken together also allow for a differentiation between mere refractive and axial myopia [22]. In this study, we analyzed four optical biometry devices with the same myopic children to see whether there were clinically significant differences in the outcomes of the measurements that might lead to confusion or deviating interpretations regarding the current status and progression of the child's myopia. A reliable measurement of AL and assessment of the AL growth rate from two consecutive AL measurements are required for a proper evaluation of a current or future therapeutic intervention that aims to reduce excessive axial growth and thus reduces or prevents further myopic progression.

Previous comparisons of biometers were mostly published on the parameters of IOL power prediction for use in cataract surgery. Jeon et al. evaluated the agreement between ocular biometry outcomes in 112 eyes of patients undergoing cataract surgery measured by the IOLMaster and Lenstar and found high agreement with narrow 95% LoA [23]. A comparison of the Myah, Pentacam AXL, and IOLMaster in myopic children was performed by Sabur and Takes [24]. Rauscher et al. evaluated the feasibility and repeatability of Lenstar biometry measurements in a pediatric population and found that repeatability improved with age [25]. Ye et al. evaluated the accuracy of the Myopia Master in terms of AL, keratometry, and refractive measurement in children with ametropia and concluded that this three-in-one device provides the desired values with high efficiency and accuracy [26].

In our analysis, all biometers showed good repeatability in AL measurement, with values ranging between 0.04 to 0.06 mm. Any AL measured with the Lenstar was, on average, longer by 0.02 mm compared to the AL measured by the IOLMaster ($p < 0.001$). This is considered a small offset between the devices and would become relevant only if both devices are used to assess AL and axial growth in one subject. As long as the same device is used for the longitudinal analysis of the same subjects in follow-up visits, the observed offset is of no importance. Our findings on the differences between the IOLMaster and Lenstar go along with the study of Jeon et al. [23], who found in a subgroup analysis that Lenstar measures a longer AL than IOLMaster only in longer (rather myopic) eyes and described that Lenstar may be more influenced by the media factor since it uses the principle of reflectometry through the medium of the object. The IOLMaster uses a 1050 nm wavelength laser, where the Lenstar uses an 820 nm super luminescent diode laser. The difference in the transmittance of the wavelength due to the turbidity of the medium and the error caused by the increase in the length of the measurement object are combined [23]. The largest variance between AL measurements was found when comparing IOLMaster and Myopia Master (95% LoA − 0.06 to 0.08 mm).

While AL is the primary biometric determinant of an eye's refractive error, the dimension, curvature, and refractive index of each individual ocular structure contribute to the refractive state [27]. Here, the software of the Myopia Master also holds a tool to analyze which part of the eye differs from an age-dependent Gullstrand eye and to tell whether a child's myopia is either caused by a high refractive power of the cornea or lens, or rather mostly or exclusively by an increased axial elongation of the eye bulb [28]. Regarding lens thickness, Jos et al. showed that the onset of myopia can be delayed by a decrease in the central thickness of the lens [29]. However, as this segment of the eye was only analyzed with the Lenstar and IOLMaster, it was not further evaluated with regard to repeatability and reproducibility in this study. Regarding anterior corneal power prediction, no statistically significant difference was found between the first and the second measurement with the same biometer. When comparing the measurements with the IOLMaster, the Myopia Master measures meanK significantly lower by a mean of 0.21 D. This was also described by Pedersen et al., who found that the mean corneal curvature was significantly flatter when measured with the Myopia Master than with the IOLMaster in a cohort of subjects between the ages of 19 to 41 years [18]. The IOLMaster uses a telecentric method to measure the curvature of the cornea by projecting a light source with 18 points in a distance of 1.5, 2.4, and 3.2 mm from the center of the cornea [30], where the Myopia Master uses four equally spaced points and a ring projected onto the cornea to measure the central corneal curvature [31]. It is likely that these differences in measurement methods have caused a slight difference in the keratometry results.

The normal growth pattern of a 16-year-old child shows an axial elongation of less than 0.05 mm/year [15]. According to our results, this axial growth rate can only be reliably detected, i.e., at a probability of 95%, if the two measurements will be about 10 months (e.g., for Lenstar) to 13.4 months (e.g., for Myah) in time apart from each other. In other words, if the two measurements are less than this time interval apart, the assessment of the axial growth rate will not be sufficiently reliable. From ▶ **Table 2**, one can also draw, for each biometer employed, how far two consecutive AL measurements must be apart to reliably detect a certain change in AL growth. For example, a 6-year-old myopic child has a true AL growth of 0.3 mm/yr, which is assumed to be about 0.1 mm/yr above normal age-matched eye growth of emmetropes (cf. 0.2 mm/yr is 50th percentile annual growth for 6-year-olds in the data of Truckenbrod et al. [15]). At what point can this increased growth be detected with the biometers? Answer: to reliably detect an AL growth of 0.1 mm/yr, the child should not be scheduled earlier for a second AL measurement than 5 to 6.7 months after the first one. Our study provides insight in the actual reliability of AL measurements with the biometers investigated. For the practitioner, it is helpful to know what reliability from the measurements are to be expected. This is of particular importance for the practitioner who will use two consecutively measured AL values to determine the subject's current axial growth rate in myopia management. In a practical approach, if a reduction in axial growth due to the child's myopia treatment intervention of at least 0.05 mm/yr is to be reliably detected, the two consecutive AL measurements of the child should be not less than 12 months (i.e., 11 months to 13.4 months) apart.

CONCLUSION BOX

Already known:

- Myopia onset and progression can be described as a deviation from a normal eye growth pattern.
- It is recommended to use the same biometer in follow-up visits when monitoring AL growth in children.

Newly described:

- The intra-subject repeatability of AL measurements in children is comparable to the repeatability in adults.
- In myopia control management, children's individual axial eye growth should be monitored in a time interval not shorter than 6 months.

Conflict of Interest

The authors declare that they have no conflict of interest.

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