Feasibility and repeatability of ocular biometry measured with Lenstar LS 900 in a large group of children and adolescents

Franziska G Rauscher1,2, Andreas Hiemisch2,3, Wieland Kiess2,3 and Ralph Michael1,4

1Institute for Medical Informatics, Statistics, and Epidemiology (IMISE), Leipzig University, Leipzig, Germany, 2Leipzig Research Centre for Civilization Diseases (LIFE), Leipzig University, Leipzig, Germany, 3Department of Women and Child Health, University Hospital for Children and Adolescents and Center for Pediatric Research (CPL), Leipzig University, Leipzig, Germany, and 4Institut Universitari Barraquer, Universitat Autònoma de Barcelona, Barcelona, Spain

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Abstract

Purpose: To evaluate the feasibility and repeatability of Lenstar LS 900 biometry measurements in a paediatric population.

Methods: Children were examined as part of the LIFE Child Study (Leipzig Research Centre for Civilization Diseases), a population-based study in Leipzig, Germany. Altogether, 1917 children, aged from 3.5 to 17.5 years, were assessed with the Haag Streit Lenstar LS 900. Three consecutive measurements of the right eye were analysed for axial length, central corneal thickness, anterior chamber depth, aqueous depth, lens thickness and flat and steep corneal radii. The number of successful measurements and repeatability were evaluated for each parameter and three age bands (3.5 to 6.5 years, 6.5 to 10.5 years and 10.5 to 17.5 years).

Results: Best measurement feasibility was found for axial length and central corneal thickness (91% to 100%), followed by flat and steep corneal radii (86% to 100%), anterior chamber and aqueous depth (76% to 92%) and lens thickness (50% to 81%), with higher numbers for older children. Repeatability values (in mm) were: axial length 0.025 to 0.035; central corneal thickness 0.003 to 0.027; aqueous depth 0.024 to 0.058; anterior chamber 0.024 to 0.054; lens thickness 0.034 to 0.067. An overall trend showed better repeatability for older children, especially for central corneal thickness, aqueous depth and lens thickness.

Conclusions: For ocular biometry in the paediatric population, axial length, central corneal thickness, flat and steep corneal radii can be measured very reliably even in children from 4 years old onward using the Lenstar LS 900. Lens thickness can be quantified in a limited number of younger children. Repeatability was high for all variables investigated. Repeatability improved with age, reaching adult values in the adolescent age band. Established repeatability limits can be applied in future studies as a quality parameter.

Introduction

It has become a major focus to understand the development and progression of refractive errors in children and adolescents, especially with regard to myopia, with its increasing prevalence worldwide. Monitoring the development of refractive error requires knowledge of ocular biometry.1–3 Biometry has been investigated as part of large cross-sectional cohort studies in children,4–7 as well as in longitudinal investigations of children.8–15 Various methods are currently available (e.g., ultrasound, partial coherence interferometry, optical low coherence reflectometry, low coherence interferometry and swept-source optical coherence tomography; for background on those methods,
see the review by Kouombo Mekountchou et al.16). Optical low-coherence reflectometry (OLCR) with the Lenstar LS 900 (Haag-Streit, haag-streit.com) has been employed in clinical and research settings for a number of years; for in-depth details on the method, see Schmid.17 Its advantages include a high signal-to-noise-ratio, high repetition rate, high resolution and low power at the cornea, thereby allowing for serial measurements. These make the instrument especially suitable for measurements in children.17

In the clinical setting, precise and rapid measurement of eye length and eye shape is essential for investigating eye growth regulation and myopia. Both the researcher and clinician need to know the repeatability and the limits of precision of the device or method used to measure the biometry of the eye.

Repeatability has been assessed for the Lenstar LS 900 in a number of studies in adults. However, few of the previous works investigated healthy participants: data for repeatability of axial length was presented for 24 adults (22–45 years of age),17 for 29 adults (22–28 years of age)18 and for seven adults.19 Other studies have examined repeatability in 76 eyes of 38 adults (20–63 years old),20 40 adults (range 18–37 years),21 102 subjects (18–56 years of age)22 and 28 myopic adults (18–40 years of age).23

To date, there are only two studies examining the repeatability of the Lenstar LS 900 in children.17,24 However, the analysis of Sahin et al.24 was based on intraobserver correlation coefficients. Such assessment does not adequately investigate the repeatability of measurements. Further, Schmid presented repeatability for axial length only (63 children aged 7–15 years).17 Other studies have measured children’s eyes with the Lenstar LS 900 as part of an agreement investigation without presenting data on the repeatability of the measurements.25–29

A few studies have investigated the repeatability in children based on partial coherence interferometry (PCI) employed in the IOL Master 500 (Carl Zeiss Meditec, zeiss.com).31–33 Quinn and co-workers,30 and Hussin et al.33 investigated the repeatability of axial length; Huynh et al.34 focused on corneal radii32 while Carkeet et al.31 presented data on axial length and anterior chamber depth. Based on these differences in measurement technique, such data cannot serve to estimate the repeatability for the Lenstar LS 900. Therefore, the aim of the current study is to evaluate the repeatability of the Lenstar LS 900 for the first time, for a full set of biometric variables in a large cohort of children and adolescents.

Prior to investigating repeatability, the measurement success in children is of interest. The LIFE Child Study puts an emphasis on supporting participation success by creating a fun, child-friendly environment; this has led to a high acceptance rate for the study programme.34 This assessment approach was applied to the eye examination from the beginning. Therefore, the first aim of the current analysis is investigation of the feasibility of biometry measurement in children, as it was previously suggested that the Lenstar measurement routine could be unsuccessful.35–37 The second aim is to compute repeatability of the obtained variables, as well as providing reference values for the repeatability of the Lenstar LS 900 in children’s eyes. Normative data for repeatability is essential, thereby enabling evaluation of measurements before the subsequent computations for ocular biometry in children, i.e., unreliable data can be identified as outliers by comparison of individual repeatability to the repeatability limits obtained here. Furthermore, as agreement depends on repeatability, agreement investigations can be carried out based on our results, assessing the validity of biometry measurements for different devices. Therefore, the current analysis presents metrology of the Lenstar LS 900 by investigating the feasibility and repeatability for ocular biometry.

**Methods**

**Device**

Measurement of biometry using the Lenstar LS 900 has been described previously.17,27,38 Optical low-coherence reflectometry by the Lenstar LS 900 employs an 820 μm superluminescent diode to measure corneal thickness, anterior chamber depth, aqueous depth, crystalline or intraocular lens thickness and axial length. Furthermore, 950 μm light is used to assess central corneal topography in image analysis using two rings, 1.65 mm and 2.30 mm in diameter (for a corneal radius 7.8 mm) with 16 points in each circle, for a total of 32 points, reflected off the air / tear interface. Additionally, the horizontal iris width (white-to-white) measured by fitting the best circle with the lowest error square to the detected edge of the pupil. At the same time, pupil size is assessed using the same methodology.

The Lenstar LS 900 identifies reflections of the measurement beam at transitions in optical media or optical boundaries with signal peaks. By this technique, optical surfaces are presented for the corneal front surface, corneal back surface, lens front surface, lens back surface, retinal surface and choroid. Based on this information, the following parameters are computed: central corneal thickness (CCT), anterior chamber depth (ACD) - defined as the distance between the front surface of the cornea and the front surface of the lens, aqueous depth (AD) - defined as the distance between the back surface of the cornea and the front surface of the lens, lens thickness (LT), flat corneal front surface radius (R1) and steep corneal front surface radius (R2).

The Lenstar LS 900 prompts a mandatory calibration once per week, following a standard procedure. A single operator performed all measurements; the operator is a
fully qualified optometrist with work experience in measuring biometry and additional training in child epidemiology, thus creating a friendly measurement environment for the child and parent at each visit.

Subjects

To evaluate the feasibility and repeatability of biometry measurements by the Lenstar LS 900, the current study analysed repeated measurements carried out as part of the LIFE Child Study (Leipzig Centre for Civilization Diseases) in Leipzig, Germany. Participants stem from the city of Leipzig and close proximity. Leipzig is a city in central Germany with more than 550,000 inhabitants. LIFE Child is a network of various medical subspecialties investigating the reasons behind civilization diseases, and examining children from the womb to adulthood. LIFE aims at unraveling the interplay between genetic predisposition, metabolism, environment and individual lifestyle. Children examined as part of the LIFE Child Study undergo a series of tests and examinations (e.g., questionnaires, anthropometry, 3-D body scans, blood analysis, etc., see Poulain et al. for details). The LIFE Child Study excludes children suffering from any chronic, chromosomal or syndromal diseases. The current data on children and adolescents focused on participants of the optometric examination of the LIFE Child Study.

The parents of the participating children were informed about the study programme, the long-term use of data and the right to withdraw from the study. Written informed consent was obtained from the parents of all participants. Oral consent is additionally obtained from all children and from age 12 onwards, written consent was provided by the participating adolescents. Participants have the right to withdraw from the study at any time. The LIFE Child Study adheres to the tenets of the Declaration of Helsinki and approval for the study was obtained from the Ethics Committee of the Medical Faculty of the University of Leipzig (Reg. No. 264-10-19042010); ethical approval for the optometric examination (Reg. No. 089-13-11032013) was furthermore obtained. The study has been registered with the ClinicalTrials.gov trial number NCT02550236.

Testing was carried out without cycloplegia under scotopic conditions. Measurements were obtained sequentially at one sitting, with a brief moment between them, in order to save the findings, during which time the children were allowed to sit back. Participants remained seated during all repeated measurements; head and chin were re-positioned before each measurement. Subjects placed their chin on a chin rest, pressed their forehead against a forehead strap and aligned the investigated eye to the visual axis by means of a central fixation target. The participants were asked to fixate on the internal red light of the device, and the image of the eye was focused on the monitor by the examiner. Before the measurement, the participants were asked to blink to spread an optically smooth tear film over the cornea. Children were instructed to keep both eyes open and look directly at the fixation target; the instrument’s built-in occluder was positioned over the non-measured eye without touching the participant. Scans were taken in automatic release mode.

The current research is based on the Lenstar LS 900 baseline visit for each participating child between January 2014 and June 2018 (n = 1917). Data from at least one Lenstar measurement needed to be present for a child to be included in our investigations. Subsequently, 10 children were excluded for clinical reasons (two with a history of congenital cataract, two with nystagmus, one with history of high intra-ocular pressure, one with iris coloboma, two for wearing contact lenses during the measurement and two because they were of non-European descent). A further eight children were excluded because of non-physiological results of the lens thickness (LT) measurement (50% thicker than average for these children). This resulted in data from 1899 children being analysed (Figure 1). The Lenstar has a proprietary quality check mechanism which withholds erroneous measurements for some variables. There may be cases where it saves a measurement for AL, but not for LT, for example. This in-built proprietary quality check mechanism was not evaluated in the present study. To examine feasibility and repeatability, we included all children with three repeated measurements for at least one of the biometric variables. Data were taken from the right eye of each child.

We subdivided the children in six groups of comparable sample size, sectioned by sex and partitioned into three age bands: pre-school children (3.50 to 6.49 years), primary school children (6.50 to 10.49 years) and adolescents (10.50 to 17.49 years) (Figure 1).

Statistics

In general, multiple measurements ensure measurement quality and can help to improve data quality. The feasibility for a variable was expressed as the percentage of successful readings compared to the total number of children analysed (n = 1899). The output of three consecutive measurements for one given variable was required to count as a successful reading. Repeatability of the three measurements was expressed as the within-subject standard deviation (Sw), which was calculated from a one-way analysis of variance (ANOVA), where each subject is treated as a group, following the guidelines of McAlinden. This quantity can also be computed by taking the square root of the pooled variance (arithmetic
mean of individual variances) which describes the representative variability of all subjects. The definition of the pooled variance does not refer to any underlying distribution, and therefore is a simple and robust point estimator to characterise the spread of the data.

We calculated the repeatability limit \( r_w \) as a reference interval using the following formula:

\[
r_w = 1.96 \times S_w
\]

This calculated repeatability limit gives the interval within which 95% of measurements lie. In a common approach, McAlinden et al.\(^4\) analysed the difference between two measurements; 95% of the differences obtained lie in this interval. This method focuses on the difference of measurements, as in the original Bland Altman approach,\(^41,42\) and therefore includes a factor of \( \sqrt{2} \). Our computation of the repeatability limit \( r_w \) is without a factor of \( \sqrt{2} \) as we employ the Pythagorean mean of standard deviations across subjects. We prefer the concept of a 95% reference interval for the measurements themselves, as described in ISO 5725-2,\(^43\) because we did not compare two different measurement technologies. We provide the repeatability \( S_w \) so that the reference interval can be computed in different ways, including the mentioned factor of \( \sqrt{2} \).

By obtaining a repeatability limit across all data, one can assume inconsistencies in the measurement if a measured value lies outside this limit. Recommendations based on this will be given in the Discussion. Differences in repeatability for sex and comparing the youngest against the oldest age band were evaluated using two-sample F-tests.

**Results**

Data of 1899 children were analysed. See Figure 1 for the number of children in each age band and Table A1, for the percentage of data obtained for children and adolescents for each variable. Best feasibility was found for axial length (AL) and CCT, with 91% in the youngest age band (3.5 - 6.5 years) and 100% in the two older age bands (Table A1 and Figure 2). Considering corneal curvature (R1 and R2), about 13% in the youngest age band, about 2% in the middle age band and 1% in the oldest age band were not measured successfully. An age trend was also noted for AD and ACD, with missing measurements in about 24%, 12% and 9% of the youngest, middle and oldest age bands, respectively. The smallest number of successful measurements was obtained for lens thickness, with about 50%, 30% and 20% of the youngest, middle and oldest age bands, respectively, who could not be measured (see Table A1 for exact numbers).

Ocular biometry using the Lenstar LS 900 resulted in very good repeatability for the children investigated (Figure 3 and Table A2). Repeatability for AL was 0.025 mm to
0.035 mm; CCT: 0.003 mm to 0.027 mm; AD: 0.024 mm to 0.058 mm; ACD: 0.054 mm to 0.024 mm; LT: 0.034 mm to 0.067 mm; corneal radii: 0.014 mm to 0.025 mm (R1) and 0.022 mm to 0.033 mm (R2). A general trend showed better repeatability for older children, especially for CCT, ranging from 0.0250 mm in the youngest age band to 0.0035 mm in the oldest age band. This age effect was statistically significant; F-test \( p < 0.001 \). An improvement in repeatability with age \( (p < 0.001) \) (Figure 3) was also observed for LT, ranging from 0.066 mm in the youngest age band to 0.038 mm in the oldest age band. A similar age trend was seen for AD and ACD. There was no obvious variation of repeatability with sex (Figure 3 and Table A2) apart from the steep corneal radius (R2), where the trend observed in Figure 3 showed lower repeatability in boys \( (p < 0.001) \).

The repeatability limit is presented in Table 1; it follows the same trends described above, and therefore statistically significant differences with age or sex for the repeatability limit were not tested here. The data showed (see Table 1 for exact data) repeatability limits for AL of \( \pm 0.05 \) mm to \( \pm 0.07 \) mm (with a small improvement for older children, see Figure 3). For AD and ACD, repeatability improved with age \( (\pm 0.05 \) mm to \( \pm 0.11 \) mm for AD); likewise repeatability for LT was better for older children \( (\pm 0.07 \) mm versus \( \pm 0.13 \) mm). Corneal radii showed repeatability limits between \( \pm 0.03 \) mm and \( \pm 0.05 \) mm for R1 and \( \pm 0.04 \) mm to \( \pm 0.06 \) mm for R2. Again, best repeatability was found in the older age bands. The strongest age effect was observed for CCT, where the repeatability limit for the youngest and oldest age bands were \( \pm 0.07 \) mm and \( \pm 0.008 \) mm, respectively. No sex effect was apparent in the investigated repeatability, apart from corneal radii where a bigger variance was found in boys (see Figure 3).

**Discussion**

**Feasibility**
The Lenstar LS 900 software computes and saves only what are deemed to be reliable measurements to the database. The operator is unable to influence these cut-off criteria. Three consecutively saved measurements for one given variable were needed to count as a successful reading. The output of three consecutive measurements for one given variable was needed to count as a successful reading.

Three consecutively saved measurements for one given variable are needed to count as a successful or feasible reading. All measurements obtained here were taken by a single operator and we followed the inbuilt calibration routines of the device; therefore, we did not evaluate operator or calibration-related factors on feasibility. However, there are some study-related factors: The LIFE Child project prepared a special child-friendly environment for all measurement routines, which provided a calm explanation to the participating children, including using entertaining animation to help the child sit still and fixate the target. This has probably resulted in better feasibility, which may not be reached in a busy clinical practice. Also the children originated from an urban environment of a large German city.
It remains to be determined whether this environment, with its increased sensory stimuli affected the findings. The Lenstar LS 900 using OLCR was very successful in measuring AL, CCT, R1 and R2, and had good success for AD and ACD. However, LT measurements in children were less successful. Only 50% of the measurements were successful in the youngest group. This improved with age, reaching about 80% in the oldest age band (Table A1). Lens surface detection using OLCR is difficult in children because of their very clear media. Previous studies have reported that some OLCR variables can be more difficult to obtain under certain measurement conditions. For example, previous research on pseudophakic eyes showed that very clear surfaces of the intraocular lens were sometimes not detected by the device, thereby introducing measurement error for the LT variable. This is directly applicable to the results of the present study, as our data showed less successful results for LT, and related to that for ACD and AD. Cases with LT measurements always had ADC and AD measurements, but no case with LT present was missing ACD or AD. Some cases had ACD and AD present, but were missing LT findings. This is probably due to the anterior or posterior lens surface not being identified during the measurement process. Non-detection of the anterior lens surface leads to unsuccessful data for ACD,
AD and LT, whereas non-detection of the posterior lens surface probably leads to missing values for LT only.

Buckhurst and co-workers investigated feasibility in adults aged 41–96 years scheduled for cataract surgery, and found that 10% of patients could not be measured with the Lenstar LS 900 in their study due to dense cataracts. In addition, Hui and coworkers reported that 38 of 160 eyes could not be measured with the Lenstar LS900 in comparison with 28 eyes using the IOLMaster 500; the latter employs PCI. In that study, in addition to dense cataracts, poor fixation and lack of cooperation with the examination were also causes of failed measurements. In general, differences in the number of successful measurements between OLCR and PCI may depend on device technology, since measurements with the Lenstar LS 900 may require better cooperation of the participant (the IOLMaster 500 requires three different positions and release procedures, whereas the Lenstar LS 900 acquires all parameters in a single position with one release procedure). Wang and colleagues dealt with measurement error for certain Lenstar LS 900 variables by manual review and subsequent exclusion of data disrupted by blinking or unstable fixation from the final analyses.

Repeatability

Measurements of ocular biometry presented with excellent repeatability in the children examined (Table A2). The repeatability of optical low coherence reflectometry by the Lenstar LS 900 was investigated systematically in children for the first time in the current study. Schmid presented the only previous data set for repeatability in children by the Lenstar LS 900. His analysis investigated axial length for 63 children (7–15 years of age) with a result of 0.025 mm, termed as “precision”. The AL repeatability found in the present study was slightly worse than that of Schmid. However, their S.D. was obtained by averaging the standard deviation of the measurements per subject, rather than computing the square root of the pooled variance, also known as within-subject-S.D. They used a different device and different methods of analysis. Their method is likely to produce a smaller S.D., a numerical estimate of this effect results is a 15% difference; therefore our results cannot be compared directly.

Other previous work employing the Lenstar in children were agreement studies with other devices or inter-observer investigations. Previous investigations of repeatability in children’s eyes are available for the PCI technology IOLMaster 500 (determined as the difference of two measurements with a mean difference for AL and ACD of 0.006 mm and 0.009 mm, respectively). Additionally, Hussin reported a mean difference for AL of 0.004 mm (S.D. = 0.019 mm). However, the different devices used and different methods of analysis do not allow direct comparison with the within-subject S.D. of the current analysis.

The repeatability of the Lenstar LS 900 device in adults has been examined in a number of studies. However, few of these investigated healthy adults, and exclusion criteria included pre-existing ocular surface pathology, history of eye trauma, prior refractive surgery, contact lens wear, use of eye drops or the inability to fixate on the internal fixation target. Results on healthy adults present better repeatability when compared with patients with eye conditions.

While several studies have investigated biometry in cataract patients, these will not be used for comparison with the current data. A comparison of the repeatability of ocular biometry using the Lenstar LS 900 in children with that of healthy adults is presented in Table 2.
reference data on adults, reaching adult values in the adolescent age band (comparison of Table A2 with Table 2). AL repeatability in the current study ranged from 0.025 mm to 0.035 mm (Table A2, in comparison with previous adult data ranging from 0.01 mm to 0.025 mm (see Table 2). The repeatability of CCT in children ranged from 0.0032 mm to 0.027 mm; this overlaps with previous adult data (see Table 2), ranging from 0.0015 mm to 0.014 mm. For ACD (adult data was 0.02 mm to 0.052 mm) and AD (adult data: 0.02 mm to 0.03 mm), the current study observed findings of 0.054 mm to 0.024 mm and 0.024 mm to 0.058 mm, respectively. For LT the children’s data (from 0.033 mm to 0.067 mm) had worse repeatability in the youngest age group, although the oldest children were similar to the one data set available for adults (0.03 mm). The capability and cooperation of the subject when fixating the target directly influences measurements of ocular biometry. In children, the quality of fixation, and therefore the measurement precision, is likely to differ from that in adults. The repeatability of AL in children was slightly higher than for healthy adults investigated with the same device. These differences could be caused by poorer fixation in restless children. However, they may have little clinical significance, as using the Bennett-Rabbetts schematic eye, a difference in axial length of 0.09 mm corresponds to a difference in refractive error of 0.25D. For both AD and ACD, the child and adult data offered similar repeatability. Also, with regard to CCT, R1 and R2, children presented with similar or better repeatability when compared with adults. This suggests that the cornea in children can be measured reliably at any age. Lens data showed similar repeatability for adolescents and halved repeatability in younger children compared to the one set of repeatability findings available for LT in healthy adults. The Lenstar LS 900 fixation target is designed to minimise accommodation. However, there might be some variability in the accommodative response of children, which may have led to the increased limits of repeatability for LT in younger children.

AL might have an effect on the feasibility and repeatability for CCT, R1, R2, AD or LT. Therefore, we compared AL for successful readings versus unsuccessful readings. Similarly, a comparison was done for AL when the values would be included by our repeatability limit, versus AL when the values would be excluded. This was done separately for all three age bands. We found only minor differences in the median AL for feasibility and repeatability for CCT, R1, R2, AD and LT. For instance, AL in the youngest age band for not feasible LT measurements was 22.05 mm, versus 22.15 mm for feasible LT measurements. The mean AL for cases that would be excluded by our repeatability limit was 22.03 mm, compared with 22.15 mm for included cases (considering the youngest age band as well).

**Repeatability limits**

For quality assurance, the evaluation of measurement performance is important. As first suggested for biometry by McAlinden et al., and emphasised for other ocular data in children, the current study presents repeatability limits to enable future research to use these findings as a first step for quality assurance.

Our calculated repeatability limit gives the range within which 95% of measurements lie (see Table 1). Following this, we assume inconsistencies if the measurement lies outside this 95% repeatability limit. We suggest applying this rule ex post to the measurement data for succeeding analyses with the Lenstar LS 900. Therefore, data only enter subsequent analysis if their repeatability lies within the established limit for this variable. In this way, the repeatability limit can be used as a quality cut-off to accept a measurement for succeeding analyses. Future studies or clinical measurements on children can implement the repeatability limits based on the current large dataset. Such reference limits help reject inconsistent results before subsequent analysis, or in clinical practice, where they would indicate if measurements should be repeated.

**Conclusions**

Optical low-coherence reflectometry can be used in children from 4 years of age onward for reliable ocular biometry. However, lens thickness can be accessed only in a limited number of children. The repeatability of CCT, AD, ACD, LT and AL was excellent. Repeatability improved with age, with slightly worse values in younger compared with older children. Secondly, older children presented with similar data compared with previously reported findings on adults, reaching adult ranges in the adolescent age band.

Multiple measurements serve as a quality indicator. Based on three repeated measurements per subject, the repeatability limits presented as part of this investigation serve as reference values for reliable measurements. Measurements outside of this repeatability limit should be excluded from further evaluations, e.g., computation of prevalence.

This methodological work is fundamental for the recent research focus of screening for refractive error in children, as ocular biometry is essential when investigating individual progression of refractive error as well as extracting information on its prevalence.

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Conflict of interest
The authors report no conflicts of interest and have no proprietary interest in any of the materials mentioned in this article.

Author contributions
Franziska G Rauscher: Conceptualization (lead); Data curation (lead); Formal analysis (lead); Funding acquisition (lead); Investigation (lead); Methodology (equal); Project administration (equal); Resources (equal); Software (equal); Supervision (equal); Validation (supporting); Visualization (equal); Writing-original draft (equal); Writing-review & editing (equal).

Andreas Hiemisch: Conceptualization (supporting); Data curation (supporting); Project administration (equal); Resources (equal); Supervision (equal); Writing-review & editing (supporting).

Wieland Kiess: Funding acquisition (lead); Project administration (supporting); Resources (equal); Supervision (equal).

Ralph Michael: Formal analysis (supporting); Investigation (supporting); Methodology (equal); Software (equal); Validation (lead); Visualization (equal); Writing-original draft (equal); Writing-review & editing (equal).

References
1. Grosvenor T & Scott R. Role of the axial length/corneal radius ratio in determining the refractive state of the eye. Optom Vis Sci 1994; 71: 573–579.
2. Iribarren R. Crystalline lens and refractive development. Prog Retin Eye Res 2015; 47: 86–106.
3. Adams AJ. Axial length elongation, not corneal curvature, as a basis of adult onset myopia. Am J Optom Physiol Opt 1987; 64: 150–152.
4. Hashemi H, Khabazkhoob M, Miraftab M et al. Axial length to corneal radius of curvature ratio and refractive errors. J Ophthalmic Vis Res 2013; 8: 220–226.
5. Rozema J, Dankert S, Iribarren R, Lanca C & Saw SM. Axial growth and lens power loss at myopia onset in Singaporean children. Invest Ophthalmol Vis Sci 2019; 60: 3091–3099.
6. Ojaimi E, Rose KA, Morgan IG et al. Distribution of ocular biometric parameters and refraction in a population-based study of Australian children. Invest Ophthalmol Vis Sci 2005; 46: 2748–2754.
7. Zadnik K, Mutti DO, Friedman NE & Adams AJ. Initial cross-sectional results from the Orinda Longitudinal Study of Myopia. Optom Vis Sci 1993; 70: 750–758.
8. Tideman JWL, Polling JR, Jaddoe VWV, Vingerling JR & Klaver CCW. Growth in foetal life, infancy, and early childhood and the association with ocular biometry. Ophthalmic Physiol Opt 2019; 39: 245–252.
9. Tao Z, Deng H, Zhong H et al. A longitudinal study of the effect of ocular biometrics measures on myopia onset. Graefes Arch Clin Exp Ophthalmol 2020; https://doi.org/10.1007/s00417-020-05010-1
10. Lee JTL, Guo X, Li Z et al. Progression and longitudinal biometric changes in highly myopic eyes. Invest Ophthalmol Vis Sci 2020; 61: ARVO E-Abstract 34.
11. Li T, Jiang B & Zhou X. Axial length elongation in primary school-age children: a 3-year cohort study in Shanghai. BMJ Open 2019; 9: e029896.
12. Mutti DO, Mitchell GL, Jones LA et al. Axial growth and changes in lenticular and corneal power during emmetropization in infants. Invest Ophthalmol Vis Sci 2005; 46: 3074–3080.
13. Mutti DO, Hayes JR, Mitchell GL et al. Refractive error, axial length, and relative peripheral refractive error before and after the onset of myopia. Invest Ophthalmol Vis Sci 2007; 48: 2510–2519.
14. Brown NP, Koretz JF & Bron AJ. The development and maintenance of emmetropia. Eye 1999; 13: 83–92.
15. Tideman JWL, Polling JR, Vingerling JR et al. Axial length growth and the risk of developing myopia in European children. Acta Ophthalmol 2018; 96: 301–309.
16. Koumbo Mekountchou IO, Conrad F, Sankaridurg P & Ehrmann K. Peripheral eye length measurement techniques: a review. Clin Exp Optom 2020; 103: 138–147.
17. Schmid GF. Axial and peripheral eye length measured with optical low coherence reflectometry. J Biomed Opt 2003; 8: 655–662.
18. Schulle KL & Bernsten DA. Repeatability of on- and off-axis eye length measurements using the lenstar. Optom Vis Sci 2013; 90: 16–22.
19. Verkicarla PK, Mallen EA & Atchison DA. Repeatability and comparison of peripheral eye lengths with two instruments. Optom Vis Sci 2013; 90: 215–222.
20. Cruysberg LP, Doors M, Verbakel F et al. Evaluation of the Lenstar LS 900 non-contact biometer. Br J Ophthalmol 2010; 94: 106–110.
21. Chen W, McAlinden C, Pesudovs K et al. Scheimpflug-Placido topographer and optical low-coherence reflectometry biometer: repeatability and agreement. J Cataract Refract Surg 2012; 38: 1626–1632.

22. McAlinden C, Gao R, Yu A et al. Repeatability and agreement of ocular biometry measurements: Aladdin versus Lenstar. Br J Ophthalmol 2017; 101: 1223–1229.

23. Zhao J, Chen Z, Zhou Z, Ding L & Zhou X. Evaluation of the repeatability of the Lenstar and comparison with two other non-contact biometric devices in myopes. Clin Exp Optom 2013; 96: 92–99.

24. Sahin A, Gursoy H, Basmak H et al. Reproducibility of ocular biometry with a new noncontact optical low-coherence reflectometer in children. Eur J Ophthalmol 2011; 21: 194–198.

25. Gursoy H, Sahin A, Basmak H et al. Lenstar versus ultrasound for ocular biometry in a pediatric population. Optom Vis Sci 2011; 88: 912–919.

26. Louidot C, Zanin E, Fogliarini C et al. Ocular biometry in children with hypermetropia: utility of the Lenstar LS 900 optical biometer (Haag-Streit(R)). J Fr Ophtalmol 2011; 34: 369–375.

27. Wang X, Dong J, Tang M et al. Effect of pupil dilation on biometric measurements and intraocular lens power calculations in schoolchildren. PLoS One 2018; 13: e0203677.

28. Hashemi H, Jafarzadehpur E, Ghaderi S et al. Ocular components during the ages of ocular development. Acta Ophthalmol 2015; 93: e74–e81.

29. Hashemi H, Heydarian S, Khabazkhoob M et al. Keratometry in children: Comparison between auto-refractokeratometer, rotating scheimpflug imaging, and biograph. J Optom 2019; 12: 99–110.

30. Quinn GE, Francis EL, Nipper KS et al. Highly precise eye length measurements in children aged 3 through 12 years. Arch Ophthalmol 2003; 121: 985–990.

31. Carkeet A, Saw SM, Gazzard G, Tang W & Tan DT. Repeatability of IOLMaster biometry in children. Optom Vis Sci 2004; 81: 829–834.

32. Huynh SC, Mai TQ, Kifley A et al. An evaluation of keratometry in 6-year-old children. Cornea 2006; 25: 383–387.

33. Hussin HM, Spry PG, Majid MA & Gouws P. Reliability and validity of the partial coherence interferometry for measurement of ocular axial length in children. Eye (Lond) 2006; 20: 1021–1024.

34. Quante M, Hesse M, Dohnert M et al. The LIFE child study: a life course approach to disease and health. BMC Public Health 2012; 12: 1021.

35. Hui S & Yi L. Comparison of two optical biometers in intraocular lens power calculation. Indian J Ophthalmol 2014; 62: 931–934.

36. Buckhurst PJ, Wolfssohn JS, Shah S et al. A new optical low coherence reflectometry device for ocular biometry in cataract patients. Br J Ophthalmol 2009; 93: 949–953.

37. Holzer MP, Mamsa M & Auffarth GU. Accuracy of a new partial coherence interferometry analyser for biometric measurements. Br J Ophthalmol 2009; 93: 807–810.

38. Rohrer K, Frueh BE, Walti R et al. Comparison and evaluation of ocular biometry using a new noncontact optical low-coherence reflectometer. Ophthalmology 2009; 116: 2087–2092.

39. Poulain T, Baber R, Vogel M et al. The LIFE Child study: a population-based perinatal and pediatric cohort in Germany. Eur J Epidemiol 2017; 32: 145–158.

40. McAlinden C, Khadka J & Pesudovs K. Precision (repeatability and reproducibility) studies and sample-size calculation. J Cataract Refract Surg 2015; 41: 2598–2604.

41. Bland JM & Altman DG. Measuring agreement in method comparison studies. Stat Methods Med Res 1999; 8: 135–160.

42. Bland JM & Altman DG. Applying the right statistics: analyses of measurement studies. Ultrasound Obstet Gynecol 2003; 22: 85–93.

43. ISO 5725 - Accuracy (trueness and precision) of measurement methods and results - Part 2: Basic method for the determination of repeatability and reproducibility of a Standard measurement method - Including Technical Corrigendum 1:2002. International Organization for Standardization, 2002.

44. Wegener A, Müller-Breitenkamp U, Dragomirescu V & Hockwin O. Light scattering in the human lens in childhood and adolescence. Ophthalmic Res 1999; 31: 104–109.

45. Rauscher FG, Lange H, Yahiaoui-Doktor M et al. Agreement and repeatability of noncycloplegic and cycloplegic wavefront-based autorefraction in children. Optom Vis Sci 2019; 96: 879–889.

46. Lopez-Miguel A, Correa-Perez ME, Miranda-Anta S et al. Comparison of central corneal thickness using optical low-coherence reflectometry and spectral-domain optical coherence tomography. J Cataract Refract Surg 2012; 38: 758–764.
## Appendix

### Table A1. Feasibility as percentage of successful three Lenstar LS 900 measurements in 1899 children (right eyes)

| Age bands      | Sex   | Axial length (AL) | Central corneal thickness (CCT) | Flat corneal radius (R1) | Steep corneal radius (R2) | Aqueous depth (AD) | Anterior chamber depth (ACD) | Lens thickness (LT) |
|----------------|-------|-------------------|--------------------------------|--------------------------|---------------------------|------------------|-------------------------------|-------------------|
| 3.5–6.5 years | Female| 92                | 92                             | 88                       | 88                        | 76               | 76                            | 52                |
|                | Male  | 91                | 91                             | 86                       | 86                        | 76               | 76                            | 50                |
| 6.5–10.5 years| Female| 100               | 100                            | 99                       | 99                        | 87               | 87                            | 68                |
|                | Male  | 99                | 99                             | 97                       | 97                        | 89               | 89                            | 70                |
| 10.5–17.5 years| Female| 100               | 100                            | 100                      | 100                       | 91               | 91                            | 78                |
|                | Male  | 100               | 100                            | 99                       | 99                        | 92               | 92                            | 81                |

Data presented as percentage (%). These values were the basis of the repeatability evaluations. See Figure 1 for exact numbers of participants in each age range to transfer percentages to number of children. ACD, (corneal epithelium to lens surface); AD, (corneal endothelium to lens surface).

### Table A2. Repeatability (Sw) for variables measured by Lenstar LS 900 in children (right eyes)

| Age bands      | Sex   | Axial length (AL) | Central corneal thickness (CCT) | Flat corneal radius (R1) | Steep corneal radius (R2) | Aqueous depth (AD) | Anterior chamber depth (ACD) | Lens thickness (LT) |
|----------------|-------|-------------------|--------------------------------|--------------------------|---------------------------|------------------|-------------------------------|-------------------|
| 3.5–6.5 years | Female| 0.0345            | 0.0274                         | 0.0214                   | 0.0282                    | 0.0530           | 0.0449                        | 0.0664            |
|                | Male  | 0.0344            | 0.0227                         | 0.0255                   | 0.0327                    | 0.0581           | 0.0537                        | 0.0670            |
| 6.5–10.5 years| Female| 0.0267            | 0.0108                         | 0.0200                   | 0.0237                    | 0.0353           | 0.0333                        | 0.0455            |
|                | Male  | 0.0304            | 0.0073                         | 0.0203                   | 0.0280                    | 0.0320           | 0.0314                        | 0.0353            |
| 10.5–17.5 years| Female| 0.0266            | 0.0032                         | 0.0148                   | 0.0222                    | 0.0243           | 0.0241                        | 0.0338            |
|                | Male  | 0.0246            | 0.0037                         | 0.0171                   | 0.0271                    | 0.0326           | 0.0324                        | 0.0415            |

All units in millimeters (mm). Repeatability Sw is given as within-subject standard deviation, obtained from a one-way ANOVA. ACD, (corneal epithelium to lens surface); AD, (corneal endothelium to lens surface).