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RESEARCH

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Repeatability and agreement of multispectral refraction topography in school children before and after cycloplegia

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Abstract

Background: The purpose of this study was to evaluate the repeatability and agreement of multispectral refraction topography (MRT) in measuring retinal refraction before and after cycloplegia in children. The results of this study will provide valuable insights into the accuracy and reliability of MRT as a tool for assessing retinal refraction in pediatric patients.

Methods: Children aged 7 to 18 years old were recruited for this prospective research. The central and peripheral retinal refraction was measured three times using multispectral refraction topography (MRT) before and after cycloplegia. The retinal deviation value (RDV) was used to describe the average peripheral refractive error of the retina. In addition, objective refraction (OR) and subjective refraction (SR) measurements were also performed.

Results: A total of 60 children with a mean age of 10.50 ± 1.81 years were enrolled. Before cycloplegia, all the central and peripheral retinal refraction parameters showed good repeatability with the lowest intraclass correlation coefficient (ICC) being 0.78 in the retinal deviation value from 45° eccentricity to 53° of the retina (RDV 45–53). After cycloplegia, the repeatability of MRT was significantly enhanced (lowest ICC = 0.91 in RDV-I). The 95% limits of agreement (LoA) of the central refraction and OR ranged from − 2.1 to 1.8 D before cycloplegia, and from − 1.69 to 0.27 D after cycloplegia. The 95% LoA of the central refraction and SR ranged from − 1.57 to 0.36 D after cycloplegia. All the 95% LoA demonstrated high agreement.

Conclusions: The MRT shows high agreement with autorefractometry and experienced optometrist in measuring central refraction. Additionally, the MRT provides good repeatable measurements of retinal peripheral refraction before and after cycloplegia in schoolchildren.

Keywords: Agreement, Repeatability, Retinal peripheral refraction

Introduction

Myopia has emerged as a significant health issue in East and Southeast Asia due to its rapidly increasing prevalence over the past few decades, affecting 80 to 90% of young people in certain regions [1]. Thus, the prevention and control of myopia is an important public health issue that has attracted great attention from the World Health Organization and the Chinese government.

In recent years, a growing number of studies have found that peripheral hyperopia refractive status plays a crucial role in myopia progression. Previous animal experiments have found that applying negative lenses to induce hyperopia defocusing stimulation in monkey eyes can cause myopia in monkeys [2, 3], while applying positive lenses to induce myopia defocusing stimulation can cause hyperopia in monkeys [4]. Optical interventions based on defocus theory, such as multifocal soft lenses (MFSCL) [5] and orthokeratology [6], have been shown to successfully delay axial growth by 30% to 55% [7]. However, there are also views that there is no necessary causal relationship between relative peripheral hyperopia defocusing and the development of myopia in children [8]. The exact relationship between peripheral refraction and ocular growth has not been elucidated, and one reason may be the errors and limitations of human peripheral refraction measurement techniques. Previous methods for measuring peripheral refraction include subjective eccentric refraction [9], wavefront measurements sensor [10], streak retinoscopy [11], and photo refraction with a power refractor [12]. WAM-5500 (Grand Seiko Co., Hiroshima, Japan), a binocular, open-field, infrared autorefractor and keratometer, is widely utilized in clinical settings to measure central and peripheral retinal refraction due to its well-documented repeatability [13, 14]. However, these methods can only detect a small area of the retina and cannot accurately detect the peripheral defocus of each region of the retina. Further, the process has high requirements for patient cooperation, and it is time-consuming and difficult to adapt to clinical practice [15, 16].

To address these limitations, multispectral refraction topography (MRT, Thondar, Shenzhen, China), a novel multispectral-based computing system, was designed to measure the spherical equivalence (SE) of a 53-degree fundus field of view within 2–3 s. MRT simultaneously obtains the refractive power of all retinal regions, including the central and peripheral retina, within a certain range. Its accuracy and repeatability have been validated in model eyes and adults [17–19]. Given that children are the main target of myopia prevention and control, MRT should be mainly applied to the examination of children's peripheral refraction. To our knowledge, there are no articles describing the repeatability and effectiveness of MRT tests in children. Therefore, the purpose of this study is to evaluate the repeatability of the measurements obtained using the MRT device in children with and without cycloplegia and assess the agreement among the refractive measurements made using MRT, automated refraction (NIDEK ARK-1; NIDEK, Aichi, Japan), and subjective refraction.

Results

Sixty children were recruited in this study, and the average age was 10.50 ± 1.81 years (range: 7–16 years). Retinal refractive measurement was performed using MRT (Thondar, Shenzhen, China). The parameters obtained through MRT for retinal analysis included the following: central refractive diopter at 5° (Center-D); refraction difference values (RDV) for circle areas centered on the macula at 15° intervals, such as RDV-15, RDV-30, RDV-45, and total refraction difference value (TRDV) representing the average peripheral retinal refraction from the center to 15°, 30°, 45°, and the entire peripheral retina (including the fovea); annular refraction difference values at 15° intervals, like RDV 15–30 and RDV 30–45, indicating the average refraction of concentric areas at different angles (with a maximum measurement range of 53°, and RDV45–53 representing the most peripheral annular data); and the quadrant of the retina categorized as inferior, superior, nasal, and temporal (RDV-I, RDV-S, RDV-N, and RDV-T) (see Fig. 1).

Intraoperator repeatability

Table1 shows the repeatability of MRT in central and peripheral refraction measurements in patients before cycloplegia. All the central and peripheral retinal refraction parameters showed good repeatability. The ICC values were all above 0.75. The ICC values of the different quadrants were found to be lower than those of the concentric areas. After cycloplegia, the ICC values for all peripheral retinal parameters showed significant improvement, as indicated in Table 2. Particularly noteworthy is the visible enhancement in ICC values for the various quadrants within the cycloplegia group compared to those in the non-cycloplegia group.

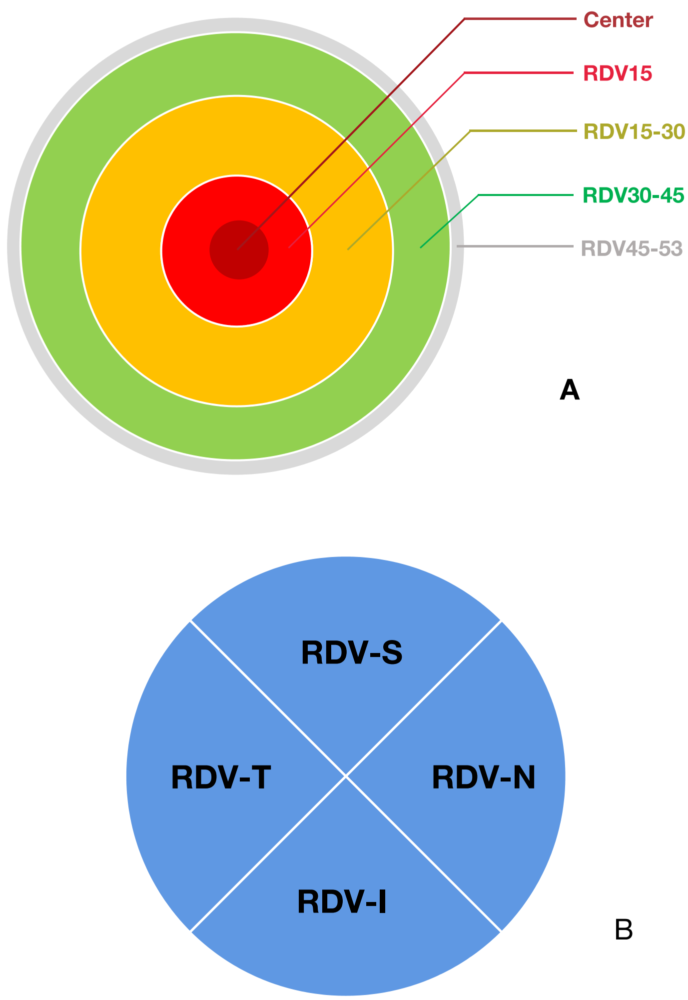

Fig. 1 Schematic of MRT outcomes (right eye). **A** Schematic of annulus outcomes; **B** schematic of quadrant outcomes

Table 1 Intraobserver repeatability outcomes of central and peripheral refraction using MRT before cycloplegia

Parameters	Mean (D)	SD	ICC
Center-D	− 1.85	2.08	0.93
TRDV	− 1.39	2.09	0.89
RDV15	− 1.75	2.07	0.93
RDV30	− 1.49	2.05	0.93
RDV45	− 1.37	2.07	0.92
RDV15-30	− 1.40	2.04	0.93
RDV30-45	− 1.23	2.10	0.90
RDV45-53	− 1.53	2.23	0.78
RDV-S	− 1.60	2.08	0.86
RDV-I	− 1.35	2.24	0.79
RDV-T	− 1.99	2.09	0.90
RDV-N	− 0.72	2.34	0.82

SD: standard deviation; ICC: intraclass correlation coefficient and 95% confidence interval

Table 2 Intraobserver repeatability outcomes of central and peripheral refraction using MRT after cycloplegia

Parameters	Mean (D)	SD	ICC
Center-D	− 1.11	1.97	0.95
TRDV	− 0.33	2.06	0.97
RDV15	− 1.0	1.96	0.97
RDV30	− 0.82	1.96	0.98
RDV45	− 0.43	2.01	0.98
RDV15-30	− 0.75	1.95	0.98
RDV30-45	− 0.22	2.07	0.97
RDV45-53	− 0.06	2.23	0.94
RDV-S	− 0.65	2.02	0.93
RDV-I	− 0.43	2.15	0.91
RDV-T	− 0.90	2.01	0.96
RDV-N	0.38	2.30	0.96

SD: standard deviation; ICC: intraclass correlation coefficient and 95% confidence interval

Agreement

Objective refraction (OR) was performed using NIDEK ARK-1 autorefractometry (NIDEK ARK-1; NIDEK, Aichi, Japan). Subjective refraction (SR) was conducted by an experienced optometrist. The mean spherical equivalence (SE) for OR before cycloplegia was − 2.13 ± 2.04 diopters (D) (range − 9.25 to + 1.25 D), while the mean central refraction (Center-D) measured by MRT was − 1.80 ± 2.04 diopters (D) (range − 7.47 to + 1.53 D). The results showed good agreement between the autorefractometry and MRT in central refractive measurement (ICC = 0.88). Figure 2 shows the Bland–Altman plots comparing OR and MRT before cycloplegia. The 95% LoA ranged from − 2.1 to 1.8 D, indicating a good agreement. Pearson correlation analysis showed a strong correlation between the central refractive measurement values of the automatic refractometer and MRT ($R = 0.88$, $P < 0.001$).

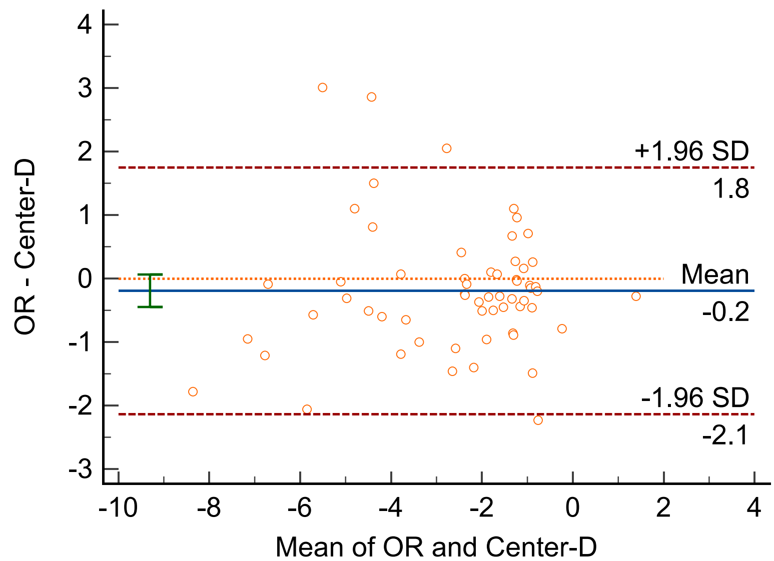

Fig. 2 Bland–Altman plots between OR and Center-D before cycloplegia

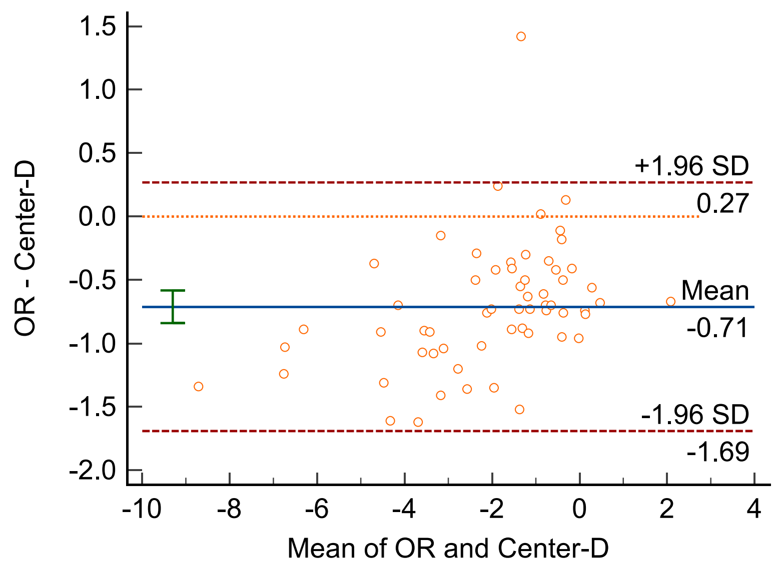

Fig. 3 Bland–Altman plots between OR and Center-D after cycloplegia

Then we analyzed the central refraction of OR and SR and MRT after cycloplegia. The mean SE for OR and SR after cycloplegia was − 1.75 ± 2.10 D (range − 9.38 to + 1.75 D) and − 1.75 ± 2.08 D (range − 9.25 to + 1.88 D), respectively. The 95% LoA of the central refraction of OR or SR ranged from − 1.69 to 0.27 D and − 1.57 to 0.36 D after cycloplegia, respectively, suggesting that cycloplegia could enhance the agreement given that the accommodation was relaxed (Fig. 3, Fig. 4).

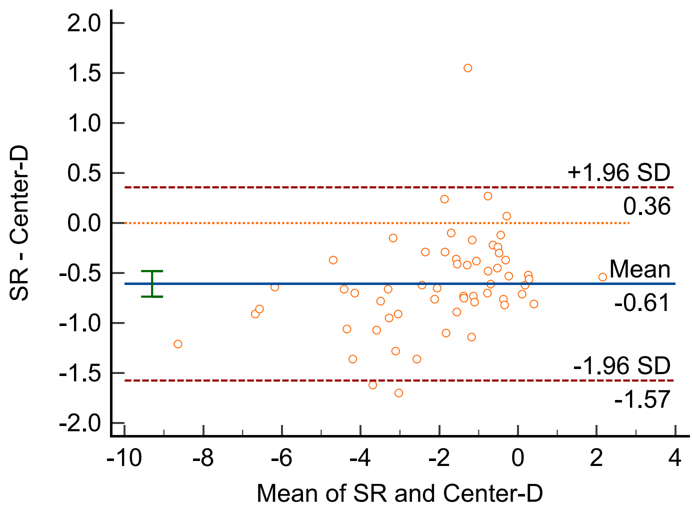

Fig. 4 Bland–Altman plots between SR and Center-D after cycloplegia

Discussion

Over the past 20 years, peripheral hyperopic defocus has garnered research interest in the pathogenesis of myopia, and peripheral refraction is of great significance in vision research.

Eyes with emmetropia and hyperopia often have relative myopia peripheral defocus, while the eyes with myopia have relative hyperopia peripheral defocus [20, 21]. Defocus of the peripheral retina affects the eye length and visual development in both animals and humans [22–25]. Mutti et al. [26] conducted a longitudinal study on 822 cases of children aged 5–14, and discovered that children with myopia had more relative hyperopic defocus than children with emmetropia. Therefore, measurement of the peripheral refractive error becomes an important aspect in clinical application. The widely used open-field computer refractometer, such as WAM-5500, is an indirect measurement method. By allowing the patient to rotate their eyeballs or head to a certain angle, the peripheral retina is exposed, and the refractometer refracts from the front to obtain the peripheral retinal refraction at different fixation angles [14]. However, this measurement method has a long measurement time, a complex process, and a small number of measurement data points, which cannot reflect the overall refractive state of the retina. Based on the above reasons, there has been little research on the peripheral diopter of children in the past. Such disadvantages can be overcome by MRT, a novel device that can measure the large areas of peripheral refraction. It can calculate and generate optical defocusing data within the 0°–53° field of view angle range of the retina in a short period of time. Compared to the windowed computer refractometer used in previous studies, it has the advantages of shorter measurement time and higher retinal refractive information density. Meanwhile, MRT can obtain over 1 million dense data points and automatically calculate RDV based on image analysis and algorithms, providing more objective and accurate results compared to previous studies. However, before widespread clinical application and promotion, it is necessary to verify the repeatability and reproducibility of multiple measurements. Previous studies have reported excellent reproducibility and agreement of MRT in adults [18, 19], but the reproducibility and agreement in children has not been reported yet. This study explored the repeatability of using MRT to measure central and peripheral refraction before and after cycloplegia in children. The central refraction results were also compared with the OR and SR measurements obtained under the same conditions. To the best of our knowledge, this study was the first to evaluate the repeatability of MRT in children.

Our study demonstrated that all the central and peripheral retinal refraction parameters exhibited good repeatability before and after cycloplegia, with ICC values for both annular and quadrant regions exceeding 0.75. Compared to traditional devices, this method shows a clear advantage. Previous studies utilizing the Grand Seiko WAM-5500 open-field autorefractor to compare the repeatability of central and peripheral refraction in adults at two visits found that repeatability was highest centrally and decreased with increasing eccentricity [14]. A potential explanation is that when the eye rotates to focus on peripheral targets, the measurement beam may not align with the pupil center. Additionally, as the measurement angle increases, the peripheral measurement angle may exceed the pupil's diameter range. Conversely, MRT measurements do not require subjects to change their gaze position, thereby avoiding measurement errors caused by pupil center misalignment. Furthermore, MRT can quickly obtain a substantial amount of refractive information from the retina, resulting in consistent repeatability from the central to the peripheral regions. Our study is in line with the research of Lu et al. [18]. However, the ICC value of central and peripheral refraction before cycloplegia was found to be lower than the ICC value reported by Lu et al. [18]. In their study, the ICC value of central and peripheral refraction was consistently higher than 0.97 regardless of whether cycloplegia was used. We believe that the main reason for this discrepancy is that the two studies selected different subjects. Their study focused on adults, while our study specifically targeted children. It is widely recognized that children without cycloplegia exhibit greater accommodation power compared to adults. Previous studies [27, 28] found that accommodation inevitably affects the peripheral defocus state. Whatham et al. studied the influence of accommodation on peripheral refraction in myopes using an autorefractor with a custom near-fixation target [27]. They found that the SE of the peripheral retina was more hyperopic relative to central refraction at all eccentricities, except the temporal retina at 20° and 30° at distance. Lundstro¨m et al. used a Hartmann–Shack wavefront sensor to assess the change in peripheral refraction under accommodation [28]. It was discovered that there was an inconsistent change in peripheral refraction in myopia between far and near vision. Additionally, it was found that the repeatability of MRT was significantly enhanced after cycloplegia, consistent with the results of Lu et al. [18]. Regarding the errors caused by cycloplegia, dilating the pupils can lead to increased spherical aberration. However, according to the study introducing the design of MRT [17], a smaller entrance pupil was chosen to control spherical aberration (the diameter of the entrance pupil is 1.4 mm for the imaging module, smaller than the typical diameter of 2.5 mm–4.0 mm of the human pupil). In our opinion, pupil dilation did not significantly reduce accuracy despite an increase in repetitiveness.

Our study found that the repeatability of retinal refraction was slightly worse with the four quadrants compared to concentric circles, whether before or after cycloplegia. This finding is consistent with the research results from Lu et al. [18]. At the same time, we also found that the peripheral refraction repeatability of the four quadrants was inconsistent, and peripheral hyperopia defocus presented asymmetric distribution, with RDV-N > RDVI > RDV-S > RDV-T. This is consistent with the research results of Lu et al. [18]. The specific mechanism was not clear, which might be related to the asymmetry of curvature of the cornea and lens edge, the shape of the eyeball, and the unequal pressure of the eyelid on the cornea. Further studies may be needed. In the future, when designing peripheral myopic defocus to control myopia, asymmetric design can be considered.

Our study confirmed the excellent reliability of the MRT for central refraction measurements both before and after cycloplegia. It also showed a high level of agreement with autorefractometry and experienced optometrist. These findings are consistent with previous research results [18, 19]. It should be noted that both before and after cycloplegia, the Center-D of MRT showed mild hyperopia deviation compared with OR or SR. This is because the Center-D of MRT measured the mean refraction within the 5° range of the macular fovea, rather than the refraction of the macular fovea itself.

At present, there are few studies on the repeatability and agreement of MRT, which is worth repeating. This is the first study on children. Research has proven that automatic detection of children's peripheral refraction is possible. The innovation in peripheral refraction measurement will also aid in the study of myopia control. Our study has several limitations. First, the number of children included was not large enough, and the children were not divided into different refraction groups. Therefore, larger samples including different refraction groups should be adopted in future studies. Secondly, the average age was 10 years in our study. The repeatability and agreement of MRT in children 6 years and younger is still unknown. Thirdly, we only assessed the repeatability of MRT without comparing it with other peripheral wavefront autorefractors. A gold standard in measuring peripheral refraction remains non-existent. Future studies should compare MRT with other devices to gain insights on the introduction of MRT in clinical applications.

Conclusion

The central refraction measurements in children before and after cycloplegia showed good repeatability with MRT and were consistent with autorefractometry and experienced optometrist. MRT, as a technological innovation in peripheral retinal refractive measurement, also demonstrated good repeatability and agreement in overall peripheral refractive measurement in children. This lays a strong foundation for future widespread application.

Materials and methods

Patients

In this study, 60 subjects who visited the Children's Hospital of Fudan University for health examination from August 2023 to September 2023 were recruited. All the subjects were treated according to the tenets of the Declaration of Helsinki. This trial has been registered in the Chinese Clinical Trial Registry on 21 July 2023 (ChiCTR2300073817).

The enrolled patients met the following inclusion criteria: age 7–18 years, best corrected visual acuity ≧ 20/25, astigmatism diopter < 3.0 D, no history of ocular surgery or trauma, no ocular or systemic diseases except for refractive errors, no history of using atropine ophthalmic solutions, and no history of using contact lens, such as orthokeratology or multifocal soft lenses.

Instrument and methods

MRT is a novel multispectral imaging technology based on a simplified optical model. It can enhance the clarity of blurred retinal images using a refractive compensation system. The detailed specific principle of MRT has been introduced by Huang et al. [17]. MRT was first developed based on an optical system of multispectral fundus camera. This camera is capable of capturing a series of images at different focus positions using infrared wavelength. Image analysis was performed and an algorithm was used to decouple and generate the refractive value of each imaging data point. This approach could determine the SE of 128 × 128 points on a 53-degree field of view of the fundus, with a data point of 0.5° in between. During the recording session, a fixation target consisting of a 550-nm LED will be used to direct the gaze of the eye and regulate eye movements.

All subjects underwent basic ophthalmologic examinations, including visual acuity examination, slit-lamp examination of the anterior segment, and fundus evaluations. Retinal refractive measurement was performed using MRT (Thondar, Shenzhen, China). Objective refraction (OR) was performed using NIDEK ARK-1 autorefractometry (NIDEK ARK-1; NIDEK, Aichi, Japan). Subjective refraction (SR) was conducted by an experienced optometrist. Initially, the MRT and OR were performed before cycloplegia. Next, tropicamide 0.5% (Bausch & Lomb Pharmaceutical Co., Ltd, Shandong, China) was used five times, at 5-min intervals, to induce cycloplegia until the pupil diameter reached 7–8 mm in order to relax the accommodation. The MRT, OR, and SR examinations were repeated by the same doctor to minimize the operator-related error. All MRT measurements were examined three times to assess the intraobserver repeatability. The mean of three consecutive autorefraction results was collected and presented as sphere (S) and cylinder (C) measurements to represent the refractive error value. The final refractive error was recorded as the spherical equivalence (SE), and the SE value was the basis for grouping. The equation was $SE = S + C/2$.

MRT can measure the refractive power in specific regions of the central and peripheral retina. The retinal deviation value (RDV) was used to describe the average peripheral refractive error of the retina. The mean refraction within the 5° range of the macular fovea is indicated by Center-D. Peripheral refractive power is represented by the retinal deviation value (RDV), which refers to the sum of the refractive power within a specific point or region of the retina. This study employs two methods to represent retinal refraction: annular and quadrant methods. TRDV denotes the sum of refractive power within the 0°-53° visual field range. The annular recording refers to calculating the retinal refractive power in concentric circles with the macula as the center, specifically for eccentricities 0–15, 0–30, 0–45, 15–30, 30–45, and 45–53 degrees. The quadrant recording refers to the sum of refractive power in the inferior, superior, temporal, and nasal quadrants of the retina (Fig. 1). The measurement quality was estimated by a computer to avoid the influence of iris reflection, eye blinking, and dim illumination, and only those results with a quality score of > 80% were recorded for further analysis.

Statistical analysis

All statistical analyses were performed using SPSS software (version 22.0; SPSS Inc., Chicago, IL, USA) and Medcalc software (version 24.0; IBM Corporation, Armonk, NY). The parameters that meet the normal distribution are statistically described using mean ± standard deviation, and paired sample *t*-tests are used to analyze the differences between the two measurements. The parameters of the non-normal distribution are described using the median and quartile, and the differences between measurements are compared using Wilcoxon signed rank test. Pearson correlation was used to evaluate the relationship between Center-D and SE. To assess the intraoperator repeatability of MRT, one-way analysis of variance (ANOVA) was used to calculate the intraclass correlation coefficient (ICC). An ICC > 0.75 is considered to indicate good measurement reliability, while a P value of < 0.05 is considered to be statistically significant. This study included data only from the right eye for analysis.

The mean of the three MRT measurements was used in assessing agreement with the SR and OR. For the agreement evaluation, the MedCalc statistical software (version 18.2.1, Ostend, Belgium) was used to draw the Bland–Altman plots. The 95% limit of agreement (LoA) was drawn according to the mean difference ± 1.96 SD between two methods, and it indicates the measurement error of these methods [29].

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None.

Author contributions
Conception and design: XX and AW and CY. Collection and assembly of data: XX and WZ. Data analysis and interpretation: XX and AW. Manuscript writing: XX. Anken Wang and Chenhao Yang contributed equally to this work and share corresponding authorship. All authors read and approved the final manuscript.

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Availability of data and materials
The data sets used and analyzed during the current study are available from the corresponding authors upon reasonable request.

Declarations

Ethics approval and consent to participate
This study was approved by the Ethics Committee of Children's Hospital of Fudan University and all procedures adhered to the tenets of the Declaration of Helsinki. Written informed consent was obtained from the children's parents or guardians.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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