Repeatability and Consistency of Multispectral Refraction Topography in School Children Before and After Cycloplegia

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Research Article

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Additional Declarations: No competing interests reported.
Abstract

Background

To evaluate the repeatability and consistency of multispectral refraction topography (MRT) in measuring retinal refraction before and after cycloplegia in children.

Methods

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

Results

A total of 60 children with mean age of 10.50 ± 1.81 years were enrolled. Before cycloplegia, all the central and peripheral retinal refraction parameters showed good repeatability (lowest intraclass correlation coefficient (ICC) = 0.78 in 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 showed high consistency.

Conclusions

MRT shows high consistency with autorefractometry, experienced optometrist in measuring central refraction. In addition, MRT provides good repeatable measurements of retinal peripheral refraction before and after cycloplegia in schoolchildren.

Introduction

Myopia is the most common refractive error and a major reason for visual impairment. The prevalence of myopia is increasing worldwide and is particularly high in Asian countries. It affects 80–90% of young people in some parts of East and Southeast Asia [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 30–55% [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]. 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 [13, 14].

To address these limitations, multispectral refraction topography (MRT, Thondar, Shenzhen, China), a novel multispectral-based computing system, was designed to measure the spherical equivalent (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 adults [15, 16]. 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 consistency 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). The mean spherical equivalent (SE) before and after cycloplegia was −2.13 ± 2.04 D and −1.75 ± 2.10 D for OR, respectively. The mean SE for SR after cycloplegia was −1.75 ± 2.08 D.

Intraoperator Repeatability

Table 1 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 different quadrants were worse than the concentric areas. However, the repeatability of these parameters significantly improved after cycloplegia. After cycloplegia, all the peripheral retinal parameters showed good initial repeatability (Table 2). Notably, the RDV for the different quadrants were improved visibly in the cycloplegia group compared with that in the non-cycloplegia group.
Table 1
Intraobserver repeatability outcomes of central and peripheral refraction using MRT before cycloplegia.

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

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.

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

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

Consistency

Table 3 summarizes the consistency between MRT and OR before cycloplegia. The results showed good consistency between the automatic refractometer and MRT in central refractive measurement, and the Wilcoxon signed rank test showed a median difference of 0.33D between measurement methods, with a statistical difference ($P < 0.05$); The 95% LoA in the instrument room ranges from −2.1 to 1.8D (Fig. 1). Pearson correlation analysis showed a strong correlation between the central refractive measurement values of the automatic refractometer and MRT.

Table 3
Central refraction agreement outcomes between OR and MRT before cycloplegia. [M ($P_{25}$ − $P_{75}$)]

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Central refraction</th>
<th>Z</th>
<th>P</th>
<th>ICC (95% CI)</th>
<th>Pearson Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>OR</td>
<td>-2.13(-3.97, -1.25)</td>
<td>-2.50</td>
<td>0.01</td>
<td>0.88(0.81 ~ 0.93)</td>
<td>0.88 &lt;0.001</td>
</tr>
<tr>
<td>Center-D</td>
<td>-1.80(-3.88, -1.17)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
OR: spherical equivalent refraction using autorefractometry; Center-D: central refraction using MRT.

Wilcoxon Signed Ranks Test.

Table 4 shows the consistency between MRT and OR after cycloplegia. The results showed good consistency between the automatic refractometer MRT in central refractive measurement (ICC = 0.97). The Wilcoxon signed rank test showed a median difference of 0.55D between automatic refractometer and MRT, with with a statistical difference (P < 0.001); Table 5 shows the consistency between MRT and SR after cycloplegia. Those results showed good consistency between the experienced optometrist and MRT in central refractive measurement (ICC = 0.97). The Wilcoxon signed rank test showed a median difference of 0.55D between experienced optometrist and MRT, with with a statistical difference (P < 0.001). 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 consistency given that the accommodation was relaxed (Fig. 2, Fig. 3).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Central refraction</th>
<th>Z</th>
<th>P</th>
<th>ICC (95%CI)</th>
<th>Pearson Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>OR</td>
<td>-1.75(-3.82, -0.88)</td>
<td>-6.24</td>
<td>&lt;0.001</td>
<td>0.97(0.95  ~ 0.98)</td>
<td>0.97 &lt;0.001</td>
</tr>
<tr>
<td>Center-D</td>
<td>-1.20(-2.75, -0.39)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

OR: spherical equivalent refraction using autorefractometry; Center-D: central refraction using MRT. Wilcoxon Signed Ranks Test.

Table 5 shows the consistency between SR and MRT after cycloplegia. [M (P25 ~ P75)]

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Central refraction</th>
<th>Z</th>
<th>P</th>
<th>ICC (95%CI)</th>
<th>Pearson Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR</td>
<td>-1.75(-3.72, -0.75)</td>
<td>-6.18</td>
<td>&lt;0.001</td>
<td>0.97(0.95  ~ 0.98)</td>
<td>0.97 &lt;0.001</td>
</tr>
<tr>
<td>Center-D</td>
<td>-1.20(-2.75, -0.39)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SR: spherical equivalent refraction form experienced optometrist; Center-D: central refraction using MRT. Wilcoxon Signed Ranks Test.

Discussion

For the past few years, peripheral hyperopic defocus has become an area of research interest in the pathogenesis of myopia and peripheral refraction is of great significance in the field of vision research. Eyes with emmetropia and hyperopia often have relative myopia peripheral defocus, while the eyes with myopia have relative hyperopia peripheral defocus [17, 18]. Defocus of the peripheral retina affects the eye length and visual progress in both animals and humans [19–22]. Mutti et al [23] 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 (Grand Seiko Co., Hiroshima, Japan), 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 [24]. 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 consistency of MRT in adults [15, 16], but the reproducibility and consistency 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 our best knowledge, this study was the first to evaluate the repeatability of MRT in children.

Our study showed that all the central and peripheral retinal refraction parameters showed good repeatability before and after cycloplegia. This is consistent with the research results of Lu et al [15]. However, the ICC value of central and peripheral refraction before cycloplegia was obviously lower than the ICC value of Lu et al [15]. The ICC value of central and peripheral refraction in their article was all higher than 0.97 with or without cycloplegia. We believe that the main reason for this discrepancy is that the two studies chose different subjects. They chose adults, while our study chose children. It is well known that children without dilated pupil have more accommodation power than adults. Previous studies [25, 26] 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 [25]. They found that the SE of the peripheral retina was more hyperopic relative to central refraction at all eccentricity, except the temporal retina at 20° and 30° at distance. Lundström et al used a Hartmann-Shack wavefront sensor to assess the change in peripheral refraction under accommodation [26]. They discovered that the peripheral refraction in myopia showed an inconsistent change between far and near vision. In addition, we found that the repeatability of MRT was significantly enhanced after the cycloplegia. This is consistent with the research results of Lu et al [15].
Our study found that the repeatability of retinal refraction with the four quadrants was slightly worse than that with concentric circles, regardless of whether before or after cycloplegia. This is consistent with the research results of Lu et al [15]. 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 [15]. 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 that the MRT had excellent repeatability for central refraction measurements before and after cycloplegia and maintained a high degree of consistency with autorefractometry, experienced optometrist. This is consistent with previous research results [15, 16]. It should be noted that, whether before and after cycloplegia, the Center-D of MRT showed mild hyperopia deviation compared with OR or SR, because the Center-D of MRT measured the mean refraction within the 5° range of macular fovea, rather than the refraction of macular fovea.

At present, there are few studies on the repeatability and consistency of MRT, which is worth repeating. This is the first study on children. It is proved that children's peripheral refraction can be automatically detected. The innovation of peripheral refraction measurement will also be helpful to 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 consistency 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 inexistent. Future Studies should compare MRT with other devices to gain insights on the introduction of MRT in clinical applications.

**Conclusion**

MRT demonstrated good repeatability in central refraction measurements in children before and after cycloplegia, and had good consistency with autorefractometry, experienced optometrist. As a technological innovation in peripheral retinal refractive measurement, MRT has good repeatability and consistency in children's peripheral refractive measurement as a whole, laying the 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 $\geq$ 20/25, astigmatism diopter $< 3.0$ D, no ocular surgery or trauma history, no ocular and systemic diseases except for refractive, no history of use of atropine ophthalmic solutions, and no history of contact lens, such as orthokeratology and multifocal soft lenses.

**Instrument and Methods**

MRT is a novel multispectral imaging technology based on a simplified reduced optical model. It can compensate for the blur retinal image to clear the image using a refractive compensation system (Fig. 4). The detailed specific principle of MRT has been introduced by Luo et al [15].

All subjects underwent basic ophthalmologic examinations, including visual acuity examination, slit-lamp examination of the anterior segment, and fundus evaluations. The examinations were conducted between 11 am and 5 pm by an experienced doctor to avoid the influence of diurnal variation [27]. 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, with an interval of 5 min to induce cycloplegia until the pupil diameter reached 7–8 mm 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 evaluate the intraobserver repeatability. We collected the mean of three consecutive autorefraction results conducted as the refractive error value, which is presented as sphere (S) and cylinder (C) measurements. The final refractive error was recorded as the spherical equivalent (SE), and the SE value was the basis for grouping. The equation was $SE = S + C/2$.

The parameters obtained using MRT for further analysis were as follows: central refractive diopter $5^\circ$ (Center-D); the refraction difference value (RDV) of circle areas centered on macular with an increment of $15^\circ$, RDV-15, RDV-30, RDV-45, and total refraction difference value (TRDV), which indicates the average peripheral retinal refractive error from the center to $15^\circ$, $30^\circ$, $45^\circ$, and total peripheral retina refraction (including the fovea); the annular refraction difference value with intervals of $15^\circ$, RDV 15–30, RDV 30–45, which indicates the average refraction of the concentric areas with different angles (the maximum measurement range of MRT is $53^\circ$, and the RDV45–53 represent the most peripheral annular data); the quadrant of the retina which was defined as inferior, superior, nasal, and temporal (RDV-I, RDV-S, RDV-N, and RDV-T)(Figure 5). 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). ICC > 0.75 is considered good measurement reliability. P value of < 0.05 is considered statistically significant. This study only included data from the right eye for analysis.

The mean of the three MRT measurements was used in assessing consistency with the SR and OR. For the consistency 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 [28].

**Declarations**

**Acknowledgements**

None.

**Author contributions**

Conception and design: XX & AW & CY. Collection and assembly of data: XX & & WZ. Data analysis and interpretation: XX & 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.

**Funding**

None

**Availability of data and materials**

The data used to support the findings of this study are available from the corresponding authors upon request.

**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 that they have no competing interests.

**References**


Figures
Figure 1

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

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

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

Multispectral Refractive Topography (MRT)
Figure 5

Schematic of MRT outcomes (right eye)

A: Schematic of annulus outcomes; B: Schematic of quadrant outcomes