Underestimation of astigmatism without cycloplegic refraction in preschool children

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Research article

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Abstract

Significance: It is generally believed that cycloplegia optometry had no effect on astigmatism. The comparison was all made on the spectacle plane. There is a dearth of studies on the influence from corneal plane.

Purpose: Study on the difference between cycloplegic and noncycloplegic measurements of astigmatism on corneal plane.

Methods: This is a retrospective study. Vertexing the total ocular astigmatism to the corneal plane. To transpose astigmatism into $J_0$ and $J_{45}$ components by Fourier transformation. The changes of astigmatism measured with and without cycloplegic were compared from corneal plane. Data were compared by paired $t$ test.

Results: The changes of the total ocular astigmatism were significantly different on corneal plane (total ocular astigmatism: $t = -2.31, P < .05$; $J_0$ components: $t = -2.71, P < .01$; $J_{45}$ components: $t = -1.09, P > .05$). The magnitude of total ocular astigmatism generally increased after cycloplegia (2.12 ± .87 D vs 2.07 ± .89 D). 37 eyes (32.17%) had a change value greater than 0.25 D. The proportion of with-the-rule total ocular astigmatism increased (from 90.43–92.17%) and that of oblique total ocular astigmatism decreased (from 9.57–7.83%). While the changes of anterior corneal astigmatism were no significantly different.

Conclusion: There were underestimation of total ocular astigmatism without cycloplegic refraction in preschool children. The proportion of with-the-rule astigmatism increases after cycloplegia.

Introduction

Refractive error is the main cause of low vision in children,\(^1\)–\(^2\) and astigmatism is the main refractive error. Because of the strong accommodating power of 3-6-year-old children, it is easy to cause underestimation of hyperopia and overestimation of myopia without cycloplegia optometry.\(^3\)–\(^6\) So cycloplegic refraction remain the gold standard for measuring refractive status in children.\(^4\) It is generally believed that cycloplegia optometry has no effect on astigmatism.\(^7\)–\(^9\) However, previous studies on the influence of astigmatism were all carried out on the spectacle plane. The corneal plane should be taken into account when performing astigmatism treatments surgeries, cataract surgeries or matching contact lens. This study is the first to report the influence from corneal plane.

Materials And Methods

This study followed the tenets of the Declaration of Helsinki and was approved by our institutional review board. Informed consent was obtained from each subject’ parents after explanation of the nature of the study. To analysis astigmatism in the form of positive-cylinders.
Participants Selection

We conducted a retrospective study of children diagnosed with refractive astigmatism $\geq 1.00$D who presented at the outpatient ophthalmology clinics at Lianyungang Maternal and Child Health Hospital during June 2018 to December 2018. Excluding organic diseases of eyes such as cataract, glaucoma, keratoconus, irregular astigmatism, nystagmus and children with strabismus. We analyze the right eye data only. Finally, a total of 115 right eyes met the inclusion criteria (53 females and 62 males). The mean age was $4.8 \pm 1.0$ years.

Examination Protocol And Collect Parameters

To use 1% cyclopentolate hydrochloride eye drops to perform cycloplegia (one drop each time, once every 8 minutes, four times in total). After each time, pressed the lacrimal sac for 3 minutes, and waited for at least 30 minutes after four times until the pupillary reaction to light disappeared or only the weak light reflex remained. All measurements were performed by the same experienced ophthalmologist, checked the right eye first, then the left eye. Used a fully automatic computer optometry/ corneal curvature meter of NIDEK ARK-1 (Japan) to measure the flat curvature radius(R$_1$), steep curvature radius(R$_2$), and meridian of R$_1$, the refractive error pre- and post-cycloplegic. Measured two times, took the mean value of the results with confidence $\geq 8$. The NIDEK ARK-1 measured the radius of corneal curvature within 3.3 mm of the center of the cornea.

Data Analysis And Calculations

To convert all manifest refraction data from the spectacle to the corneal plane (adjusting for vertex distance), as the intended first optical surface is always the cornea.$^{10}$ The spherocylindric refraction in this example is vertexed to the corneal plane as shown below:

Spherocylindric form: $+1.75-3.25 \times 180$

Cross cylinder form @ spectacle: $+1.75 \times 90$ and $-1.50 \times 180$

Vertex: 12.00 mm (ARK-1 sets the vertex to 12 mm)

Vertex formula from spectacle plane ($REF_s$) to corneal plane ($REF_c$)$^{11,12}$:

$$REF_c = \frac{1000 \times REF_s}{1000 - REF_s \times V_{vertex} (mm)}$$

(1)

Substituting the values from the example
Cross cylinder form @ cornea: 1.79 × 90 and −1.47 × 180

Vertex: 0 mm

Minus cylinder form: 1.79–3.26 × 180

Plus cylinder form: -1.47 + 3.26 × 90

To compute corneal front surface power, the change in media for the light rays is from air (n = 1.000) to cornea (n = 1.376), so, as Holladay and Waring\textsuperscript{13} and Mandell\textsuperscript{14} have recommended, the correct formula for computing the power and any change in power would be

$$K_a = \frac{1.376 - 1.000}{r_a} = \frac{0.376}{r_a}$$

(2)

where $r_a$ is the anterior radius of curvature of the cornea (m) and $K_a$ is the front surface corneal power (D).

So the magnitude of anterior corneal astigmatism (ACA) was derived by the following formula:

$$ACA = \frac{0.376}{R_1} - \frac{0.376}{R_2}$$

(3)

$R_1$ is anterior corneal curvature radius of the flat, $R_2$ is anterior corneal curvature radius of the steep.

Both of the total ocular astigmatism and anterior corneal astigmatism are converted into the positive-cylinders form. The with-the-rule astigmatism is defined as axis from 75 degrees to 105 degrees, the against-the-rule astigmatism is defined as axis from 0 degrees to 15 degrees and 165 degrees to 180 degrees, and the oblique astigmatism is defined as axis from 16 degrees to 74 degrees and 106 degrees to 164 degrees.

To transpose the positive-cylinders form ($S, +C \times \beta$) of refractive astigmatism into J0 and J45 components by Fourier transformation\textsuperscript{15-16}:

$$J_0 = -\frac{C}{2} \times \text{COS}(2\beta)$$

$$J_{45} = -\frac{C}{2} \times \text{SIN}(2\beta)$$

(4) \textsuperscript{15-16}
Statistical Methods

This was a retrospective study. SPSS statistics software package version 17.0 for Windows (IBM, Armonk, NY, USA) was used for the statistical analysis. The magnitude of total ocular astigmatism, anterior corneal astigmatism, and their $J_0$ and $J_{45}$ components were normal distribution. They were expressed as mean ± standard deviation. Data were compared by paired $t$ test. Statistical significance was assumed at $P < .05$.

Results

The changes of the total ocular astigmatism and $J_0$ components were significantly different pre- and post-cycloplegic on corneal plane (total ocular astigmatism: $t = -2.31$, $P < .05$; $J_0$ components: $t = -2.71$, $P < .01$). The other changes were no statistically significant (Table 1).

<table>
<thead>
<tr>
<th></th>
<th>Pre-cycloplegic</th>
<th>Post-cycloplegic</th>
<th>$t$</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACA</td>
<td>2.74 ± 0.85</td>
<td>2.77 ± 0.79</td>
<td>-0.89</td>
<td>.38</td>
</tr>
<tr>
<td>$ACA_{J0}$</td>
<td>1.32 ± 0.42</td>
<td>1.34 ± 0.39</td>
<td>-1.03</td>
<td>.30</td>
</tr>
<tr>
<td>$ACA_{J45}$</td>
<td>-0.05 ± 0.36</td>
<td>-0.03 ± 0.36</td>
<td>-1.09</td>
<td>.28</td>
</tr>
<tr>
<td>TOA</td>
<td>2.07 ± 0.89</td>
<td>2.12 ± 0.87</td>
<td>-2.31</td>
<td>.02</td>
</tr>
<tr>
<td>$TOA_{J0}$</td>
<td>0.99 ± 0.43</td>
<td>1.02 ± 0.43</td>
<td>-2.71</td>
<td>&lt; .01</td>
</tr>
<tr>
<td>$TOA_{J45}$</td>
<td>-0.01 ± 0.32</td>
<td>-0.02 ± 0.31</td>
<td>0.85</td>
<td>.40</td>
</tr>
</tbody>
</table>

Abbreviations: TOA, Total Ocular Astigmatism; $TOA_{J0}$, $J_0$ components of Total Ocular Astigmatism; $TOA_{J45}$, $J_{45}$ components of Total Ocular Astigmatism; ACA, Anterior Corneal Astigmatism; $ACA_{J0}$, $J_0$ components of Anterior Corneal Astigmatism; $ACA_{J45}$, $J_{45}$ components of Anterior Corneal Astigmatism.

The comparison of total ocular astigmatism between with and without cycloplegia refraction:

The magnitude of total ocular astigmatism generally increased after cycloplegia (from 2.07 ± 0.89 D to 2.12 ± 0.87 D). Specifically, the magnitude of total ocular astigmatism increased in 87 eyes (75.65%) after cycloplegia, 28 eyes (24.35%) increased larger than 0.25 D, with the largest change from 2.22 D to 2.81 D. Meanwhile, the magnitude of total ocular astigmatism decreased in 25 eyes (21.74%), 9 eyes (7.83%) decreased more than 0.25 D, with the largest change from 3.59 D to 2.72 D. The value of total ocular astigmatism remained unchanged in 3 eyes (2.61%). In conclusion, 37 (32.17%) eyes had astigmatism value changes of more than 0.25 D.
(from 90.43–92.17%), and the proportion of oblique total ocular astigmatism decreased (from 9.57–7.83%). In 82 eyes (71.30%), the positive value of J₀ components of total ocular astigmatism increased, and 33 eyes (28.70%) decreased. The distribution of the total ocular astigmatism with and without cycloplegic refraction on double angle vector diagram were shown in Fig. 1.

**Discussion**

To our knowledge, this is the first clinical study of the difference of astigmatism refractive errors with and without cycloplegic refraction from the corneal plane. In this study, we analyzed the astigmatism changes between pre- and post-cycloplegic refraction on the corneal plane. We found that the changes of total ocular astigmatism were statistically significant. Specifically, the positive value of J₀ components of total ocular astigmatism generally increased, it means that after cycloplegia, the with-the-rule component of total ocular astigmatism was increased, which mainly caused by the change of lenticular astigmatism. The lenticular astigmatism are great majority against-the-rule astigmatism. This suggests that this type of astigmatism provides a compensatory effect for the astigmatism of the anterior corneal surface, which is normally with-the-rule in the normal population. Duke-Elder considers that lenticular astigmatism can counteract with-the-rule corneal astigmatism and superimpose against-the-rule corneal astigmatism, however, the oblique astigmatism rule is not clear. The ciliary muscle relaxes under cycloplegia condition occurring causing the tighten of the zonular fibers allowing the crystalline lens to decrease curvature and thickness, and leading to an decrease in the crystalline lens refractive power. As a result, the ability of the crystalline lens to counteract the with-the-rule anterior corneal astigmatism is weakened. It results in the increasing of the proportion of with-the-rule total ocular astigmatism and the magnitude of total ocular astigmatism. On the contrary, the value of astigmatism, which was characterized by superposition, become smaller.

Astigmatism is a common optical disorder and exists in most human eyes in subtle amounts. Astigmatism affects visual acuity and contrast sensitivity and compared to other refractive errors, is more difficult to treat. Previous studies have reported the prevalence of astigmatism from 11.3% up to 70% in related studies. Due to the strong accommodating power of 3-6-year-old children, it is necessary to obtain accurate refractive power with cycloplegia refraction, and it remains the gold standard for measuring refractive status in children. The possibility of glaucoma induced by cycloplegia in adults is greatly increased. Therefore, it is usually to perform optometry for adults without cycloplegia. However, before astigmatism treatments surgeries and cataract surgeries on adults, we need to analyze the astigmatism refractive errors from the corneal plane. Therefore, it is necessary to analyze the changes of astigmatism before and after cycloplegia on corneal plane. This study found that there was statistical significance in the changes of total ocular astigmatism with and without cycloplegic refraction from corneal plane in preschool children. Although the conclusion cannot be directly applied to adults, but it reminds us that this problem should be considered before laser surgery and cataract surgery in adults. Whether the difference of total ocular astigmatism before and after cycloplegia is one of the reasons for the poor effect of surgeries remains to be further studied.
As we known that cycloplegia can lead to significant changes in the sphere, i.e. increase in hyperopic sphere, decrease in myopia sphere. Nevertheless, astigmatism is the difference between the maximum and the minimum power, which is actually the difference between the utmost and the minimal sphere. We observed that the change in the amount of astigmatism appeared statistical significance on corneal plane. Therefore, on the corneal plane, not only does the sphere changes post-cycloplegic, but also the difference between the largest and smallest power, that is, astigmatism changes.

Previous studies had shown that the astigmatism were affected by many factors, such as extraocular muscles and accommodation. Astigmatism can causes near and far blurred vision in children. Prevention of astigmatic amblyopia, we mainly focus on distance vision. The accommodation was relaxed after cycloplegia. Therefore, the correction of astigmatism should be based on the refractive status after cycloplegia.

Declarations

Contributors

Jian Lin drafted the manuscript and contributed in preparation of the study protocol and conceptualised and conducted all statistical analyses and were the primary author of the article.

Funding

None.

Competing interests

None declared.

Patient consent for publication

Not required.

Ethics approval

The study protocol was approved by the Lianyungang Maternal and Child Health Hospital, adhered to the tenets of the Declaration of Helsinki.

Data availability statement

No data are available.

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The authors have no proprietary or commercial interest in any of the materials discussed in this article.
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References


Figures
Figure 1

Double angle vector diagram showing the distribution of the TOA with and without cycloplegic refraction.