Metric Causes of Refractive Errors of the Eye

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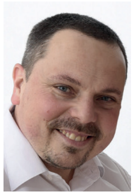

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SUMMARY

Aims: To confirm current knowledge about the causes of refractive errors in adults. To evaluate the influence of systemic, i.e., primary curvature and, on the other hand, axial causes of refractive errors of the eye, in comparison with the Gullstrand model of the eye expressed by axial length and corneal curvature ratio.
Material and Methods: The basic sample included 60 eyes of 30 subjects with an average age of 22.3 ±1.1 years. There were 3 men and 27 women in the group. They were young, generally healthy individuals, without serious eye pathologies. The basic sample was divided into research (n = 36) and control group (n = 24). We measured the axial length of the eye using the IOL MASTER 500 optical biometer (Carl Zeiss Meditec, Jena, Germany). We measured the topographic and keratometric values of the cornea using the Pentacam HR device (Oculus GmbH, Wetzlar, Germany). We obtained the objective refraction values by measuring them on a standard instrument automatic refractometer TRK-1P (Topcon Corp., Tokyo, Japan). We determined the axial length of the eye (AXD), the average value of keratometry (KRT) and the spherical equivalent of the refractive error (SE) as significant variables. The evaluation of variables was carried out by comparison with the Gullstrand model of the eye.
Results: We calculated the ratios of the median axial length of the eye and the median keratometry in the research group with myopia (AXD/KRTM = 3.18 with IQR 0.1) and the control group (AXD/KRTK = 2.93 with IQR 0.1). The difference between the two groups was statistically significant ($p < 0.001$). The percentage expression of axial and curvature causes of ametropia was 72/28% in the myopic group and 83/17% in the control group.
Conclusion: Our study confirmed that the AXD/KRT parameter is a significant indicator of the cause of the refractive state of the eye, with the important influence of axial length on this parameter.
Key words: optical biometer, Pentacam, refractometry, keratometry, axial length

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INTRODUCTION

According to the World Health Organization (WHO), refractive errors are one of the most common causes of visual impairment. According to the study by authors Naidoo et al. [1], in 2010, almost 101 million people worldwide were affected by uncorrected refractive error. Almost every human eye is affected by some refractive error, regardless of whether it is corrected with glasses or contact lenses [2].

Refractive errors are the result of incorrect adjustment of the axial length of the eye and its optical power, which is manifested, among other things, by a blurred image on the retina. This incorrect adjustment can occur in newborns, but due to the process of emmetropization of the eye, it decreases and may disappear completely during the lifetime of the individual [3]. The process of emmetropization represents the reduction of the refractive error at birth to a state of emmetropia. The development of the eye includes the process of lengthening the eye, i.e., increasing its axial length and reducing the optical power of the eye. Several clinical studies [4–6] have found that if the eye has, for example, a cataract or ptosis, the emmetropization process fails.

In the case of the physiological development of the eye, the ratio between the axial length of the eye and the corneal keratometry is important for the resulting refractive state of the eye. Guggenheim et al. [7] state in their study that the relationship between the axial length of the eye and the curvature of the cornea is genetically determined.

In the study by Mei-Ju et al. [8], the relationship between myopia and some parameters of the eye was evaluated. It was found that more myopic eyes usually have a larger axial length and, from the point of view of keratometry, a flatter cornea. According to the study by Vojniković et al. [9], where the causes of refractive errors are analyzed from a physical point of view, we can assume that the cause of refractive error is always determined by the ratio of axial (length) and systemic (curve or index) causes.

In foreign studies, the evaluation of the AXD/KRT parameter, which is the ratio of axial length and the average value of keratometry, also appears in this context. The AXD/KRT parameter can be used as a reference value in children in whom cycloplegic refraction is difficult to determine. For example, based on the ratio of the AXD/KRT parameter and the comparison of axial length and keratometry itself, the authors of the study [10] better estimated the refractive state of the eye in children aged 3 years.

The aim of our study was to confirm the causes of the refractive state of the eye in a group of young healthy individuals in connection with current studies. We compared the basic parameters of the eye, axial length and average keratometry with the parameters known from the Gullstrand eye model. We assumed that the ratio of axial length and keratometry (AXD/KRT) of eyes with myopia (research group) would differ at a statistically significant level from the group of probands with emmetropia and hyperopia (control group).

MATERIAL AND METHODS

The basic set consisted of 30 subjects and 60 eyes (n = 60) with an average age of 22.3 ±1.1 years. There were 3 men and 27 women in the set. These were mainly young and generally healthy individuals. Serious eye pathologies were not diagnosed by the ophthalmologist.

We divided the set of 60 eyes into research and control, regardless of affiliation with a given proband. In the research set (n = 36), we cumulated the results of probands with a negative spherical equivalent (SE < -0.25 D), and probands with a positive SE (SE ≥ 0 D, n = 24) were cumulated in the control set. The median SE values of the probands in the research group were -2.5 D and the interquartile range, i.e., IQR = 1.75 with a median cylinder value of -0.5 D and IQR = 0.25. In the control group, the median SE was +0.5 D and IQR 0.5, with a median cylinder value of -0.5 D and IQR 0.75. This difference in SE in both groups was statistically significant ($p < 0.001$). The mean age of the probands when compared in these two sets, on the other hand, was not significantly different at the statistically significant level ($p = 0.64$).

The axial length of the eye was measured using the IOL MASTER 500 optical biometer (Carl Zeiss Meditec, Jena, Germany). The topographic and keratometric values of the cornea were measured using the Pentacam HR (Oculus GmbH, Wetzlar, Germany). Objective refraction values were obtained using a standard TRK-1P refractometer (Topcon Corp., Tokyo, Japan). For our study, we determined the axial length of the eye (AXD), the average keratometry value (KRT) expressed as the average value of the radius of the anterior corneal surface, and the spherical equivalent of the refractive error (SE) as significant variables.

Based on the knowledge of the parameters of the Gullstrand eye model [9], we determined the significance of the initial values of the axial and curvature causes of ametropia. For the axial length, we used a starting value of 24 mm and for the average curvature of the anterior surface of the cornea, 7.7 mm. We performed the measurement and subsequent calculation separately for the research and control groups. Thus, each proband's eye was directly confronted with this model. The deviation of each proband's eye from the model parameter was expressed numerically and subsequently as a percentage. The resulting percentage expression of the prevailing cause is the sum of these deviations.

The examination results were recorded in an MS EXCEL spreadsheet (Microsoft, Washington, USA) and then statistically evaluated using the statistical program, Statistica version 12 (StatSoft GmbH, Hamburg, Germany) and MedCalc (MedCalc Software Ltd, Ostend, Belgium). The Kolmogorov–Smirnov test was used to determine the normality of the data. This test revealed a non-parametric distribution of the data in all sets ($p < 0.05$). For this reason, we subsequently used the non-parametric Wilcoxon test to determine the mutual agreement of two variables, and the Spearman correlation coefficient for correlations. The statistical significance level was chosen at $p = 0.05$.

RESULTS

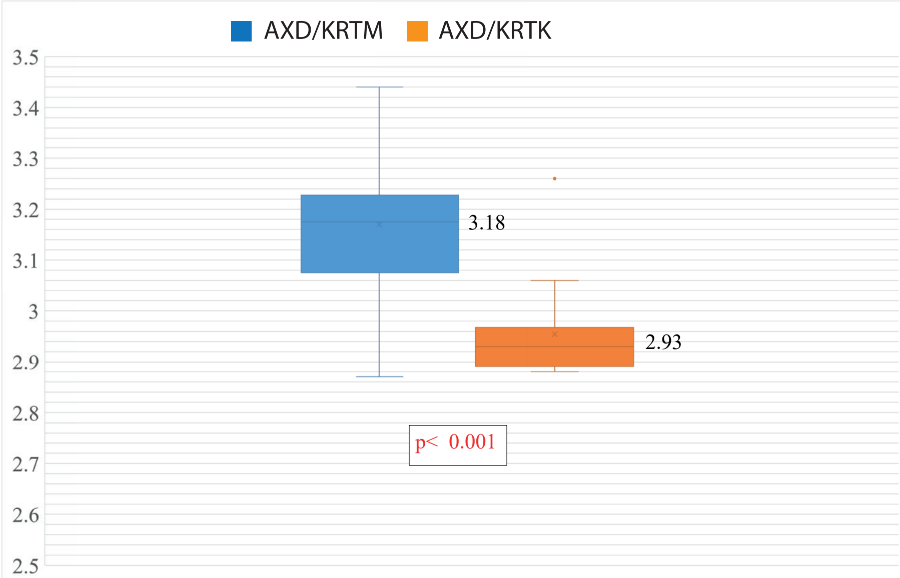
The median axial length of the study group was 24.2 mm with an IQR of 1.0 mm. The median values of the average keratometry of the anterior surface of the cornea in this group were 7.7 mm with an IQR of 0.3 mm. In the control group, we calculated the median axial length of the eye to be 22.9 mm with an IQR of 0.8 mm and the median values of the average keratometry were 7.7 with an IQR of 0.2 mm. The calculated percentage of the cause of ametropia in the study group was therefore 72% / 28%. In the control group, it was 83% / 17%. In both cases, the axial cause was more significant at the expense of the systemic, specifically the curvature (or radius), cause. In the myopic group, we measured a higher proportion of the curvature cause than in the control group (28% vs. 17%).

We then calculated the ratio between the axial length of the eyes and the average keratometry in all measured probands (AXD/KRT). The median values of this variable were 3.18 with an IQR of 0.1 in the research group (AXD/KRTM) and 2.93 with an IQR of 0.1 in the control group (AXD/KRTK) (Graph 1). The difference was significant at the selected statistical level ($p < 0.001$).

Finally, we also evaluated the correlation between AXD/KRT and the spherical equivalent of the eyes (SE). A strong and negative correlation was achieved between these variables ($r = -0.7$, $p < 0.05$).

DISCUSSION

The results of our study show how axial and systemic, in our case mainly curvature causes, contribute



Graph 1. Axial length median (horizontal solid line) to keratometry median ratio in myopes (AXD/KRTM) and control group (AXD/KRTK) with expression of average values (cross), IQR (box) and range of outlying data. The IQR shows the range of data from the lower quartile Q1 to the upper quartile Q3

to the refractive state of the eye. In none of the studied cases did the standard initial value of axial length and average keratometry occur, which could indicate changes in the refractive index of the cornea or the lens (index cause of refractive error). By evaluating the data, we confirmed the current knowledge about the causes of refractive errors. In both of our groups, the axial length of the eyes had a decisive influence on the refractive state of the eyes (72% in myopes and 83% in the control group), compared to the parameters of the Gullstrand eye model. In the study by Demir et al. [11], a statistically significant correlation was found between the axial length of the eye and the spherical equivalent of refraction ($r = -0.6$ at $p < 0.001$).

Furthermore, this study found that probands who had both myopic parents had higher myopia and axial length than probands with non-myopic parents. Monitoring changes in axial length is an important control mechanism for the onset of myopia. Another study by Mutti et al. [12] reported that rapid changes in axial length can be used as a predictive factor for the onset of myopia 2 to 4 years before its actual onset. Dong et al. [13] investigated the relationship between the size of refractive error and some eye parameters. This study found that the incidence of total myopia or high myopia was significantly associated with the incidence of high axial length (OR 3.71 and 5.89, respectively).

In a study by Stone et al. [14], it was reported that the refractive state of the eye is influenced by the shape of the eye. In myopic eyes, the eyes were most often elongated. In hyperopic eyes, the most common eye shape was flat, and in emmetropic eyes, the most common eye shape was spherical. The overall elongation of the eye in myopic eyes is likely to have an effect on the more pronounced presence of curvature causes of refractive errors in our study group.

Other studies mentioned above point to a broader context of the studied issue. For example, Dogan et al. [15] in their study also revealed statistically significant differences ($p < 0.001$) in the parameters of myopic, hyperopic and emmetropic eyes. The average axial length in the myopic group of eyes was 24.5 ±0.6 mm, in the hyperopic group 22.3 ±0.6 mm and in the emmetropic group 23.4 ±0.6 mm. In our study, we also measured different values of the average axial length of the eyes for the research group of myopes (24.1 ±0.8 mm) and the control group (emmetropic and hyperopic by 23.1 ±0.4 mm). This finding underlines the importance of measuring and comparing the size of the axial length of the eye.

Interesting findings that demonstrate the greater importance of the axial length of the eye at the expense of keratometry were obtained when comparing our keratometric data with data from other studies. For example, in the study by Krupa et al. [16], the average keratometry values in the groups were very similar. In myopes 7.7 ±0.3 mm, in hyperopes 7.7 ±0.2 mm and in emmetropes 7.7 ±0.2 mm. In our group, the average value of the curvature of the anterior surface of the cornea was only slightly different when comparing the research group of myopes (7.7 ±0.2 mm) and the control group (myopes and hyperopes it was 7.8 ±0.1 mm). Another study by Zhou et al. [17] reports similar average keratometry values for both the low myopia and the moderate and high myopia groups (7.8 ±0.2 mm, 7.8 ±0.3 mm and 7.8 ±0.2 mm).

The influence of axial and curvature causes on the refractive state of the eye can also be expressed by the ratio AXD/KRT (axial length/corneal radius curvature). The clinical significance of this variable can be seen in a more unambiguous determination of the refractive error of the eye even in the phase when, for example, these errors are not yet manifested by changes in spherical and cylindrical refraction. For example, in the study by Hasmemi et al. [18], the average value of AXD/KRT is 3.0. In myopes with an average SE of -5.0 D, it was already 3.4, and in hyperopes with an average SE of more than +5 D, it was 2.6. In our case, the median AXD/KRT in the research myopic group was 3.18 with an IQR of 0.1 and in the control group (emmetropic and hyperopic) was 2.93 with an IQR of 0.1. In another study, Jiang et al. [19] reported that the AXD/KRT parameter increases between the ages of 6 and 11 years. The axial length of the eyes of boys and girls increases by approximately 0.156-0.174 mm per year in the emmetropic group. On the contrary, the corneal keratometry parameters tend to stabilize.

Correlations of various ocular metric parameters indicate their interdependence. The study by Klein et al. [20] reported that the spherical equivalent of the eye (SE) is strongly negatively correlated with the axial length of the eye ($r = -0.45$, $p < 0.05$) and positively with the corneal curvature ($r = 0.19$, $p < 0.05$), and that the axial length of the eye is positively correlated with the corneal curvature ($r = 0.34$, $p < 0.05$). In agreement with our data, a significant correlation was also found in this foreign study between the AXD/KRT ratio and the spherical equivalent ($r = -0.6$, $p < 0.05$).

The limitations of the study can be seen in the relatively small sample size (n = 60), further limited by a small age range (21–25 years). The conclusions of the study cannot therefore be extrapolated to the period of more significant changes in the axial length of the eye. The results of the study should not be influenced by pathological changes in the eye, since all probands underwent an eye examination, during which no significant general or ocular pathologies were demonstrated. Another limitation may be the dependence between the data of the right and left eyes, which may partially influence the results of the statistical tests used [21].

CONCLUSION

Our study aimed to evaluate the influence of systemic and axial causes on the refractive state of the eye. We compared the data with the standard eye model according to Gullstrand. We demonstrated a statistically significant difference in the AXD/KRT parameter between the myopic and control research groups. Our study confirmed that the AXD/KRT parameter, also used in other international studies, is a significant indicator of the cause of the refractive state of the eye. Last but not least, our results confirm the fact that the frequency of axial causes of refractive error of the eye is more numerous than systemic ones.

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