

INITIAL RESULTS AND EXPERIENCES WITH ABERROMETER ITRACE

Beneš P.^{1,3}, Petrová S.^{1,2}, Veselý P.^{1,2},
Synek S.^{1,2}

¹ Department of Optometry and Orthoptics, Faculty of Medicine, Masaryk University Brno

² Department of Ocular Pathologies and Optometry, St. Anne's University Hospital, Brno

³ RUBÍN Optician, Brno

Mgr. Pavel Beneš, Ph.D.

Department of Ocular Pathologies and Optometry, St. Anne's University Hospital, Brno

Pekařská 53

656 91 Brno

e-mail: optika.rubin@seznam.cz

SUMMARY

Purpose: To evaluate obtained data by using a relatively novel devices and their results which are important eg. in refractive and cataract surgery.

Material and methods: The study included 66 eyes (n = 66). Subjects were represented by 32 women and 1 man whose age was 22.5 years ± 1.2 years (min. 21, max. 26 years) without any signs of potential eye disease. Duration of the study was 3 months. Results were compared with the measurements using the auto-refract-kerato-ono-pachymeter (TRK 1P, Topcon, Japan), Keratograph 5M (Oculus, Germany) and aberrometer iTRACE (Hoya, Japan).

Results: After 3 months were statistically compared keratometry values of corneal anterior surface detected by all devices. They provided to be comparable. Furthermore the values of objective refraction and pachymetry were detected.

Conclusion: Results of this study show a statistically significant correlation values of objective refraction using devices TRK and iTRACE (r = 0.66 at p = 0.05) and showed a significant relationship between the keratometric data for all the devices. All used methods and devices are possible to reliably and use for valid evaluation parameters of the eye.

Key words: aberrometry, low and high orders aberrations, keratometry, topography, pachymetry

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INTRODUCTION

Thanks to the ever more precise work of ophthalmologists, increasingly stringent demands are also being placed on the manufacturers of various ophthalmological instruments. New and sophisticated devices are able to offer a far more precise analysis of the obtained data on individual ocular tissues, which subsequently leads to more precise and valid procedures performed on the eye.

One of the new devices is iTrace (HOYA i TRACE, representative for the Czech Republic Spirit Medical), an analyser of visual functions and the optical system of the eye. This class 1 laser instrument serves for determining refractive errors, wavefront and corneal topographic data of the optical system of the eye. Components of the instrument include 2 laser diodes, the first of which emits radiation at a wavelength of 785 nm. Its maximum output is 50 mW, with a collimated beam at an output of 4.6 mW, ranked within class 3b. The second diode has a wavelength of 655 nm, with a maximum possible output of up to 2.5 mW, the beam is with a divergence of 2 mrad and is ranked within class 3a.

The basic functions that can be determined using the device may include: recording of an image of the eye, measurement using 256 luminous spots (fig. 1), which are highlighted after measurement and can be used for calculation of wavefront data in the form of Zernike polynomials, in which the size of the scan is adapted to the width of the pupil. It is also possible to record an image of projected Placido rings, from which it analyses topographic data of the anterior surface of the cornea. The software generates a display of the individual measurements and all the data is archived in an external computer. The device also detects actual centration, its focusing and alignment. Overall it thus combines the wa-

vfront data of the cornea and the entire system of the eye, and then with the help of software also evaluates the analysis of aberrations of the ocular lens.

The range of measurement is up to +/- 15 D for sphere, +/- 10 D cylinder. Pupil width is detected within the range of 2.5 mm to 8.0 mm, automatic differentiation of the right and left eye. The precision and reproducibility of measurement is given at +/- 0,10 D. The power supply of the device corresponds to the norm for healthcare facilities.

The lens of the device enables display even of very small details and thus enables us to determine the total objective refraction of the eye. The refraction map is limited by the width of the pupil upon measurement, its values are calculated on the basis of recorded images of individual points. The laser beams emitted into the eye are focused on the retina, where they are reflected from its surface (thus creating a secondary light source) and subsequently projected back in a direction out from the eye. The principle of a thin laser beam is used for measurement, thus ensuring independent measurement of each point. The transmission of the beam is within the range of milliseconds.

The procedure upon examination of the client is identical to measurement on the instruments that are usual for ophthalmological practice. The client sits behind the instrument and places his/her chin and forehead on the rests. It is recommended that the examination is performed in a dark room in order to ensure maximum pupil width. The other eye which is not being examined should be covered with an occluder. The client looks straight ahead to a point at an endless distance with a through-gaze in the head of the instrument. In the case that we measure the value of dynamic refraction, ordinary illumination is ensured during examination, and a text is placed for close up reading before the through-gaze in order to

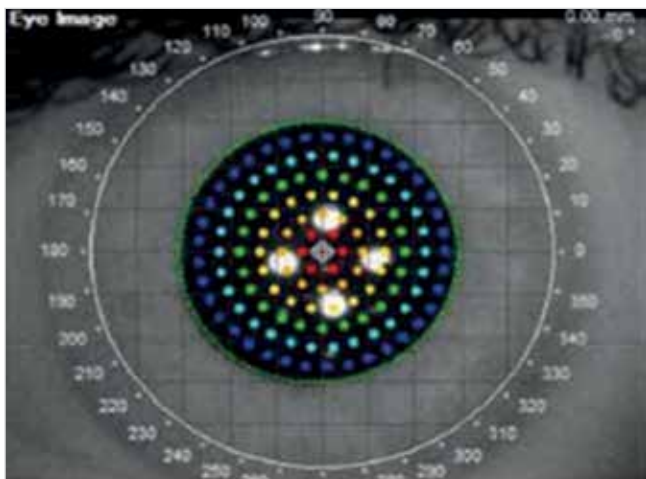


Fig. 1 Highlighting of measured points

achieve maximum accommodation.

Higher order aberrations (HOAs) are more complex defects of the optical system of the eye than lower order aberrations. These include spherical ametropias such as myopia, hypermetropia and also astigmatism. Higher order aberrations cause secondary optical phenomena, which cause problems with night vision, glare and halo effect, blurred vision or double vision and the defect known as starburst (fig. 2). [1-3]

No eye provides an entirely perfect image. Every eye is affected by a certain degree of higher order aberrations, which influence the perceived quality of vision.

The human eye is affected by chromatic but above all also monochromatic aberrations, which may be characterised by transversal deviations, expressed in milliradians. The beam used for display is composed of two components – horizontal and vertical deviation. The data measured on the level of the pupil then illustrates a deflection map. This is created by longitudinal beams expressed as an inverted value of the distance between the level of the entrance pupil and the point on the optical axis which the deviated beams intersect. We can refer to these deviations as aberrations or wavefront aberrations, the difference of which depends on the path of the optical beam. [2, 4]



Fig. 2 Secondary optical phenomena – glare (Visionauthorities.com 2015)

The Hartmann-Shack aberrometer is a typical representative of aberrometers. It uses an infrared LED ray which falls upon the retina, or an infrared diode laser. Depending on the size of the refractive error of the eye, the reflected wavefronts are more or less deflected from its referential level in comparison with those that would be formed in a normal eye without a refractive error. The wavefronts then pass through a system of optical elements and are analysed with the help of a sensor.

The Tscherning aberrometer uses a fixed range of two-dimensional testing beams which are simultaneously emitted into the client's eye. Partial beams are generated by the centre of the hole membrane which is located in the path of the wide laser beam. The hole membrane is then displayed on the level in front of the retina, and for this purpose it must compensate the possible spherical defects of the client's eye. During the subsequent data analysis beams are deflected from points outside of the axis onto a detector, and again compared with the referential position.

This measurement is more precise and less sensitive to potential movements of the eyes. However, the Tscherning aberrometer has a smaller dynamic range between the individual points in comparison with the Hartmann-Shack aberrometer.

Higher order aberrations are defects of display which affect the wavefront, passing through the optical media of the eye. These structures include the lachrymal film, cornea, intraocular fluid, ocular lens and vitreous body. Abnormal curvature of the cornea or ocular lens may be worsened by deformation of the wavefront. A significant higher order aberration may also occur in the case of a scar on the cornea caused e.g. after an injury or surgical procedure on the eye. Cataracts also cause higher order aberrations. An aberration may also occur in the case of dry eye syndrome, in which the layer of the lachrymal film on the surface of the eye is breached. [2, 4]

The majority of ocular afflictions are also relatively easy to detect with the help of instrument equipment and examination techniques which today are ranked amongst the regular standard. As a result, aberrometers are used in specialised centres also for example in the diagnosis of incipient keratoconus, in which it is possible to detect vertical corneal coma even below the values of $0.2 \mu\text{m}$. In the case of measurement of keratokonic eyes it is thus possible to determine increased values of higher order aberrations and Zernike coefficients up to the 4th order, except for horizontal trefoil, and also vertical and horizontal tetrafoil. It is also possible to encounter higher values of aberrations up to the sixth order. In the 7th and 8th order the values of aberrations are usually not so pronounced. [5, 7]

We can also present higher order aberrations as the difference in micrometres between the referential and given wavefront, which as a rule is defined by the diameter of the pupil. If a wavefront measured before an ideal wavefront it acquires positive values, in the opposite case negative values. The difference between the ideal and current wavefront is called aberration.

In 1934 Fritz Zernike published the first information about wavefronts and aberrations. He defined a set of “polyno-

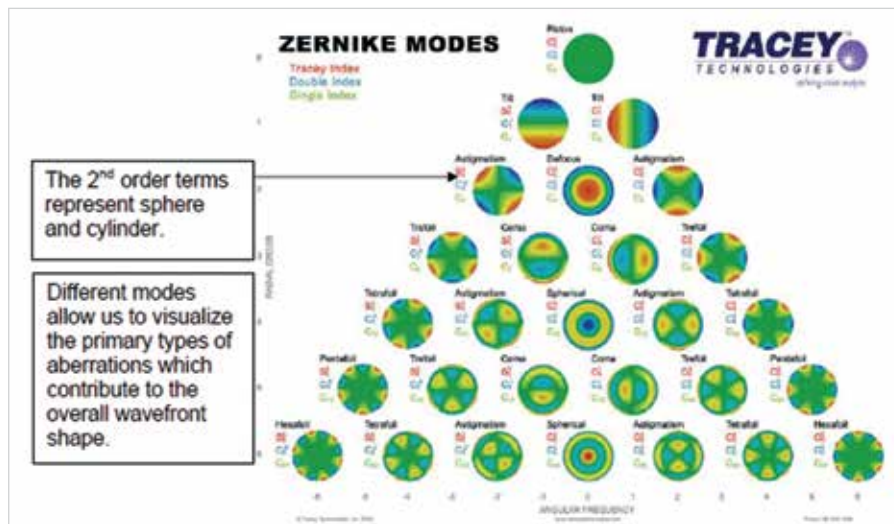


Fig. 3 Zernike's pyramid of aberrations (Tracey Technologies 2015)

mials”, which describe the shape of the circular area of the optical surface. Each polynomial thus defines a certain optical aberration – defect. A wavefront aberration can be described as a unit or can be divided according to type and its severity described with the help of own individual parameters. Zernike divided aberrations into six orders, depending on their complexity (fig. 3, Tracey Technologies 2015).

The coefficient of each Zernike polynomial expresses the RMS (root mean square) in microns. RMS means the mean quadratic value of each Zernike polynomial which forms a wavefront. Overall RMS demonstrates how the given wavefront differs from an ideal wavefront. The greater the RMS, the more significant the higher order aberration.

Higher order aberrations can be corrected by special glasses lenses, contact lenses or a refractive procedure which amongst other factors modifies the shape of the cornea. The aim of such correction is to compensate for the difference between the ideal and measured wavefront.

Using the obtained images it is easy to determine the large and dynamic range of lower and higher order aberrations, and

thus to display a wavefront analysis of the optical system of the eye (fig. 4 and 5). If warm colours (red) are used for display, this represents a wavefront which is located on the referential level. If cold colours (blue) are used, this illustrates a delay in measurement in comparison with the referential level.

In order to ensure correct centration of the optical axis of the client's eye and the axis of the laser beam, an optometer is built into the device, which amongst other factors serves for relaxing the accommodation of the measured eye within the scope of +7.0 D to -5.0 D.

All the initial settings for data display are in a two-dimensional mode, the individual eyes can be overlapped over one another.

METHOD

The aim of the study is to compare the parameters of the anterior segment of the eye, which were measured using various instruments. The intention was to determine whether it is possible to compare the obtained values mutually, or how they mutually correlate.

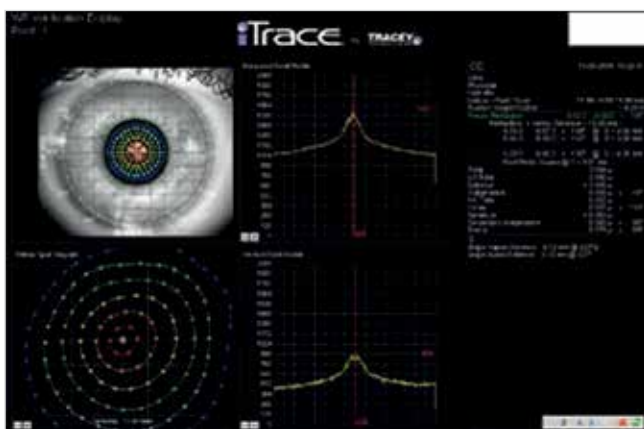
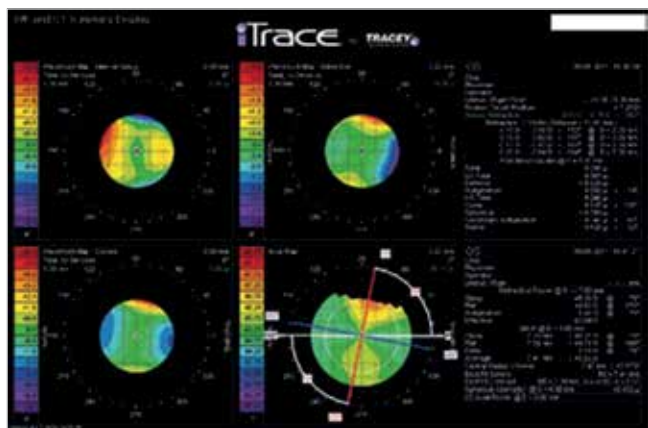


Fig. 4 Summary illustration of detected points and aberrations, including graphic expression of horizontal and vertical profile of position of detected points.



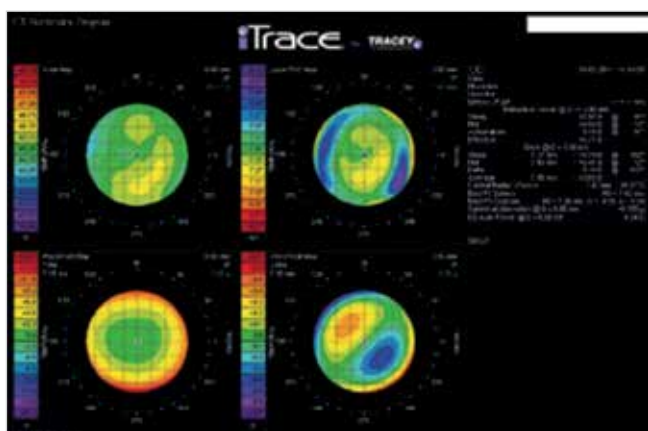
Fig. 5 Itemisation of individual aberrations and keratometry, graphic evaluation of Zernike polynomials (up to 6th order) of optical media of the eye of lower and higher order aberrations.



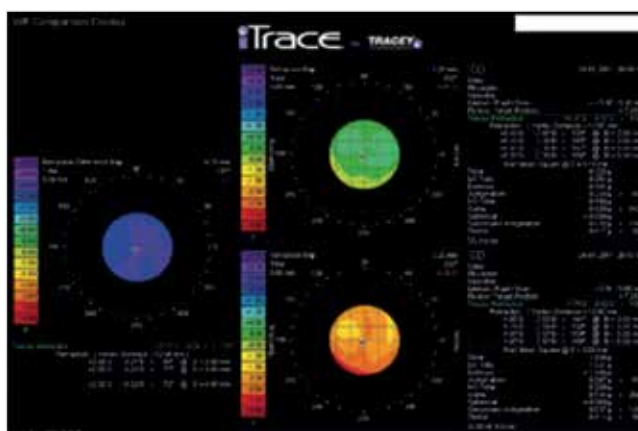
Obr. 6 Výchozí zobrazení dat ve 2D, mapa celkové wavefront analýzy (vpravo nahoře), mapa aberací rohovky (vlevo dole) a aberace vnitřní optiky oka (vlevo nahoře)



Obr. 7 Placido kruhy



Obr. 8 Topografická analýza



Obr. 9 Analýza schopnosti akomodace

The first measurement was conducted on an **iTRACE aberrometer** (HOYA i TRACE, representative for Czech Republic Spirit Medical), the second on a corneal topograph **Keratograph 5M** (Oculus) and the third was then a determination of values using an **autorefracto-keratro-ono-pachymeter** (Topcon, TRK 1P, representative for Czech Republic Topcomed). During the measurement of the values of objective refraction, the patient is asked to fix upon a point at an endless distance ahead, which is enabled by the through view in the measuring head of the device. This should bring about a sufficient relaxation of the tone of the patient's ciliary muscle, which is one of the conditions for precise determination of the results of objective refraction.

The measuring range of the device is within the values of sphere $-30.0\text{ D}/+25.0\text{ D}$, cylinder to $\pm 12.0\text{ D}$, all in steps of 0.25 D . The minimum pupil diameter is 2.0 mm . The lowest measurable value of the radius of curvature of the anterior surface of the cornea is 5.0 mm , the maximum 13.0 mm (in steps of 0.01 mm). The size of intraocular pressure can be determined within a range of $1\text{-}60\text{ mmHg}$. [3, 8-10]

It was thus possible to conduct a mutual comparison of a large quantity of data. All the measurements were conducted at the centre of the Department of Optometry and Orthop-

gics of the Faculty of Medicine at Brno University, at the Department of Ocular Pathologies and Optometry at St. Anne's University Hospital, Brno, between the months of January and March 2015.

Values of objective refraction, radii of curvature of the anterior surface of the cornea, corneal aberrations and total aberrations of the eye were observed. These are important data especially in the preparation of corneal and refractive procedures. The results can be subsequently and repeatedly checked, reproducibility of measurements was thus ensured. The determined measurements were recorded and subsequently statistically processed using the program Statistica 12, CZ-Czech single-user version from the company StatSoft®, which is available to students and employees of Masaryk University.

Results of study

The randomised trial included 66 eyes ($n=66$) which had not undergone any corneal or refractive procedures. The subjects were 33 individuals with an average age of $22.5\text{ years} \pm 1.2\text{ years}$ (min. 21 years, max. 26 years), see fig. 10. Refractive errors were represented in the following numbers: 30 myopic eyes, 5 hypermetropic eyes and 31 eyes with astigmatism.

TRK 1P – obtained values: objective refraction – sphere: $-1.5 \text{ D} \pm 2.5 \text{ D}$ (min. -8.0 D , max. $+3.25 \text{ D}$), cylinder: $-0.5 \text{ D} \pm 0.9 \text{ D}$ (min. -4.5 D , max. -0.25 D), cylinder axis: $95^\circ \pm 64,4^\circ$ (min. 10° , max. 180°). Keratometric data is as follows: steepest meridian - K1 acquires values $7.62 \text{ mm} \pm 0.23 \text{ mm}$ (min. 7.21 mm , max. 8.04 mm), flattest meridian – K2 is after $7.77 \text{ mm} \pm 0.24 \text{ mm}$ (min. 7.28 mm , max. 8.34 mm), see fig. 7. For a clearer comparison,

the compared values of keratometry are presented in table 2. In the case that a centre works with values of the cornea which are stated in dioptres, the values are as follows: K1 $44.30 \text{ D} \pm 1.3 \text{ D}$ (min. 42.0 D , max. 46.75 D), K2 $43.46 \text{ D} \pm 1.4 \text{ D}$ (min. $40,5 \text{ D}$, max. $46,25 \text{ D}$). The size of corneal astigmatism, which is determined by the difference between the flattest and steepest meridian, shows values $-0.9 \text{ D} \pm 0,64 \text{ D}$ (min. -4.0 D , max. $0,0 \text{ D}$).

Table 1 Comparison of values of objective refraction for components spherical, cylinder and axis.

Objective refraction	Sphere (D)	Cylinder (D)	Axis (°)
TRK 1P	-1.5	-0.5	95.0
iTRACE	-1.81	-0.74	99.5

Table 2 Comparison of keratometric values

Keratometry (mm)	K1	K2	deviation
TRK 1P	7.62	7.77	0.24
iTRACE	7.67	7.84	0.33
Keratograph 5M	7.60	7.79	0.25

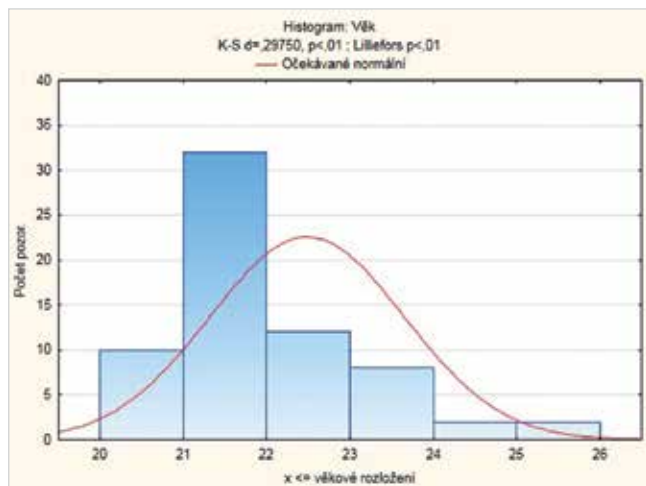


Fig. 10 Histogram of probands age distribution

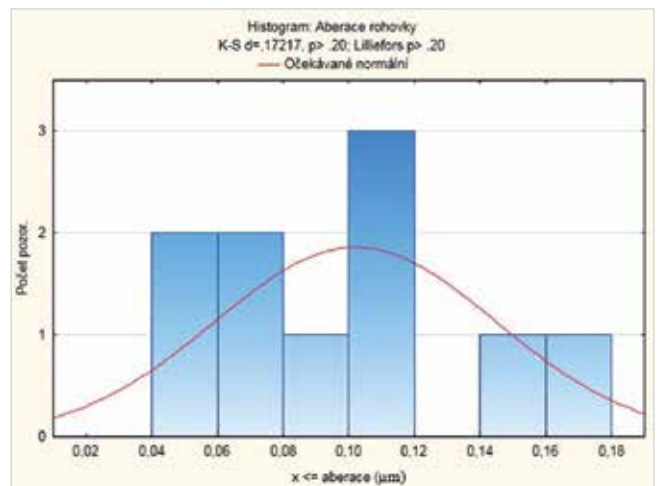


Fig. 11 Corneal aberrations

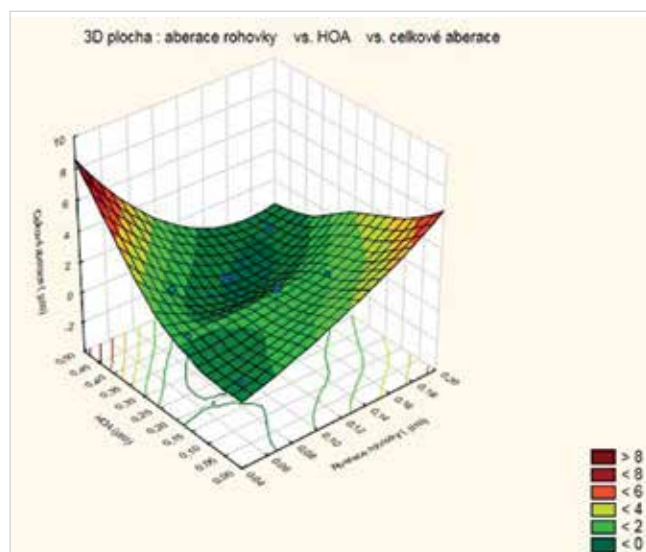


Fig. 12 Corneal aberrations versus total aberrations

Further parameters which were measured include pachymetric data, which show values of $0.560 \mu\text{m} \pm 0.033 \mu\text{m}$ (min. $0.497 \mu\text{m}$, max. $0.641 \mu\text{m}$). Data on the level of intraocular pressure was then recorded by the noncontact method. This is $16.0 \text{ mmHg} \pm 2.25 \text{ mmHg}$ (min. 12.0 mmHg , max. 23 mmHg). The mutual correlation of the values of intraocular pressure and pachymetry is statistically significant on the level of $p = 0.05$.

iTRACE – values of objective refraction – sphere: $-1.81 \text{ D} \pm 2.6 \text{ D}$ (min. -7.75 D , max. $+6.12 \text{ D}$), cylinder: $-0.74 \text{ D} \pm 0.74 \text{ D}$ (min. -4.25 D , max. -0.12 D), cylinder axis: $99.5^\circ \pm 59.3^\circ$ (min. 0° , max. 177°). The values of objective refraction measured using TRK and iTRACE correlate mutually on a statistically significant level of $p = 0.05$ ($r = 0.66$), table 1.

Keratometry is as follows. K1 $7.67 \text{ mm} \pm 0.33 \text{ mm}$ (min. 7.20 mm , max. 8.75 mm), K2 $7.84 \text{ mm} \pm 0.34 \text{ mm}$ (min. 7.28 mm , max. 9.03 mm). Mutual comparisons with other methods are presented in table 2 and in images 16a, b. From the images

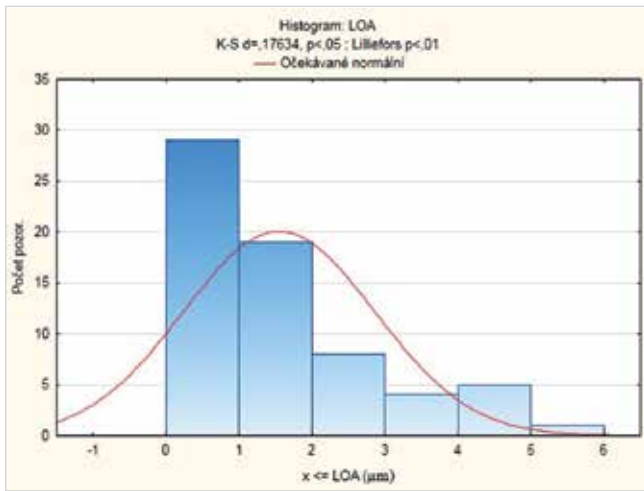


Fig. 13 Histogram of low order aberrations values

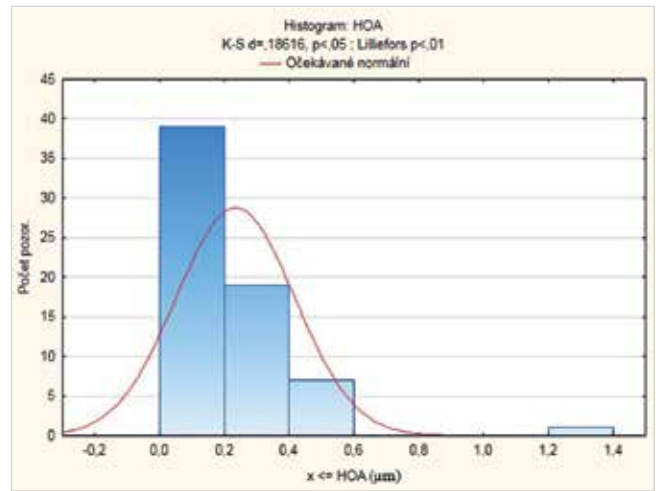


Fig. 14 Histogram of high order aberrations values

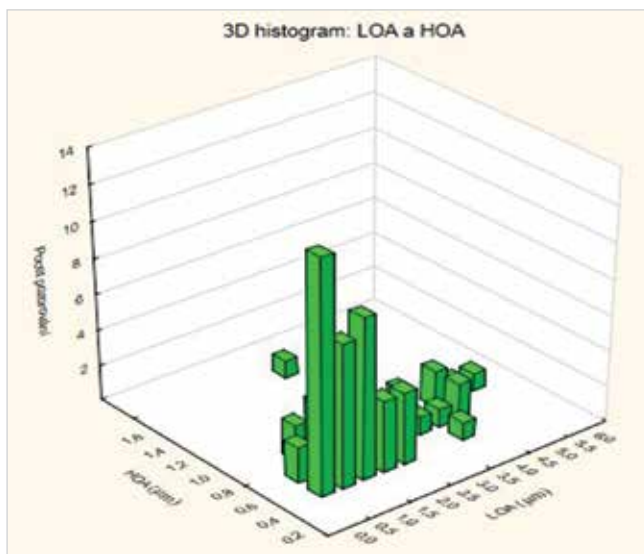


Fig. 15 Graphic display of low and high order aberrations

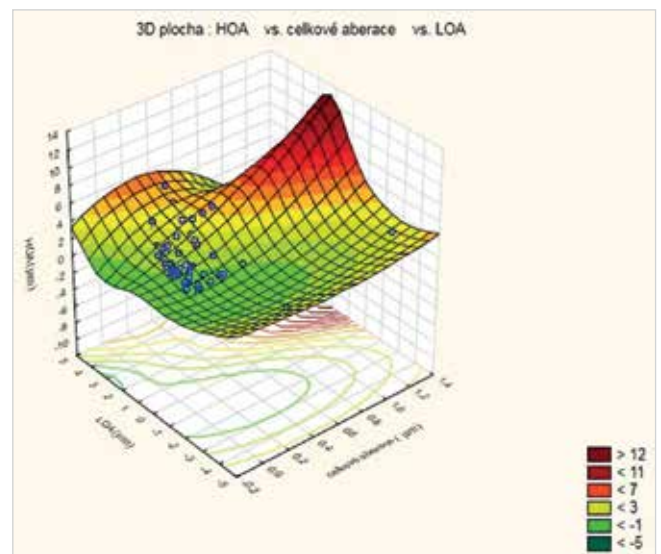


Fig. 16 Graphic comparison of total aberrations of the eye compared with low and high order aberrations

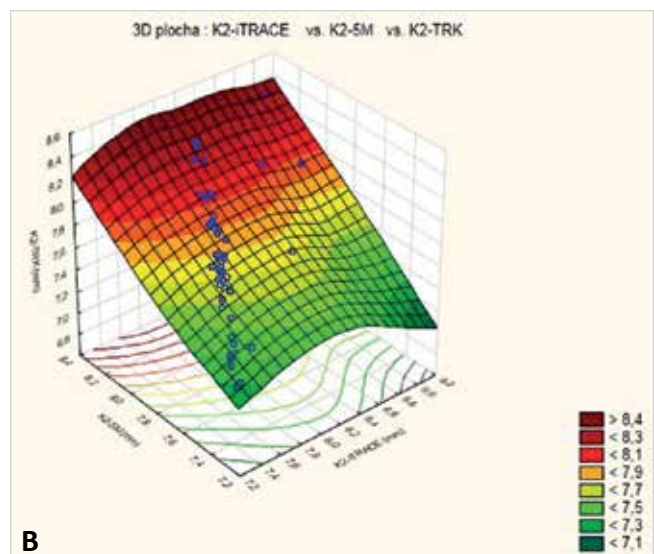
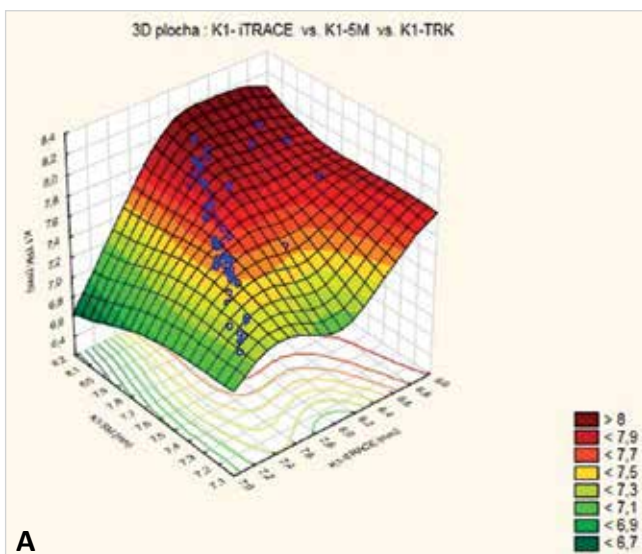


Fig. 17 a) Correlation of K1 values measured by TRK, iTRACE and Keratograph 5M, b) the same measurements for K2 values

there is an evident significant correlation of all three methods.

All higher order aberrations of the cornea show values of $0.102 \mu\text{m} \pm 0.418 \mu\text{m}$ (min. -0.04 , max. 0.190), all higher order aberrations of the entire eye are $0.994 \mu\text{m} \pm 1.415 \mu\text{m}$ (min. -3.75 , max. 4.24), see fig. 11 and 12.

All lower order aberrations of the entire eye share a value of $1.549 \mu\text{m} \pm 1.312 \mu\text{m}$ (min. 0.111 , max. $5.054 \mu\text{m}$), (histogram see fig. 13) and higher order aberrations show values of $0.234 \mu\text{m} \pm 0.181 \mu\text{m}$ (min. $0.043 \mu\text{m}$, max. $1.304 \mu\text{m}$), histogram see fig. 14.

Total aberrations are then illustrated in fig. 15 and 16.

Data which showed average ranges was collected as valid, and entered in green. If a record was entered in yellow, this represented a borderline value. In the case that values are entered in red, this represents unreliable data.

Keratograph 5M – was used to determine keratometric values, which are as follows. K1 $7.60 \text{ mm} \pm 0.24 \text{ mm}$ (min. 7.20 mm , max. 8.07 mm), K2 $7.79 \text{ mm} \pm 0.25 \text{ mm}$ (min. 7.29 mm , max. 8.31 mm), see fig. 17. Table 2 then presents a comparison of the keratometric values with the other devices.

DISCUSSION

Bao et al. (2009) in their study tested the hypothesis as to whether the human eye has a tendency to be entirely without higher order aberrations. On the basis of their research it was determined that within a group of emmetropes there are significantly higher values only in the 3rd order of Zernike polynomials. In a group of myopics they analysed 5 orders of significantly higher values. [3, 5]

In a study by Amano et al. (2004), the authors dealt with the relationship between higher order aberrations and age. The measurement was conducted on 75 patients with the help of a Hartmann-Shack sensor instrument. It was determined that both values, corneal aberrations ($r = 0.307$ at $p = 0.007$) and total aberrations of the eye ($r = 0.334$ at $p = 0.0033$) correlated with age. RMS did not change with age ($r = 0.153$ at $p = 0.1895$). RMS of spherical aberration changed with age ($r = 0.153$, $p = 0.0068$). [6, 7]

An interesting relationship between higher order aberrations and keratoconus was investigated by Alió et al. (2006). In their study they measured 80 eyes, which were divided into two groups. The first group comprised 40 eyes of 20 asymptomatic subjects without ocular pathologies. The se-

cond group comprised 40 eyes of 25 patients with keratoconus. Amongst other matters, a difference was determined in RMS spherical aberration and coma in groups one and two (0.38 and 0.35 microns versus 1.06 and 2.9 microns in group two). The authors therefore hold the view that the measurement of higher order aberrations can help in the timely diagnosis of keratoconus [2, 7].

CONCLUSION

With the help of individual and modern instruments we have the possibility of obtaining a large quantity of data, which is essential not only in optometric but also in ophthalmological practice, especially in refractive surgery.

Higher order aberrations are calculated as a rule from the 6 millimetre central zone of the surface, which is recorded during examination. For certain types of refractive procedures such as laser correction of hypermetropia, the recommended ablation zone is 9 mm. Thanks to continuous advances it is possible to encounter devices which provide and measure with the help of a larger number of luminous spots. An example is iDesign, which works with 1200 spots. Others from relatively new generations may include Visionix L 79 AKR/Topo, a representative of multi-combination, using 1500 spots in measurement. This year, the instrument Visionix VX 120 was presented within the framework of the traditional optics, optometry and ophthalmology exhibition in Brno, and incorporates a range of diagnostic methods such as: auto-refractometry, keratometry, topography, aberrometry, pachymetry, tonometry and pupillometry. During measurement it evaluates the resulting findings also on 1500 luminous spots. Each of these devices has its advantages, but also possible functions which may extend the entire course and time during examination.

However, the results of this study demonstrate that there is a statistically significant correlation of the values of objective refraction obtained using the devices TRK and iTRACE ($r = 0.66$ at $p = 0.05$). In the next part of the study we demonstrated a significant dependency between the keratometric data in the case of all the used instruments. We can therefore conclude from our results that all the used methods and instruments can be used in order to obtain a reliable and valid assessment of the parameters of the eye.

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