·Clinical Research·

Comparison of two types of visual quality analyzer for the measurement of high order aberrations

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Abstract

• **AIM: To compare the difference and agreement of KR-1W and iTrace for measurement of high order aberrations.**

• **METHODS: KR-1W and iTrace were respectively used in a group of healthy people (40 volunteers, 32 eyes) to measure the high order aberration (HOA) of corneal, internal and total ocular. The clinical difference and agreement of two instruments were respectively evaluated by paired-samples *t*-test and Bland-Altman analysis.**

• **RESULTS: The paired-samples *t*-test showed that the corneal HOA measured by the two instruments had no statistical differences (P>0.05); but the internal and total ocular HOA had significant statistical differences (P<0.05), and the mean results measured by iTrace were higher than that of KR-1W. However, Bland-Altman analysis revealed that the HOA of corneal and internal were all in 95% limits of agreement; and just one point of total ocular HOA was beyond the 95% limits of agreement.**

• **CONCLUSION: KR-1W and iTrace were consistent well in the measurement of corneal, internal and total ocular HOA, especially for the cornea.**

• **KEYWORDS:** KR-1W; iTrace; high order aberration; difference; agreement

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INTRODUCTION

A number of systems developed as clinical tools for the assessment of wavefront aberrations of the eye are currently available. The broadening of clinical applications for these instruments favored the quick expansion into all visual health-related practices, particularly cataract surgery. Visual function analyzer could provide pupillomerty, keratometry, and autorefraction assessment, allowing to acquire wavefront data and topography data simultaneously. Aberrometry presents larger applications than just enhancing the quality of the ablation zone in an excimer laser treatment. So the choice of the most appropriate machine depends mainly on the clinical practice. Making a practical comparison between the available devices is not an easy task because of the variety of principles used, such as ray tracing, Hartmann-Shack, Tscherning, and automatic retinoscopy.

Wavefront sensors can be divided into 2 categories: outgoing and ingoing. Outgoing aberrometers operate by placing a point source of light on the retina and determining the shape of the wavefront emerging from the eye. Point source of light on the retina emits diverging spherical wavefronts that pass through the crystalline lens and the cornea to exit the eye. Ingoing aberrometers operate by examining how wavefronts external to the eye are altered as they pass through the optics of the eye. The Hartmann-Shack aberrometer is an outgoing wavefront aberrometer. The ray-tracing system is an ingoing aberrometry sensor.

The purpose of this study is to provide a number of technical and practical parameters that may be useful in choosing an aberrometer for daily clinical practice. The total optical aberration of an eye is the sum of all rays entering and exiting the eye. Internal aberration refers to light rays that are mainly disturbed in the anterior segment.

We measured high order aberration (HOA) of corneal, internal and total ocular using a KR-1W (based on Hartmann-Shack) and iTrace (based on ray tracing) to compare the difference and agreement of KR-1W and iTrace for measurement of HOA. We note that our results only represent the devices as they were made available to us during the study period. Because the devices undergo constant alteration and improvement, we advise potential users to verify all parameters for each model and device.

SUBJECTS AND METHODS

Eighty eyes of 40 healthy young adults (mean age 26.5±4.5y)

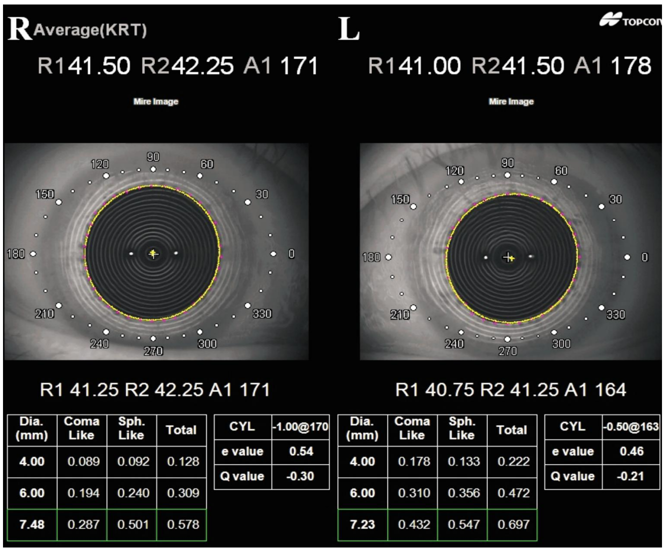

Figure 1 Corneal topography in KR-1W.

were examined with two clinical wavefront analyzers without the instillation of dilating eye drops. The volunteers were informed about the objective of the study. The study adhered to the principles outlined in the Declaration of Helsinki. Inclusion criteria were healthy eyes with a corrected distance visual acuity of 20/20. Exclusion criteria consisted of active ocular disease, other ocular diagnosis that might after optical quality, history of ocular refractive surgery or other surgery, and history of contact lens use during the last month. Patients with pupils smaller than 4.0 mm under low mesopic conditions were also excluded. So there were only 32 eyes aberrations used to be analysed. Due to the lack of a gold standard method to measure ocular aberrations, this study did not focus on determining which device exhibited the most objective measurements.

Aberrometry was performed in each eye at a single visit with: KR-1W (Topcon, Japan), iTrace (Tracey, USA). KR-1W uses the Hartmann-Shack principle to measure aberrations and iTrace uses the ray-tracing principle to measure aberrations in the eye. A minimum of 3 readings per eye were obtained with each aberrometer. Patients had a 10min interval between different devices. Measurements of HOAs were performed in a dark room with the lights switched off after ten minutes rest. The patient fixated on the target, which having the lowest brightness, aim to obtain the maximum physiologic pupil dilation. All eyes were measured without instillation of mydriatics to avoid drug-related variability. Illuminance was measured at the same location in the patient's eye with the patient's head on the chin rest. All measurements were taken soon after the patient blinked to reduce tear film-related HOA deterioration. The measurements of corneal topography and aberration in KR-1W were completed by autofocus (Figure 1) and then the aberration result can be calculated by this system (Figure 2). But the measurements of corneal

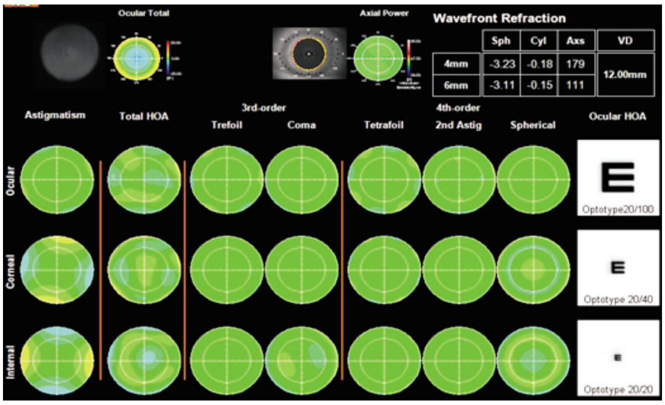

Figure 2 Aberration measurement figure in KR-1W.

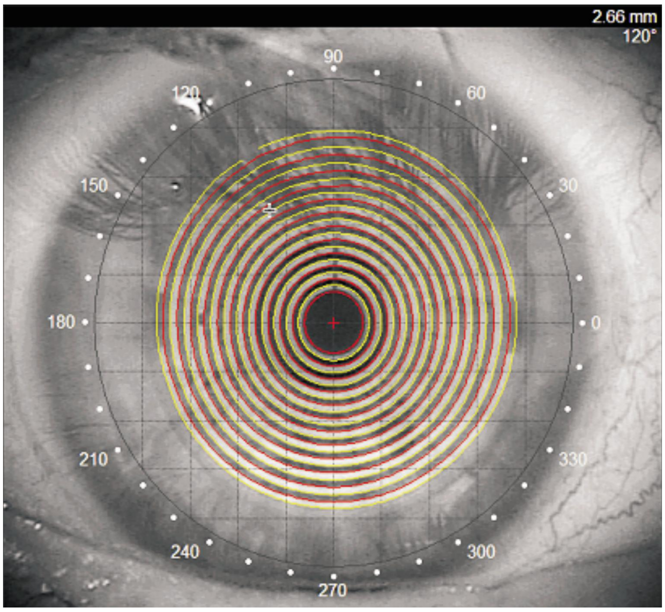

Figure 3 Corneal topography in iTrace.

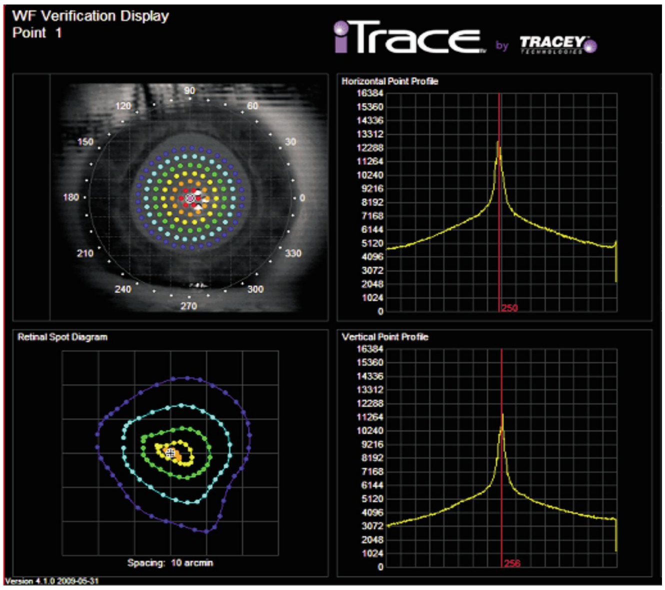

Figure 4 Aberration measurement figure in iTrace.

topography in iTrace need manually focused on corneal center when the placido rings on the cornea continuous and smooth (Figure 3) and the aberration measurements should focused on visual axis (Figure 4).

The Hartmann-Shack aberrometer measures the shape of the wavefront that is reflected out of the eye from a point source on the fovea. Basically, the subject fixates on a small ray of light that is projected onto the retina. A narrow beam of light is directed into the eye and forms a small point of light that acts as point source. That light is then reflected back through the pupil. The light rays that are scattering off the retina and emanating out of the eye are focused by an array of small lenses (called lenslets or microlenses), which intercepts the emerging wavefront and subdivides the outgoing wavefront into multiple beams. The beams focus on a video sensor, which captures the array of spot images. In an aberration-free scenario, each lenslet intercepts part of the wavefront that is flat and is traveling in the direction of the axis of the lenslet. The multiple beams of light generated by the lenslet array are focused onto a video sensor, which captures images coming from the lenslet array. The result is a grid of uniformly spaced spots.

In the ray-tracing system, a thin laser beam passes through the optical system and is projected into the eye parallel to the visual axis and determines the location of the beam on the retina. Normally, this collimated beam would focus to a point on the fovea. However, aberrations in the eye cause the beam to deflect and strike the retina away from the fovea, causing a shift in the location of the light spot on the retina. An imaging system is then used to project the retinal spot onto a position sensor. This sensor records the position of the beam relative to the fovea, which gives the transverse ray error for a particular pupil entry point. Once the position of the first light spot on the retina is determined, using the photodetector, the laser beam is moved to a new position and the location of the second light spot on the retina is determined. Because of this particular characteristic and to ensure that eye motion effects will not affect the measurement significantly, a rapid-scanning and position-sensing technology is required with this technique. It is noteworthy that the trace sensor measures 1 ray at a time in the entrance pupil rather than measuring all rays at the same time. This characteristic may be useful in determining the aberration values in highly aberrated eyes because it decreases the chance of crossing the rays.

The data of the HOA of corneal, internal and total ocular of both instruments with a 4-mm pupil diameter were collected. Direct statistical comparison of the parameters was done using a paired t-test with a significance level of 95%. We used SPSS version 19.0 (SPSS Inc. CA, USA) for windows. Agreement between the 2 devices was analyzed with Bland-Altman plots, where differences between the devices were plotted against mean values. The mean difference (bias) and 95% limits of agreement (LoA) were calculated. The LoA were computed as the mean difference ±1.96 standard deviation (SD), and they represent the limits of the range for the 95% of differences between the two instruments.

Table 1 The HOA of corneal, internal and total ocular measured by KR-1W and iTrace ($\bar{x} \pm s$, μm)

Instruments	n	Corneal HOA	Internal HOA	Total ocular HOA
KR-1W	32	0.128±0.031	0.098±0.030	0.104±0.039
iTrace	32	0.137±0.046	0.162±0.061	0.157±0.047
t		-1.174	-6.339	-5.461
P		0.249	0.000	0.000

RESULTS

Table 1 showed the HOA of corneal, internal and total ocular measured by KR-1W and iTrace. There was no statistical difference in corneal HOA between two groups ($P>0.05$, paired-samples t-test). There were statistically statistical differences in internal and total ocular HOA between two groups ($P<0.001$, paired t-test), and the mean results measured by iTrace were higher than that of KR-1W.

The clinical agreement of the HOA of corneal, internal and total ocular measured by two instruments was evaluated by Bland-Altman analysis. Figure 5 showed the HOA of corneal and internal were all in 95% LoA; and just one point of total ocular HOA was beyond the 95% LoA. In this research, the mean difference of corneal HOA measured by KR-1W and iTrace was -0.01 μm, while the limits of the range for the 95% of differences were -0.10-0.08 μm. Thirteen eyes' (40.6%) results of corneal HOA measured by KR-1W were higher than that of iTrace. Within the limits of mean difference ±1.96 SD, the maximum absolute value of difference of corneal HOA measured by two instruments was 0.088 μm. It can be seen that the mean differences are symmetrically close to zero.

In this research, the mean difference of total ocular HOA measured by KR-1W and iTrace was -0.05 μm, while the limits of the range for the 95% of differences were -0.16-0.05 μm. Seven eyes' (21.9%) results of corneal HOA measured by KR-1W were higher than that of iTrace. The maximum absolute value of difference of total ocular HOA measured by two instruments was 0.199 μm. It can be seen that the mean differences are concentratedly distributed blow to zero, which meaned the mean results of internal HOA measured by iTrace were higher than that of KR-1W (Figure 6).

In this research, the mean difference of internal HOA measured by KR-1W and iTrace was -0.05 μm, while the limits of the range for the 95% of differences were -0.16-0.05 μm. Five eyes' (15.6%) results of corneal HOA measured by KR-1W were higher than that of iTrace. The maximum absolute value of difference of internal HOA measured by two instruments was 0.167 μm. It can be seen that the mean differences are concentratedly distributed blow to zero, which meaned the mean results of internal HOA measured by iTrace were higher than that of KR-1W (Figure 7).

Above all, our study showed KR-1W and iTrace were consistent well in the measurement of corneal, internal and total ocular HOA, especially for the cornea.

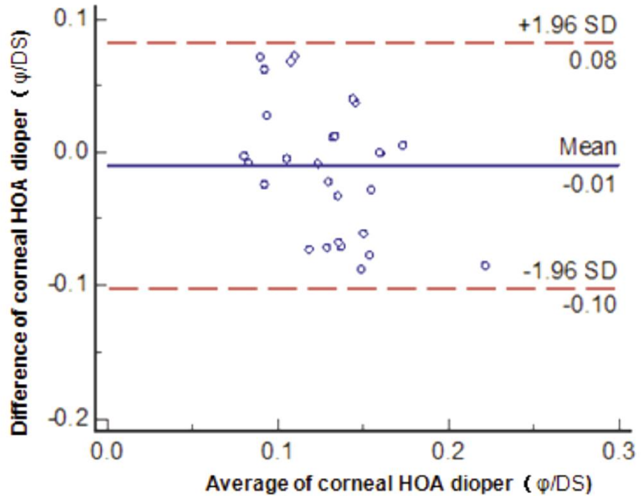

Figure 5 The Bland-Altman of the corneal HOA The upper and lower horizontal lines represent the upper and the lower LoA (mean difference ±1.96 SD), respectively. The middle line represents the mean difference between the aberrometers.

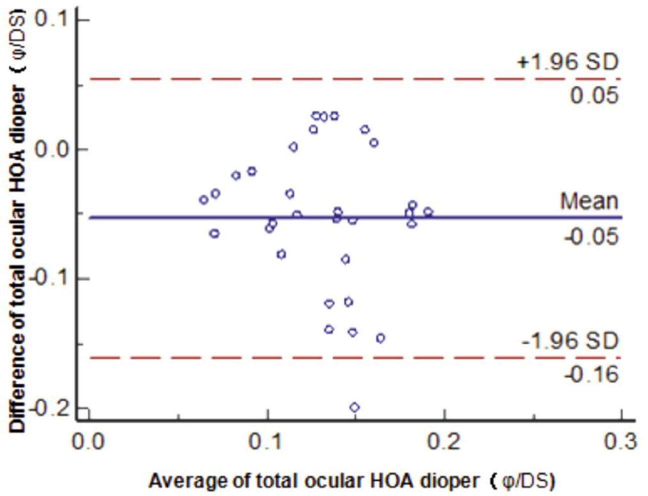

Figure 6 The Bland-Altman of the total ocular HOA The upper and lower horizontal lines represent the upper and the lower LoA (mean difference ±1.96 SD), respectively. The middle line represents the mean difference between the aberrometers.

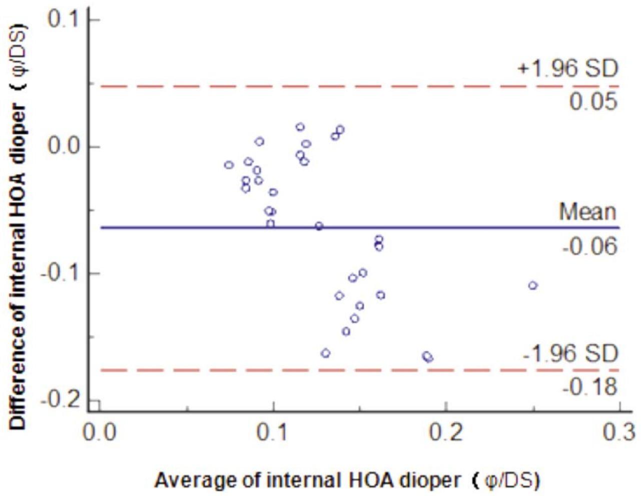

Figure 7 The Bland-Altman of the internal HOA The upper and lower horizontal lines represent the upper and the lower LoA (mean difference ±1.96 SD), respectively. The middle line represents the mean difference between the aberrometers.

DISCUSSION

Aberrometers incorporate wavefront analysis to define the refractive parameters of the eye. A wavefront aberration is defined as the deviation of a reflected wave to a reference unaberrated wave. Nowadays, more attention is paid to the use of the wavefront aberration in ophthalmology [1-2], especially in the field of improving optical quality, such as cataract surgery [3], refractive surgery [4-5] and amblyopia treatment[6].

KR-1W and iTrace could provide pupillomerty, keratometry, and autorefraction assessment, allowing to acquire wavefront data and topography data simultaneously and have had great repeatability in widespread clinical application [7-10]. The healthy subjects was examined to compare the following devices: IOLMaster, Lenstar, SMI Reference Unit 3, Javal, Pentacam and KR-1W [11]; the OPD Scan and iTrace [12]. But the comparision between KR-1W and iTrace has not been repoted.

In this research, the total ocular HOA measured by KR-1W and iTrace were 0.157 μm and 0.104 μm, which is comparable to the results in previous studies[13-14]. The results showed that there was no statistical difference in the corneal HOA measured by the two instruments, while there were significant statistical differences in the internal and total ocular HOA ($P<0.05$), and the mean results measured by iTrace were higher than that of KR-1W.

Moreno-Barriuso and Navarro [15] concluded in their comparison between laser ray-tracing and Hartmann-Shack aberrometry that both methods are equally valid and later found a close match between the Zernike coefficient values obtained by Hartmann-Shack and laser ray tracing. Although both studies were performed in aboratory settings and not with clinical wavefront analyzers such as those used in the present study.

One explanation for this discrepancy in our study might be the differences in the algorithm to locate either the chief ray of each lenslet image or the different principle used by two aberrometers. Consequently, any disparity of mathematical calculation, used by each device, can give slightly different results.

Another parameter that can interfere with results is the measuring center of wavefront aberrometry. The Hartmann-Shack aberrometer operated by placing a point source of light on the retina and determining the shape of the wavefront emerging from the eye, which means the HOAs of corneal, internal and total ocular were calculated through the corneal center. The ray-tracing aberrometer operated by examining how wavefronts external to the eye are altered as they pass through the optics of the eye, which means the corneal HOA was calculated through the corneal center, while the HOAs of internal and total ocular were calculated through the optic axis of the eye. The location of the measuring center was essential factor in wavefront analysis. Measuring center importance relies in the control of light intensity, which defines the point spread function of the visual system. Therefore, there was no statistical difference in the corneal HOA measured by the two instruments, while there were significant statistical differences in the internal and total ocular HOA.

However, significant differences found in the internal and total ocular HOA suggest that certain measurements are not always consistent between devices, and hence, should be interpreted carefully. We believe that these differences can be attributed to design variations between the aberrometers, such as sensor architecture and the wavefront decomposition algorithm.

The results of HOA of internal and total ocular HOA obtained with the KR-1W and iTrace wavefront analyzers are not interchangeable and, therefore, direct comparison between the results obtained in different studies would be of limited value. These results imply, therefore, that wavefront analysis without cycloplegia, although desirable as it corresponds to more natural viewing conditions, should be performed carefully. Further study is needed to establish the level of agreement between the two methods on cyclopleged and on-cyclopleged human eyes to determine the extent of differences attributable to the accommodative response and/or microfluctuations triggered by the fixation targets used by the wavefront analyzers.

Both aberrometers could provide pupillomerty, keratometry, and autorefraction assessment, allowing to acquire wavefront data and topography data and the data of point spread function or modulation transfer function simultaneously, allowing to analyzing the data comprehensively and clinically applying widespread in preoperative [16], postoperative [17-19] and other [20] examinations. Each had its own strengths and weaknesses in clinical application. Though both could provide the value of point spread function or modulation transfer function, iTrace could provide the value of modulation transfer function with different pupil diameter. And it could predict postoperative optical quality and visualize the letter E with different contrast and resolution with some special settings. However, it could only provide the value modulation transfer function within the constrast of 30 cycles per degree. While KR-1W could provide the value modulation transfer function within the constrast of 120 cycles per degree and the analysis of modulation transfer function horizontally and vertically. However it could not predict postoperative optical quality. In addition, due to the existence of HOA often cause the failure of amblyopia treatment[6], visual quality analyzer will also be applied as regular inspection program in amblyopia treatment.

In addition to these clinical applications above, the advantage of KR-1W is in respect of examination in ocular surface disease relative to iTrace, such as dry eye disease[21]. KR-1W could measure dry eye ten times continuously and record the effect of tear film break-up on aberrations and film meibomian glands. While the advantage of iTrace is in respect of examination in optical quality with some extent of media opacity. For example, it could estimate the preoperative corneal and total ocular HOAs and predict postoperative optical quality for the patient with low visual acuity before cataract surgery and it could help to choose appropriate intraocular lens for the patient with large value of corneal HOA before cataract surgery and perform right optometry and glasses taking for the patient corneal opacity.

In summary, this study evaluated which variables were comparable and which were different between 2 aberrometers using the same eyes, which showed similarities between 2 aberrometers, particularly measuring corneal HOAs. In practice, clinicians can choose the appropriate instrument more objectively according to their patient's individual ocular problems.

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