Original Article

Impact of tear optics on the repeatability of Pentacam AXL wave and iTrace in measuring anterior segment parameters and aberrations

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Purpose: To assess impact of tear optics on repeatability of a Scheimpflug device with a Hartmann Shack aberrometer and a ray tracing aberrometer. **Methods:** One hundred healthy and 100 postrefractive surgery eyes underwent dry eye evaluation including Schirmer's test and tear film break-up time (TBUT). They underwent optical quality analyzer (OQAS, Visio metrics S.L, Terrassa, Spain) to assess objective scatter index (OSI), three scans each on Pentacam AXL wave (OCULUS Optikgerate Gmbh, Wetzlar, Germany), iTrace (Tracey™ Technologies, Texas, USA) for flat, steep keratometry, thinnest corneal thickness, root mean square higher-order aberrations (RMS HOA), RMS lower-order aberrations (LOA), spherical aberrations, RMS COMA. Repeatability of Pentacam AXL wave and iTrace in healthy and postrefractive eyes (OSI >1 vs OSI <1) was studied using within-subject standard deviation (Sw) test–retest repeatability (TRT), coefficient of variation (COV). **Results:** OSI showed an inverse association with TBUT ($P < 0.001$). All measurements with Pentacam AXL wave with OSI < 1 had excellent repeatability, intraclass correlation coefficient (ICC) ranging from 0.88 for HOA, to 0.92 for LOA. The Sw, TRT, and COV of all aberration measurements were significantly lower (better) than those of iTrace. In eyes with OSI ≥1, the repeatability with Pentacam AXL wave dropped with ICC ranging from 0.77 for HOA, to 0.84 for LOA with lower Sw, TRT, and COV of all aberration measurements as compared to iTrace. Maximum variation was seen with HOA and minimum with LOA. **Conclusion:** Tear optics affected repeatability of Pentacam wave and iTrace. Pentacam wave had better repeatability in eyes with a poor tear film as compared to iTrace. Thus, the tear film can impact repeatability of an instrument and it is important to assess the tear film prior to imaging patients, which can change the way we interpret and image these patients.

Key words: Aberrations, iTrace, OSI, Pentacam AXL wave, repeatability

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The advances in keratorefractive surgery have driven the need of more precise anterior segment measurements and more reliable devices.[1] In this era of rapid advancements in technology, it is imperative for a keratorefractive surgeon to have access to highly precise and accurate measurements of various anterior segment parameters for intraocular lens calculations, corneal surgeries, fitting of advanced contact lenses, and modern laser refractive surgery planning and monitoring outcomes.[2]

Corneal topographers enable measurement of various anterior segment parameters.[3] Aberrometers provide wavefront analysis that aid in detailed evaluation of the imperfections in the optical system from the tear film to anterior, posterior cornea, and the lens leading up to the fovea.

Pentacam AXL wave topography system (OCULUS, Optikgeräte GmbH, Wetzlar Germany) is a combination of Scheimpflug tomography, optical biometry, and Hartman–Shack aberrometry. It performs five major functions in one measurement; objective refraction, total eye wavefront using Hartman–Shack technology, retro-illumination, optical biometry, and anterior segment tomography.[4]

iTrace system (Tracey Technologies Corp. TX, USA) is another commonly used aberrometer, which uses a combination of corneal topography along with a ray-tracing aberrometer, delivering information about refractive, wavefront and corneal topographic data of the human optical system.[5]

Precision of measurements of these devices can be influenced by abnormalities of the tear film, as the tear film is the first encountered refractive layer. Dry eye is a multifactorial disease of tears and ocular surface. It is one of the most common entities in ophthalmology practice with a prevalence ranging between 3.9 and 16.7%.[6,7] This can potentially alter several topographic and aberrometric measurements in day-to-day practice and thereby influence outcomes of refractive interventions.

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New technologies like optical quality analysis system (OQAS, Visio metrics S.L, Terrassa, Spain) objectively assess tear film in a noninvasive way. The objective scatter index (OSI), which is a parameter obtained from OQAS, has shown good repeatability and thus can used in assessment of tear film abnormalities.[8,9] OSI is the ratio between integrated light in the periphery ring and central peak of the double-pass (DP) image and represents impact on the DP image caused due to the aberration and scattering.

There is no study in literature which has studied the effect of alteration of tear film optics on the repeatability of these advanced devices. Our current study aims to assess the impact of tear film abnormality on the repeatability of topographic and aberrometric parameters in Pentacam AXL wave and iTrace.

Methods

This was a prospective, cross-sectional observational study conducted at a tertiary care eye hospital, Bengaluru, India after obtaining approval from institutional research and ethics committee. The study was conducted in accordance with the principles of the Declaration of Helsinki. All eligible patients were explained about the study and included after obtaining a written informed consent.

The study population consisted of two groups, postrefractive surgery and normal group. Postrefractive group included participants who had undergone LASIK (Laser-assisted *in situ* keratomileusis) at least 6 months ago, with no intraoperative or postoperative complications. Normal group included participants who visited the eye hospital for routine assessment and who have had no previous ocular surgeries. Patients using any other eye drops other than lubricants those with ectatic diseases as keratoconus, corneal scarring, active ocular allergy, glaucoma, uveitis, any other ocular and systemic comorbidities affecting ocular fixation and ability to sit through scans, and pregnant or lactating women were excluded from the study. Normal patients with a history of rigid contact lens wear within 4 weeks and soft contact lens wear within 2 weeks of acquisition of the Scheimpflug imaging were also excluded from the study.

The dry eye evaluation included Schirmer's test and tear film break-up time (TBUT) assessment. The analysis of the quality of vision and the tear film was done using the OQAS (Visiometrics S.L, Terrassa, Spain). Schirmer's test was performed using the Schirmer's test strip, and the results were noted at 5 min after placing the strip in the eye. This was followed by the TBUT test by instilling sodium fluorescein dye into the lower fornix, asking the patient to blink and then watch for the first area of break in the tear film, which is taken as the TBUT. Three readings of TBUT were done to improve the reliability of results. Dry eye evaluation using Schirmer's and TBUT were performed as the last tests in the study. Before any of the study related tests, it was ensured that no lubricating eye drops were instilled at least 2 h prior.

Each patient underwent scans on the three machines namely Pentacam AXL wave, iTrace, and the OQAS. Machine order for the patients and the scan sequence of the eye in patients with both eyes included were determined using a computerized table of random numbers.

The Pentacam AXL wave system was calibrated before acquisition of the scan by the manufacturer. Under scotopic condition with a natural pupil between 9 AM and 3 PM, images were captured by a single experienced technician. This helped to minimize the effects of diurnal variation and interobserver variations. Any application of topical medications was avoided before the scan. Each eye underwent three consecutive topography examinations using the standard resolution mode (25 images per second). Repositioning of the patients' heads in between the three consecutive scans was done in order to ensure that each scan was independent and also to prevent fatiguability of the subjects. Only the scans with quality specification of "OK" were included in the study.

The parameters analyzed on Pentacam AXL wave included keratometry flat (K1), steep keratometry (K2), thinnest corneal thickness (TCT) and the aberrometric parameters, including root mean square higher-order aberrations (RMS HOA), RMS lower order aberrations (LOA), spherical aberrations (SA), RMS COMA, and wavefront refractions. All aberrometric parameters were measured in 4 mm pupil size.

The internal optometer incorporated in the iTrace system was used for the alignment of the patient's line of sight with the laser axis, then the iTrace aberrometer automatically centered onto the pupil, verifying focus and alignment and captured the data. The best scan, where all of the reflected Placido rings devoid of missing ring edges, was included in the final analysis of data. The total eye aberrations at 4 mm pupil size were studied.

The aberrometric parameters analyzed included RMS HOA, LOA, SA, and RMS Coma, similar to those analyzed on the Pentacam AXL wave. Each eye underwent a single scan on the OQAS, and it was included in the study only if quality specification showed "OK." The OSI value was recorded. OQAS gives real-time measurements of the effects of changes in the tear film on optical quality and assesses the optical quality of the tear film in 0.5 s intervals. It allows a measurement of the visual quality in between each blink, which is correlated with the potential visual acuity at each time point. Other than OSI, it also gives the modulation transfer function (MTF) which were calculated at an artificial pupil size of 4 mm. The tear film analysis program of OQAS records dynamic changes of the OSI values and calculates the mean OSI over 20 s and its standard deviation (mean OSI). Mean OSI is what gives us an indicator of tear film disturbances [Fig. 1]. A mean OSI > 1 was considered as abnormal [Fig. 2].[10]

Based on the OSI values, the study population was further divided into four groups:

1. Postrefractive surgery eyes with OSI >1
2. Postrefractive surgery eyes with OSI <1
3. Normal eyes with OSI >1
4. Normal eyes with OSI <1

Statistical analysis

Statistical analysis was performed using the Medcalc Version 19.4.1 (MedCalc Inc., Ostden, Belgium). All continuous variables were assessed for normality of distribution using Kolmogorov–Smirnov test. Continuous variables were tested using difference in their mean/median. Spearman's correlation was done to evaluate the correlation between TBUT in patients and optical quality as defined by their OSI values from OQAS.

Repeatability was assessed by within-subject standard deviation (Sw), test–retest variability (TRT) and within-subject coefficient of variation (COV = 100 × Sw/overall mean). The Sw

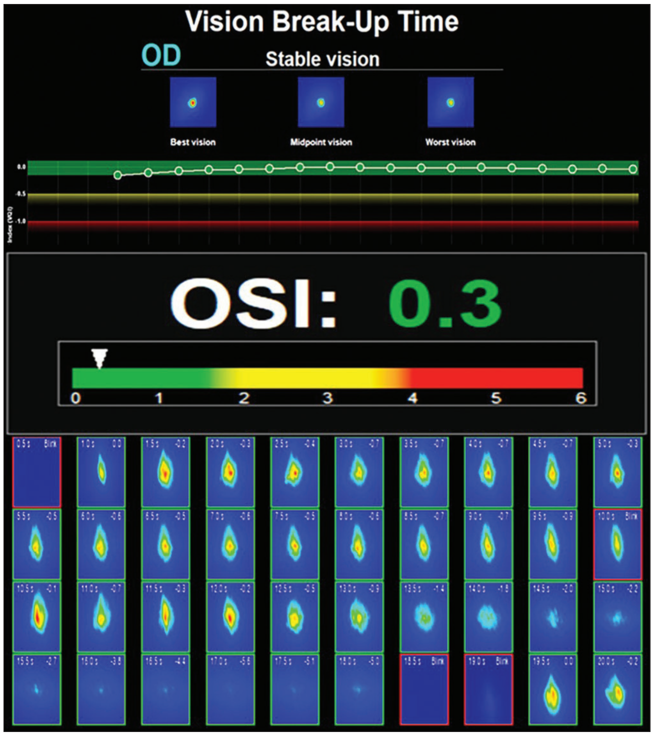

Figure 1: Representative image of tear film analysis with an optical quality analysis system (OQAS). Objective scatter index (OSI) is shown over a period of time and with blinks noted. The OSI is less than 1 suggestive of good tear film optics

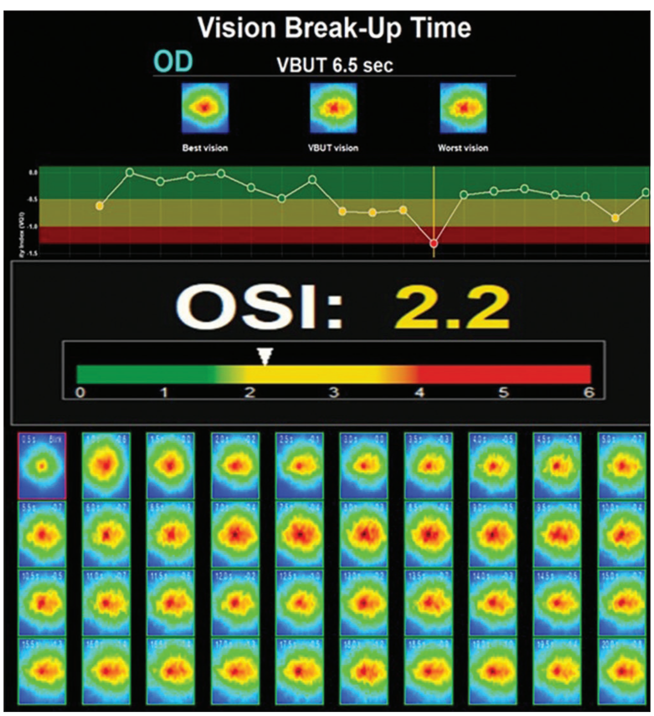

Figure 2: Representative image of tear film analysis with an optical quality analysis system (OQAS) with the objective scatter index (OSI) more than 1 suggestive of poor tear film optics

was calculated as the square root of the within-subject mean square error. The TRT was calculated as 2.77 times Sw. The COV is a statistical measure of the dispersion of data around

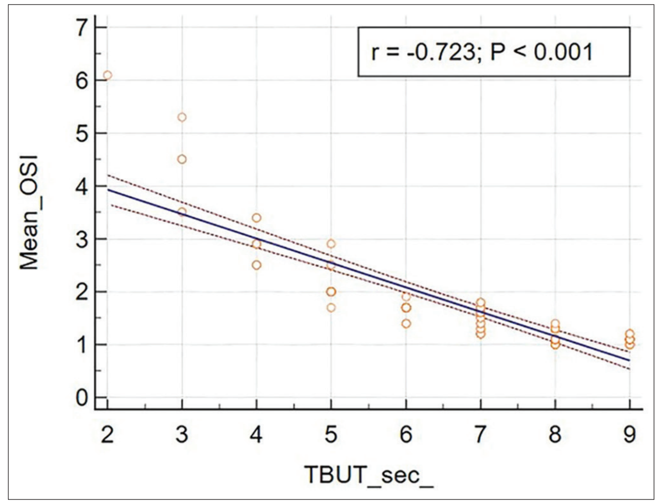

Figure 3: Graph showing negative correlation between tear film break-up time (TBUT) and mean objective scatter index (OSI)

mean and is represented as the ratio of the standard deviation to the mean. Intraclass correlation coefficient (ICC), which is a measure of the repeatability of measurements, was also performed.

Results

Data from 100 healthy eyes of 80 patients with a mean age of 29.54 ± 3.21 years and 100 postrefractive eyes of 60 patients with a mean age of 28.32 ± 3.78 years were analyzed.

Out of 100 healthy eyes, 79 had mean OSI <1 and 21 with mean OSI ≥ 1. In postrefractive group, out of 100 eyes, 58 had mean OSI < 1 and 42 had mean OSI ≥ 1.

Table 1 denotes mean and the standard error of mean values of Schirmer and TBU) in healthy and postrefractive eyes with OSI < 1 and OSI ≥ 1. The Mean TBUT was <10 s in both normals and postrefractive surgery eyes but with a normal Schirmer >20 mm suggestive of a purely evaporative dry eye component. A lower TBUT was noted in those with OSI >1 as compared to those with OSI <1. Mean TBUT was lower in postrefractive eyes as compared to healthy eyes. An inverse association was thus noted between TBUT and OSI (r = -0.723, P < 0.001) [Fig. 3]. This implies that those with a lower TBUT were associated with relatively poorer tear film related quality of vision as ascertained by mean OSI.

Table 2 shows the Sw, TRT, and COV for wavefront refraction, flat keratometry, steep keratometry, TCT, RMS HOA, RMS LOA, RMS COMA, and SA derived from Pentacam AXL wave in healthy eyes in those with mean OSI <1.

In COV studied for keratometric or pachymetric indices, maximum variation was seen with thinnest pachymetry and least for keratometry. However, the level of COV increased for aberrometric measurements, the highest being for HOA.

ICC above 0.8 was obtained in all parameters suggesting good repeatability in normal eyes. Further, LOA were associated with better repeatability than HOA in normal eyes. Measured sphere had the highest repeatability with least COV, whereas measured axis had the highest COV among the measure wavefront refraction.

Table 1: Mean and the standard error of mean values of Schirmer and TBUT in both healthy and postrefractive eyes with a mean OSI <1 and mean OSI ≥1

	Healthy eyes (*n*=100 eyes)		Post Refractive eyes (*n*=100 eyes)	
	Mean OSI <1 (*n*=79)	Mean OSI ≥1 (*n*=21)	Mean OSI <1 (*n*=58)	Mean OSI ≥1 (*n*=42)
TBUT (s)	9±0.21	7.9±0.48	8.6±0.31	5.1±0.24
Schirmer (mm)	25±0.47	20±0.98	27±0.34	22±0.47

TBUT – Tear film break-up time, OSI – objective scatter index

Table 2: Repeatability (with 95% CI) of wavefront refraction, flat keratometry, steep keratometry, TCT, RMS HOA, RMS LOA, RMS COMA, and SA derived from Pentacam AXL wave in healthy eyes with those having a mean OSI<1

	Sw	TRT	COV (%)	ICC
Sphere	0.65 (0.40-0.84)	1.80 (1.48-2.44)	10.2 (8.6-13.9)	0.89
Cylinder	0.66 (0.43-0.86)	1.82 (1.52-2.39)	14.5 (11.02-17.9)	0.88
Axis	19.2 (13.7-23.5)	53.18 (41.6-64.3)	19.7 (15.6-24.3)	0.83
Flat keratometry	0.22 (0.19-0.27)	0.60 (0.51-0.73)	0.2 (0.1-0.6)	0.98
Steep keratometry	0.11 (0.08-0.13)	0.31 (0.25-0.36)	1.1 (0.5-1.8)	0.96
TCT measurement	9.23 (7.11-10.54)	25.56 (21.36-28.50)	2.5 (0.2-3.6)	0.97
RMS HOA	0.024 (0.016-0.033)	0.066 (0.042-0.079)	8.3 (6.4-11.7)	0.88
RMS LOA	0.112 (0.07-0.23)	0.31 (0.1-0.46)	4.4 (2.6-6.9)	0.92
RMS COMA	0.016 (0.013-0.026)	0.044 (0.024-0.067)	5.5 (3.6-7.8)	0.89
SA	0.01387 (0.0093-0.031)	0.038 (0.023-0.054)	5.1 (3.1-7.6)	0.91

TCT – thinnest corneal thickness, RMS HOA – root means square of higher-order aberrations, RMS LOA – Root mean square of lower-order aberrations, RMS COMA – Root mean square of coma, SA – Spherical aberration, Sw – within-subject standard deviation, TRT – test–retest variability, COV – within-subject coefficient of variation, ICC – intraclass correlation coefficient, CI – confidence interval, OSI – objective scatter index

Table 3: Comparison of repeatability of total aberrations derived from Pentacam AXL wave and iTrace in healthy eyes with a mean OSI <1

Parameter	Pentacam AXL wave	iTrace
RMS COMA		
Sw (D)	0.016 (0.013-0.026)	0.023 (0.01-0.045)
TRT (D)	0.044 (0.024-0.067)	0.063 (0.041-0.089)
COV (%)	5.5 (3.6-7.8)	6.8 (4.8-9.6)
ICC	0.89	0.84
RMS HOA		
Sw (D)	0.024 (0.016-0.033)	0.034 (0.022-0.048)
TRT (D)	0.066 (0.042-0.079)	0.094 (0.045-0.14)
COV (%)	8.3 (6.4-11.7)	9.7 (6.32-12.2)
ICC	0.88	0.82
RMS LOA		
Sw (D)	0.112 (0.07-0.23)	0.159 (0.07-0.22)
TRT (D)	0.31 (0.1-0.46)	0.44 (0.31-0.57)
COV (%)	4.4 (2.6-6.9)	6.2 (3.3-8.7)
ICC	0.92	0.89
SA		
Sw (D)	0.01387 (0.0093-0.031)	0.023 (0.012-0.038)
TRT (D)	0.038 (0.023-0.054)	0.064 (0.039-0.080)
COV (%)	5.1 (3.1-7.6)	7.04 (4.63-9.25)
ICC	0.91	0.88

RMS HOA – Root means square of higher-order aberrations, RMS LOA – Root mean square of lower-order aberrations, RMS COMA – Root mean square of coma, SA – Spherical aberration, Sw – within-subject standard deviation, TRT – test–retest variability, COV – within-subject coefficient of variation, ICC – Intraclass Correlation Coefficient, OSI – objective scatter index

Table 3 shows the comparison of repeatability measurements of aberrations from both devices in normal eyes with mean OSI < 1. The Sw, TRT, and COV of all the aberration measurements were lower (better) than those of iTrace. A smaller Sw indicates higher repeatability. Pentacam AXL wave also had better ICC values for all aberration parameters compared to iTrace indicating better repeatability.

Table 4 shows Sw, TRT, and COV for wavefront refraction, flat keratometry, steep keratometry, TCT, RMS HOA, RMS LOA, RMS COMA, and SA derived from Pentacam AXL wave in healthy eyes with those having mean OSI ≥ 1.

As compared to eyes with OSI <1, the Sw, TRT, and COV were higher (poorer repeatability) for all parameters studied. The COV studied was the highest for HOA, among aberrometric measurements, and least for LOA.

ICC above 0.8 was obtained in all parameters except RMS HOA and RMS COMA. Measured sphere had an ICC 0.88 as compared to axis with an ICC of 0.82.

Table 5 shows the comparison of repeatability measurements of aberrations from both devices in normal eyes with mean OSI ≥1. The Sw, TRT, and COV of all aberration measurements in Pentacam AXL wave were lower (better) than those of iTrace and better ICC values for all the aberration parameters compared to iTrace indicating better repeatability in eyes with OSI >1 for Pentacam AXL wave.

Table 6 shows repeatability for anterior segment parameters and aberrations for postrefractive eyes with mean OSI <1. It shows a similar trend as in healthy eyes. In the COV for keratometric and pachymetric indices, maximum variation was seen with the thinnest pachymetry and least for keratometry.

Table 4: Repeatability (with 95% CI) of wavefront refraction, flat keratometry, steep keratometry, TCT, RMS HOA, RMS LOA, RMS COMA, and SA derived from Pentacam AXL wave in healthy eyes with those having a mean OSI ≥1

	Sw	TRT	COV (%)	ICC
Sphere	0.78 (0.38-0.92)	2.1 (1.34-3.24)	12.2 (8.4-14.6)	0.88
Cylinder	0.79 (0.40-0.96)	2.2 (1.62-3.5)	16.5 (10.1-19.4)	0.86
Axis	23.2 (11.8-24.5)	64.2 (38.5-72.3)	20.3 (14.9-26.6)	0.82
Flat keratometry	0.27 (0.16-0.38)	0.74 (0.42-0.83)	0.3 (0.2-0.6)	0.93
Steep keratometry	0.16 (0.06-0.21)	0.44 (0.22-0.52)	1.3 (0.4-2.4)	0.94
TCT measurement	10.1 (6.32-13.29)	27.9 (20.68-30.4)	3.2 (0.9-4.9)	0.90
RMS HOA	0.037 (0.013-0.049)	0.102 (0.036-0.163)	9.4 (5.9-13.2)	0.77
RMS LOA	0.152 (0.09-0.38)	0.42 (0.08-0.53)	4.9 (2.5-7.8)	0.84
RMS COMA	0.028 (0.014-0.041)	0.077 (0.022-0.089)	6.1 (3.3-8.9)	0.79
SA	0.0192 (0.0089-0.039)	0.052 (0.019-0.069)	5.9 (3.4-8.6)	0.83

TCT – thinnest corneal thickness, RMS HOA – Root means square of higher-order aberrations, RMS LOA – Root mean square of lower-order aberrations, RMS COMA – Root mean square of coma, SA – Spherical aberration, Sw – within-subject standard deviation, TRT – test–retest variability, COV – within-subject coefficient of variation, ICC – intraclass correlation coefficient, CI – confidence interval, OSI – objective scatter index

Table 5: Comparison of repeatability of total aberrations derived from Pentacam AXL wave and iTrace in healthy eyes with a mean OSI ≥1

Parameter	Pentacam AXL wave	iTrace
RMS COMA		
Sw (D)	0.028 (0.014-0.041)	0.032 (0.02-0.056)
TRT (D)	0.077 (0.022-0.089)	0.063 (0.035-0.092)
COV (%)	6.1 (3.3-8.9)	7.3 (4.7-9.9)
ICC	0.79	0.76
RMS HOA		
Sw (D)	0.037 (0.013-0.049)	0.048 (0.024-0.061)
TRT (D)	0.102 (0.036-0.163)	0.094 (0.049-0.17)
COV (%)	9.4 (5.9-13.2)	10.2 (6.5-13.8)
ICC	0.77	0.74
RMS LOA		
Sw (D)	0.152 (0.09-0.38)	0.18 (0.07-0.22)
TRT (D)	0.42 (0.08-0.53)	0.44 (0.11-0.62)
COV (%)	4.9 (2.5-7.8)	7.3 (3.5-9.8)
ICC	0.84	0.81
SA		
Sw (D)	0.0192 (0.0089-0.039)	0.031 (0.012-0.043)
TRT (D)	0.052 (0.019-0.069)	0.064 (0.034-0.092)
COV (%)	5.9 (3.4-8.6)	7.8 (4.2-10.6)
ICC	0.83	0.79

RMS HOA – Root means square of higher-order aberrations, RMS LOA – Root mean square of lower-order aberrations, RMS COMA – Root mean square of coma, SA – Spherical aberration, Sw – within-subject standard deviation, TRT – test–retest variability, COV – within-subject coefficient of variation, ICC – intraclass correlation coefficient, OSI – objective scatter index

However, COV increased for aberrometric measurements, the highest being for HOA.

ICC above 0.8 was obtained in all parameters suggesting good repeatability in postrefractive eyes with LOA having better repeatability than HOA.

Table 7 shows the comparison of repeatability measurements of aberrations from both devices in postrefractive eyes with mean OSI <1. The Sw, TRT, and COV of all aberration measurements were lower (better) than those of iTrace. Pentacam AXL wave had better ICC values for all aberration parameters compared to iTrace indicating better repeatability.

Table 8 shows the Sw, TRT, and COV for wavefront refraction, flat keratometry, steep keratometry, TCT, RMS HOA, RMS LOA, RMS COMA, and SA derived from Pentacam AXL wave in post refractive eyes with those having mean OSI >= 1.

As compared to eyes with OSI <1, Sw, TRT, and COV were higher (poorer repeatability) for all parameters studied. The COV studied was the highest for HOA, among aberrometric measurements, and least for LOA.

ICC above 0.8 was obtained in all parameters except RMS HOA, RMS COMA, and SA.

Table 9 shows comparison of repeatability measurements of aberrations from both devices in postrefractive eyes with mean OSI ≥ 1. As in healthy eyes, the Sw, TRT, and COV of all aberration measurements in Pentacam AXL wave were lower (better) than those of iTrace and better ICC values for all the aberration parameters compared to iTrace indicating better repeatability in eyes with OSI ≥ 1 for Pentacam AXL wave.

Discussion

A stable tear film is not only important for maintaining the ocular surface homeostasis and preventing dry eyes but is also vital as the first refracting medium encountered by light entering the eye. As clinicians, we are aware that patients with dry eyes do present with fluctuations and alterations in quantity and quality of vision due to alterations in the way the light is refracted into the eye. Similarly, light projected from imaging devices including topographers and aberrometers should also undergo an alteration with the fluctuation of the tear film, thereby affecting precision.

In practice, fluorescein break-up time (FBUT) is by far most widely performed examination to help in assessing tear film stability. Although FBUT measurement using fluorescein dye is a minimally invasive technique, fluorescein instillation can destabilize tear film. The Schirmer test, on the other hand, is most commonly used to measure tear production, which is an indispensable component of examination in patients with Dry

Table 6: Repeatability (with 95% CI) of flat keratometry, steep keratometry, TCT, RMS HOA, RMS LOA, RMS COMA, and SA derived from Pentacam AXL wave in postrefractive eyes with a mean OSI<1

	Sw	TRT	COV (%)	ICC
Flat keratometry	0.27 (0.12-0.32)	0.74 (0.51-0.83)	0.3 (0.0-0.8)	0.94
Steep keratometry	0.14 (0.05-0.15)	0.38 (0.25-0.47	1.4 (0.3-1.9)	0.92
TCT measurement	10.12 (7.64-10.92)	28.03 (21.36-31.6)	2.9 (0.1-4.2)	0.94
RMS HOA	0.031 (0.013-0.043)	0.085 (0.042-0.103)	9.1 (5.9-12.2)	0.83
RMS LOA	0.109 (0.06-0.28)	0.31 (0.1-0.49)	4.5 (2.8-7.2)	0.90
RMS COMA	0.022 (0.014-0.039)	0.055 (0.022-0.072)	5.7 (3.4-8.2)	0.87
SA	0.015 (0.008-0.034)	0.041 (0.021-0.059)	5.4 (2.8-7.9)	0.89

TCT – thinnest corneal thickness, RMS HOA – Root means square of higher-order aberrations, RMS LOA – Root mean square of lower-order aberrations, RMS COMA – Root mean square of coma, SA – Spherical aberration, Sw – within-subject standard deviation, TRT – test–retest variability, COV – within-subject coefficient of variation, ICC – intraclass correlation coefficient , CI – confidence interval, OSI – objective scatter index

Table 7: Comparison of repeatability of total aberrations derived from Pentacam AXL wave and iTrace in postrefractive eyes with a mean OSI <1

Parameter	Pentacam AXL wave	iTrace
RMS COMA		
Sw (D)	0.022 (0.014-0.039)	0.034 (0.4-0.059)
TRT (D)	0.055 (0.022-0.072)	0.094 (0.031-0.12)
COV (%)	5.7 (3.4-8.2)	7.1 (4.2-10.4)
ICC	0.87	0.85
RMS HOA		
Sw (D)	0.031 (0.013-0.043)	0.045 (0.02-0.062)
TRT (D)	0.085 (0.042-0.103)	0.12 (0.039-0.17)
COV (%)	9.1 (5.9-12.2)	9.9 (6.1-13.4)
ICC	0.83	0.80
RMS LOA		
Sw (D)	0.109 (0.06-0.28)	0.18 (0.06-0.26)
TRT (D)	0.31 (0.1-0.49)	0.49 (0.29-0.78)
COV (%)	4.4 (2.6-6.9)	6.5 (3.2-9.1)
ICC	0.90	0.88
SA		
Sw (D)	0.015 (0.008-0.034)	0.026 (0.011-0.043)
TRT (D)	0.041 (0.021-0.059)	0.072 (0.039-0.094)
COV (%)	5.4 (2.8-7.9)	7.8 (4.3-9.6)
ICC	0.89	0.86

RMS HOA – Root means square of higher-order aberrations, RMS LOA – Root mean square of lower-order aberrations, RMS COMA – Root mean square of coma, SA – Spherical aberration, Sw – within-subject standard deviation, TRT – test–retest variability, COV – within-subject coefficient of variation, ICC – intraclass correlation coefficient, OSI – objective scatter index

eye disease (DED).[11] The mean TBUT for both the normals and postrefractive surgery groups was <10 s with a normal Schirmer, suggesting of evaporative dry eyes according to standard grading.[12]

The OQAS allows an objective assessment of intraocular scattering[13] and objectively measures the effect of optical aberrations. The tear film analysis of OQAS records dynamic changes of the OSI values and calculates the mean OSI over 20 s and its standard deviation (Mean OSI). Mean OSI gives us an indicator of tear film disturbances. An inverse relation was found between the TBUT and mean OSI, which implies a worsening of quality of vision with the severity of DED. This is similar to findings shown in other studies that have measured optical quality in patients with fluctuating vision due to poor ocular surface and found that dry eye and poor ocular surface can significantly contribute to poorer optical quality.[9] Parameters on the OQAS such as OSI and mean OSI, MTF, and Strehl's ratio have shown good repeatability and reproducibility even in dry eye patients, and hence, mean OSI can be a useful tool to gauge tear optics.

Although there have been studies that have looked at how alterations of tear film osmolarity and dry eyes alter the repeatability of instruments, there has been no study in literature to the best of our knowledge which has used the optical quality analyzer (OQAS, Visio metrics S.L, Terrassa, Spain) and studied the influence of tear film optics on repeatability of these modern imaging devices. We utilized mean OSI, which is an indicator of quality of the film, or in simple terms, ocular surface stability, and studied its influence on repeatability of Pentacam AXL wave and iTrace. The optical principle most commonly used in aberrometers is the Hartmann–Shack, as used in the Pentacam AXL wave, followed by the ray tracing aberrometry, used in the iTrace.

Previous repeatability studies have been conducted predominantly on healthy subjects. Studies done on repeatability in Scheimpflug-based topographers such as by Kumar *et al*.[2] showed TRT for Keratometry in healthy eyes of 0.28, which was comparable to our study in eyes with OSI < 1 with a TRT of 0.31.

The Sw, TRT, and COV were higher in eyes with OSI ≥ 1, suggesting poorer repeatability for keratometry, pachymetry, and total ocular aberrations with increasing objective scatter.

We found poorer repeatability in all parameters studied when we looked at those eyes with an OSI < 1 as compared to those with OSI ≥ 1, with maximum variation for anterior segment parameters seen with thinnest pachymetry and least for keratometry. While looking at aberrations, maximum variation was seen with HOA and least with LOA.

One can expect that the unstable tear film can result in an irregular surface and disrupt the anterior segment and aberrations measurements. With tear-film instability, the quality of the refractive surface is unpredictable, often changing between blinks.

Table 8: Repeatability (with 95% CI) of flat keratometry, steep keratometry, TCT, RMS HOA, RMS LOA, RMS COMA, and SA derived from Pentacam AXL wave in postrefractive eyes with a mean OSI ≥1

	Sw	TRT	COV (%)	ICC
Flat keratometry	0.32 (0.13-0.46)	0.88 (0.48-0.99)	0.5 (0.0-0.9)	0.92
Steep keratometry	0.18 (0.05-0.22)	0.49 (0.23-0.68)	1.8 (0.5-2.2)	0.90
TCT measurement	10.65 (7.3-12.23)	29.5 (20.6-41.2)	3.3 (0.3-4.9)	0.93
RMS HOA	0.046 (0.016-0.062)	0.12 (0.06-0.18)	9.8 (5.2-14.1)	0.78
RMS LOA	0.14 (0.07-0.32)	0.38 (0.11-0.56)	4.8 (2.4-7.6)	0.84
RMS COMA	0.037 (0.018-0.051)	0.102 (0.06-0.19)	6.2 (3.6-9.4)	0.79
SA	0.021 (0.011-0.039)	0.058 (0.023-0.076)	6.1 (3.1-9.6)	0.80

TCT – thinnest corneal thickness, RMS HOA – Root means square of higher-order aberrations, RMS LOA – Root mean square of lower-order aberrations, RMS COMA – Root mean square of coma, SA – Spherical aberration, Sw – within-subject standard deviation, TRT – test–retest variability, COV – within-subject coefficient of variation, ICC – intraclass correlation coefficient, CI – confidence interval, OSI – objective scatter index

Table 9: Comparison of repeatability of total aberrations derived from Pentacam AXL wave and iTrace in postrefractive eyes with a mean OSI ≥1

Parameter	Pentacam AXL wave	iTrace
RMS COMA		
Sw (D)	0.037 (0.018-0.051)	0.041 (0.3-0.062)
TRT (D)	0.102 (0.06-0.19)	0.113 (0.034-0.22)
COV (%)	6.2 (3.6-9.4)	7.5 (4.1-11.2)
ICC	0.79	0.78
RMS HOA		
Sw (D)	0.046 (0.016-0.062)	0.059 (0.03-0.076)
TRT (D)	0.12 (0.06-0.18)	0.16 (0.032-0.24)
COV (%)	9.8 (5.2-14.1)	10.1 (6.3-14.6)
ICC	0.78	0.76
RMS LOA		
Sw (D)	0.14 (0.07-0.32)	0.23 (0.05-0.36)
TRT (D)	0.38 (0.11-0.56)	0.63 (0.24-0.86)
COV (%)	4.8 (2.4-7.6)	6.9 (3.4-9.7)
ICC	0.84	0.81
SA		
Sw (D)	0.021 (0.011-0.039)	0.035 (0.013-0.052)
TRT (D)	0.058 (0.023-0.076)	0.096 (0.04-0.13)
COV (%)	6.1 (3.1-9.6)	7.4 (4.1-10.2)
ICC	0.80	0.79

RMS HOA – Root means square of higher-order aberrations, RMS LOA – Root mean square of lower-order aberrations, RMS COMA – Root mean square of coma, SA –Spherical aberration, Sw – within-subject standard deviation, TRT – test–retest variability, COV – within-subject coefficient of variation, ICC – intraclass correlation coefficient, OSI – objective scatter index

In our study, ICC for all parameters in Pentacam AXL wave including aberrations were >0.8, suggesting good repeatability in OSI <1 group; however, ICC dropped in all parameters when we looked at those eyes with an OSI ≥1, with ICC <0.8 for RMS HOA and RMS COMA.

On comparing repeatability of aberrations in Pentacam AXL wave and iTrace, all parameters in iTrace had higher (poorer repeatability) Sw, and TRT with a larger COV for all aberrations. Maximum variation was seen with HOA, SA and least with LOA.

Even in iTrace when we compared repeatability of aberrations in eyes with OSI <1 and OSI ≥1, there was poorer repeatability in those with higher OSI, with ICC for RMS HOA and RMS LOA and SA <0.8 with OSI ≥1.

There have been studies that have looked at effect of tear osmolarity and repeatability. Epitropoulos *et al*.[14] showed that IOL lens master device resulted in intraocular lens power calculation difference of more than 0.5 D in over 10% of hyperosmolar eyes. In their study, tear hyperosmolarity was found to be associated with lower repeatability while looking at keratometry. Artificial tear substitutes in dry eye patients have been shown to be effective in improving the corneal optical quality by overall improving the higher-order aberrations[15] and several ectasia parameters detected on Scheimpflug imaging of the anterior corneal surface.[16] Koh *et al*.[17] reported that ocular forward light scattering and corneal backward light scattering from the anterior cornea were significantly greater in dry eyes as compared to normal eyes using the Oculus Scheimpflug imaging system. Zemova *et al*.[18] showed that there was no association between dry eye and topographic changes in keratoconus patients by a Pentacam topographer.

Thus, analyzing tear optics and quality of vision can not only have a role in correctly imaging these patients and interpreting their scans, poor visual quality can also impact quality of life of these patients. It is important to evaluate subjective symptoms and quality of life scores in addition to objectively measuring the tear film with tools such as the OQAS, which can play an important role in our approach to manage and treat these patients and provide satisfactory postoperative treatment outcomes.

Conclusion

In conclusion, eyes with poorer tear optics (mean OSI ≥1) had lower repeatability both in Pentacam AXL wave and iTrace. Repeatability in eyes with an OSI ≥1 was better in Pentacam AXL wave as compared to iTrace. Thus, a hybrid topographer and an aberrometer had a better repeatability than a pure aberrometer in eyes with poorer tear optics, and this does highlight the future role and utility of hybrid devices that would replace conventional devices.

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Conflicts of interest

There are no conflicts of interest.

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