



RESEARCH ARTICLE

Comparison of anterior corneal aberrometry, keratometry and pupil size with Scheimpflug tomography and ray tracing aberrometer in moderate and high refractive error

Aishwarya Jha^{1*}, Jyoti Gangta², Neha Kapur³

Abstract

Background: Keratometry is essential for assessing corneal curvature, refractive power, and astigmatism. Advances in imaging, such as topography and tomography, have improved measurement accuracy for surgical planning and disease diagnosis. The Pentacam HR® uses Scheimpflug imaging for higher-order aberrations (HOAs), while iTrace® employs ray tracing for wavefront aberrometry.

Aim: This study compared anterior corneal wavefront aberrations, keratometry, astigmatism axis, and pupil size measurements between Pentacam HR® and iTrace® in moderate and high refractive error.

Methodology: A retrospective observational study at a tertiary care hospital in north India analysed 202 eyes from 107 healthy volunteers under mesopic conditions. Parameters included spherical aberration (Z40), vertical coma (Z3-1), horizontal coma (Z3+1), trefoil (Z3-3, Z3+3), keratometry (K1, K2), and pupil size.

Results: The mean age was 26.73 ± 5.05 years. Significant differences were noted in keratometry: Pentacam HR® recorded higher K Flat (43.78 ± 1.70 D vs. 41.38 ± 3.64 D, $p < 0.001$) and K Steep (45.09 ± 1.84 D vs. 43.19 ± 3.49 D, $p < 0.001$). K Flat Axis differed ($p = 0.013$), while K Steep Axis did not ($p = 0.419$). Pupil size was larger with iTrace® (5.71 ± 0.91 mm vs. 2.90 ± 0.62 mm, $p < 0.001$). Coma (Z3-1), trefoil (Z3-3), and trefoil (Z3+3) showed significant differences ($p < 0.001$), while spherical aberration (Z40) ($p = 0.828$) and horizontal coma (Z3+1) ($p = 0.200$) did not. Bland-Altman plots showed poor agreement for axis measurements, moderate for keratometry, and better for HOAs.

Conclusion: Significant differences in keratometry, pupil size, and HOAs indicate that Pentacam HR® and iTrace® measurements are not interchangeable. Clinicians should consider these discrepancies, especially in high refractive error cases.

Keywords: HOA, Pentacam HR®, iTrace®, Scheimpflug Imaging, Ray Tracing, Corneal Topography, Corneal Tomography.

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Introduction

Keratometry is a fundamental ophthalmic technique used to measure the curvature of the cornea, the transparent anterior structure of the eye responsible for directing light onto the retina (Martin, R. (2018). It plays a crucial role in evaluating corneal shape, determining refractive power, and diagnosing astigmatism, making it an essential tool in clinical ophthalmology. (Gurnani, B., & Kaur, K. (2023)

Various imaging modalities, including slit-scanning elevation topography, Placido disc-based keratoscopy, Scheimpflug imaging, and optical coherence tomography, enable precise keratometric evaluation. (Fan, R., Chan, T. C. & *et al.* 2018). Each technology employs distinct principles to measure higher-order aberrations (HOA). The Pentacam HR® (Oculus Optikgeräte GmbH, Wetzlar, Germany) utilizes a rotating Scheimpflug system to generate tomographic data and derive corneal HOA. (Motlagh, M. N., Moshirfar, M., *et al.* 2019). Aberrometers such as iTrace® (Tracey Technologies Corp., Houston, TX, USA) employ ray tracing to capture consecutive wavefront measurements within milliseconds,

thereby mitigating the influence of ocular motion. (Bayhan, H. A., Bayhan, S. A., *et al.* 2014)

In contrast, Hartmann-Shack technology records a single-shot wavefront image, offering high-resolution assessments. Additionally, automated retinoscopy, based on dynamic retinoscopy, projects a slit-shaped light beam onto the retina and captures its reflection through an array of rotating photodetectors, providing a comprehensive analysis of ocular aberrations. (Visser, N., Berendschot, T. T. J. M., Verbakel, *et al.* 2011)

Beyond keratometry and HOA assessment, pupil size and decentration significantly influence postoperative visual outcomes in corneal refractive surgery. (Yang, Y., Thompson, *et al.* 2002 and Khalifa, M. A., Allam, W. A., & *et al.* 2012). If surgical centration is based on a constricted pupil, subsequent pupil dilation under mesopic conditions may induce a decentred ablation profile, potentially compromising optical quality. This is particularly relevant in wavefront-guided ablation treatments, where higher-order aberration correction amplifies sensitivity to decentration. A similar challenge arises in cataract surgery, where aspheric intraocular lenses (IOLs) are implanted under pharmacologically dilated pupils. (Atchison, D. A. 1991) Any shift in pupil centration postoperatively could affect optical performance, necessitating precise centration strategies. (Mrochen, M., Kaemmerer, *et al.* 2001)

As imaging technologies continue to advance, an important clinical question is whether different devices provide comparable keratometric and aberrometric measurements. The Pentacam HR® and iTrace® use different optical principles for assessing keratometry and wavefront aberrations, but few studies have directly compared their measurements. This study aims to evaluate and compare anterior corneal spherical and coma aberrations, keratometry, astigmatism axis, and pupil size between these two devices to determine their reliability, accuracy, and potential interchangeability in clinical practice.

Methodology

This retrospective study was conducted on healthy adult volunteers at a tertiary eye care setup in north India between January 2024 and January 2025, with approval from the hospital's Internal Scientific Committee.

Inclusion Criteria

Participants had clear corneas and a refractive error with a spherical equivalent greater than ± 3.00 diopters (D).

Exclusion Criteria

Those with a refractive error less than ± 3.00 D, active or residual ocular diseases (e.g., HSV keratitis, uveitis, glaucoma, cataracts, amblyopia, retinal disease, corneal dystrophies), prior intraocular or keratorefractive surgery, or an inability to cooperate with examinations were excluded.

All participants underwent standardized mesopic (20 lux) measurements using the Pentacam HR® and iTrace®, conducted by a single observer (SG). Proper head positioning and fixation were ensured before automatic image acquisition.

- Pentacam HR® (software version 1.30r04) employs rotating Scheimpflug imaging for anterior/posterior corneal topography, elevation, pachymetry, anterior chamber parameters, and pupil size. It captures 25 meridional images, generating a 3D anterior segment model with 138,000 elevation points. Corneal wavefront data were derived using Zernike polynomial expansion over a 6 mm zone.
- iTrace® (software version 6.3.3) utilizes ray tracing to measure total ocular HOA, keratometry, corneal topography, and pupil size. It directs a laser beam via an x-y scanner, with aberration measurements controlled by an acoustic optical deflector. Corneal aberrometry is obtained from Placido-based topography and ray tracing, with data converted into Zernike polynomials. Scans with misalignment or artifacts were discarded, and measurements were repeated for optimal quality. Pentacam scans were accepted only if the quality score (QS) was 'OK,' while iTrace® 256 points were verified individually.

Key recorded anterior corneal parameters from the central 6 mm included spherical aberration (Z_4^0), vertical (Z_3^{-1}) and horizontal coma (Z_3^{+1}), trefoil (Z_3^{-3} , Z_3^{+3}), K1, K2, steep and flat axis, and pupil size. Data were recorded using Microsoft Excel and analyzed with R software (version 4.3.2). A paired-sample t-test assessed differences between iTrace® and Pentacam HR® values, while Bland-Altman analysis evaluated agreement between the two devices for corneal and optical parameters in moderate-to-high refractive errors.

Sample Size and Statistics

The study primarily aims to compare corneal keratometry, pupil size, and anterior corneal aberration parameters (coma, trefoil, and spherical) measured by iTrace and Pentacam. Aside from the type-I error and the power of the test (assumed to be 5% and 80%, respectively), other parameters necessary for calculating the sample size include the inherent variation of the test statistic under the null and alternative hypotheses, as well as the clinically relevant difference between the two measurements.

Actual sample size

The study included approximately 200 patients with moderate or high refractive error who presented at our hospital between January 2024 and January 2025.

Statistical analysis

Hypothesis testing was conducted, with most variables being continuous. A paired sample t-test was applied to

determine the statistical significance of differences between measurements taken by iTrace and Pentacam.

Other statistical analyses included the Bland-Altman analysis to evaluate whether variations in measurement differences remained within clinically acceptable limits.

Results

The study analysed 202 eyes from 107 individuals, with a mean age of 26.73 ± 5.05 years, ranging from 18 to 44 years. A paired t-test was performed to compare anterior corneal parameters measured using the Pentacam HR® and iTrace® in 202 eyes. A comparative analysis revealed significant differences between Pentacam HR® and iTrace® in measurements of K Flat, K Steep, pupil size, and several higher-order aberrations (Table 1). Significant differences were observed in multiple keratometric values. The Pentacam HR® reported higher mean values for flat keratometry (K Flat: 43.78 ± 1.70 D) compared to iTrace® (41.38 ± 3.64 D), with a mean difference of 2.40 ± 3.17 D ($p < 0.001$). Similarly, steep keratometry (K Steep) was significantly higher in the Pentacam HR® (45.09 ± 1.84 D) than in iTrace® (43.19 ± 3.49 D), with a mean difference of 1.90 ± 2.95 D ($p < 0.001$). The flat axis (K Flat Axis) also demonstrated a significant difference ($98.67 \pm 73.07^\circ$ vs. $85.00 \pm 68.32^\circ$, $p = 0.013$). However, no statistically significant difference was found in the steep axis (K Steep Axis) between the two devices ($p = 0.419$).

Pupil size measurements exhibited a marked discrepancy, with iTrace® reporting significantly larger values (5.71 ± 0.91 mm) compared to Pentacam HR® (2.90 ± 0.62 mm), with a mean difference of -2.81 ± 0.95 mm ($p < 0.001$).

Regarding higher-order aberrations (HOAs), coma (Z_3^{-1}) ($p < 0.001$), trefoil (Z_3^{-3}) ($p < 0.001$), and trefoil (Z_3^{+3}) ($p < 0.001$) showed significant differences between devices. In contrast,

spherical aberration ($p = 0.828$) and coma (Z_3^{+1}) ($p = 0.200$) did not demonstrate statistically significant variation.

These findings suggest that while both devices provide corneal topography and aberrometry data, their measurements are not directly interchangeable, particularly for keratometry, pupil size, and specific HOAs.

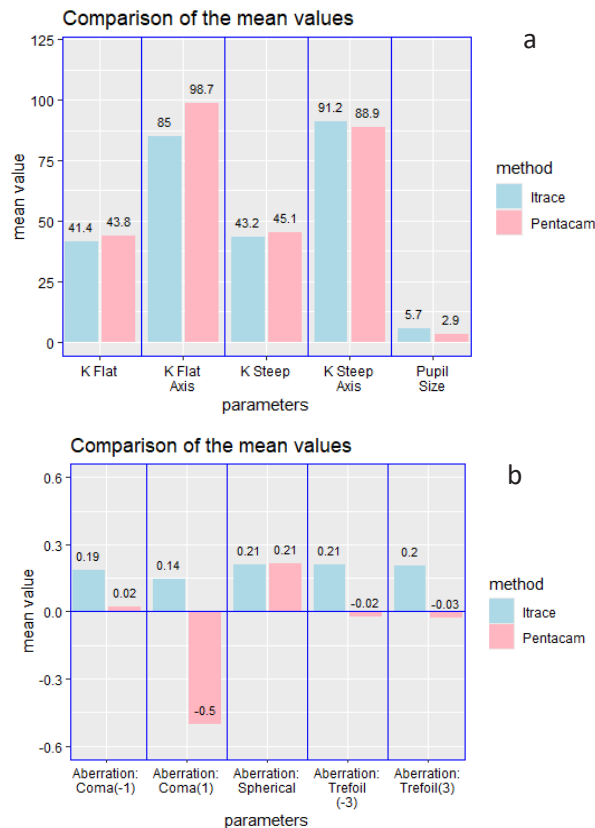
Comparison of mean aberration values between I Trace and Pentacam

The Bland-Altman plots assess the agreement between Pentacam and iTrace measurements for various corneal and optical parameters. The K steep axis and K flat axis exhibit large variability, indicating poor agreement between the devices. K steep and K flat values show moderate agreement, with some dispersion around the mean difference. Pupil size measurements also demonstrate variability, suggesting a degree of discrepancy. In contrast, higher-order aberrations (coma, spherical, and trefoil) generally show better agreement, with tightly clustered data points and narrower limits of agreement. These findings suggest that while some parameters are interchangeable between Pentacam and iTrace, others require cautious interpretation due to significant measurement differences (Graph 1).

The Bland-Altman analysis evaluates the agreement between Pentacam HR® and iTrace® measurements for keratometry and higher-order aberrations (HOAs). In the Graph 2, 3K Flat (a) and K Steep (c) show moderate agreement, but the wider limits of agreement indicate variability between the two devices. This suggests that while these keratometric values may be comparable, some dispersion around the mean difference limits their interchangeability. The graphs (b) and (d) illustrate K Flat Axis and K Steep Axis, which exhibit large variability, especially in the K Flat Axis. This significant spread indicates

Table 1: Result of paired comparison (Paired t test)

Parameters	N	Pentacam		ITrace		Diff=Pentacam-Itrace		p-value (paired t-test)
		Mean	SD	Mean	SD	Mean	SD	
K Flat	202	43.78	1.70	41.38	3.64	2.40	3.17	0.000
K Flat Axis	202	98.67	73.07	85.00	68.32	13.67	77.44	0.013
K Steep	202	45.09	1.84	43.19	3.49	1.90	2.95	0.000
K Steep Axis	202	88.87	29.07	91.23	39.09	-2.37	41.48	0.419
Pupil Size	202	2.90	0.62	5.71	0.91	-2.81	0.95	0.000
Aberration								
Coma (-1)	202	0.02	0.21	0.19	0.37	-0.17	0.42	0.000
Coma (1)	202	-0.50	7.18	0.14	0.17	-0.65	7.18	0.200
Spherical	202	0.21	0.15	0.21	0.36	0.01	0.40	0.828
Trefoil (-3)	202	-0.02	0.16	0.21	0.39	-0.23	0.42	0.000
Trefoil (3)	202	-0.03	0.16	0.20	0.43	-0.23	0.46	0.000



Graph 1: Comparison of Mean Values for Aberration Parameters Between iTrace and Pentacam

poor agreement and inconsistency in axis determination, suggesting that these measurements are not reliably interchangeable between the devices. In contrast, (f, g, h, i, j) graphs, which represent HOAs (Coma Z_3^{-1} & Z_3^{+1} , Trefoil Z_3^{-3} & Z_3^{+3} , and Spherical Aberration), demonstrate tighter clustering of data points and narrower limits of agreement. This indicates better consistency between Pentacam HR® and iTrace® for these parameters, making them more reliable for comparative use. In graph (e), pupil size measurements exhibited substantial discrepancies, with iTrace® reporting significantly larger values compared to Pentacam HR.

Overall, while HOAs show strong agreement, keratometric values, particularly axis measurements, require cautious interpretation due to significant variability between the two devices.

Discussion

Keratometric measurements are essential for accurate intraocular lens (IOL) power calculation, refractive surgery planning, and monitoring corneal ectasia. (McAlinden, C., Khadka, J., & *et al.* 2011). Our study compared keratometric and corneal aberration measurements obtained using the Pentacam HR® and iTrace® devices to assess their agreement and interchangeability in eyes with moderate and high refractive errors.

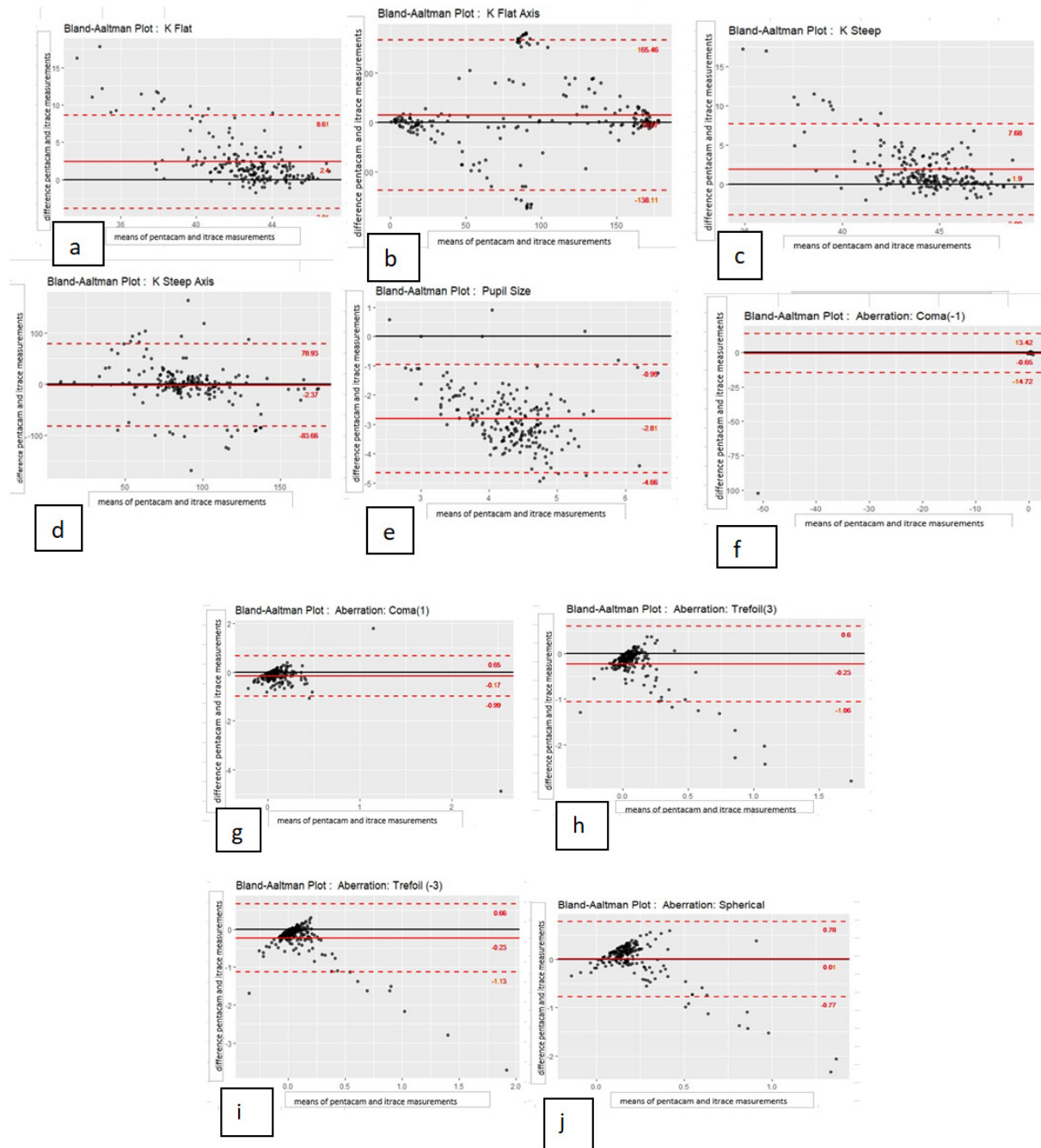
Our analysis of 202 eyes from 107 individuals revealed significant differences in multiple keratometric values between the two devices. The Pentacam HR® reported higher mean values for flat keratometry than iTrace®. Similarly, steep keratometry (K Steep) was significantly higher in the Pentacam HR® compared to iTrace®. These findings contrast with previous studies that have reported good agreement between Scheimpflug and Placido-based topographers for anterior keratometric measurements. (Tajbakhsh, Z., Salouti, R., *et al.* 2012 and Huang, J., Savini, G., *et al.* 2015)

Tajbakhsh *et al.* found comparable anterior keratometric values between Pentacam HR® and the TMS-4® topographer, suggesting interchangeability. (Tajbakhsh, Z., Salouti, R., *et al.* 2012) However, our results indicate that significant discrepancies exist between Pentacam HR® and iTrace®, making direct substitution less feasible, particularly in eyes with higher refractive errors.

The flat axis (K Flat Axis) also demonstrated a significant difference between the devices, though no significant difference was found in the steep axis. This aligns with Zhang *et al.*, who observed strong inter-device agreement in astigmatism magnitude and vector components (Zhang, Y., Dong, J., *et al.* 2020), but our findings suggest variability in specific axis measurements, particularly in cases with moderate to high astigmatism. These discrepancies may be attributed to differences in the measurement principles of each device. The Pentacam HR® uses a Scheimpflug imaging system, while the iTrace® employs ray-tracing aberrometry and Placido-disc topography, which can lead to variations in data acquisition and interpretation. (Kanczler, P., Khoramnia, R., & *et al.* 2021)

Pupil size measurements exhibited substantial discrepancies, with iTrace® reporting significantly larger values compared to Pentacam HR®. This discrepancy is consistent with the findings of Tabernero *et al.*, who reported that aberrometers measure larger pupil sizes due to lower luminance levels compared to corneal topographers. (Tabernero, J., Atchison, D. A., & *et al.* 2009). Such differences in pupil size measurement are clinically relevant, as they can influence wavefront aberration analysis and surgical planning (Calossi, A. 2007). The differences in measurement techniques used by the two devices may explain this variation: iTrace® uses a ray-tracing aberrometry approach with lower luminance, whereas Pentacam HR® employs a Scheimpflug camera with higher luminance, potentially leading to a smaller pupil diameter measurement. (Tabernero, J., Atchison, D. A., & *et al.* 2009)

Regarding higher-order aberrations (HOAs), our study found significant differences in coma (Z_3^{-1}), trefoil (Z_3^{-3}), and (Z_3^{+3}) measurements between devices. In contrast, spherical aberration and coma (Z_3^{+1}) did not show statistically significant differences. These findings align with the study by



Graph 2: The Bland-Altman plots showing agreement between I trace and Pentacam (a) K flat, (b) K flat axis, (c) K steep, (d) K steep axis, (e) Pupil size, (f) Coma⁽⁻¹⁾, (g) Coma⁽¹⁾, (h) Trefoil⁽³⁾, (i) Trfoil⁽⁻³⁾, (j) Spherical

Visser *et al.*, who reported variability in HOA measurements between different aberrometers, despite good repeatability within each device (6). Atchison *et al.* also highlighted that discrepancies in HOA values can arise due to differences in measurement techniques and pupil zone scanning. (Atchison, D. A., Suheimat, M., *et al.* 2016)

Notably, our study observed that anterior corneal spherical aberration (Z40) measured with Pentacam HR® was

significantly higher than with iTrace®, consistent with Heidari *et al.*, who reported significant differences in (Z40) values among different aberrometers, including Pentacam HR® and OPD-Scan III® (Heidari, Z., Mohammadpour, *et al.* (2020). The tendency of Pentacam HR® to record a more positive (Z40) compared to aberrometers has been documented in previous studies. (18) This may be due to differences in measurement zones, as iTrace® scans a smaller corneal

diameter compared to Pentacam HR®, leading to variations in the captured data.

Despite significant differences in (Z40) measurements, our study found strong agreement between Pentacam HR® and iTrace® for vertical coma (Z_3^{-1}) and horizontal coma (Z_3^{+1}), with a statistically significant positive correlation. This supports the findings of Wang *et al.*, who reported that coma aberrations are less sensitive to pupil size variations compared to spherical aberrations (Wang, L., Dai, E., Koch, D. D., & *et al.* 2003). Similarly, Visser *et al.* found no significant differences in vertical coma (Z_3^{-1}) and horizontal coma (Z_3^{+1}) measurements among multiple aberrometers. (Visser, N., Berendschot, T. T. J. M., *et al.*, 2011)

The discrepancies between Pentacam HR® and iTrace® can be attributed to fundamental differences in their measurement principles. Pentacam HR® uses Scheimpflug imaging to capture a three-dimensional reconstruction of the anterior and posterior corneal surfaces, while iTrace® relies on ray-tracing aberrometry and Placido-based corneal topography. (Shankar, H., Taranath, D., *et al.*, 2008) Differences in the illumination conditions, measurement zones, and processing algorithms used by these devices contribute to the observed variations in keratometric and HOA values. Furthermore, our study suggests that these differences may become more pronounced in eyes with moderate to high refractive errors, where corneal curvature variations and optical properties influence measurement accuracy.

While both Pentacam HR® and iTrace® provide valuable corneal topography and aberrometry data, their measurements are not directly interchangeable, particularly for keratometry, pupil size, and specific HOAs in eyes with moderate to high refractive errors. The discrepancies between these devices are influenced by differences in measurement techniques and illumination conditions, as well as variations in corneal curvature in eyes with moderate and high refractive errors. Clinicians should be cautious when comparing results between these devices, particularly in preoperative planning for refractive and cataract surgery. Further studies involving larger sample sizes and diverse clinical conditions are warranted to better understand the clinical implications of these discrepancies.

Conclusion

Both Pentacam HR® and iTrace® offer valuable corneal topography and aberrometry data, but their measurements are not directly interchangeable, particularly for keratometry, pupil size, and higher-order aberrations (HOAs) in eyes with moderate to high refractive errors. Variations in measurement techniques, illumination conditions, and corneal curvature contribute to these discrepancies. Clinicians should exercise caution when comparing results, especially for preoperative planning in refractive and cataract surgery. Further studies with larger and more diverse samples are needed to clarify the clinical impact of these differences.

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Institutional Review Board Statement

The study was reviewed and approved by the hospital's internal scientific committee.

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