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Evaluation of agreement among four different methods for measuring inter-pupillary distance in healthy adults

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ABSTRACT

Background: The aim of this study was to assess the agreement between four different methods of measuring interpupillary distance.

Methods: This cross-sectional study evaluated IPD in healthy adults using four methods, including corneal reflex and limbus-based manual methods, autorefractometer and mobile application (Warby Parker). Data analysis was conducted in SPSS version 27, and intraclass correlation coefficient and Bland-Altman plots were employed to assess the agreement between these methods.

Results: A total of 90 individuals with a mean age of 34.58±8.86 years participated in this study. There was no significant relationship between age and IPD (*P*>0.132). The ICC indicated good statistical agreement between the methods (ICC=0.918, 95% CI:0.845-0.953). Also, Bland-Altman analysis showed that the 95% limits of agreement were not wide in most comparisons and were clinically acceptable. The highest difference was observed between the limbus-based manual method and the mobile application (mean difference: 0.67±1.30 mm, 95% LoA: -3.23 to 1.89 mm), and the lowest difference occurred between the autorefractometer and the manual corneal reflex method (mean difference: -0.05±0.84 mm, 95% LoA: -1.70 to 1.60 mm).

Conclusion: According to the results, the lowest difference in measuring IPD that was statistically and clinically significant was noted between the autorefractometer and the manual corneal reflex method and the highest difference was found between the limbus-based method and the mobile application. It is recommended to use standard methods for achieving accurate measurements and the results obtained from mobile applications should not be the only basis for clinical decision-making.

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Introduction

Interpupillary distance (IPD) refers to the distance between the centers of the two pupils of the eye(1). It varies with age and is larger in men than in women (1,2). It has also been reported to vary between races (3), yet some studies have reported no racially significant difference in this distance (4,5)

IPD plays an important role in the optical correction of patients requiring spectacles. To obtain proper correction with spectacles, it is necessary to align the optical centers of the lenses with the visual axes, which is achieved by determining the IPD of the eyes (6). If the optical centers of the two lenses do not coincide with the centers of the pupils—or align with the IPD—prismatic effects will be induced.6 Misalignment between the optical centers of the spectacle lenses and the centers of the pupils leads to eye fatigue and discomfort and, in cases with high refractive error, causes diplopia(7).

Accurate measurement of IPD is critical for diagnosing ocular hypotelorism (small IPD) and hypertelorism (large IPD) in some syndromes and skeletal anomalies (8,9). IPD is also

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associated with ocular deviations (10) and serves important clinical applications in assessing convergence and the accommodative convergence-to-accommodation ratio (11). Previous studies have shown that IPD is related to stereopsis and depth perception, with smaller IPD associated with better stereopsis (12,13).

There are various methods for measuring IPD. Typically, this is accomplished in the clinic using a ruler. There are also special devices called pupillometer for measuring IPD. Additionally, with the spread of viral diseases, different mobile applications have been developed to measure IPD (14) Given the importance of accurate IPD assessment, especially in optometric examinations and spectacle fitting, this study evaluated the agreement between four different methods of IPD measurement: corneal reflex-based and limbus-based manual methods, autorefractometer, and mobile application. The results of this study can help identify the accuracy and reliability of each method and will ultimately improve measurement standards and reduce potential errors in clinical settings.

Methods

This cross-sectional study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of Zahedan University of Medical Sciences (ethical code: IR.ZAUMS.REC.1404.251). Participants included healthy adults visited at the Optometry Clinic of Shahid Razmjoo Moghadam Medical Center in Zahedan. The objectives of the study were initially explained, and interested individuals were recruited on an informed voluntary basis. A written consent form was obtained from all participants.

The eligibility criteria included age of 20 to 50 years, no systemic or ocular disease, and no history of cosmetic or ocular surgery. Individuals with a history of head and eye trauma, obvious eye deviation, or facial and skull deformities were excluded from the study.

First, a comprehensive ocular examination was performed, including slit-lamp bio-microscopy and direct ophthalmoscopy. Refractive errors was then assessed by an auto-refractometer (Charops CRK1, Shanghai, China) followed by subjective refraction. Four different methods were used to measure IPD.

The manual method or Viktorin's method

This method involves manual measurement of the distance between two ocular markers, such as the pupil center or the limbus, using a millimeter ruler (1). The participant was seated 40 cm away from the examiner and was instructed to look into the examiner's open eye. First, the ruler's zero mark was aligned with the temporal limbus of the participants' left eye while the examiner viewed with the right eye and closed the left eye to prevent parallax error. Then, the reading at the nasal limbus of the participant's right eye was recorded while the examiner's left eye was open and the right eye closed.

The same measurement was repeated using the corneal reflex while patients looked into a penlight positioned within the examiner's open eye. To measure the IPD for near vision, a target or penlight was placed in line with the participant's nose. The distance between the outer limbus of one eye and the inner limbus of the opposite eye, as well as the distance between the corneal reflexes, was then measured. During measurement, to improve accuracy, the examiner alternated fixation between eyes by closing one eye while viewing with the other, corresponding to the eye being examined.

The autorefractor method

In this method, the participant was seated comfortably at an autorefractor (Charops CRK1, Shanghai, China); their forehead and chin were placed on the designated rests of the device; and the IPD was measured automatically.

The Warby Parker application (version 115.0.0/13388)

This is considered one of the most accurate smartphone applications for measuring IPD (15). Using the phone's front-facing camera and facial recognition algorithms, the application detects the exact location of the pupil centers to calculate IPD. The person examined must look at the mobile screen without spectacles while holding the mobile at arm's length and follow the prompts so that the measurement is completed.

The sequence of measurement methods was random, and all measurements were performed in one session. There was a 5-minute interval between each method. Each method was used three times for each individual and the average was recorded.

Data Analysis

SPSS version 27 was used to analyze the data. The normality of the data was assessed using the Kolmogorov-Smirnov test. The data were described in terms of mean, standard deviation, and 95% confidence interval. Repeated-measures analysis of variance was performed to examine differences between the four methods and the effect of gender on IPD. The Pearson correlation test was also used to explore the correlation between age and IPD. Intraclass correlation coefficient (ICC) and 95% limits of agreement (LoA) were used to statistically examine the agreement of the data obtained by the four methods.

In the agreement analyses, ICC less than 0.50 was classified as poor, ICC greater than 0.5 and less than 0.75 as moderate, ICC greater than 0.75 and less than 0.90 as good, and ICC greater than 0.90 as very good (16). The 95% LoA was calculated as the mean difference ± 1.96 standard deviation of the difference between two measurement methods. Following previous studies, an LoA of ±2 mm was defined as clinically acceptable agreement between the methods (17) In addition, Bland-Altman plots were used to show the agreement of the four methods. $P<0.05$ was considered statistically significant.

Result

A total of 90 individuals (52 males and 38 females) with a mean age of 34.58 ± 8.86 years (ranging from 20 to 50 years) participated in this study. Table 1 shows the mean and standard deviation of IPD measured by the four methods in the male and female groups.

The Pearson correlation coefficient did not show a significant relationship between age and the measured values of IPD ($P>0.132$). Repeated-measures analysis of variance showed a statistically significant difference between the measurement methods ($F_{3,264} = 46.52$, $P<0.001$, ŋ2 = 0.346). However, gender did not have a statistically significant effect on IPD ($F_{1,88}=1.76$, $P= 0.118$, ŋ2 = 0.020).

The results of paired test with Bonferroni correction showed that the IPD obtained via the manual limbus-based manual method was significantly greater than those of other methods ($P<0.001$). Additionally, the mobile application yielded a significantly higher IPD compared to both the manual corneal reflex method and the autorefractometer ($P<0.025$).

Also, in the manual techniques, near IPD was significantly higher with the limbus-based method than the manual corneal reflex method (mean difference: 1.10; 95% CI: 0.95-1.42; $P < 0.001$, d = 0.671).

Table 1. Mean and standard deviation of IPD measured using four different methods in males and females

		Males	Females	Total
Manual limbus-based method	Far	64.16±3.11	63.44±2.76	63.86±2.98
	Near	61.95±3.22	61.18±2.99	61.62±3.13
Manual corneal reflex-based method	Far	63.14±3.19	62.36±2.75	62.81±3.02
	Near	60.83±3.22	60.10±2.92	60.52±3.10
Autorefractometer		63.17±2.99	62.21±2.93	62.77±2.99
Phone application		63.52±2.64	62.72±2.99	63.18±2.80

The ICC for the agreement between the four measurement methods was 0.918 (95% CI: 0.845-0.953), indicating high and statistically significant agreement between the methods ($P<0.001$).

Examination of pairwise agreements between the four methods showed that the ICC between the mobile application and the limbus-based method was 0.933 (95% CI: 0.861-0.964), between the mobile application and the manual corneal reflex method was 0.955 (95% CI: 0.927-0.971), and between the mobile application and the autorefractometer was 0.976 (95% CI: 0.946-0.987).

Also, the agreement between the limbus-based method and the manual corneal reflex method was 0.961 (95% CI: 0.160-0.990), between the limbus-based method and the autorefractometer was 0.937 (95% CI: 0.542-0.979), and between the manual corneal reflex method and the auto-refractometer was 0.980 (95% CI: 0.970-0.987). Figure 1 shows Bland–Altman plots and 95% LoAs comparing the four methods of IPD measurement.

The mean difference in IPD between the mobile application and the limbus-based method was -0.67±1.30 mm, with a 95% LoA of -3.23 to 1.89 mm. This value was 0.37±1.17 mm between the mobile application and the manual corneal reflex method, with a 95% LoA of -1.92 to 2.66 mm.

When comparing the mobile application with the auto-refractometer, the mean difference was 0.42±0.80 mm, with a 95% LoA of -1.14 to 1.99 mm. Also, the mean difference between the limbus-based method and the manual corneal reflex method was 1.04±0.60 mm, with a 95% LoA of -0.13 to 2.22 mm.

Regarding the comparison between the limbus-based method and the auto-refractometer, the mean difference was 1.09±1.03 mm and the 95% LoA was -0.93 to 3.12 mm. Finally, the mean difference between the auto-refractometer and the manual corneal reflex method was -0.05±0.84 mm, with a 95% LoA of -1.70 to 1.60 mm.

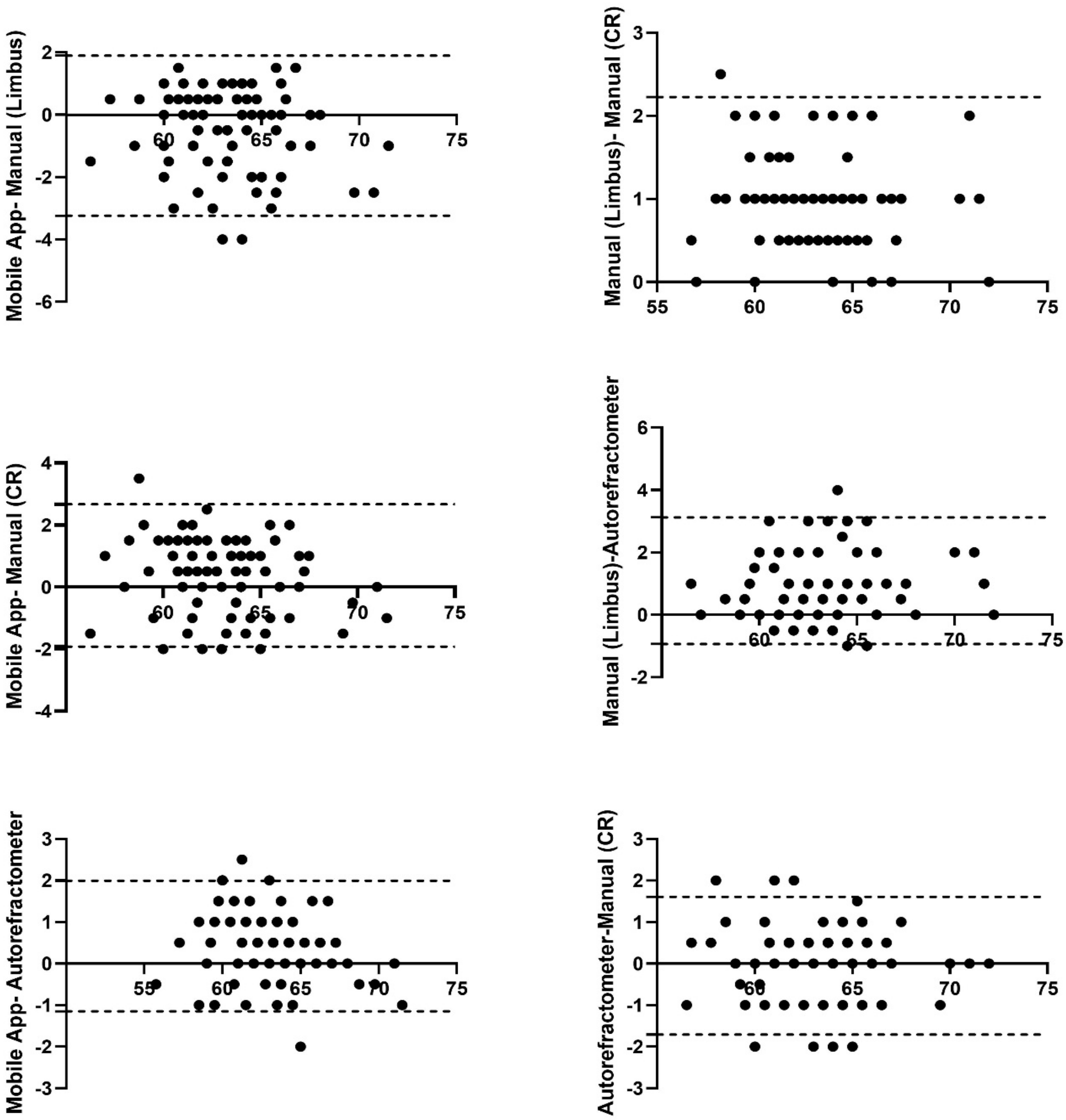

Figure 1. Bland-Altman plot exhibiting the agreement of four different methods of IPD measurement, including manual limbus-based method, manual corneal reflex method, autorefractometer, and mobile application. The vertical axis shows the difference between the two methods, and the horizontal axis shows the mean values of the two methods for each individual. The dashed lines show the 95% limits of agreement.

Discussion

IPD measurement plays an important role in optometric examinations, in addition to prescribing and dispensing of spectacles. Misalignment of the optical centers of spectacle lenses relative to IPD can cause prismatic effects in the spectacles. The prism created in cases with high refractive error is unacceptable, which highlights the importance of accurate measurement of IDP.[6] In this study, we evaluated the agreement of four different methods of measuring IPD in healthy individuals. Our results showed that the limits of agreement for some of these methods are within the clinically acceptable range.

The results of this study demonstrated no significant correlation between age and IPD. In one study, the authors reported an increase in IPD with increasing age in the first 17 years of life (18). Another study also found a 3% increase in IPD in males during adolescence (19). A major reason for the discrepancy between the results of our study and the previous two studies could be related to the age of the participants. In this study, people over 20 years of age were examined, and their ocular and facial parameters were relatively stable, with no change in IPD. Consistent with the present study, another study reported an increase in IPD from childhood to age 20, followed by stability thereafter (20).

Although the results of this study did not show a statistically significant difference in IPD between the two genders, but according to the Table 1, it was found that IPD is larger in males than in females, confirming previous research(18,21) One of the reasons for this difference is the greater transverse width of the face in men than in women(22), which can affect the position of the orbit and eyes and increase IPD in men compared to women.

A difference of 2 mm between various methods of IPD measurement is considered clinically acceptable (17). Although this study revealed very good statistical agreement between the four methods (ICC > 0.9), the Bland-Altman analysis showed that approximately 86.6% cases had limits of agreement between the mobile application and the manual limbus-based method within ±2 mm. this suggested that, while agreement was generally good, it may not consistently meet the threshold for clinical acceptability between these two methods. In comparison, the agreement between the limbus-based method and the autorefractometer was within ±2 mm in 90% of cases. For the mobile application method and the manual corneal reflex method, 97% of cases were within ±2 mm. This agreement increased to 98.8% when comparing the mobile application with the autorefractometer, as well as the manual corneal reflex method with the limbus-based method. Finally, comparison between the autorefractometer and the manual corneal reflex method showed that 100% of cases were within ±2 mm, indicating very high clinically agreement between these two methods.

Accordingly, the highest clinical disagreement was noted between the mobile application and the limbus-based method, while the highest agreement was found between the manual corneal reflex method and the autorefractometer. Therefore, the autorefractometer can be considered a reliable option for measuring IPD, while the use of mobile applications—especially compared to the limbus-based method—requires more caution while interpreting the results.

Some studies have shown good statistical and clinical agreement, while others have reported unacceptable clinical agreement between different methods of IPD measurement(14,23) One reason for these mixed results could be the criteria used to assess agreement, as some studies have defined good agreement solely based on statistically significant findings and high ICC values, even if the limits of agreement obtained are not clinically acceptable(10).

One of the reasons for the clinical differences between methods could be the variation in the reference points used to measure IPD. This is consistent with our results, since the highest IPD values were obtained through the manual method of using limbus markers. The difference in IPD values obtained with the limbus-based method compared to other techniques that are based on corneal reflex can be explained by the kappa angle, which refers to the difference between the pupillary and visual axes (14). In corneal reflex-based techniques, the reference point for measurement is the corneal reflex, which is slightly away from the center of the pupil, which is used in the manual method of using limbus markers. The corneal reflex is typically located nasally to the center of the pupil; therefore, the limbus-based manual method yields higher IPD values than other methods (14)

Various sources of error have also been explored in relation to the manual measurement method, including parallax error due to the large difference in IPD between the patient and the examiner, incorrect distance between the patient and the examiner, and incorrect position of the measuring instrument (ruler), all of which can result in inaccurate measurement(1,14) In one study, it was shown that the obtained values differed between a manual method and the autorefractometer, such that the mean IPD was 57.04 ± 3.46 mm as measured by the manual method and 60 ± 3.74 mm based on the autorefractometer(24)

Although in this study the highest agreement was achieved between the autorefractometer and the manual method based on corneal reflex, it should be noted that the autorefractometer is designed to measure refractive errors, and factors such as head movement and eye movement when positioning the device to in front of each eye can reduce the accuracy of this technique in measuring IPD. Also, low light conditions while using the autorefractometer can cause the pupil size to change compared to the manual method, causing errors in measurement. Therefore, it is necessary to consider these points when measuring IPD with the autorefractometer method to improve accuracy.

This study had some limitation. Restricted age range, including only adults, is one of the limitations of this study. It is recommended that future studies extend this research to cover children and older adults as well.

Conclusions

Based on the results of this study, the highest clinical agreement in IPD measurement was obtained between the auto-refractometer and the manual corneal reflex method, and the highest discrepancy was found between the manual limbus-based method and the mobile application, which could be due to the difference in the measurement reference point, movement errors, and lighting conditions. Therefore, caution should be exercised when using mobile applications for accurate measurement of IPD.

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Ethical issues

The authors declare that this study was conducted in accordance with the principles of Helsinki Declaration and was approved by the Ethics Committee of Zahedan University of Medical Sciences (Ethics Code: IR.zaums.REC.1404.251) Written Informed Consent was obtained from all participates to participate in the study.

Conflicts of Interest

The authors of this study have no conflicts of interest to report.

Author Contribution

Conceptualization: M.M , S.F
Methodology: M.M , S.F
Software: M.M
Validation: M.M, T.R
Formal analysis: M.M
Investigation: M.M, S.F
Resources: S.F, A.E
Data curation: S.F, A.E
Writing-original draft: M.M
Writing- review and editing: S.F, M.M
Visualization: M.M, S.F, A.E
Supervision: M.M, T.R
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