SCIENTIFIC REPORT

Comparison of anterior chamber depth measurements using the IOLMaster, scanning peripheral anterior chamber depth analyser, and anterior segment optical coherence tomography

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Aim: To compare anterior chamber depth measurements by three non-contact devices—the IOLMaster, scanning peripheral anterior chamber depth analyser (SPAC), and Visante anterior segment optical coherence tomography (AS-OCT)

Methods: Prospective, cross sectional study of 497 phakic subjects over 50 years of age attending a community clinic in Singapore. Anterior chamber depth of the right eye was measured using all three techniques by the same investigator. Depth measurements were made from the corneal epithelium to the anterior lens surface. The values obtained were compared using Bland–Altman analysis.

Results: 232 men and 265 women were examined (mean (SD) age, 63.4 (7.9) years). Mean anterior chamber depth was 3.08 (0.36) mm with IOLMaster, 3.10 (0.44) mm with SPAC, and 3.14 (0.34) mm with AS-OCT. A significant difference was present between the anterior chamber depth measurements recorded by the three devices ($p < 0.0001$). Mean differences between the measurements were: AS-OCT v IOLMaster, 0.062 (0.007) mm (95% limits of agreement, -0.37 to 0.25 mm) ($p < 0.0001$); AS-OCT v SPAC, 0.035 (0.011) mm (-0.44 to 0.51 mm) ($p = 0.0001$); SPAC v IOLMaster, 0.027 (0.012) mm (-0.57 to 0.50 mm) ($p = 0.027$).

Conclusions: AS-OCT gave systematically deeper anterior chamber measurements than SPAC and IOLMaster. However, as the differences found were small they are unlikely to be clinically important.

Accurate measurements of ocular dimensions have gained considerable importance with the development and increasing popularity of cataract and keratorefractive surgeries. Precise biometry is critical in attaining the desired postoperative refractive outcome, and the estimation of central anterior chamber depth is vital in newer theoretical biometric formulas for intraocular lens (IOL) power calculations^{1–3} and for the implantation of phakic IOLs^{4–5} and newer accommodative IOLs. Eyes with primary angle closure glaucoma share certain biometric characteristics such as a shallow anterior chamber depth, thick lens, anterior lens position, small corneal diameter, short axial length, and small radius of corneal curvature.^{6–8} Among these, shallow anterior chamber depth is regarded as a cardinal risk factor for angle closure in most racial groups, and anterior chamber depth measurement has shown some promise as a screening parameter for angle closure.⁹

While contact ultrasound biometry is often used for anterior chamber depth measurement, newer non-contact devices have recently been introduced. The IOLMaster (Carl Zeiss Meditec,

Jena, Germany) measures axial length, anterior chamber depth, and corneal curvature with high precision (≤ 5 μm) and good resolution (12 μm).^{10–13} Using an optical method of measuring anterior chamber depth, IOLMaster was found to produce reliable and reproducible measurements¹³ and is advantageous over ultrasound methods as it is a non-contact and operator independent device. The anterior segment optical coherence tomography (AS-OCT, VisanteTM, Carl Zeiss Meditec, Dublin, California, USA) is a new non-contact imaging method that provides high resolution cross sectional images of the anterior segment using 1.3 μm infrared light.^{14–15} AS-OCT can identify a high proportion of persons with angle closure¹⁶ but it can also be used for measuring anterior chamber dimensions, including anterior chamber depth and corneal thickness. The scanning peripheral anterior chamber depth analyser (SPAC, Takagi, Japan) is another recently developed non-contact device which uses optical principles to assess the peripheral and central anterior chamber depth. SPAC indirectly evaluates the iris profile and has been advocated for screening for angle closure.^{17–19} We compare the anterior chamber depth measurements using the IOLMaster, AS-OCT, and SPAC in phakic eyes.

METHODS

We recruited 497 phakic subjects over the age of 50 years from a community polyclinic in Singapore. The study was approved by the ethics review board of the Singapore Eye Research Institute and was carried out in accordance with the tenets of the Declaration of Helsinki. The exclusion criteria were a history of glaucoma, previous intraocular surgery or penetrating eye injury, corneal disorders such as corneal endothelial dystrophy, corneal opacity, or pterygium preventing anterior chamber depth measurement, and the recent use of contact lenses or topical drugs. Consecutive eligible subjects were enrolled in the study, with their written informed consent.

IOLMaster, AS-OCT, and SPAC measurements were made in all subjects in the same order under standardised dark conditions (20 lux) by a single experienced operator.

Instruments

IOLMaster

The IOLMaster uses the principle of partial coherence interferometry (PCI) to measure the axial length of the globe, but the anterior chamber depth is measured by optical principles using a non-PCI method. The anterior chamber depth is measured along the visual axis from the corneal epithelium

Abbreviations: AS-OCT, anterior segment optical coherence tomography; IOL, intraocular lens; PCI, partial coherence interferometry; SPAC, scanning peripheral anterior chamber depth analyser

Table 1 Mean differences in central anterior chamber depth measurement (mm) and true anterior chamber depth between each pair of instruments

Measure	Comparison	Mean (SE)	95% CI	p Value	
Central ACD	AS-OCT v IOLMaster	0.062 (0.007)	0.048 to 0.076	<0.0001*	<0.0001†
	SPAC v IOLMaster	0.027 (0.012)	0.003 to 0.051	0.027*	0.08†
	AS-OCT v SPAC	0.035 (0.011)	0.014 to 0.056	0.001*	0.004†
True ACD	SPAC v AS-OCT	0.084 (0.011)	0.063 to 0.105	<0.0001*	

*Paired *t* test (assuming a constant mean difference).†Bonferroni corrected *p* value.

ACD, anterior chamber depth; CI, confidence interval; SE, standard error of mean.

to the anterior crystalline lens. The IOLMaster takes five simultaneous anterior chamber depth measurements and the mean of these five readings is used. Subjects were asked to blink just before measurements were taken in order to spread an optically smooth tear film over the cornea.

AS-OCT

To carry out AS-OCT imaging in a non-accommodated state, the subject's refractive correction was used to adjust the internal fixation target for the patient's distance correction. Scans were centred on the pupil and taken along the horizontal meridian (nasal-temporal angles at 0–180°). The scan was optimally aligned when the optically produced corneal reflex was visible as a vertical white line along the centre of the cornea. The default fixation angle (zero) position in the AS-OCT corresponds to the image aligned along the visual axis. If the scans were noticeably off horizontal, the fixation angle was adjusted to align the image along the geometric axis. The AS-OCT images were processed later using internal specific software that readjusts for image distortions arising from the corneal optical transmission properties. The images with the best quality were selected, and using the instrument's custom software, anterior chamber depth was measured as the distance from the corneal epithelium to the crystalline lens anterior pole. The "true anterior chamber depth"—that is, the distance from the corneal endothelium to the anterior lens surface—was also recorded.

SPAC

The principles for SPAC measurements and data analysis have been described previously.¹⁷ In brief, SPAC scans the anterior chamber depth from the optical axis to the temporal limbus in approximately 0.66 seconds, taking 21 consecutive slit lamp images at 0.4 mm intervals from the visual axis. The light from

the slit lamp is in the visible spectrum and is projected from the temporal side at an angle of 60° from the optical axis. The camera records cross sectional slit images from the anterior cornea to the anterior iris. The SPAC measurement of anterior chamber depth is done automatically three times by the instrument and the mean of the anterior chamber depth values at each point is displayed in the printout against distance (in mm) from the visual axis. The central anterior chamber depth value is measured along the visual axis. The radius of curvature, the corneal thickness, and the "true anterior chamber depth"—that is, the distance from the corneal endothelium to the anterior lens surface—is displayed. The SPAC anterior chamber depth value (corneal epithelium to anterior lens) was calculated by summing the corneal thickness and true anterior chamber depth measurements.

All anterior chamber depth measurements thus included corneal thickness to enable comparison between the three devices.

Statistical analysis

The anterior chamber depth measurements by the three devices were compared using Bland-Altman analysis.²⁰ Plots of the differences between the instrument measures against the mean of the measures were used to assess the agreement between the instruments, and the 95% limits of agreement were calculated. These plots are useful for examining any systematic bias—the amount by which one instrument consistently overestimates the other—as well as the variability about this difference (the spread of errors). They can also reveal any relation between the difference and the size of the measurement, and the absence of a consistent bias. In these cases, a regression approach was used to calculate the 95% limits of agreement.²¹ Difference in measurements between methods was assessed using the paired *t* test. The right eye of all subjects was employed for the analysis, using Stata 9.1 statistical software (StataCorp LP, Texas, USA).

RESULTS

In all, 497 subjects were examined. Their mean (SD) age was 63.4 (7.9) years, range 50.2 to 86.6; 432 of the subjects (86.9%) were Chinese, and there were 265 women (53.3%). The mean spherical equivalent refraction was −0.12 (2.36). The mean anterior chamber depth was 3.08 (0.36) mm with the IOLMaster, 3.10 (0.44) mm with SPAC, and 3.14 (0.34) mm with AS-OCT. A significant difference was present between the anterior chamber depth measurements recorded by the three devices (F test, two way analysis of variance; *p* < 0.0001). The results of the interdevice comparisons, including the mean differences in central anterior chamber depth and true anterior chamber depth, are shown in table 1.

Figure 1 shows that there was a constant bias of deeper anterior chamber depth with the AS-OCT compared with the IOLMaster. Figure 2 shows that at shallower anterior chamber depths the IOLMaster tended to give higher values than SPAC, while at deeper anterior chamber depths, SPAC tended to give

Figure 1 Bland-Altman plot for central anterior chamber depth comparing Visante AS-OCT with IOLMaster. The 95% limits of agreement were −0.25 mm to 0.37 mm. ACD, anterior chamber depth; IOL M, IOLMaster; OCT, optical coherence tomography.

Figure 2 Bland-Altman plot for central anterior chamber depth comparing SPAC with IOLMaster, using regression based limits of agreement. ACD, anterior chamber depth; IOL M, IOLMaster; SPAC, scanning peripheral anterior chamber depth analyser.

higher values than the IOLMaster. Figure 3 shows there was also a tendency towards higher readings with AS-OCT when compared with SPAC for persons with shallow anterior chambers, while the SPAC device tended to give higher values when the anterior chamber was deeper. The differences increased as the magnitude of the differences increased, making the use of constant limits of agreement misleading. Figures 2 and 3 therefore used regression based limits (which are shown as slopes, as the 95% limits were not constant).

DISCUSSION

The accuracy of a measuring instrument is an essential factor when selecting a device for clinical purposes. None of the three devices studied require contact with the eye and all can be operated by a trained technician. We found significant differences in the anterior chamber depth measurements between IOLMaster, SPAC, and AS-OCT. In general, AS-OCT measured the highest values and the IOLMaster the lowest. Our results are consistent with a report by Baikoff *et al.*²² who found that AS-OCT measurements of anterior chamber depth were generally deeper by 110 microns than those made by IOLMaster. The 95% limits of agreement were narrower for AS-OCT and IOLMaster, suggesting that these two instruments have good agreement. There was also a constant bias of deeper anterior chamber depth with the AS-OCT compared with the IOLMaster (fig 1).

There are several possible explanations for these differences. First, cycloplegic agents were not used in this study. For AS-OCT imaging, accommodation was minimised by adjusting the fixation target using the subject's refractive correction, whereas IOLMaster and SPAC do not have a non-accommodative fixation target. Thus patients undergoing evaluation by the SPAC and IOLMaster may have had different states of accommodation. Accommodation would be expected to lead to reduction in anterior chamber depth, and indeed the IOLMaster and SPAC tended to give shallower anterior chamber depth measurements than the AS-OCT. A second possible explanation is pupil size. Vogel *et al.*¹³ reported that the IOLMaster can give inaccurate measurements in subjects with small pupils. We did not measure pupil size in this study, but it is conceivable that differences in the isolation of the central axis may have resulted in variations in anterior chamber depth measurements. The use of an infrared light source in the AS-OCT may keep the pupil size unaltered, thereby presumably giving a more accurate anterior chamber depth value. A third

Figure 3 Bland-Altman plot for central anterior chamber depth comparing SPAC with Visante AS-OCT, using regression based limits of agreement. ACD, anterior chamber depth; OCT, optical coherence tomography; SPAC, scanning peripheral anterior chamber depth analyser.

possible explanation for the detected differences is the selection of the axis of measurement. The IOLMaster and SPAC measure anterior chamber depth along the visual axis, whereas AS-OCT measures it along the geometric axis, by adjusting the fixation angle setting in the device. A recent study reported that a centring error of 0.5 mm away from the eye's geometric centre gave a 20 μ undervaluation for anterior chamber depth by AS-OCT.²² Being in the geometric axis, the AS-OCT measurements probably reflects a more accurate estimation of anterior chamber depth, and this explains to some degree why the AS-OCT values tended to be the highest. Finally, IOLMaster and SPAC both measure anterior chamber depth by optical methods whereas AS-OCT uses infrared energy. Relying on different physical principles should not alter the findings, however, and we believe this is an unlikely explanation for the differences.

It was also interesting to note that the differences in anterior chamber depth measurement between SPAC and the other two devices could be positive or negative depending on the mean anterior chamber depth (figs 2 and 3). For example, when comparing SPAC with the IOLMaster, SPAC appeared to give larger values when anterior chamber depth was deeper (fig 2). A possible explanation is that SPAC measures anterior chamber depth at various points from the visual axis along the anterior iris (reference plane). The central anterior chamber depth is measured automatically by the instrument by drawing a vertical line connecting the corneal endothelium at the centre of cornea and this reference plane. This method may have led to variations in the measurements at different anterior chamber depths, possibly due to different iris profiles in subjects with shallow and deep anterior chambers.

Our study had some limitations. The reproducibility of anterior chamber depth measurements was not evaluated. The examiner dependent variability in the results was not examined, and studies have shown that optical measuring devices like IOLMaster and SPAC are, to a large extent, operator independent.¹³⁻¹⁷ Anterior chamber depth measurements by AS-OCT are also not automatic and hence examiner subjectivity cannot be ruled out. However, a recent study has reported that AS-OCT gave consistent results with better reproducibility in measuring anterior chamber depth than IOLMaster.²²

Conclusions

Our study showed that there was good agreement between the three non-contact devices for measuring anterior chamber

depth, although there were small but significant differences in the measurements. AS-OCT gave systematically deeper anterior chamber measurements than SPAC and IOL-Master. There appears to be a systematic bias towards higher AS-OCT values with deeper anterior chambers. However, as the differences found were small they are unlikely to be clinically important.

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Conflict of interest: KK has a Japanese patent on SPAC (Japanese patent No 3878164). DSF has been a paid consultant to Carl Zeiss-Meditec. TA has received research funding and travel support from Carl Zeiss Meditec.

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