Comparison of Three Methods of Measuring Corneal Thickness and Anterior Chamber Depth

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PURPOSE: To compare three different methods of measuring corneal thickness (CT) and anterior chamber depth (ACD).

DESIGN: Prospective clinical trial (Medical University of Vienna, Austria).

METHODS: Central CT (CCT), CT at four peripheral points, and central ACD were measured in 88 eyes of 44 healthy subjects with the Pentacam (rotating Scheimpflug camera; Oculus, Wetzlar, Germany), Orbscan I (scanning-slit topography system; Orbtek Inc, Salt Lake City, Utah, USA), and AC-Master (partial coherence interferometry; Zeiss Meditec, Jena, Germany), and the results were compared.

RESULTS: The upper (lower) limits of agreement for CCT measurements were 7.9 (−22.2) μm between AC-Master and Pentacam, 17.6 (−32.5) μm between AC-Master and Orbscan, and 25.2 (−25.9) μm between Pentacam and Orbscan. Correlation was high between all three methods (r = 0.94 to 0.97). The upper and lower limits of agreement for ACD were 0.174 (−0.251) mm between AC-Master and Pentacam, 0.406 (−0.004) mm between AC-Master and Orbscan, and 0.384 (0.095) mm between Pentacam and Orbscan. Correlation was high between the three methods (r = 0.96 between Orbscan and Pentacam; others 0.92). Correlation was lower for the CT measurements at the four peripheral points.

CONCLUSIONS: The CCT and ACD values obtained by Pentacam, Orbscan, and AC-Master measurements correlated well and showed few outliers. The two new systems (Pentacam, AC-Master) provide a reliable, easy-to-use, noncontact method of measuring CCT and ACD. Larger differences occurred only when measuring peripheral CT values, especially between AC-Master and the other two methods. (Am J Ophthalmol 2006;141:7–12. © 2006 by Elsevier Inc. All rights reserved.)

PARALLEL TO THE DEVELOPMENTS OF SURGICAL technique in cataract and refractive surgery, the accurate measurement of corneal topography, anterior chamber depth, thickness of the crystalline or artificial lens, and eye length has gained in importance. Until recently, ultrasound biometry has been a common method for measuring corneal thickness (CT) and anterior chamber depth (ACD). However, this method is operator dependent. The most common method is applanation ultrasound, requiring corneal contact, which may lead to false results due to indentation of the cornea. The measuring results also depend on the exact axial placement of the probe relative to the center of the cornea. Like all contact methods, it may be uncomfortable for the patient or even lead to damage of the corneal epithelium. Thus, noncontact methods are preferred for biometry of the eye.

An accurate noncontact ocular biometry technique, based on the dual laser beam partial coherence interferometry (PCI) principle, has been developed in the past decade. The PCI technology has been used for precise axial length measurements and resulted in the commercially available IOL Master (Carl Zeiss Meditec, Jena, Germany). However, the IOL Master uses a photographic (not PCI) technique for measuring ACD. Therefore, the AC-Master (Zeiss Meditec) has been developed for PCI measurements of central corneal thickness (CCT) and ACD as well as lens thickness. The precision of this technique is in the micron region, and it is highly reproducible.

In addition, several other optical (non-PCI) methods for imaging and measuring the corneal surface and the anterior chamber of the eye have been developed recently and are already commercially available. One of these is the Pentacam (Oculus, Wetzlar, Germany), which uses a rotating Scheimpflug camera to image the anterior segment of the eye. It is also a noncontact method, and it is...
specifically designed to calculate a three-dimensional model of the anterior segment, including data for corneal topography (also of the posterior corneal surface), CT (pachymetry), ACD measurements, and measurements of lens opacity and lens thickness.

An already established instrument for analysis of cornea and anterior chamber, which does not make use of the Scheimpflug principle, is the Orbscan (I) scanning-slit topography system (Orbtek Inc, Salt Lake City, Utah, USA).\(^1\)\(^1\)\(^7\)\(^8\) It uses a horizontally moving slit beam to produce multiple slit images of the anterior segment and provides data for (anterior and posterior) corneal topography and ACD.

However, little is known about the reliability of the different measuring techniques. In particular, it is not entirely clear whether the results of the different methods (PCI, scanning-slit, Scheimpflug method) are comparable and whether they can be used interchangeably. The purpose of this study was to compare CT and ACD measurements by the AC-Master with those of the Pentacam and the Orbscan in a number of healthy subjects.

**METHODS**

**EIGHTY-EIGHT EYES OF 44 YOUNG VOLUNTEERS WERE INCLUDED IN THIS PROSPECTIVE STUDY.** The subjects had to be healthy except for myopia/hyperopia and/or astigmatic ametropia. Exclusion criteria were other ocular diseases such as glaucoma and retinal pathology, or any history of ocular surgery, including (refractive) laser surgery. The volunteers were informed about the purpose of the study and had to give informed consent before inclusion. The study was performed in adherence to the Declaration of Helsinki. Ethics committee approval was not required for this study.

First, the refraction of each eye was determined with an automated refractometer (Zeiss Meditec, Jena, Germany). Contact lenses had to be removed at least 12 hours before the measurements. Both eyes of every subject were measured with the Pentacam, the Orbscan, and finally the AC-Master. Thirty minutes were scheduled for the examination time for each subject. All examinations were performed by the same experienced examiner.

The Pentacam system consists of the Pentacam itself and a personal computer. The software is almost fully automated. After the patient’s data are entered, the program changes to imaging mode. The subject sits in front of the camera and places the chin on a chin rest. He or she is asked to fixate on a fixation target in the center of the camera. The examiner sees a real-time image of the patient’s eye on the computer screen. The image must be focused and centered manually by moving the Pentacam in the respective directions. Markings on the screen indicate the direction the operator should move the joystick of the camera. As soon as the image is perfectly aligned, the patient is asked not to move and to keep his or her eye open, and the scan is started.

The rotating camera takes multiple (25 or 50, depending on the user settings) slit images of the anterior eye segment in approximately 2 seconds with 500 true elevation points incorporated in each slit image. For this study, the “25 images per scan” option was chosen. After completing a scan, the software calculates a three-dimensional image of the anterior segment, including anterior and posterior corneal surface and lens surface as well as lens opacities. The quality of the lens data depends on the pupil size; of course, only the part of the lens visible in the pupillary aperture can be examined with the Scheimpflug camera. In this study, we did not use mydriatic eye drops because we were mainly interested in central axial biometric data. The center of the cornea is measured in each of the single images of a scan. It is therefore possible to calculate very precise values for the CCT and the (central) ACD. In the Pentacam, ACD is defined as the distance between the posterior surface of the cornea and the anterior surface of the lens.

One high-quality scan per eye was saved on hard disk. The CCT and central ACD readings were noted for each eye. Additionally, peripheral CT measurements in the 3, 6, 9, and 12 o’clock positions at a distance of 1.5 mm from the corneal center (corresponding to a circle around the center with a diameter of 3 mm) were noted.

Similar to the Pentacam, the Orbscan, the horizontally moving camera, produces multiple slit-lamp images of the eye to calculate a mathematical model of the cornea and the anterior lens surface with computer software. A real-time image of the eye is visible on the screen and has to be centered and aligned manually. The operator uses the reflections of the slit-lamp light as orientation for the correct alignment. Then the subject is asked to keep the eyes open and not to move while the scan is started. Artifacts due to eye movement during the measurement lead to an error message, and the scan has to be repeated.

Again, we noted CCT, central ACD (which is again defined as distance between posterior corneal surface and anterior lens surface), and four additional values for peripheral CT (again in the horizontal and vertical meridians of the cornea at 1.5 mm distance from the corneal center).

The AC-Master measures CT, ACD, and lens thickness from a single point of the cornea (usually the center) in one step by the PCI method. The white-to-white distance is determined from an image of the iris before performing biometry.

The principle of the dual-beam version of PCI has been reported previously.\(^7\)\(^8\) The method requires that measurements are performed along the optical axis (except for peripheral CT measurements). In the AC-Master, the patient fixes on a fixation target visible on a liquid crystal display, which serves to control the direction of gaze of the eye. The ideal position of the fixation target is calculated by the AC-Master, but can be adjusted manu-
ally. To measure along the optical axis, the four Purkinje images that result from reflections of the intraocular interfaces must be superimposed during the measurement. This can be controlled by the observer on the real-time image of the patient’s eye shown on the computer screen and, if necessary, adjusted by moving the fixation target. Each measurement consists of one or—preferably—more PCI A-scans (approximately 1 second per scan).

With the AC-Master, CT can also be measured peripherally in four meridians at distances of 1.5, 3, and 4.5 mm from the center. The patient is then asked to look at additional fixation lights incorporated in the equipment. In the AC-Master, ACD is defined as the distance between the anterior surface of the cornea and the anterior surface of the lens. Thus, CCT must be subtracted from that result before comparing the ACD values with the results of Pentacam or Orbscan.

In this study, we measured CCT and central ACD of both eyes of all subjects. Additionally, peripheral CT was measured at the 3, 6, 9, and 12 o’clock positions at a distance of 1.5 mm from the corneal center. For each measurement, several scans were performed (at least 20 for the central measurements and at least five for each peripheral point) and the mean values calculated by the AC-Master software were noted. The precision of measurements was assessed by using the standard deviation of all consecutive scans in each eye. This is our standard procedure for AC-Master measurements; however, the standard deviation is usually smaller than 2 μm for CCT measurements and smaller than 11 μm for ACD measurements, and a single scan would be sufficient in most cases.\textsuperscript{18}

All data were entered into a Microsoft Excel spreadsheet. Paired differences were calculated for all comparisons (AC-Master vs Pentacam, AC-Master vs Orbscan, and Pentacam vs Orbscan) and are presented as mean and maximum values, standard deviation, coefficient of variation, median absolute differences, and upper and lower limits of agreement (ie, 95% Wald confidence intervals of the differences).\textsuperscript{19,20} The level of statistical significance and the correlation between the three methods were calculated by the Wilcoxon matched-pairs signed rank test and Pearson correlation coefficients. Bland-Altman plots were used to find a potential dependency between differences and means of two measurements.\textsuperscript{19} P values of less than .05 were considered to be statistically significant. Statistical analysis was performed by Microsoft Excel and SPSS 12.0 software (SPSS Inc, Chicago, Illinois, USA).

\section*{RESULTS}

The mean age of the 44 subjects was 23.6 years (range, 21–32 years). The mean spherical equivalent was \(-2.15\) D (range, \(-8.5\) to \(+3.0\) D).\textsuperscript{13} There were seven contact lens wearers who removed the lenses at least 12 hours before the study. Both eyes of all subjects (88 eyes) could be measured with the three instruments. Mean total examination time was 25 minutes per subject (approximately 15 minutes for Pentacam and Orbscan, and 10 minutes for the AC-Master measurements including scan evaluation). The Pentacam turned out to be the quickest examination, followed by the Orbscan topographer. Because measurements of the peripheral CT with the AC-Master must be performed step by step.

\begin{table}[h]
\centering
\begin{tabular}{|l|c|c|c|c|}
\hline
\textbf{Characteristic} & \textbf{AC-Master} & \textbf{Pentacam} & \textbf{AC-Master} & \textbf{Orbscan} \\
\hline
\textbf{Mean paired difference ± SD} & & & & \\
CCT (μm) & \(-7.1 \pm 7.7\) & \(-7.5 \pm 12.8\) & \(-0.3 \pm 13.0\) & \\
ACD (mm) & \(-0.038 \pm 0.108\) & \(0.201 \pm 0.105\) & \(0.239 \pm 0.047\) & \\
\hline
\textbf{Maximum difference} & & & & \\
CCT (μm) & \(-27.0\) & \(-55.0\) & \(-61.0\) & \\
ACD (mm) & \(-0.448\) & \(0.473\) & \(0.540\) & \\
\hline
\textbf{Median absolute difference} & & & & \\
CCT (μm) & 8.0 & 9.0 & 7.0 & \\
ACD (mm) & 0.046 & 0.215 & 0.225 & \\
\hline
\textbf{Correlation coefficient (r)} & & & & \\
CCT (μm) & 0.974 & 0.947 & 0.940 & \\
ACD (mm) & 0.921 & 0.924 & 0.964 & \\
\hline
\textbf{Lower limit of agreement} & & & & \\
CCT (μm) & \(-22.2\) & \(-32.5\) & \(-25.9\) & \\
ACD (mm) & \(-0.251\) & \(-0.004\) & \(0.095\) & \\
\hline
\textbf{Upper limit of agreement} & & & & \\
CCT (μm) & 7.9 & 17.6 & 25.2 & \\
ACD (mm) & 0.174 & 0.406 & 0.384 & \\
\hline
\end{tabular}
\caption{Comparison of Central Corneal Thickness (CCT) and Central Anterior Chamber Depth (ACD) Values Between Three Methods of Measuring Corneal Thickness}
\end{table}
in different directions of gaze, these were the most time-consuming. Mean \( \pm \) SD CCT was 534.6 \( \pm \) 33.4 \( \mu \)m with the Pentacam, 535.0 \( \pm \) 37.8 \( \mu \)m with the Orbscan, and 527.5 \( \pm \) 31.9 \( \mu \)m with the AC-Master. Mean \( \pm \) SD ACD was 3.35 \( \pm \) 0.28 mm with the Pentacam, 3.12 \( \pm \) 0.27 mm with the Orbscan, and 3.32 \( \pm \) 0.24 mm with the AC-Master. The differences between the results of the three instruments were all statistically significant \((P < .01)\), except for CCT between Pentacam and Orbscan \((P = .81)\).

Mean and maximum paired differences, median absolute differences, correlation coefficients, and upper and lower limits of agreement between the three methods are shown in Table 1. Bland-Altman plots of the paired ACD differences against the mean values are shown in the Figure. We found no dependency between paired differences and mean values in ACD (or CCT) measurements. CCT correlated best between Pentacam and AC-Master \((r = 0.97)\). ACD correlated best between Pentacam and Orbscan \((r = 0.96)\). CCT values were higher with the Pentacam than with the AC-Master in 80% of cases (median difference: 7.0 \( \mu \)m) and higher with the Orbscan than with the AC-Master in 76% of cases (median difference: 7.0 \( \mu \)m). The Orbscan ACD values were lower than the Pentacam results in all cases (median difference: 0.23 mm) and lower than the AC-Master results in 95% of cases (median difference: 0.22 mm). There was no marked offset between measurements of right and left eyes.

The same statistics were performed for the peripheral CT measurements (four points in the 3, 6, 9, 12 o’clock positions at 1.5 mm distance from the center of the cornea). Mean CT values \( \pm \) SD at those points are shown in Table 2. Mean paired differences and median absolute differences between the three methods are shown in Table 3. The values correlated best between Pentacam and AC-Master \((r = 0.93–0.94)\). However, the median differences between AC-Master and Pentacam (Orbscan) were significantly larger than those of the CCT measurements (median differences between 17.0 and 30.0 \( \mu \)m), whereas median differences between Pentacam and Orbscan did not differ so greatly (0.3 to 5.8 \( \mu \)m). The highest difference was \(-86.0 \mu \)m between AC-Master and Orbscan at the 6 o’clock position.
and Orbscan values were highest for these peripheral points. Whether this is a result of erroneous measurements with the AC-Master or of the different measuring techniques, resulting in a bias between central and peripheral measurements, is uncertain.

The Pentacam is an easy-to-use biometry system for analysis of the anterior segment. Measurements with the Pentacam proved to be very simple, user-independent and quick (approximately 2 seconds per scan). Measurements with the Orbscan turned out to be a little more complicated and time-consuming than with the Pentacam because measurements had to be repeated more often, at least with our setup.

Apart from a few outliers, from a practical point of view, the limits of agreement between the three methods show acceptable ranges for both CCT and ACD. CCT values tended to be lower with the AC-Master than with the other two methods (mean, 0.08 μm), whereas ACD values were lower with the Orbscan than with Pentacam and AC-Master (mean, 0.22 μm). As mentioned above, differences between AC-Master and the other two methods were considerably larger for the peripheral CT measurements (mean, 16 to 31 μm). However, the differences between Orbscan and Pentacam remained low. Contrarily, correlation was higher between Pentacam and AC-Master than between Pentacam and Orbscan for the peripheral CT values.

In this study, we measured only normal corneas of healthy subjects. Therefore, we do not have data concerning the agreement between the three methods when measuring corneas with pathological alterations, or postoperative corneas. The differences between the three systems might be larger in such cases.

In summary, both the AC-Master and the Pentacam proved to be excellent noncontact methods for measuring CCT and (central) ACD in the healthy eye. Considering the different measuring techniques of the two novel devices and the Orbscan, the measurement differences between the three systems were quite small. Bigger differences appeared only when measuring peripheral CT values that might be related to the fact that the AC-Master was primarily designed to measure centrally along the optical axis with high precision and requires different directions of gaze for measuring peripheral CT values.

**REFERENCES**


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**TABLE 3. Comparison (Differences) of Corneal Thickness Values at Four Peripheral Points Between Three Methods**

<table>
<thead>
<tr>
<th>Point*</th>
<th>Mean Paired CT Difference (mean absolute difference) (μm)</th>
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<td>AC-Master, Pentacam</td>
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<tr>
<td>3 o’clock</td>
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<tr>
<td>6 o’clock</td>
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<td>9 o’clock</td>
<td>−19.7 (18.5)</td>
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<tr>
<td>12 o’clock</td>
<td>−31.3 (29.8)</td>
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</tbody>
</table>

*Measured at 1.5 mm from the center of the cornea.


REPORTING VISUAL ACUITIES

The AJO encourages authors to report the visual acuity in the manuscript using the same nomenclature that was used in gathering the data provided they were recorded in one of the methods listed here. This table of equivalent visual acuities is provided to the readers as an aid to interpret visual acuity findings in familiar units.

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<th>20 Feet</th>
<th>Decimal Fraction</th>
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- Biometry
- Digital imaging of the anterior segment