Central Corneal Thickness Measurements with Partial Coherence Interferometry, Ultrasound, and the Orbscan System

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Objective: To compare the reliability of central corneal thickness measurements (CCT) obtained with partial coherence interferometry (PCI), ultrasound pachymetry, and the Orbscan system.

Design: Cross-sectional study.

Participants: Twenty healthy subjects with CCT measurements in both eyes.

Methods: The CCT measurements were obtained with PCI, ultrasound pachymetry, and the Orbscan system. In each eye, 2 investigators performed 5 repeated measurements with each pachymetric device. Intraclass correlation coefficients (κ) were calculated and mean CCT measurements were compared.

Main Outcome Measures: The CCT measurements obtained with ultrasound pachymetry, the Orbscan system (Orbtek Inc., Salt Lake City, UT), and PCI.

Results: Mean CCT values measured with ultrasound pachymetry were significantly thicker than those measured with PCI (21.5 μm; $P<0.001$) or the Orbscan system (19.8 μm; $P<0.001$). The correlation coefficients for the intraobserver variability were 0.999 for PCI measurements, 0.983 for ultrasound pachymetry measurements, and 0.988 for Orbscan system measurements. The correlation coefficients for the interobserver variability were 0.998 for PCI measurements, 0.980 for ultrasound pachymetry measurements, and 0.988 for Orbscan system measurements. There was a slightly better consistency between ultrasound pachymetry and PCI ($\kappa = 0.96$) than between the Orbscan system and PCI ($\kappa = 0.92$) and between ultrasound pachymetry and the Orbscan system ($\kappa = 0.89$).

Conclusions: Partial coherence interferometry was the method with the least intraobserver or interobserver variability. Mean CCT as measured with ultrasound pachymetry was approximately 20 μm thicker than with the Orbscan system and PCI. However, corneal thickness measurements with ultrasound pachymetry and PCI were slightly more consistent than those of the Orbscan system and PCI. This slightly better consistency, however, may be important, especially in corneal refractive surgery. *Ophthalmology 2004;111:875–879 © 2004 by the American Academy of Ophthalmology.*

Measurement of corneal thickness has become of great interest with the rapidly increasing popularity of corneal refractive surgical procedures. To avoid complications such as postoperative keratectasia after LASIK[1–4] or perforation in radial and astigmatic keratotomy,[5] accurate corneal thickness measurements are necessary.

Currently, measurements of corneal thickness are performed mainly with ultrasound pachymetry. The Orbscan system (Orbtek Inc., Salt Lake City, UT), a scanning slit instrument that provides a thickness profile map of the cornea, recently has become commercially available.[6] It is relatively simple to use and provides noncontact measurements of the cornea. Dual-beam partial coherence interferometry,[7–9] a noninvasive optical ranging technique, was reported to enable fast, noncontact measurements of the corneal thickness with precision better than 1 μm.[10]

The purpose of this study was to compare the reliability and the mean central corneal thickness (CCT) values obtained with partial coherence interferometry (PCI), ultrasound pachymetry, and the Orbscan system. To assess interobserver variability, we also compared the measurements made by 2 separate investigators for each device.

Subjects and Methods

After the study protocol was approved by the Ethics Committee of Vienna University School of Medicine, 20 healthy subjects were studied. The nature of the study was explained and all subjects gave written consent to participate. The mean age of the 18 women and 2 men was 28.1 years (range, 22–34 years). Exclusion criteria were any eye disease, contact lens use of less than 12 hours before

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measurements, a cylindrical error of more than 1.5 diopters (D), a spherical myopic error of more than 6 D, and a spherical hyperopic error of more than 2 D. Twenty eyes were emmetropic (spherical equivalent within 0.5 D), 18 were myopic (up to –4.0 D), and 2 hyperopic (up to 0.75 D). The maximum cylindric value was 1.0 D. Two contact lens users were included in this study. They did not wear the lenses for 15 and 24 hours before the measurements, respectively.

The refractive error was measured with an autorefractometer (KR 3500 Auto Kerato-Refractometer; Topcon Inc., Paramus, NJ). Slit-lamp examination was performed with each subject to exclude ocular pathologic features.

Central corneal thickness was measured in 40 eyes of 20 healthy subjects with PCI (prototype system), ultrasound pachymetry (Paxis; Biovision Inc., Clermont-Ferrand, France), and the Orbscan system I, version 2.00. In each eye, 2 investigators performed 5 separate, sequential measurements with each pachymetric device. Measurements of the 2 noncontact methods were followed by the ultrasound pachymetry. The subjects were randomized by means of a randomization list to the sequence of the noncontact methods as well as to the sequence of investigators for ultrasound pachymetry. The second investigator was masked to the results of the previous measurements. In each subject, all measurements were performed within 1 hour of the same day.

For PCI, the subject sat on a chair, placing the chin on the chin rest and slightly pressing the forehead into the headband. The subjects kept both eyes open and fixated on the measurement beam. The method of the scanning dual-beam version of PCI has been developed in the last decade and has been described in detail elsewhere.[7–10] Briefly, an external Michelson interferometer splits a laser beam of high spatial coherence, but very short coherence length, into 2 parts, forming a dual beam. This dual light beam, containing 2 beam components with a mutual time delay introduced by the interferometer, illuminates the eye, and both components are reflected at several intraocular interfaces that separate media of different refractive indices. For the measurement of corneal thickness, these are the anterior surface and the posterior surface of the cornea. If the delay of these 2 light beam components—produced by the interferometer—equals the optical corneal thickness, an interference signal is detected. The obtained signals are similar to ultrasound A scans. The laser beam with a beam diameter of approximately 1 mm has a center wavelength of 855 nm and a power of 190 μW. The exposure time for measurements of less than 1 minute is well below the allowed maximum exposure of 47 minutes.[9–11] The system provides high resolution with a precision for CCT measurements of 0.29 μm (standard deviation) in healthy subjects.[10] It is of importance that the distances obtained by laser interferometry are optical distances, and therefore have to be divided by the group refractive index.[12] The group refractive index is the quotient of the speed of light in a vacuum and the group velocity of the light in the cornea. We calculated the group refractive index of the cornea for $\lambda = 855$ and used the value 1.3851.[13]

For the Orbscan system measurements, the subjects sat on a chair, placing the chin on the chin rest and slightly pressing the forehead into the headband. The subject kept both eyes open and fixated the fixation target. For 1 corneal thickness measurement, 40 slits are projected sequentially on the eye, 20 from the left and 20 from the right side. The corneal thickness value of the center of the cornea was taken for statistical analysis. We used the acoustic correction factor, corrected Orbscan value = 0.92 x raw Orbscan value, as proposed by the manufacturer.

No evidence of corneal pathologic features, such as keratoconus, was evident from the Orbscan measurements.

For ultrasound pachymetry, the cornea was anesthetized with topical 0.4% oxybuprocaine. The subject was then placed on the examination chair, brought into a face-up position, and was asked to look on a colored target that was placed straight ahead on the ceiling.

Both examiners, being right handed, sat on the subject's right side. Care was taken to apply the angled ultrasound probe as perpendicular as possible on the central cornea. After each subject, the probe was disinfected with alcohol. An ultrasound velocity of 1640 m/second was used.

Table 1. Correlation Coefficients (κ) for Intraobserver Variability

	Intraobserver Variability (κ)		
	Ultrasound	*Orbscan System*	*Partial Coherence Interferometry*
Right eyes			
First investigator	0.985	0.985	0.999
Second investigator	0.979	0.990	0.999
Left eyes			
First investigator	0.986	0.989	0.998
Second investigator	0.984	0.991	0.999

Statistical Analysis

Before the study, a sample size calculation was performed. This sample size calculation was based on the reproducibility data of the 3 devices in healthy subjects in our laboratory.[14] Using an α-error of 0.05 and a power of 0.80, the present study was designed to allow for detecting differences between methods of 3 μm. Accordingly, a sample size of 20 was calculated.

Intraobserver and interobserver variability (κ) were calculated separately for the right eyes and the left eyes based on a repeated-measures analysis of variance model. This method is described in detail by Kramer and Feinstein.[15] The differences between the devices in measuring mean CCT were calculated with paired t tests. The association between the individual values obtained with the 3 pachymetric devices was calculated by linear correlation analysis.

Gaussian distribution of data was ensured by the Kolomogorov Smirnoff test. In addition, we have ensured that the distribution of CCT values in the present study is not different from previously published data.[16]

Data are presented as means ± standard deviation. A P value <0.05 was considered as the level of significance.

Results

In each of the 40 eyes, 2 investigators performed 5 measurements with each pachymetric device. In sum, 1200 measurements were used for statistical analysis.

Table 2. Correlation Coefficients (κ) for Interobserver Variability

	Interobserver Variability (κ)		
	Ultrasound	*Orbscan System*	*Partial Coherence Interferometry*
Right eyes	0.986	0.987	0.999
Left eyes	0.974	0.989	0.997

Table 3. Mean Corneal Thickness (μm)

	Mean Corneal Thickness (μm)		
	Ultrasound	*Orbscan System*	*Partial Coherence Interferometry*
Right eyes	544.5 ± 35.2	524.5 ± 35.1	522.6 ± 32.2
Left eyes	542.2 ± 34.3	522.6 ± 37.3	521.2 ± 32.2

Data are represented as mean ± standard deviation.

Intraobserver Variability

The correlation coefficients (κ) for the intraobserver variability are presented in Table 1. The κ values were between 0.998 and 0.999 for PCI measurements, between 0.979 and 0.986 for ultrasound pachymetry, and between 0.985 and 0.991 for measurements with the Orbscan system.

Interobserver Variability

Table 2 shows the correlation coefficients (κ) for the interobserver variability. The κ values were between 0.997 and 0.999 for PCI measurements, between 0.974 and 0.986 for ultrasound pachymetry, and between 0.987 and 0.989 for measurements with the Orbscan system.

Difference between Devices

Table 3 shows the mean corneal thickness values as measured with each pachymetric device. The mean corneal thickness averaged for both right and left eyes was 521.9 ± 32.2 μm as measured with PCI, 543.4 ± 34.8 μm as measured with ultrasound pachymetry, and 523.6 ± 36.2 μm as measured with the Orbscan system.

Table 4 shows the statistical differences between the pachymetric devices. The values of the ultrasound pachymetric measurements were 19.8 μm larger than the values obtained with the Orbscan system and 21.5 μm larger than the values obtained with PCI. These differences were significant ($P<0.001$ each). The values measured with the Orbscan system were 1.7 μm larger than the values obtained with PCI, but this difference was not significant.

Association between Devices

The linear correlations between the 3 pachymetric devices are depicted in Figure 1. There was a somewhat higher degree of association between the values of ultrasound pachymetry and PCI ($\kappa = 0.97$ for right eyes and $\kappa = 0.95$ for left eyes) than between the values of the Orbscan system and PCI ($\kappa = 0.94$ for right eyes and $\kappa = 0.90$ for left eyes). The association between the ultrasound pachymetry and the Orbscan system was $\kappa = 0.91$ for right eyes and $\kappa = 0.86$ for left eyes.

Table 4. Differences (*P* Values) in Mean Corneal Thickness between the Pachymetric Devices

	Differences in Mean Corneal Thickness (*P* Values)		
	Ultrasound vs. Partial Coherence Interferometry	*Orbscan System vs. Partial Coherence Interferometry*	*Ultrasound vs. Orbscan System*
Right eyes	<0.001	0.285	<0.001
Left eyes	<0.001	0.498	<0.001

Discussion

The results of the present study show that PCI is the method with the least intraobserver and interobserver variability among the tested techniques. Reproducibility of the data obtained with the Orbscan system and ultrasound pachymetry was worse but still acceptable, as has been shown in previous studies.[17,18] We found that data obtained with ultrasound pachymetry showed a better correlation with PCI data than data measured with the Orbscan system. In corneal refractive surgery, however, both accuracy and precision of measurements are required.

The Orbscan system provided a mean central corneal thickness (CCT) value that was not different from the value obtained with PCI. By contrast, CCT values as measured with ultrasound pachymetry were approximately 20 μm larger than the values obtained with the other techniques. One may argue that repeated contact of the cornea by the pachymetry probe may lead to a swelling of the cornea, resulting in larger corneal thickness values. In a previous study, however, we showed that repeated contact with a pachymetry probe slightly reduced corneal thickness by 1.3 μm.[14] To date, it is difficult to estimate which of the systems is more accurate, that is, is closest to the actual value of corneal thickness. Obviously, the methods depend on the knowledge of either the refractive index of the cornea or the ultrasound velocity in the cornea.

In contrast to the results of our study, Yaylali et al[6] reported that the Orbscan system measures 23 to 28 μm thicker than ultrasound pachymetry. However, these authors did not use the acoustic correction factor, but the raw Orbscan system data instead. When multiplying their CCT values with the acoustic correction factor of 0.92, their results are comparable with the results obtained in the present study. In another study, however, comparable CCT results with the Orbscan system using the acoustic correction factor and ultrasound pachymetry were reported in normal eyes.[19]

Especially with incisional surgery, where the surgical effect is dependent on the depth of the incision and incisions are made in up to 90% of the cornea, a precise CCT measurement is necessary. For the incisions, nomograms are used that are based on ultrasound CCT measurements. When measuring CCT with the Orbscan system or PCI, one has to consider that the obtained values are different from those obtained by ultrasound. In this study, ultrasound values were approximately 20 μm larger than the values obtained with the Orbscan system or PCI. One may argue that this particular ultrasound pachymeter needs calibration. However, in a previous study,[14] we compared this particular ultrasound pachymeter with 2 other ultrasound pachymetric devices. The differences between the 3 devices were relatively small, with a maximum difference of 6 μm. Nevertheless, earlier studies reported greater differences in CCT

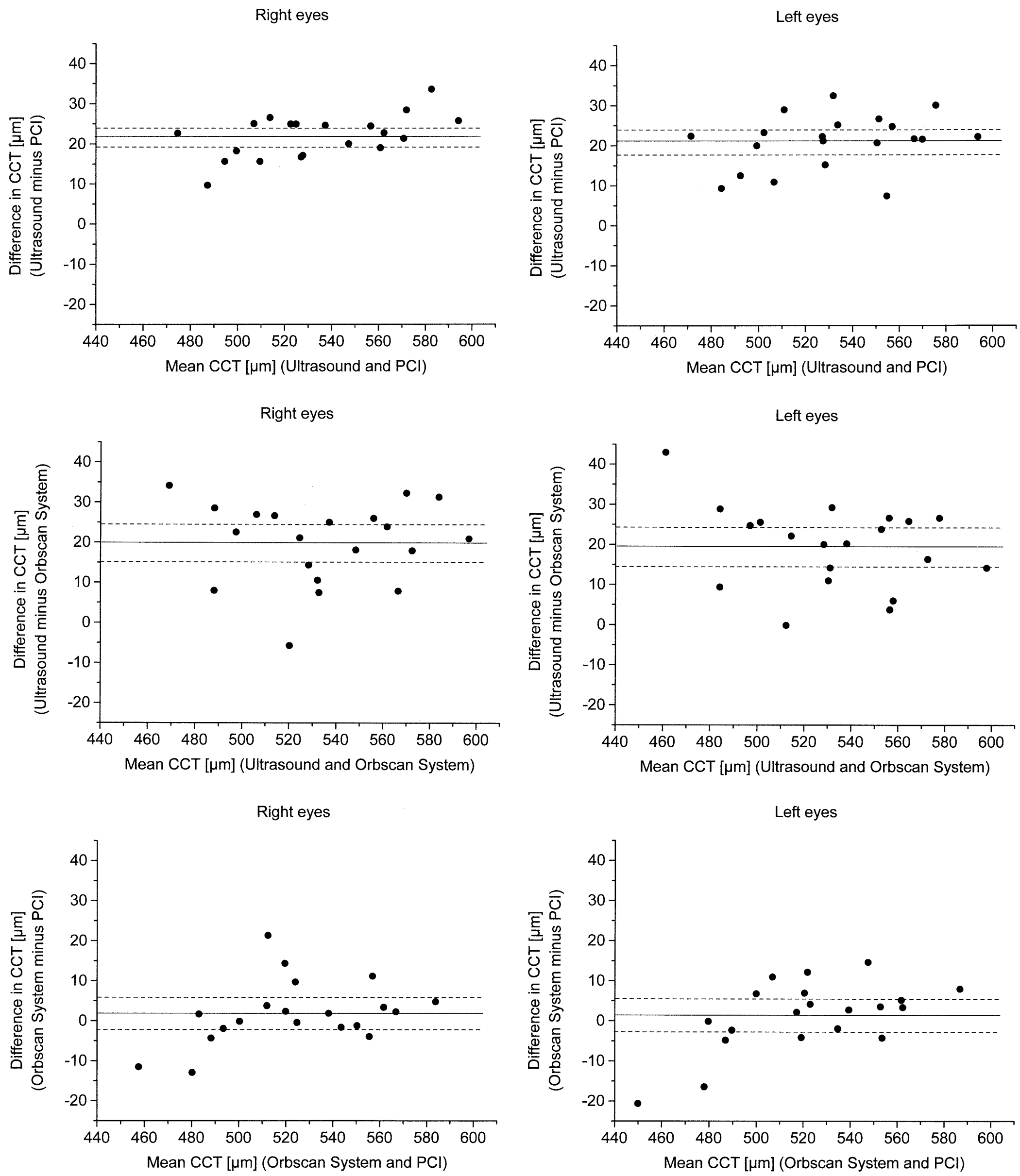

Figure 1. Between-method reproducibility. Bland–Altman plots demonstrating means and differences of measurements with the Orbscan system, ultrasound pachymetry, and partial coherence interferometry (PCI). Data are depicted separately for the right and the left eyes. The mean of the differences (solid line) and the 95% confidence interval of the differences (dashed line) are shown. CCT = central corneal thickness.

measurements, up to 49 μm between different ultrasound pachymetric devices.[20,21]

An important advantage of the PCI and the Orbscan system is a high degree of comfort for the patient. They are noncontact methods with no need for anesthesia and no risk of corneal infection. Furthermore, ultrasound pachymetry requires considerable experience, and therefore reproducibility may depend considerably on the investigator's practice with the instrument. In our study, when looking at the scattergrams, ultrasound measurements of the left eyes seem to be slightly more scattered than those of the right eyes. This may be explained by the fact that both examiners, being right handed, sat on the subjects' right sides, and therefore measuring the left eyes might have been more difficult.

In the present study, we showed that the accuracy of all employed pachymetric devices is acceptable in measuring CCT in normal corneas. However, further studies are required to evaluate the accuracy of pachymetric devices in extremely thick or thin corneas, in corneas that have undergone refractive surgical procedures, or in corneas with pathologic features.

In conclusion, the results of this study indicate that PCI is the method with the least intraobserver and interobserver variability. We showed that the Orbscan system gives the same mean corneal thickness values as PCI when using the proposed acoustic correction factor of 0.92. Mean corneal thickness values as measured with ultrasound were approximately 20 μm larger than with the Orbscan system or PCI. However, corneal thickness measurements of ultrasound pachymetry and PCI, as evidenced from the higher correlation coefficients, were slightly more consistent than those of the Orbscan system and PCI. This consistency, however, may be important, especially in corneal refractive surgery.

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