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ORIGINAL PAPER

Comparison between central corneal thickness measurements by oculus pentacam and ultrasonic pachymetry

Hani S. Al-Mezaine · Saleh A. Al-Amro · Dustan Kangave · Abdulkareem Sadaawy · Taher A. Wehaib · Saleh Al-Obeidan

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Abstract *Purpose* To compare the accuracy of central corneal thickness (CCT) measurements by the oculus pentacam scheimpflug system, with those obtained with the DGH ultrasound pachymeter (UP) and to assess the agreement between the two devices. *Methods* In a prospective study, measurement agreement was assessed in 984 eyes of 492 healthy subjects using both oculus pentacam and ultrasonic pachymetry at the Eye Consultants Center, Riyadh, Saudi Arabia. *Result* In the measurement agreement experiment, the mean CCT was 552.4 ± 37.0 µm with oculus pentacam and 544.1 ± 35.4 µm with ultrasonic pachymetry. Regression analysis showed a high correlation between the values obtained with both devices ($r = 0.912$, $P < 0.001$). Compared with UP, pentacam overestimated the CCT by a mean of 8.2 µm as demonstrated in a Bland-Altman plot. *Conclusion* the CCT measurements by the pentacam and UP are highly correlated. The pentacam agrees well with UP and is a reliable alternative to UP in CCT measurements.

Keywords Corneal thickness · Pentacam · Ultrasound · Pachymetry · Agreement

H. S. Al-Mezaine (✉) · S. A. Al-Amro · S. Al-Obeidan
Department of Ophthalmology, College of Medicine, King Saud University, PO Box 230387, Riyadh 11321, Saudi Arabia
e-mail: almez2001@hotmail.com

D. Kangave
Diabetes Research Center, College of Medicine, King Saud University, Riyadh, Saudi Arabia

A. Sadaawy · T. A. Wehaib
The Eye Consultants Center, Riyadh, Saudi Arabia

Corneal thickness measurement (CCT) is an essential factor when evaluating corneal health. It plays an important role in both diagnostic and therapeutic assessment of ocular pathologies. An ideal pachymetric device should be safe, precise, and reliable. Many tools have been used in assessing CCT, including ultrasound pachymetry (UP) [1], contact and noncontact specular microscopy (SM) [2, 3], optical coherence tomography (OCT) [4], ultrasound biomicroscopy (UBM) [5, 6], slit-scanning corneal topography (orbscan) [3, 7–11], confocal microscopy [12], and the pentacam scheimpflug system [13–19].

UP is currently viewed as the gold standard in measuring corneal thickness since it has a high degree of intraoperator, interoperator, and interinstrument reproducibility [1, 20–23]. However, this technique requires corneal contact, and the perpendicularity of the probe with respect to the cornea is often difficult to ascertain. In addition, its accuracy might be adversely influenced by changes in tissue hydration caused by ultrasound speed through the cornea [10].

The oculus pentacam is a fast, noncontact method of measuring corneal thickness, which uses a rotating

scheimpflug camera that provides a three–dimensional scan of the anterior segment of the eye [24]. From the images acquired, information regarding the anterior and posterior corneal topography, corneal pachymetry, anterior chamber depth, angle, and lens density can be evaluated. Due to video monitor control, precise positioning of the instrument's camera system is assisted by magnification, thus avoiding measurement bias due to incorrect centralization.

This prospective study was performed to compare the agreement between CCT measurements by oculus pentacam and UP in a large number of healthy subjects.

Patients and methods

The oculus pentacam (Oculus Inc., Germany) and DGH-1000 ultrasonic pachymetry (DGH technology, Inc., San Diego, CA, USA) were used to measure CCT the in a total of 984 eyes of 492 participants. The subject had to be healthy except for myopia/hyperopia and/or astigmatic ametropia. Any subjects with history of ocular pathology such as glaucoma and retinal disease, or any history of corneal disease such as subclinical or clinical keratoconus or previous ocular surgery, including refractive corneal surgery and contact lens wearing, were excluded from the study. In all patients visual acuity, refraction, intraocular pressure (IOP), and disc status were evaluated. The participants were informed about the purpose of the study and gave informed consent before inclusion.

For the oculus pentacam the patient was seated with his or her chin on a chinrest and forehead against the forehead strap and asked to fixate ahead on a target. The operator visualizes a real-time image of the patient's eye on a computer screen, with the machine marking the pupil edge and center, and the corneal apex. The operator can manually focus and align the image. Arrows are displayed on the screen that guide the operator's alignment of the instrument in the horizontal, vertical, and anteroposterior axes. To reduce operator-dependent variables, the pentacam's automatic release mode was used. In this mode, the instrument automatically determines when correct focus and alignment with the corneal apex have been achieved and then performs a scan in less than 2 s, the rotating camera captures up to 50 slit images of the anterior segment, while minute eye movements are captured by the second camera and corrected simultaneously. Each slit image consists of 500 true elevation points.

Mathematical software is used to detect the edge in each slit image, including the epithelium and endothelium of the cornea. The anterior surface of the cornea is calculated with no optical distortion and, according to the manufacturer, the tear film has no effect on measurements. Single-point pachymetric measurements of the entire cornea are calculated from the calculated front and back surfaces using ray tracing, with the calculation taking into account optical distortions. Since the center of the cornea is measured repeatedly during the rotational imaging process (in each of the images), very precise CCT measurements can be achieved. All measurements were taken by a single observer.

UP was determined using an A-scan ultrasonic pachymetry (DGH Technology, Inc.). The pachymeter was precalibrated for all measurements. The ultrasonic velocity was set at 1640 m/s. Topical anesthesia with Novesin (0.4% Benoxinate Hydrochloride) was used. CCT was measured with patients seated upright. A handheld probe was aligned as perpendicular as possible on the central cornea. Five readings were obtained and averaged. Pentacam readings were taken first to avoid any potential disturbance caused by corneal contact in the ultrasonic pachymetry. All measurements were taken between 16:00 and 21:00 by a single observer, who was blinded to the pentacam results, which were taken by another observer.

Statistical methods

The distributions of the CCT measurements of the two methods were plotted in histograms. The Mann–Whitney test was used to compare the means of the two independent groups. Student's *t*-test was used to compare two proportions from the same sample. A scatter graph and Pearson's correlation coefficient were used to investigate the linear relationship between the CCT readings by UP versus those by pentacam pachymetry. For the statistical tests, a *P*-value OF less than 0.05 indicated statistical significance.

The agreement between the two methods was investigated using A Bland-Altman plot and the mountain plot. The Bland-Altman plot is a graph of the differences between readings measured by the two methods plotted on the *Y*-axis against the means for the pairs of measurements plotted on the *X*-axis. The upper and lower limits for the 95% confidence interval for the mean differences are connected with a horizontal straight lines, thus providing a sort of band of plotted points that helps to visualize the extent of agreement between the two methods. The Bland-Altman plot is usually supplemented with the mountain plot, which provides information about the distribution of the differences between the two methods. The *Y*-axis of the graph indicates the percentiles of the distributions of the differences, while the absolute differences between the readings by the two methods is plotted on the *X*-axis. When the two methods are in perfect agreement, the mountain plot is supposed to be symmetrical about a value of zero on the *X*-axis. SPSS 11.0 software and MedCalc version 9 software were used for the statistical analyses.

Results

CCT was measured in a total of 984 eyes of 492 healthy subjects using the oculus pentacam and UP. Histograms of the distributions for the CCT measurements for the two methods are shown in Figs. 1 and 2. Both distributions followed approximately a normal distribution curve with a mean CCT of 552 ± 37.0 μm and 544.1 ± 35.4 μm for the pentacam pachymetry and UP values, respectively. The two means differed significantly ($P < 0.001$; Mann–Whitney test).

There was high correlation between the CCT readings by the two methods ($r = 0.912$, $P < 0.001$; Pearson's correlation coefficient) (Fig. 3). Furthermore, the reliability of the two methods for measuring CCT was high, as indicated by a value of Cronbach's $\alpha = 0.9542$.

The Bland-Altman plot (Fig. 4) shows a large cluster of plotted points of pentacam-ultrasound differences falling within the 95% confidence limits for the mean difference. This is an indication of strong agreement between the two methods. A total of 914/984 (93%) pentacam-ultrasound differences were within the 95% confidence interval for the mean difference and the limits of agreement between the two methods were within ±16 μm. In addition, from the Bland-Altman analysis the pentacam appeared to be overestimating the CCT by 8.2 μm compared with UP, as 95% of the differences in the readings between the pentacam and UP lay between 38.1 μm and –21.7 μm.

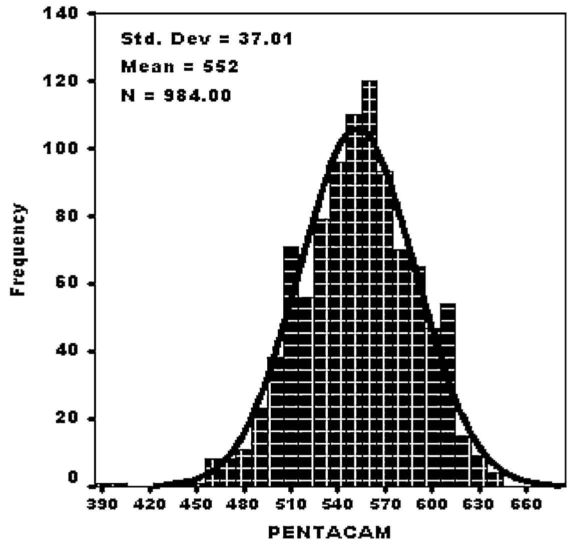

Fig. 1 Histogram of central corneal thickness as measured by OCULUS pentacam

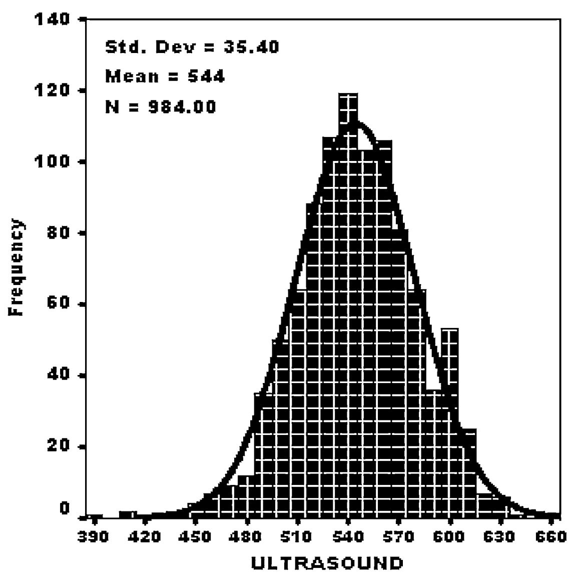

Fig. 2 Histogram of central corneal thickness as measured by ultrasound pachymetry

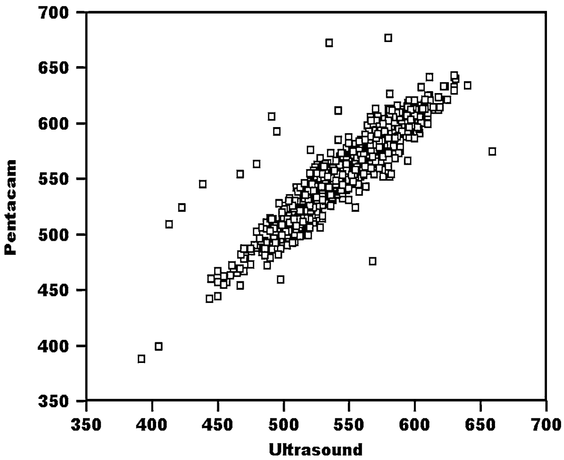

Fig. 3 A scattergraph plot of the central corneal thickness as measured by pentacam versus ultrasound pachymetry

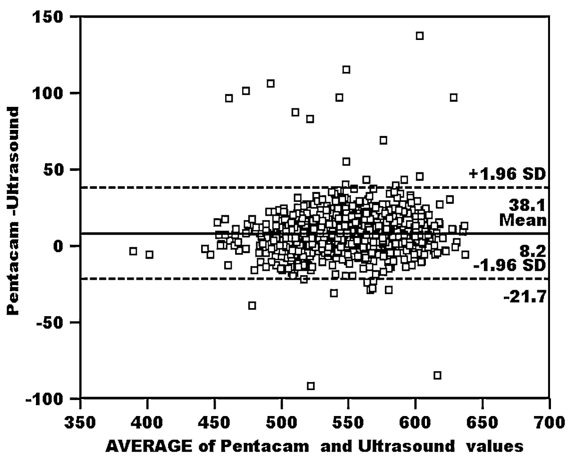

Fig. 4 Bland-Altman plot for pentacam minus ultrasound differences

The prevalence rate of outlier readings outside the 95% confidence limits was 17/984 (1.7%) for the pentacam, compared with 10/984 (1.0%) for ultrasound; the difference between the two percentages was not statistically significant ($P = 0.1814$; Student's t-test for two proportions from the same sample).

Figure 5 shows a mountain plot analysis demonstrating percentiles of the differences in the distribution of the pentacam minus UP values. The median of the differences is close to zero, which indicates good (but not perfect) agreement between the two methods. The long tails in the plot indicate that either method was susceptible to yielding outlier readings, more so for the pentacam compared to UP as can be seen in the graph.

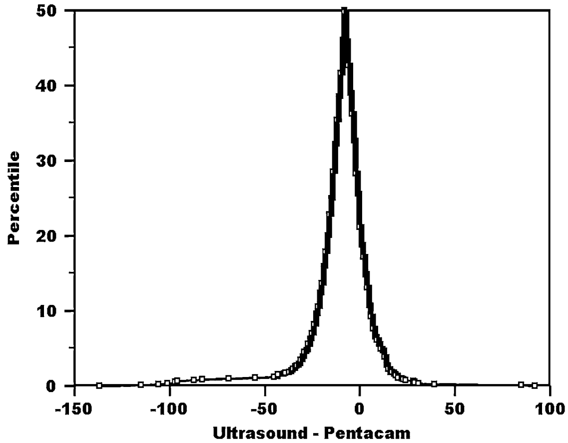

Fig. 5 Mountain plot demonstrating percentiles of differences in the distribution of pentacam minus UP values

Discussion

To our knowledge, this study reports the largest series of eyes comparing CCT measurements between pentacam and UP in healthy eyes, where we found a good agreement between the two methods.

Barkana and coauthors [15] reported a low (excellent) coefficient of repeatability and reproducibility for the pentacam scheimpflug device, indicating that a reliable estimate of CCT can be obtained in a single reading and is practically operator independent.

In the present study, pentacam and UP measurements particularly showed a highly significant correlations with a standardized regression coefficient ($r = 0.912$, $P < 0.001$; Pearson's correlation coefficient). This relation have already been seen in previous studies [13, 17].

Bland-Altman analysis showed that the limit of agreement between the pentacam and UP measurements was good (±16 μm) over a wide range of mean CCT. In addition, the analysis showed that the pentacam overestimated the CCT by 8.2 μm compared to UP, which agrees with the results in normal subjects reported previously [13, 17–19]. However, in contrast to the results of our study, O'Donnell et al. [13] found that the pentacam provides measurements that were slightly, but systematically, lower than UP

measurements. We are not sure why this discrepancy occurs, but we agree with some authors that, since the ultrasound probe requires corneal contact, the use of a handheld probe can produce an applanation force that can displace the 7- to 30-μm-thick tear film; in addition the compression may thin the epithelium, thus resulting in a slightly thinner CCT when measured with UP [6, 25].

Although a statistically significant difference was found between the mean pentacam and UP CCT measurements, from the Bland-Altman analysis the mean difference (8.2 μm) was small, and it might be argued that it is not clinically significant.

The main disadvantages of UP include the use of a local anaesthetic, which may alter the corneal thickness [26–28], and the location where the ultrasonic probe is applied, which may vary in repeated measurements because there is no fixation target for controlling eye movement [23].

Noncontact pachymetry with precise control of fixation can overcome these shortcomings. We believe that the OCULUS pentacam achieves this and gives comparable results to ultrasonic pachymetry on the central cornea. In addition, the pentacam system demonstrated stable peripheral CT measurements, probably because an internal fixation target is provided by the pentacam but is absent in ultrasonic pachymetry. In addition, there is another camera in the pentacam system that repeatedly monitors minute eye movements during the rotational imaging process [15, 19].

The Orbscan has been widely used for topographic pachymetry. It has been compared to UP giving a thicker [1, 7], thinner [29, 30], or similar central CT [11]. The pentacam is better than the Orbscan for central pachymetry because it captures 25 slit images on each acquisition with all the images involving the central corneal region. In contrast, the Orbscan takes 40 independent images (20 scans to the right, and 20 to the left) but not of all the images are scanned from the central region [27]. Further research is needed to compare CCT measurements between orbscan and oculus pentacam.

To summarize, the most important finding of this study is that pentacam measurements were close to those of UP, and that the Bland-Altman plot demonstrated good agreement to UP.

In conclusion, the results from our study are based on a large sample of 984 eyes in which the CCT was measured using the pentacam and UP. Both tools showed a high correlation. Mean pentacam measurements were 8.2 μm higher than the thickness measured by the gold-standard UP, and were consistently so over a wide range of CCT values, as shown in Bland-Altman plot. We believe that the OCULUS pentacam is a reliable alternative to ultrasound pachymetry and both tools may be used for CCT measurements in healthy corneas without serious distortion of the results.

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