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Short-term variation of central corneal thickness and axial anterior chamber depth of healthy eyes using Scheimpflug photography via the Oculus Pentacam*

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Abstract

The purpose of this study was to investigate short-term variation and intra-subject repeatability of human central corneal thickness (CCT) and axial anterior chamber depth (AACD) measurements obtained using the Oculus Pentacam. Forty consecutive images of the right eye of the anterior segment of 10 young and healthy individuals were measured with the Pentacam.

Measurements of CCT and AACD were obtained from these images and means, standard deviations, variances and repeatability of the measurements were investigated. Both parameters (CCT and AACD) showed small variation with good or excellent repeatability for all eyes. The inter-subject or overall means and standard deviations for CCT and AACD of the 10 right eyes were 0.555 ± 0.05 millimeters (or 555 ± 50 microns) and 3.206 ± 0.04 millimeters, respectively. The individual or intra-subject averages for samples of CCT and AACD measurements are also provided in this paper. Univariate normality of the data was explored with Kolmogorov-Smirnov, Lilliefors and Shapiro-Wilks tests and we found that generally the data was normally distributed although there were some exceptions.

Based on the results of this study, the Oculus Pentacam appears to provide repeatable and reliable measures for both CCT and AACD in young, normal eyes. Further research is, however, needed to determine short-term variation and repeatability of CCT and AACD with the Pentacam in more complicated eyes with, say, corneal scarring or ectasia or where refractive surgery may be an issue.

Key words: corneal topography, variance, repeatability, reliability, central corneal thickness, anterior chamber depth, Pentacam, univariate normality

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Introduction

Accurate measurement of the central corneal thickness (CCT) and central or axial anterior chamber depth (AACD) has become useful and important in both research and in clinical assessment. For instance, corneal thickness measures are crucial in refractive surgery to facilitate proper patient selection or to improve diagnosis of subtle conditions (such as *forme fruste* keratoconus). Such measurements are also useful in contact lens practice for the detection and monitoring of contact lens related complications and for diagnosing corneal disorders as well as for glaucoma assessment[1-13]. Similarly, they are important for properly understanding intra-ocular pressures obtained via applanation methods where corneal thickness can have significant influences. The importance of accurate measurement of AACD is additionally recognized in other forms of refractive surgery such as the implantation of anterior chamber phakic intraocular lenses (IOL)[4, 12]. Errors in CCT or AACD measurements can indirectly affect accurate IOL power calculation. Most formulas for the calculation of IOL power rely on an accurate estimate of the distance between the IOL and the retina. One way to calculate this distance is from the difference between ocular or axial length and AACD. There are reports[14-16] of IOL implantation for the management of keratoconus or lenticonus and thus more thorough and accurate CCT and AACD measurements would represent potentially major advances towards improved surgical or medical management of keratoconic or lenticonic patients in terms of implantation of IOL or with other methods of treatment. This paper indicates our approach to addressing, at least partially, the proper evaluation and analysis of such measurements (CCT and AACD) involving the anterior segment of the eye.

Several instruments are available for measuring CCT and AACD. One of these is the Pentacam (Oculus; Wetzlar, Germany). The Pentacam captures multiple scanning slit images of the anterior segment of the eye using a blue light emitting diode (LED) and a rotating Scheimpflug camera[17]. Amongst many other parameters of interest, this noninvasive or noncontact instrument conveniently provides topographical and aberrometry maps for both anterior and posterior corneal surfaces, corneal pachymetry maps and topographical maps of variation in anterior chamber depth. Pentacam measurements of corneal thickness are available for the entire cornea from limbus to limbus[17], but this study will concentrate only on the central corneal thickness. For the Pentacam, the AACD is defined as the distance from the posterior vertex of the corneal endothelium to the anterior surface of the crystalline lens along the optical axis. The Pentacam has been operational in ophthalmic practice and research since about 2003 and the usefulness of the Pentacam is extolled in the promotional literature[18, 19].

Recent publications using the Pentacam have reported excellent repeatability (reliability) in measurements of CCT and AACD in normal and keratoconic patients[8-12]. Amano *et al*[10] conducted a study to compare central corneal measurements and their reproducibility using a rotating Scheimpflug camera, ultrasonic pachymetry and scanning-slit corneal topography. A total of two measurements were performed on each eye of 54 subjects without ocular abnormalities. The average corneal thickness measurements by Scheimpflug, scanning-slit topography (Orbscan) and ultrasonic pachymetry were 538 ± 31.1 µm, 541 ± 40.7 µm and 545 ± 31.3 µm. They concluded that mean corneal thicknesses were comparable and the three methods had highly satisfactory measurement repeatability. Lackner *et al*[4] conducted a study to determine the validity and repeatability of AACD measurements obtained with a rotating Scheimpflug camera to scanning-slit topography in 60 healthy eyes. A total of eight measurements were performed on each eye. The mean AACD values were 3.18 ± 0.38 mm for the Pentacam and 3.23 ± 0.40 mm for the scanning-slit topography. The differences of AACD values were within clinically acceptable levels. Thus, the two methods can be regarded as interchangeable. Buehl *et al*[8] conducted a study to compare three different methods (the Pentacam, Orbscan I and AC-Master) of measuring CCT and AACD in 88 eyes of 44 healthy subjects. The mean CCT was 0.535 ± 0.03 mm with the Pentacam, 0.535 ± 0.04 mm with the Orbscan and 0.527 ± 0.03 mm with the AC-Master. The mean AACD was 3.35 ± 0.28 mm with the Pentacam, 3.12 ± 0.27 mm with the Orbscan and 3.32 ± 0.24 mm with the AC-Master. Their results indicated that the three instruments provided similar results for CCT and AACD across the subjects.[8] The AC-Master and Pentacam proved to be excellent noncontact methods for measuring CCT and AACD.[8] Measurements with the Orbscan turned out to be a little more complicated

and time-consuming because measurements had to be repeated more often.[8]

Xu *et al*[6] investigated AACD with optical coherence tomography and found a mean of 2.42 ± 0.03 mm. (See also He *et al*[5] for a study using optical pachymetry to measure AACD in elderly Chinese where the mean AACD was 2.49 ± 0.32 mm.) These studies are somewhat less relevant to ours in that their samples and methods were quite different but they do provide means for AACD that were nonetheless quite similar to that of the studies above that used methods such as the Pentacam to measure AACD.

One difficulty, however, with some of the previous publications is that the researchers typically took very few Pentacam measurements (and, for example, some took only one measurement[7, 8] per eye while others[9-12] took only two or three measurements per eye). This differs markedly from our approach where the right eye of each of the 10 subjects was measured 40 times over a short time interval.

The primary purpose of this study was to investigate the short-term variation and repeatability of multiple measurements of the CCT and AACD in healthy normal young eyes. This study provides further quantitative and qualitative evidence towards the usefulness and importance of such an instrument towards effective and accurate measurement of various ocular components within the anterior segment of the eye.

Methods

Detailed description of the subject selection and general methodology can be found in previous papers[20-22] but 10 healthy subjects (nine female and one male) of age range 21 to 34 years were selected. Rotating Scheimpflug imaging with the Oculus Pentacam was performed with the subject seated with her or his chin against the instrument chinrest and forehead against the forehead strap. Each subject was asked to keep both eyes open and to fixate on a blinking fixation target within the instrument. The Pentacam uses a 180-degree rotating Scheimpflug camera that very rapidly captures 12, 25 or 50 corneal slices or sections. Through reconstruction of the scanning slit information, 3-dimensional maps of the cornea and anterior segment of the eye are produced from which various quantities such as CCT and AACD are determined. In this study, anterior segment reconstructions were produced from 25 sections per eye. Consecutive measurements (N = 40 Pentacam scans per eye) for the right eyes of the 10 subjects were obtained. Since we wished to obtain as many measurements as possible per individual an arbitrary decision was made to use the right eyes only of subjects. This is also in keeping with best practice for statistical research where often only one eye from each subject is used to avoid a lack of independence of data[23]. (Many routine or common statistical analyses rely on all data points being independent of each other and should information for both eyes be collected for every subject in the study, then there may be lack of independence within the data.)

Measurement of each eye took about 50 minutes since subjects were requested to remove their heads from the instrument between measurements and the individual scans were saved into the instrument's computer memory. Thus after every scan (of 25 sections per eye) the Pentacam was moved backwards, realigned and refocused by the operator for the next scan to reduce or eliminate interdependence of the multiple scans per eye. The study was performed with the eyes in their natural state without use of mydriatic or other pharmaceutical agents.

Statistical analysis

From the multiple Pentacam scans the parameters analyzed were CCT and AACD. Analysis and investigation of repeatability of the data from the Pentacam was based on 40 successive scans obtained by the same operator. The CCT and AACD measurements from the Pentacam topographical maps (see Figure 1 for an example from Subject 1) were analyzed with Statistica Ver8 software. The distributions for the samples of CCT and AACD measurements were plotted using box plots, histograms and normal probability plots. Sample means and standard deviations were determined. All univariate samples for CCT and AACD were also investigated for normality using the Kolmogorov-Smirnov (K-S), Lilliefors and Shapiro-Wilks tests. Probability or p values were obtained to determine whether samples were normally distributed and whether parametric statistical tests were appropriate. Here measurements for the CCT and AACD are given in millimeters and not in micrometers (μm).

Results

An example of a typical Pentacam result from a single measurement of the anterior segment of one

subject is included in Figure 1. The column on the left side provides the subject's demographic information, and keratometric and other results for the anterior and posterior surfaces of the cornea including pachymetry and anterior chamber analysis. Figure 1 was the first measurement for Subject 1 and from the figure we can see that the CCT and AACD were 0.620 mm (or 620 microns) and 3.68 mm, respectively (see *pachymetry apex* and *AC Depth* in the bottom left column of Figure 1). Another 39 measurements (as for Figure 1) for the same subject were obtained and then the whole process was repeated for the other nine subjects.

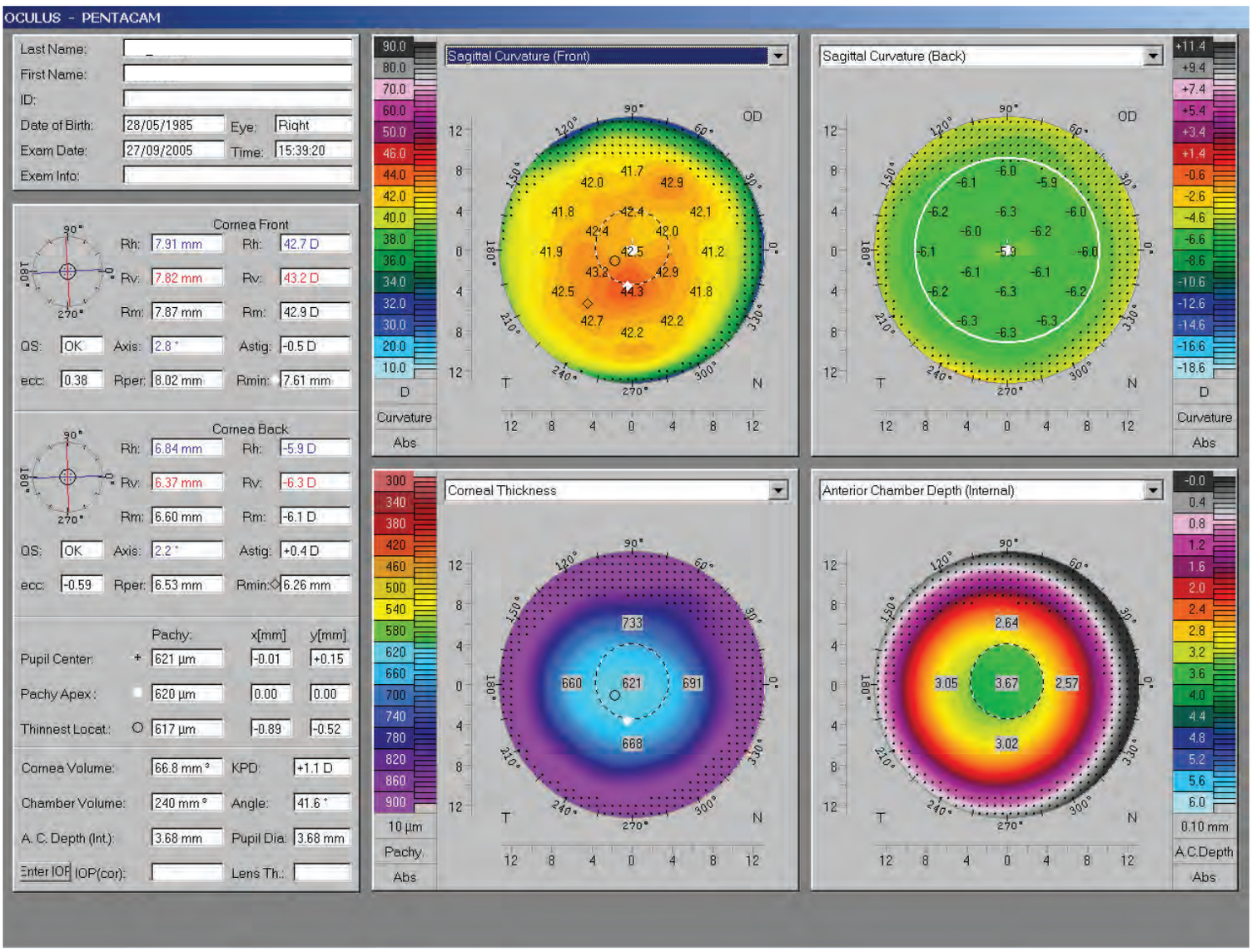


Figure 1. The first Pentacam result or measurement of the cornea and anterior segment of the right eye of Subject 1 are indicated. The anterior (the top left map) and posterior (the top right map) corneal surfaces are represented using sagittal curvature maps. Maps for corneal thickness and anterior chamber depth are also shown. Other quantitative data for the cornea and anterior segment of this subject are provided in the column towards the left side of the figure.

Tables 1 and 2 provide descriptive statistics such as means and standard deviations for the CCT and AACD measurements for all 10 subjects. Sample minima and maxima are included as well as statistics for sample skewness (whether positive or negative) and kurtosis (leptokurtosis or platykurtosis are indicated by positive or negative signs respectively). For instance, the samples for CCT and AACD for Subject 2 had profound positive skewing (1.531 and 1.374) and leptokurtosis (5.177 and 2.088). These samples should be inspected for possible outliers or other departures from univariate normality such as polymo-

dality, *et cetera*. Subjects 3, 5 and 8 also demonstrated noticeable leptokurtosis (Table 1). In Table 2 subjects 1, 2, 3 and 8 showed leptokurtosis while subject 3 also showed negative skewness.

Table 1. Sample means, standard deviations (SD), maxima and minima for the central corneal thickness measurements (in millimeters) for the 10 subjects are indicated. If skewness is clearly different from zero then the distribution of measurements is asymmetrical and either positive or negative skewing is present as per the sign of the given value. If kurtosis is clearly different from zero the distribution displays leptokurtosis (and a positive value for the statistic is seen) or platykurtosis otherwise. Further information can also be obtained from histograms and normal probability plots such as in Figures 6 to 11.

Subject	**CCT Means** (mm)	**SD** (mm)	**Minima** (mm)	**Maxima** (mm)	**Skewness**	**Kurtosis**
1	0.621	0.005	0.620	0.643	– 0.069	– 0.006
2	0.541	0.005	0.531	0.561	1.531	5.177
3	0.613	0.007	0.592	0.629	– 0.390	1.092
4	0.572	0.005	0.560	0.576	– 0.457	– 0.756
5	0.593	0.006	0.581	0.611	0.591	1.667
6	0.530	0.006	0.513	0.537	– 0.345	– 0.012
7	0.500	0.005	0.499	0.500	0.108	– 0.709
8	0.530	0.006	0.520	0.545	0.754	1.232
9	0.514	0.004	0.510	0.521	– 0.260	– 0.361
10	0.530	0.006	0.516	0.541	– 0.404	– 0.473

Table 2. Sample means, standard deviations (SD), maxima and minima for the anterior chamber depth measurements (in millimeters) for the 10 subjects are indicated. For univariate normal samples, skewness and kurtosis should be zero. (See also histograms and normal probability plots in Figures 6 to 11.)

Subject	**AACD Means** (mm)	**SD** (mm)	**Minima** (mm)	**Maxima** (mm)	**Skewness**	**Kurtosis**
1	3.688	0.033	3.620	3.790	0.433	1.277
2	2.892	0.024	2.860	2.960	1.374	2.088
3	3.290	0.040	3.170	3.380	–1.082	2.299
4	3.000	0.025	2.960	3.050	0.217	– 0.581
5	3.345	0.024	3.300	3.400	0.181	– 0.545
6	3.073	0.026	3.030	3.140	0.458	– 0.119
7	3.504	0.021	3.470	3.550	0.069	– 0.425
8	3.222	0.025	3.140	3.280	– 0.710	2.384
9	3.567	0.025	3.500	3.610	– 0.250	– 0.031

Figures 2 and 3 show the box and whisker plots for the CCT and AACD samples for the right eyes of the 10 subjects. Figure **2** shows CCT in millimeters on the *y*-axis versus the subjects along the *x*-axis. The subject means are indicated with small squares while the larger boxes indicate the means ± 1 SD and the whiskers are the means ± 1.96 SD. The CCT means ranged between about 0.49 and 0.64 mm and standard deviations were of small magnitude (see Table 1). So, repeated or multiple measurements of this parameter with the Pentacam were quite similar for each of the subjects concerned.

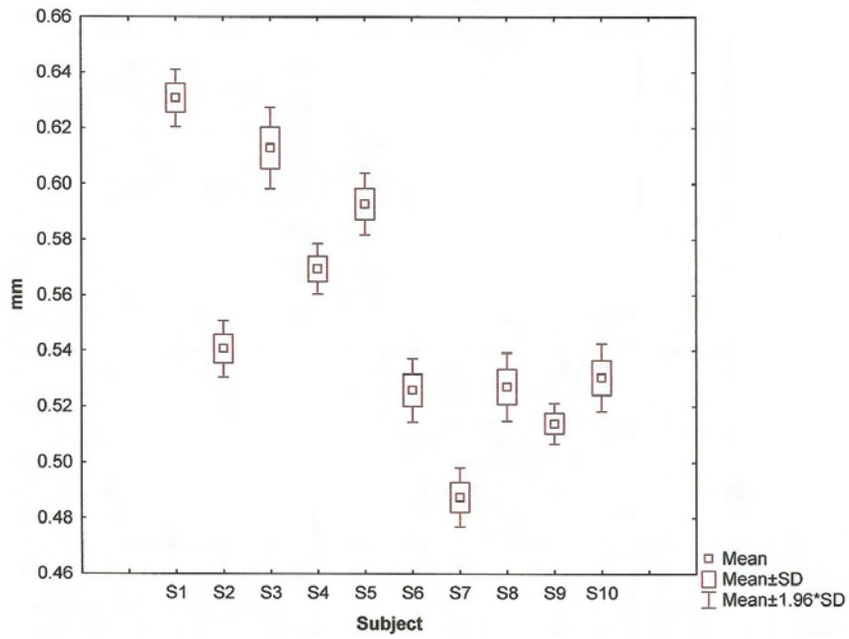


Figure 2. The box and whisker plots for central corneal thickness (CCT) measurements in millimeters (*y*-axis) for the right eyes of the 10 subjects. The labels (S1 to S10) on the *x*-axis are the subject numbers.

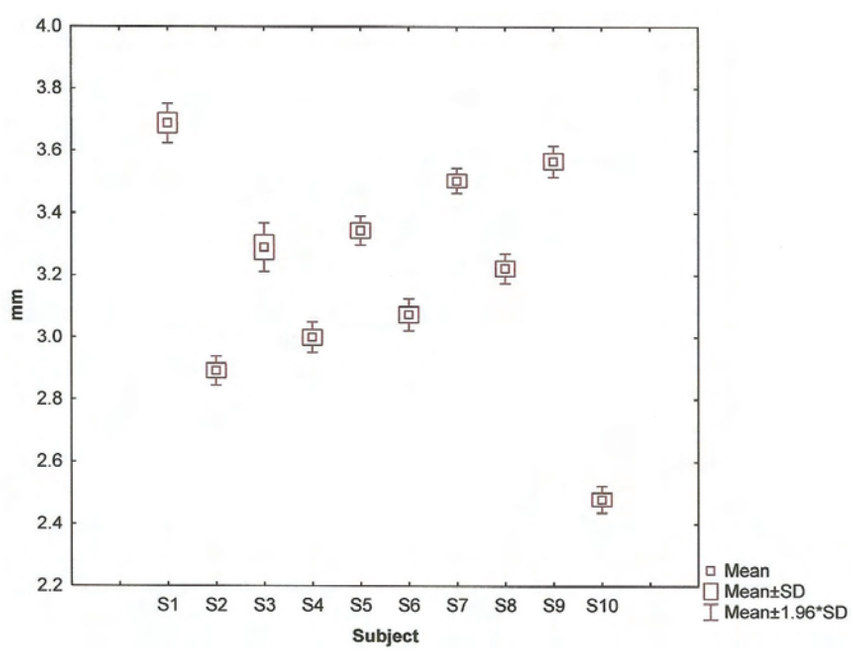


Figure 3. The box and whisker plots for measurements of axial anterior chamber depth (AACD) in millimeters (*y*-axis) for the right eyes of the 10 subjects. The labels (S1 to S10) on the *x*-axis are the subject numbers

Figures 4 and 5 include temporal profiles for the samples of CCT and AACD for all subjects (N = 40 per sample). Individual data points for each subject are connected by a profile or line which provides a way to visually present a temporal sequence of measurements. So, this plot allows one to easily inspect the repeatability and variation of the measurements of each subject.

The scales in the two figures are different but the standard deviations are larger for the AACD samples than for the CCT samples (compare the columns for SD per subject in Tables 1 and 2). Thus, for all subjects, the samples were more variable for AACD rather than CCT. The profiles appear flatter in Figure 5 than in Figure 4 but this is purely because of the scales used to represent the figures.

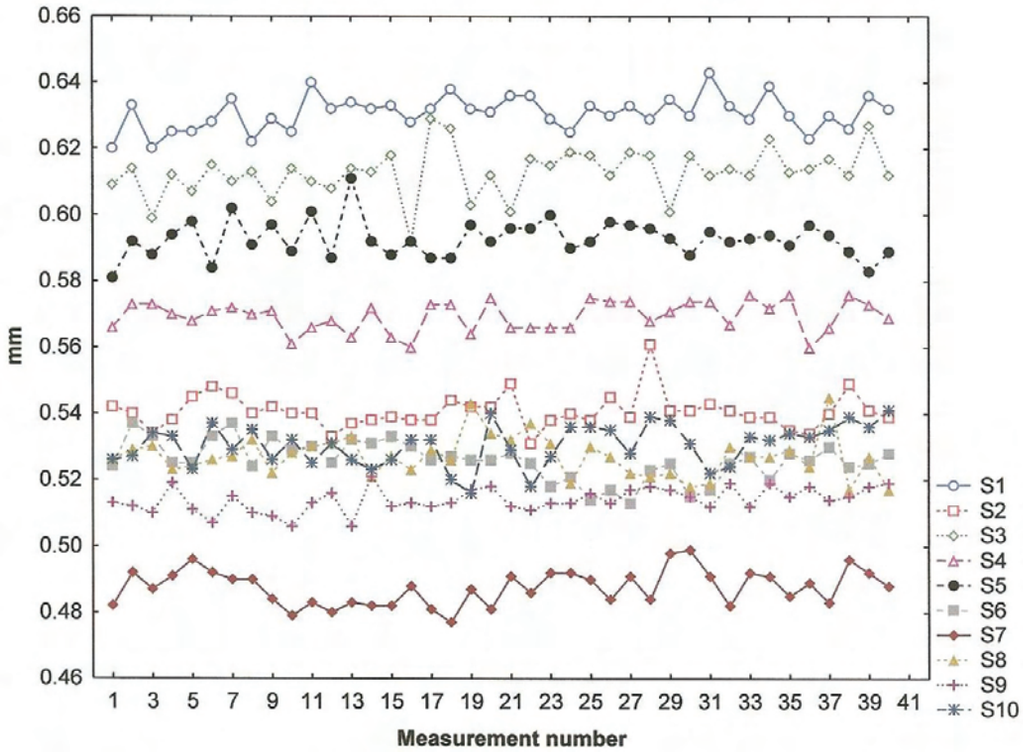


Figure 4. Profile or line plots of temporal variation of the 40 measurements of the CCT (mm) for 10 young subjects are indicated. Individual measurements for each subject (S1 to S10) are connected by a line or trajectory. For example, the CCT sample for Subject 1 (the uppermost trajectory in gray-blue with open circles) varies from 0.62 to 0.643 mm (see Table 1 for the minimum and maximum CCT for this particular sample). These trajectories are also useful for identification of possible outliers or extreme measurements within samples. Each trajectory represents a time interval of about 50 minutes.

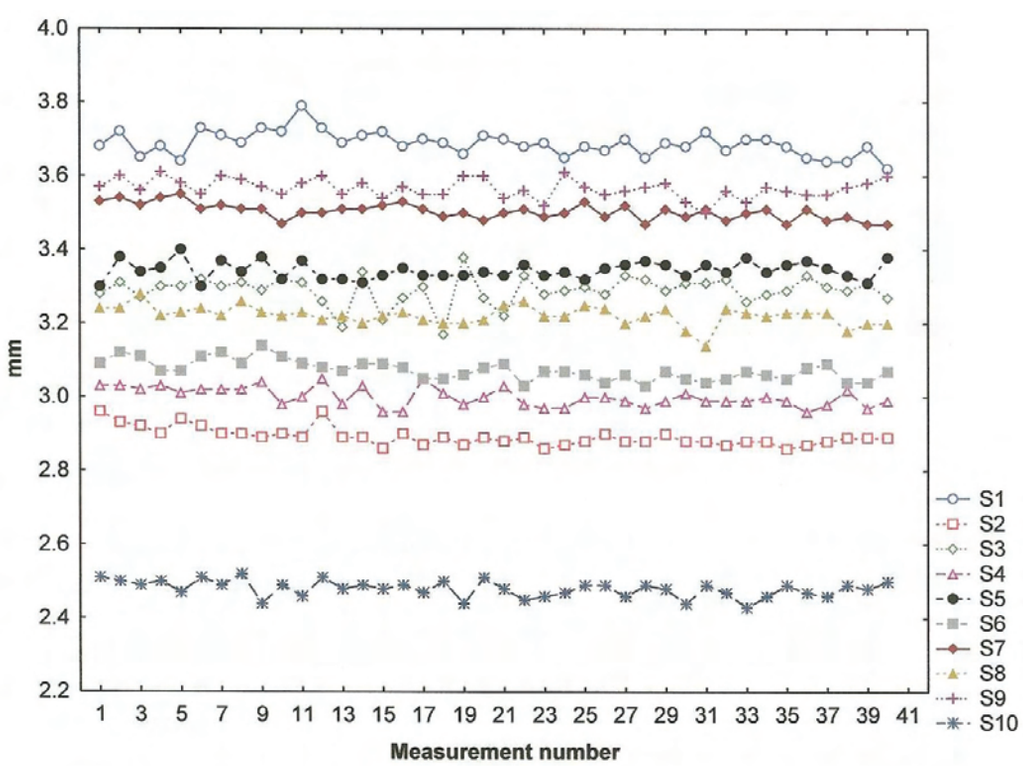


Figure 5. Trajectories of short-term or temporal variation for samples of 40 measurements of AACD (mm) for 10 young subjects are indicated. The individual measurements for subjects (S1 to S10) are connected using 10 trajectories of different colours and markers. See Table 2 for the means, standard deviations, minima and maxima for these samples.

Figures 6 and 7 respectively show histograms and normal probability plots for the samples of CCT and AACD for the first subject (S1). The histogram in Figure 6(a) shows the frequency distribution of the measurements or sample concerned. The red curve on each figure indicates the normal distribution and the sample (CCT) for Subject 1 can be observed to be approximately normally distributed as is also seen in Figures 6(a) and 6(b) where the blue circles fall close to the red line for the normal distribution. An outlier is observed in Figure 7(b), that is, a blue circle near the top of the figure falls quite far from the diagonal blue line. Normality of the samples were also tested using the Kolmogorov-Smirnov (K-S), Lilliefors and Shapiro-Wilks W (SW-W) tests (see the relevant figure captions for such results). In a K-S test for normality where the mean and standard deviation of the hypothesized normal distribution are unknown they are estimated from the sample data. The Lilliefores probability values are used in determining whether the K-S difference statistic *(d)* is significant. The test statistic *(d)* is computed from the largest difference (in absolute value) between the observed and theoretical cumulative distribution function. The SW-W test has become the preferred test of normality because of its good power properties as compared to a wide range of alternative tests.

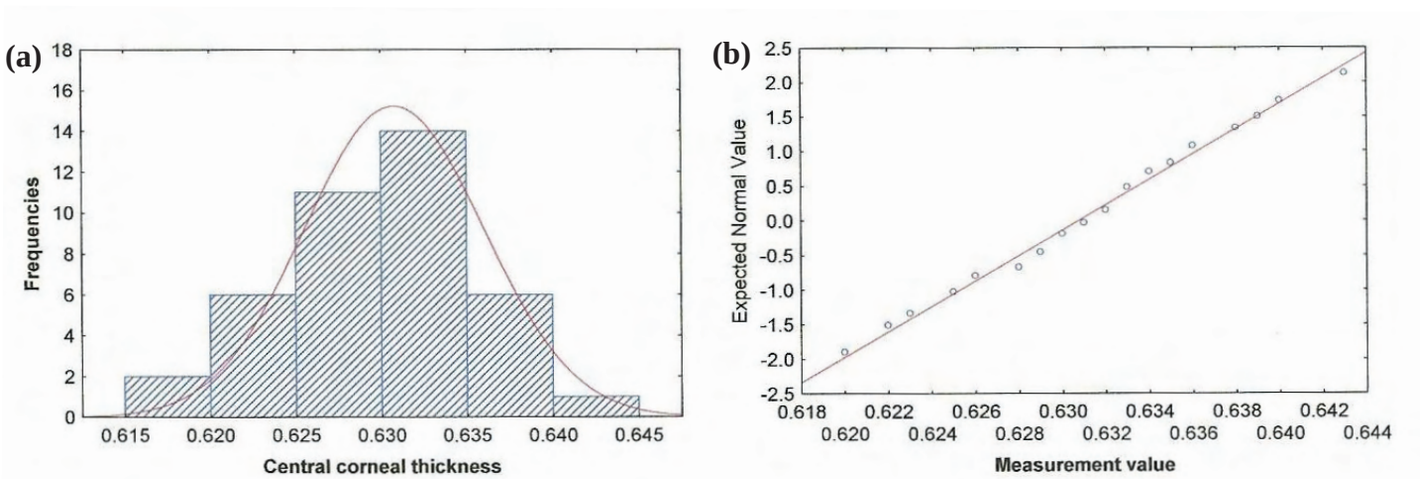


Figure 6. A histogram **(a)** and normal probability plot **(b)** for the CCT sample of subject 1. The histogram shows the frequency distribution for the CCT measurements. The bars show the specific values of measurements that occur most frequently in the sample. The curve in red indicates the normal distribution and normality of the sample is also tested using the Kolmogorov-Smirnov (K-S), Lilliefors and Shapiro-Wilks tests. The data showed a normal distribution ($p > 0.05$). (SW-W, $p = 0.8$). The graph **(a)** helps to evaluate the normality of the sample because it also shows the normal curve superimposed over the histogram. The normal probability plot **(b)** provides a quick way to visually inspect to what extent the pattern of measurements concurs with a normal distribution. The measurements (blue circles) on this plot form a linear pattern near the line in red, which indicates that the normal distribution is a good model for the data sample concerned. Notice also in Table 1 that skewness and kurtosis were almost zero for this sample.

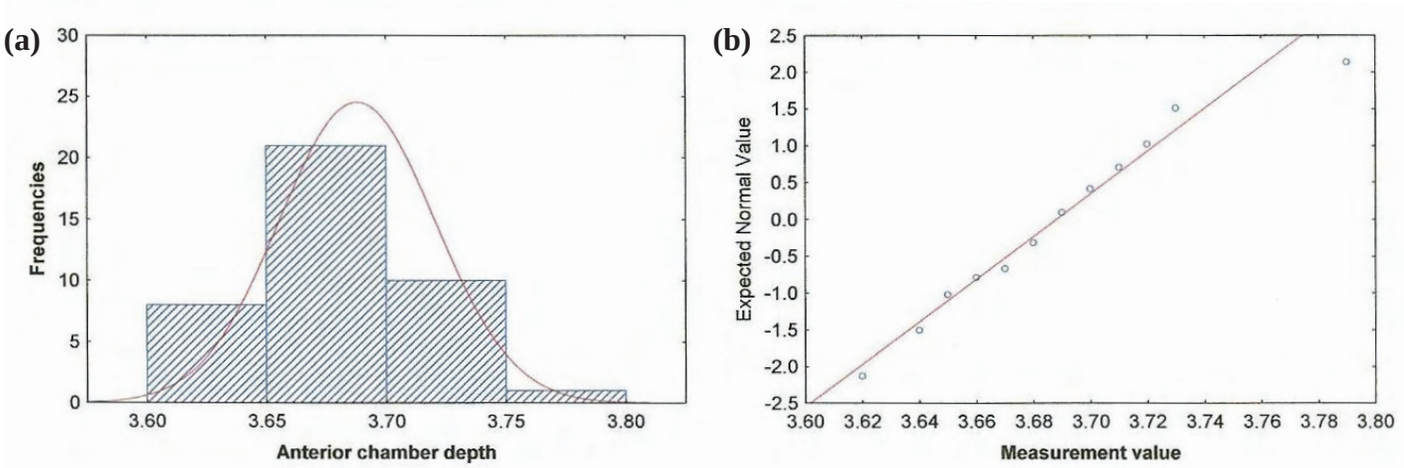


Figure 7. Histogram **(a)** and normal probability **(b)** plots for the AACD sample of subject 1. The sample was approximately normally distributed (the *p*-values for the K-S, Lilliefors and SW-W tests were all greater than 0.05). This suggests that the sample is regarded as being from a normally distributed population although a possible outlier is seen at the top of the normal probability plot (Table 2 indicates leptokurtosis of 1.277 and this quantity probably would be closer to zero should the possible outlier be removed).

Figures 8 to 11 include histograms and normal probability plots for some subjects that demonstrated departure from normality for the CCT or AACD samples. See also Tables 1 and 2 for statistics for skewness and kurtosis.

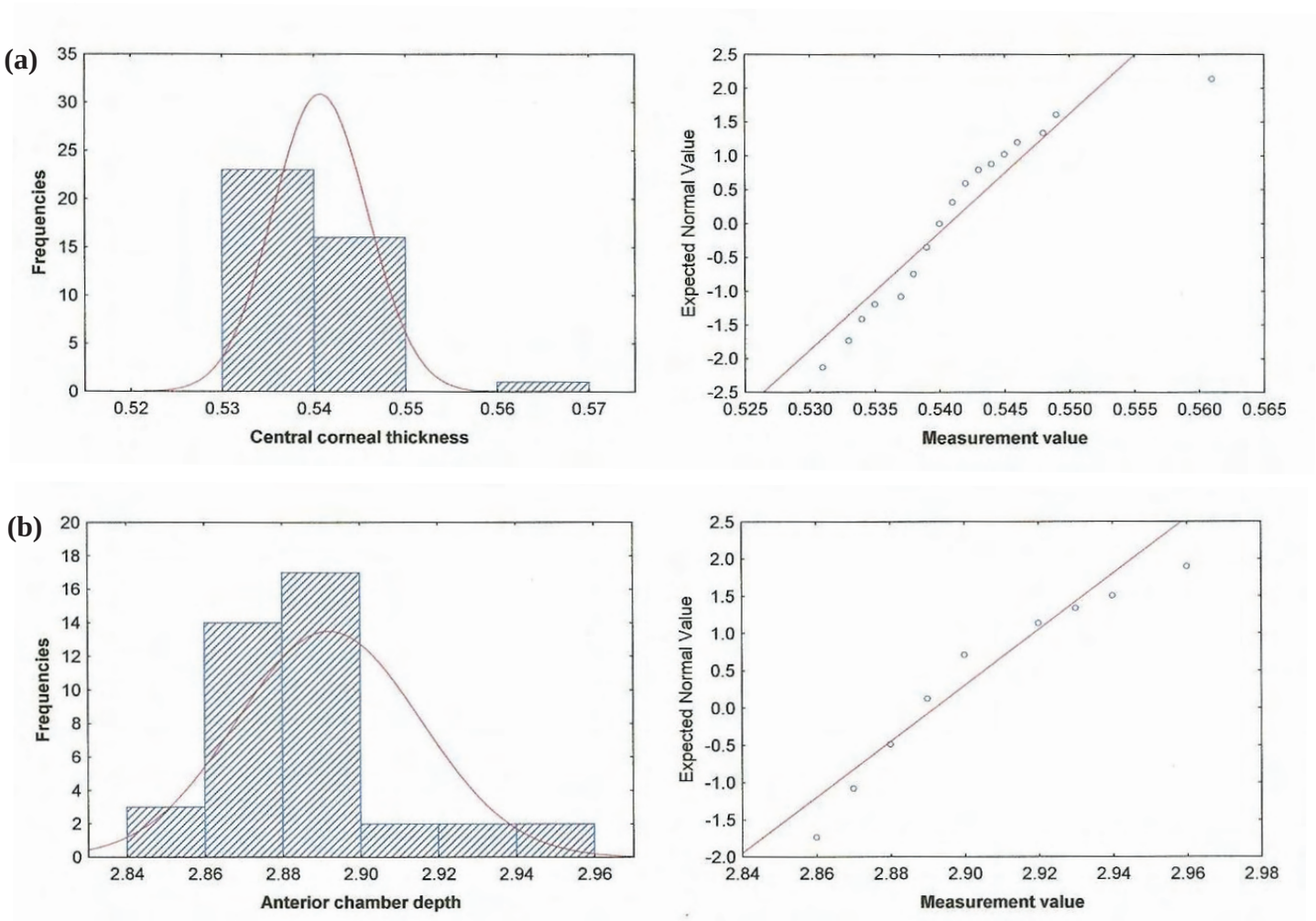
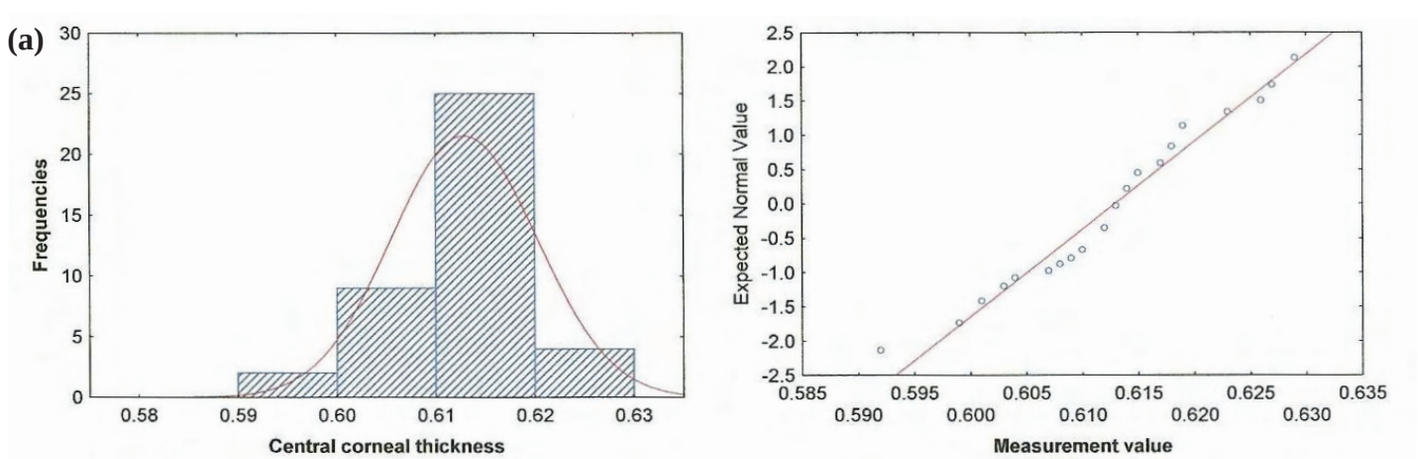


Figure 8. Histogram and normal probability plots for the CCT **(a)** and AACD **(b)** samples of subject 2. The samples were not normally distributed according to the *p*-values for the K-S and Lilliefors tests. For the SW-W tests, $p = 0.0006$ for **(a)** and 0.0002 for **(b)**. Probabilities were less than 0.05 ($p<0.05$ suggests rejection of the null hypothesis that the sample is from a normally distributed population). Tables 1 and 2 indicated profound positive skewing and leptokurtosis for both samples, that is, CCT and AACD.



(b)

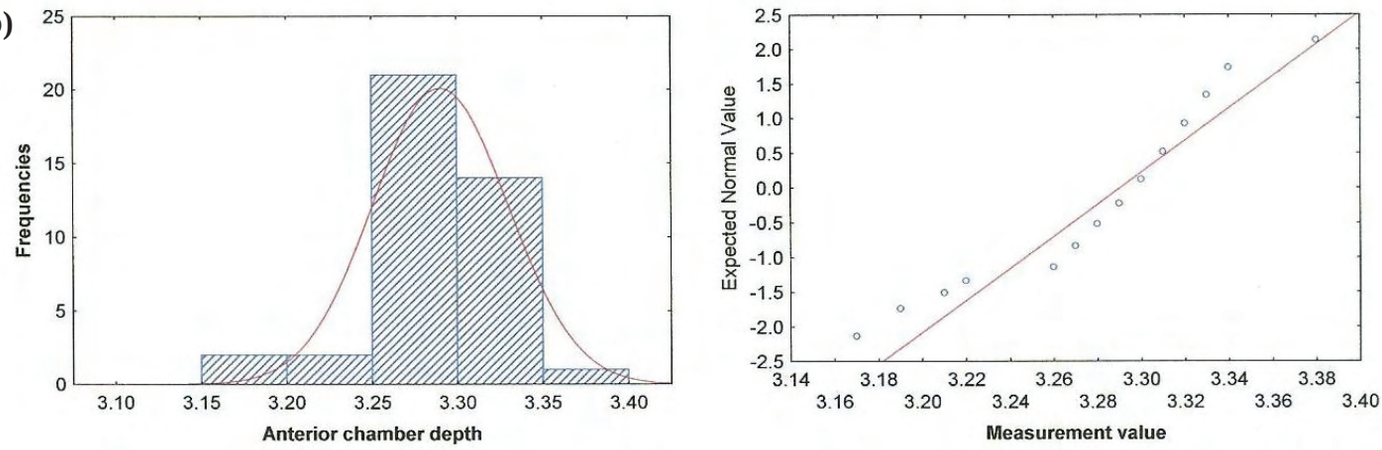


Figure 9. Histogram and normal probability plots for the CCT **(a)** and AACD **(b)** samples of subject 3. The sample for CCT **(a)** was approximately normally distributed (the *p*-values for the K-S, Lilliefors and SW-W tests were not less than 0.05 for the CCT but were less than 0.05 for the AACD ($p = 0.0023$) sample in part **(b)** .

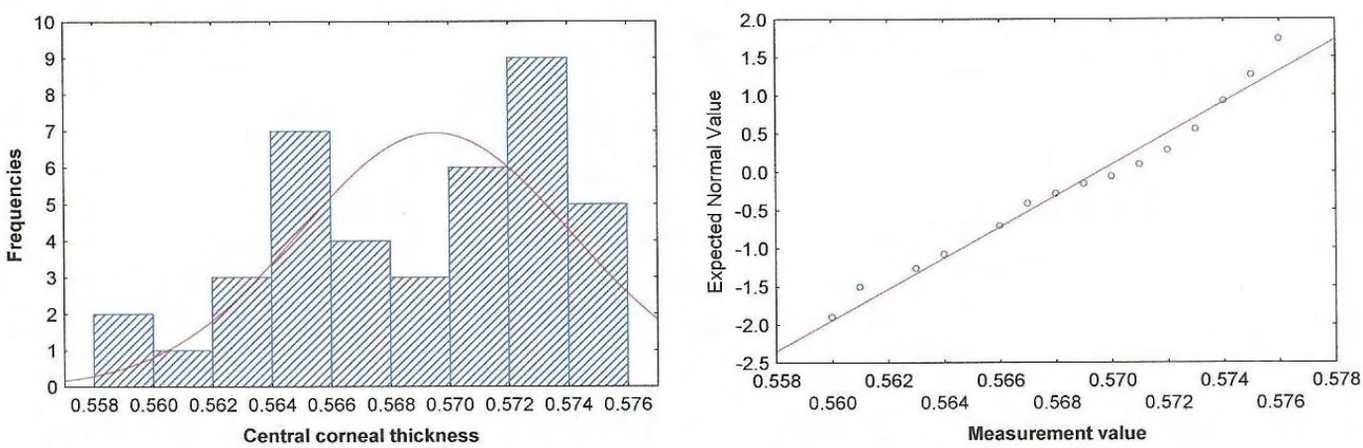
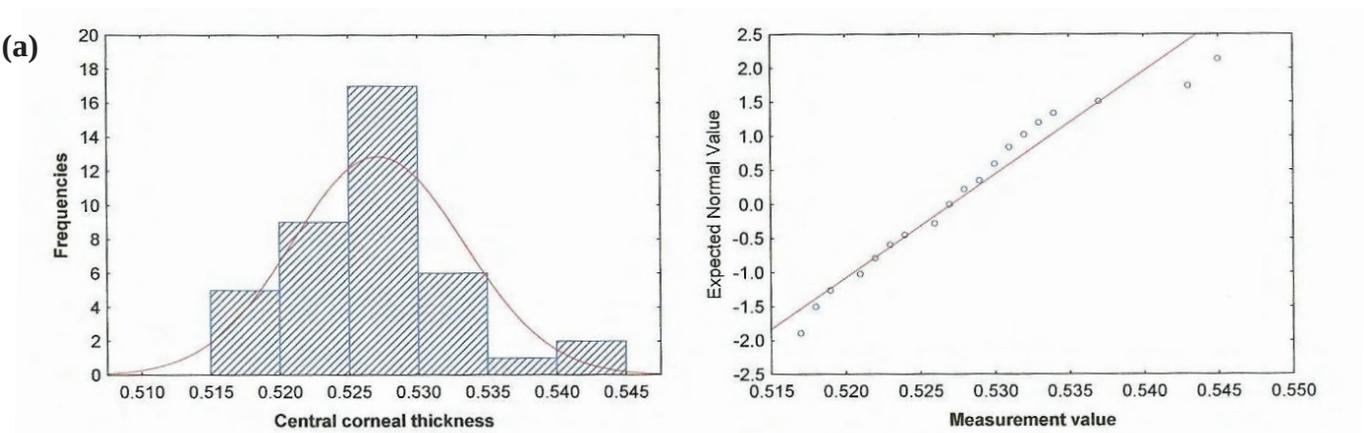


Figure 10. Histogram and normal probability plots for the CCT sample of subject 4. The sample for CCT was not normally distributed (the *p*-values for the K-S, Lilliefors, and SW-W tests ($p = 0.03$).

(a)



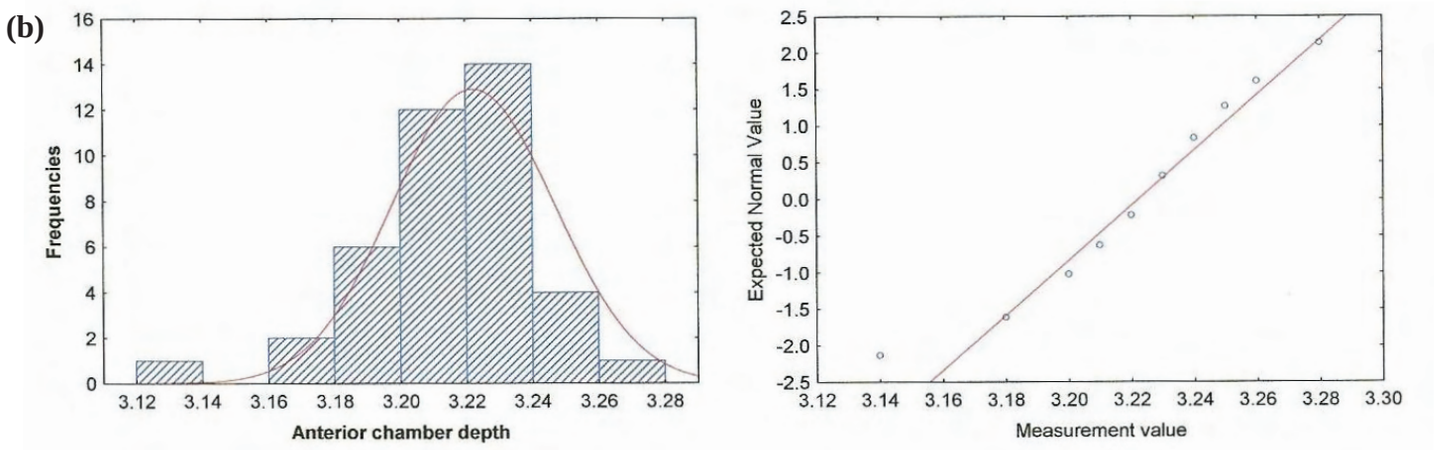


Figure 11. Histogram and normal probability plots for the CCT **(a)** and AACD **(b)** samples of subject 8. The CCT sample was approximately normally distributed, the *p*-value was greater than 0.05 but less than 0.05 for the AACD in the SW-W test.

Discussion

In this study, the individual or intra-subject means for CCT ranged from 0.514 to 0.631 mm (Table 1) while the individual means for AACD ranged from 2.480 to 3.688 mm (Table 2). The mean CCT for all the eyes or the overall inter-subject mean (for $N = 10$ eyes) was 0.555 mm while that for the overall inter-subject AACD mean was 3.206 mm. These means are not dissimilar to what might be expected for such parameters as found from the literature where, for example, intra-subject CCT is about 0.54 mm (540 microns) and intra-subject AACD is about 3.50 mm.

Ultrasound biometry has been the common method for measuring CCT and AACD. A major advantage of ultrasound biometry is that it requires minimal observer judgement and is therefore consistent and repeatable between observers[4, 8, 10-11]. However, issues such as the need for topical anesthesia, risk for infection, exact alignment at the centre of the cornea and proper handling of the probe perpendicular to the corneal surface are some possible drawbacks of this technique. These potential limitations stimulated the development of possibly more reliable, repeatable and operator independent noncontact ocular biometry techniques including the Pentacam, Orbscan, optical coherence tomography, and other optical methods for imaging and measuring the CCT and AACD of eyes.

The Pentacam allows fast, non-contact examination of the anterior segment of the individual while providing good comfort and avoiding application of topical anesthetics. The instrument provides the thickness of the entire cornea by determining the front and back surfaces of the cornea via corneal tomography with the rotating Scheimpflug camera[14]. With this instrument information regarding the anterior and posterior corneal topography, corneal thickness and anterior chamber depth and volume are also provided.

With the Pentacam in this study of 10 eyes, the measurements of CCT and AACD showed minimal variation (see the standard deviations, SD in Tables 1 and 2) and also Figures 4 and 5 where profiles are mostly flat. Thus it appears that the Pentacam measurements are largely repeatable within individuals albeit that the sample size here was only 10. This suggests that this instrument is a potentially useful clinical and research-oriented device. All samples were also investigated for normality using the Kolmogorov-Smirnov (K-S), Lilliefors and Shapiro-Wilks tests. Probabilities were used in determining whether these statistics were significant and whether there was departure from univariate normality. Most, but not all, *p* values obtained were > 0.05, indicating that most samples were essentially from normal distributions (the *p* values are included in the caption of each histogram plot for the CCT and AACD). Even though there was very good repeatability of the measurements of CCT and AACD, Figures 4 and 5 show that there is slight variability in the measurements over time. Mostly the samples of CCT for these subjects showed less variation than for the corresponding subject samples for AACD. The reasons for the variation in CCT and AACD are largely unknown. But such variation could be due to many complicated and possibly inter-related factors such as changes in the

shape of the tear layer during the process of blinking or over time, corneal hydration or dehydration, eye movements, fluctuations in intra-ocular pressure, heart rate or accommodation or iris position. Possibly, interactions between subjects and the instrument or its operator could also be contributing factors. (According to the manufacturer of the Pentacam, the tear film does not affect or influence the instrument's measurements but this seems unlikely and the authors plan to explore this issue in future studies.)

Within subjects variation for the AACD sample was generally more than for that for the CCT sample (compare corresponding intra-subject standard deviations in Tables 1 and 2). The reason for this finding is not entirely clear but could relate possibly to fluctuations in IOP or pulse and the constant flow and ebb of the aqueous humor. Perhaps small changes in iris and anterior lens position with fluctuations in aspects like ocular accommodation might be another factor. The AACD is influenced by the position and thickness of the crystalline lens and the position of the posterior corneal surface. Also, the variation could be possibly related or explained through effects with phases of respiration or local effects of changes in blood pressure. But, there are no simple explanations for the variation in CCT and AACD measurements within and amongst the subjects and a great deal of future work with other individuals or with even larger numbers of subjects will be necessary to more completely understand these complicated but intriguing issues.

Possible limitations to this study include relatively few subjects (only 10), of which most (nine of 10) were females. The ages of the subjects were limited to young university students, and gender-related issues such as hormonal and/or menstrual changes were not addressed. Further studies are required to explore some of these issues of gender and age. Although the Pentacam is capable of measuring the pachymetry of the cornea from limbus to limbus, in this study we used only the central measurements of the corneal thickness and AACD. Peripheral corneal thickness measurements were not used. One of the strengths of the study is that we took multiple (40) and successive measurements of the right eye only of all subjects. This allowed us to investigate short-term variability of the two parameters concerned in great detail and this appears to not have been previously done in other studies.

Conclusion

The relatively small variances measured for CCT and AACD samples (see Tables 1 and 2) suggests excellent repeatability and indicates the Pentacam provides consistent and repeatable information over at least the short-term. Instruments for clinical use should ideally give accurate, repeatable and valid measurements. The corneal apex CCT was used in this study (rather than pupil centre CCT, see Figure 1) but investigations as to whether it is the most repeatable corneal thickness measure remain for the future. The AACD is a very useful clinical parameter as it is used in planning IOL power calculation for cataract surgery and phakic IOL placement in refractive surgery. Therefore, the repeatability shown in measuring AACD has positive implications for clinical use where both accuracy and precision of measurements are required. Several issues remain to be investigated and, for example, further research is needed to determine the accuracy and repeatability of peripheral corneal thicknesses or limbal anterior chamber depths as obtained with the Pentacam, and whether the instrument is able to accurately measure the corneal thicknesses or other parameters in cases of corneal scarring, corneal ectasia and post-refractive surgery.

Summary

1. The Oculus Pentacam demonstrated consistent measurements and minimal short-term variation in CCT and AACD samples for ten healthy right eyes of young individuals.
2. The intra-subject means for CCT for the 10 subjects ranged from 0.500 - 0.631 mm. Standard deviations were of relatively small magnitude (0.004 - 0.007 mm).
3. The intra-subject means for AACD for the 10 subjects ranged from 2.480 - 3.688 mm. Standard deviations were of relatively small magnitude (0.021 - 0.040 mm).
4. Most intra-subject samples of CCT and AACD were apparently from normally distributed populations. This has important implications as to whether or not certain statistical methods such as parametric tests can be used with proper confidence.

   For the 10 subjects, the overall or inter-sub-

ject means and standard deviations for CCT and AACD were 0.55 ± 0.005 mm and 3.206 ± 0.03 mm, respectively.

5. The Pentacam proved to be an excellent non-contact method for measuring CCT and AACD in healthy eyes. (There is also the opportunity to study other quantities for the cornea or anterior segment where desired, such as the angles of the anterior chamber, volume of the anterior chamber, and densitometry of the crystalline lens.)
6. Measurements proved to be very simple and quick to obtain (approximately two seconds per scan). Much of the time (approximately 50 minutes) involved saving the scans into the computer memory and realigning and refocusing the instrument. Multiple scans per eye over short intervals, however, allows one to study and understand intra-subject variation in exquisite detail and should be integral parts of clinical assessments especially where complicated and potentially traumatic procedures such as refractive or corneal surgery or orthokeratology might be treatment modalities of concern.
7.

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