(26)

Evaluation of central corneal thickness measurements using Anterior Segment Optical Coherence Tomography and specular microscope

Ocena pomiarów centralnej grubości rogówki za pomocą optycznej koherentnej tomografii przedniego odcinka oka i mikroskopii lustrzanej

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Abstract: Introduction: Central corneal thickness measurements are important for diagnostic purposes. It is important to know whether automated measurements obtained with different devices are replicable.

Aim: The aim of the research was to evaluate central corneal thickness measurements taken using anterior segment optical coherence tomography and specular microscope.

Material and methods: The study group consisted of 46 eyes of 39 adult phakic patients admitted for routine cataract surgery. Central corneal thickness was measured using manual and automated mode of anterior segment optical coherence tomography and with specular microscope in automated mode.

Results: The mean central corneal thickness measured using anterior segment optical coherence tomography in a manual mode and an automated mode, as well as using specular microscopy was 559.0 $\pm$ 53.0 μm, 528.0 $\pm$ 52.0 μm and 547.0 $\pm$ 54.0 μm, respectively. There was a significant difference between measurements obtained using manual and automated mode of anterior segment optical coherence tomography ($p < .01$). There was no significant difference between measurements obtained using automated mode of anterior segment optical coherence tomography and specular microscopy ($p > .05$), as well as between measurements obtained using manual mode of anterior segment optical coherence tomography and specular microscopy ($p > .05$).

Conclusions: All central corneal thickness measurement methods, i.e. automated and manual modes of anterior segment optical coherence tomography, and specular microscopy yield correlated results. Values obtained with automated mode of anterior segment optical coherence tomography were consistently lower than results obtained with manual mode of anterior segment optical coherence tomography.

Key words: central corneal thickness (CCT), Anterior Segment Optical Coherence Tomography (AS-OCT), specular microscope.

Abstrakt: Wstęp: pomiar grubości centralnej części rogówki jest istotny dla celów diagnostycznych. Ważna jest wiedza, czy pomiary wykonane różnymi metodami mogą być traktowane zamiennie.

Cel pracy: ocena metod pomiaru centralnej grubości rogówki w zdrowych oczach soczewkowych za pomocą optycznej koherentnej tomografii przedniego odcinka oka i mikroskopii lustrzanej.

Materiał i metody: badana grupa składała się z 46 oczu 39 dorosłych pacjentów przyjętych do kliniki w celu wykonania rutynowej operacji zaćmy. Centralna grubość rogówki została zmierzona za pomocą optycznej koherentnej tomografii przedniego odcinka oka w trybie ręcznym i automatycznym oraz za pomocą mikroskopii lustrzanej w trybie automatycznym.

Wyniki: średnia wartość grubości centralnej części rogówki zmierzona za pomocą optycznej koherentnej tomografii przedniego odcinka oka w trybie ręcznym wyniosła 559,0 $\pm$ 53,0 μm, w trybie automatycznym 528,0 $\pm$ 52,0 μm, w trybie automatycznym za pomocą mikroskopii lustrzanej zaś 547,0 $\pm$ 54,0 μm.

Stwierdzono istotną różnicę w średnich wartościach pomiarów wykonanych za pomocą optycznej koherentnej tomografii przedniego odcinka oka w trybie ręcznym i w trybie automatycznym ($p < 0{,}01$).

Nie zaobserwowano istotnej różnicy w średnich wartościach pomiarów wykonanych za pomocą optycznej koherentnej tomografii przedniego odcinka oka w trybie ręcznym i mikroskopii lustrzanej ($p > 0{,}05$), a także w średnich wartościach pomiarów wykonanych za pomocą optycznej koherentnej tomografii przedniego odcinka oka w trybie automatycznym i mikroskopii lustrzanej ($p > 0{,}05$).

Wnioski: wszystkie metody pomiaru centralnej grubości rogówki, tzn. optyczna koherentna tomografia przedniego odcinka oka w trybie automatycznym i w trybie ręcznym oraz mikroskopia lustrzana, dają skorelowane wyniki.

Wartości uzyskane za pomocą optycznej koherentnej tomografii przedniego odcinka oka w trybie automatycznym są istotnie niższe od wartości uzyskanych w trybie ręcznym.

Słowa kluczowe: centralna grubość rogówki (CCT), optyczna koherentna tomografia przedniego odcinka (AS-OCT), mikroskop lustrzany.

The authors declare no conflict of interest/ Autorzy zgłaszają brak konfliktu interesów w związku z publikowaną pracą

Introduction

Central corneal thickness (CCT) measurements are important for diagnostic purposes. It is known that in applanation tonometry, which is considered a "gold standard", thin corneas produce falsely low readings and thick corneas result in falsely high readings (1). For this reason, applanation tonometry (e.g. Goldmann) should take into account CCT. It is, therefore, critical to know the exact CCT in determining accurate intraocular pressure (IOP) values. Moreover, as CCT is frequently measured by nurses or technicians with devices set in automated mode, it is important to know whether automated measurements obtained with different devices are replicable.

Aim

The aim of the study was to prospectively evaluate and compare different CCT measurement methods, namely: automated CCT measurements with a specular microscope, automated CCT measurements using anterior segment optical coherence tomography (AS-OCT) and manual CCT measurements using AS-OCT in healthy phakic eyes.

Material and methods

The analyzed data was gathered prospectively from a non-randomized consecutive series of phakic patients. All patients gave their informed consent to participate in the study. The tenets of the Declaration of Helsinki were followed for all study procedures.

The study group consisted of 46 eyes of 39 adult patients, 29 women (74.4%) and 10 men (25.6%) aged from 47 to 87 years old (mean 74.6 years, SD $\pm$ 9). All patients were phakic and were admitted to our Department for routine cataract surgery. Patients after ocular trauma, any previous ocular surgery or previous diseases affecting cornea or sclera were excluded from the study.

We performed the following CCT measurements: 1. manual measurement performed using the Heidelberg slit-lamp adapted OCT of the anterior segment of the eye (AS-OCT) with standard software which enables accurate measurements on scans using digital calipers, 2. automated measurement performed using the same anterior segment optical coherence tomography device and 3. automated measurement performed using TOPCON SP-2000P specular microscope, as a part of corneal endothelial cell density assessment (Fig. 1, 2). Both devices were calibrated by their respective manufacturers. We also recorded patient age and sex, as well as the condition of the anterior and posterior segment of the eye.

Statistical analysis involved parametric tests with all calculations carried out using Microsoft Excel software with Addinsoft XLSTAT 2008 package. Significant differences between unpaired groups were determined using two-tailed t-test for independent samples. In order to test correlations, Spearman rank-order correlation coefficient was calculated. In order to determine how measurements relate to one another, regression analysis was calculated. The significance level α of .05 was assumed for all comparisons. A Bland-Altman plot (2) was drawn to show the level of agreement between the two methods. A range of agreement (95% limits of agreement) was defined as means $\pm$ 2 SD of differences between the techniques used.

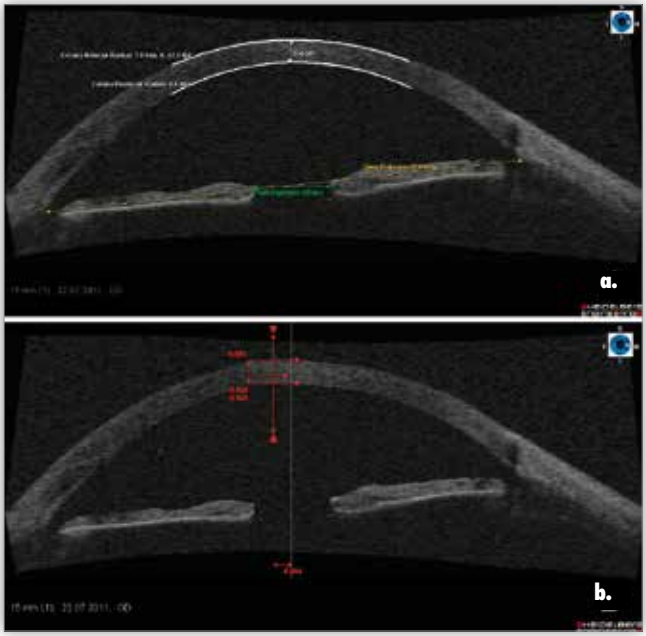

Fig. 1. AS-OCT: automated CCT measurements – a., manual CCT measurements – b.
Ryc. 1. AS-OCT: pomiar CCT automatyczny – a., i pomiar CCT ręczny – b.

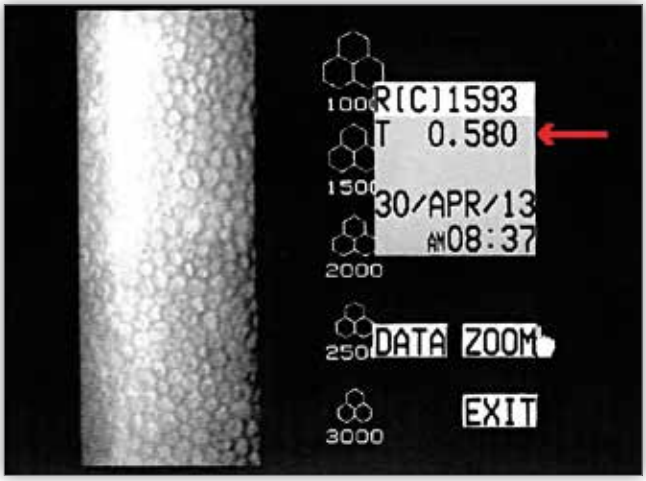

Fig. 2. Specular microscopy with automated CCT measurement.
Ryc. 2. Mikroskopia lustrzana z automatycznym pomiarem CCT.

Results

The mean CCT measured using manual AS-OCT mode, automated AS-OCT mode and automated mode of specular microscopy was was 559.0 $\pm$ 53.0 μm, 528.0 $\pm$ 52.0 μm and 547.0 $\pm$ 54.0 μm, respectively (Fig. 3). The mean difference between measurements taken using manual and automated AS-OCT modes was 30.0 μm, the mean difference between measurements taken using manual AS-OCT mode and specular microscopy was 12.0 μm, whereas the mean difference between measurements taken using automated AS-OCT mode and specular microscopy was 18.0 μm. Detailed descriptive statistics for the analysed variables are shown in Table I.

There was a significant difference between measurements obtained using manual and automated AS-OCT mode ($p < .01$). There was no significant difference between measurements obtained using automated AS-OCT mode and specular micro-

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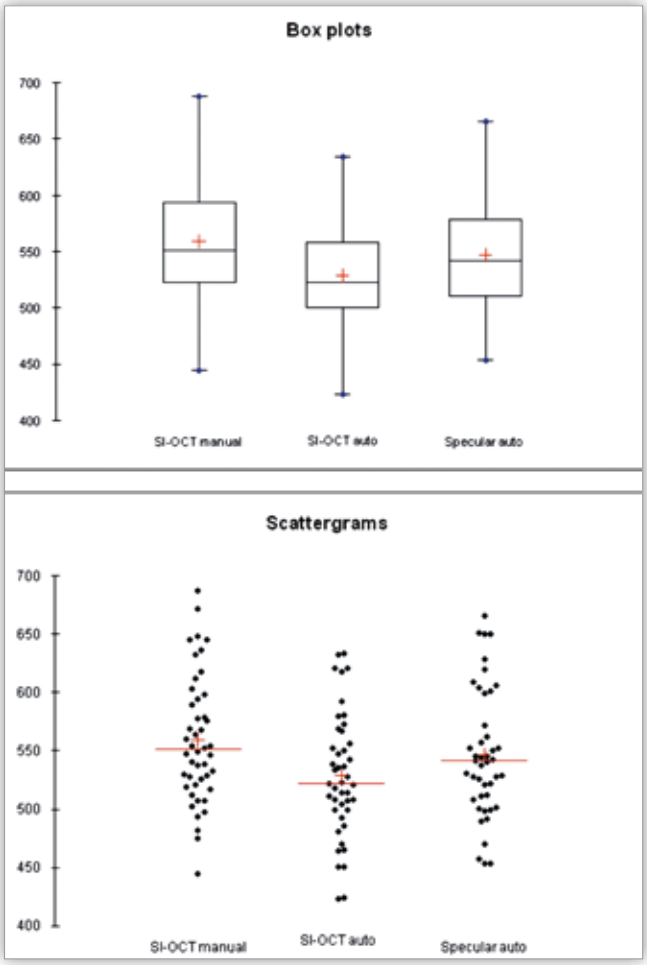

Fig. 3. Box and scatter plots of CCT measurements acquired using manual and automated AS-OCT modes, and specular microscopy (μm).

Ryc. 3. Wykresy CCT – pomiary metodą AS-OCT w trybach manualnym i automatycznym oraz za pomocą mikroskopii lustrzanej (μm).

Statistic/ Statystyki	AS-OCT manual/ tryb ręczny	AS-OCT auto/ tryb automatyczny	Specular auto/ Mikroskop lustrzany tryb automatyczny
Minimum / Minimum	445.00	423.00	454.00
Maximum/ Maksimum	688.00	634.00	666.00
Median/ Mediana	551.50	522.50	541.50
Mean/ Średnia	**559.37**	**528.95**	**547.07**
Standard deviation/ Odchylenie standardowe	53.75	52.22	54.13

Tab. I. Descriptive statistics for CCT measurements obtained using different methods (μm).

Tab. I. Statystyki opisowe pomiarów CCT uzyskanych różnymi metodami (μm).

scopy ($p > .05$), as well as between manual mode of AS-OCT and specular microscopy ($p > .05$). There was a significant correlation between measurement values obtained with all three methods ($p < .001$) (Tab. II).

Figure 4 shows regression analysis for the measurement methods used in the study: the regression line being the best-fit line. Linear regression analysis demonstrated a strong correlation between the described methods (R^2 of 0.625, 0.727 and 0.764, respectively).

The Bland-Altman analysis indicates that all measurements were within the 95% limits of agreement between the evaluated methods (mean difference ± 2*SD) and were close to the mean difference line, with no measurements being close to the limit lines (Fig. 5). This means that the studied methods provide consistently the same results which are replicable.

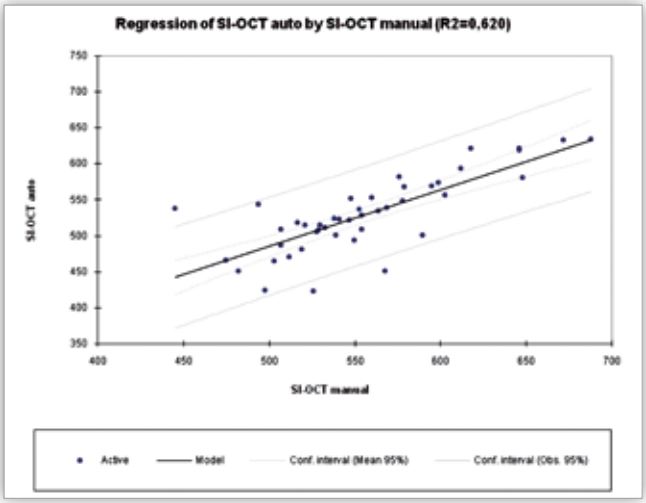

Fig. 4a. Regression analysis for manual and automated CCT measurements acquired using AS-OCT.

Ryc. 4a. Analiza regresji między ręcznymi i automatycznymi pomiarami CCT uzyskanymi za pomocą AS-OCT.

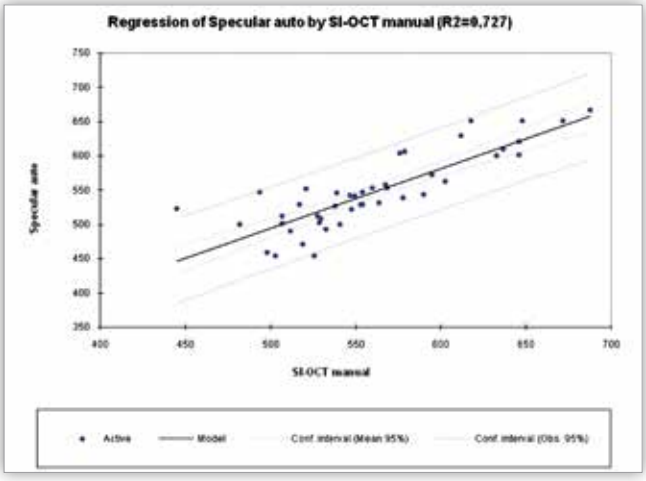

Fig. 4b. Regression analysis for manual CCT measurements acquired using AS-OCT and automated measurements obtained using specular microscope.

Ryc. 4b. Analiza regresji między ręcznymi pomiarami CCT uzyskanymi za pomocą AS-OCT i automatycznymi pomiarami CCT uzyskanymi za pomocą mikroskopii lustrzanej.

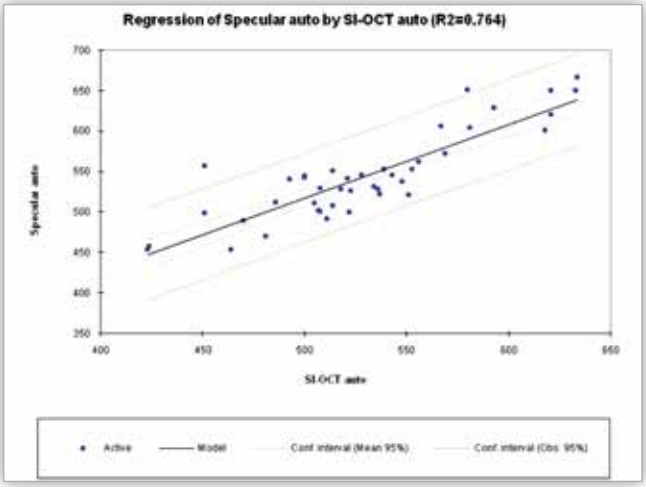

Fig. 4c. Regression analysis for automated CCT measurements obtained using AS-OCT and automated measurements obtained using specular microscope.

Ryc. 4c. Analiza regresji między automatycznymi pomiarami CCT uzyskanymi za pomocą AS-OCT i automatycznymi pomiarami CCT uzyskanymi za pomocą mikroskopii lustrzanej.

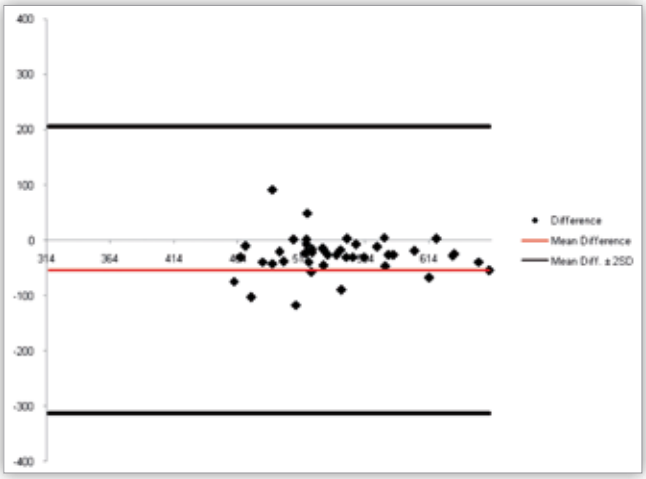

Fig. 5a. Bland-Altman plots comparing two clinical measurements – the agreement between the measurement methods. Comparison of manual and automated measurements obtained using AS-OCT.

Ryc. 5a. Wykres Blanda-Altmana ukazujący porównanie dwóch pomiarów klinicznych – zgodność między dwoma urządzeniami. Porównanie pomiarów w trybach automatycznym i ręcznym AS-OCT.

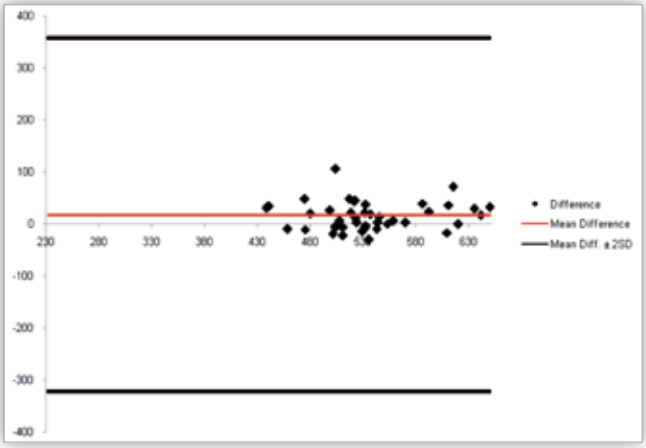

Fig. 5b. Bland-Altman plots comparing two clinical measurements – the agreement between the measurement methods. Comparison of manual measurements obtained using AS-OCT and automated measurements obtained using specular microscope.

Ryc. 5b. Wykres Blanda-Altmana ukazujący porównanie dwóch pomiarów klinicznych – zgodność między dwoma urządzeniami. Porównanie ręcznych pomiarów uzyskanych za pomocą AS-OCT i automatycznych pomiarów uzyskanych za pomocą mikroskopii lustrzanej.

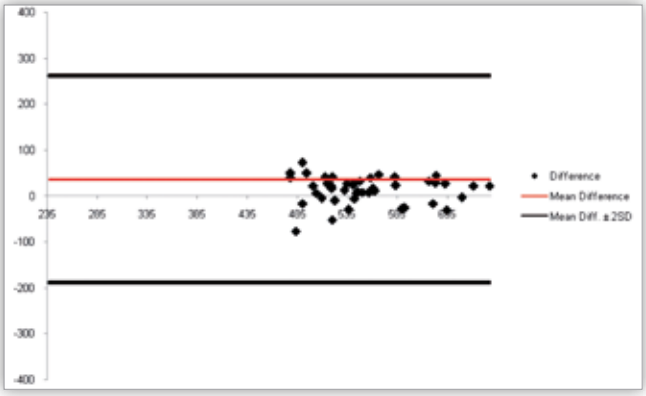

Fig. 5c. Bland-Altman plots comparing two clinical measurements – the agreement between the measurement methods. Comparison of automated measurements obtained using AS-OCT and automated measurements obtained using specular microscope.

Ryc. 5c. Wykres Blanda-Altmana ukazujący porównanie dwóch pomiarów klinicznych – zgodność między dwoma urządzeniami. Porównanie automatycznych pomiarów uzyskanych za pomocą AS-OCT i automatycznych pomiarów uzyskanych za pomocą mikroskopii lustrzanej.

Discussion

Central corneal thickness measurement is an important aspect of clinical diagnosis in ophthalmology. It enables ophthalmologists to plan corneal refractive or nonrefractive procedures, to control the accuracy of applanation tonometry, estimate the risk of primary open-angle glaucoma, evaluate progression of keratoconus and is a component of ocular biometry with dystrophic corneas and endothelial diseases (3–5). There is a number of methods for assessing CCT, i.e. Scheimpflug-based, ultrasound based, slit-scanning and optical coherence tomography based techniques (6). Central corneal thickness measurement methods may also be divided into automated and manual: automated – eg. AS-OCT, OLCR (Optical Low Coherence Reflectometry), specular microscope and manual – eg. AS-OCT, or Cirrus HD-OCT (which uses SD-OCT technology) (3). SL-OCT (Heidelberg slit-lamp adapted OCT of the anterior segment of the eye) is a device which obtains non-contact, cross-sectional scans of the anterior segment and enables evaluating pachymetry, anterior chamber angle, flap thickness and more. Specular microscopy (TOPCON SP-2000P), which is the part of corneal endothelial cell density measurements, enables obtaining corneal thickness measurements and endothelium images for the central zone and four peripheral areas. It is a method of choice for CCT measurement in cases where endothelial cell count is needed (i.e. before or after cataract surgery or refractive procedures) (7). The most commonly used method for CCT measurement, considered the gold standard, is ultrasound (US) pachymetry. Its advantages are cost-effectiveness, simplici-

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	AS-OCT Manual/ tryb ręczny		AS-OCT Auto/ tryb automatyczny		Specular Auto/ Mikroskop lustrzany tryb automatyczny	
variables/ zmienne	correlation coefficient/ współczynnik korelacji	p / wartość p	correlation coefficient/ współczynnik korelacji	p / wartość p	correlation coefficient/ współczynnik korelacji	p / wartość p
AS-OCT Manual/ tryb ręczny	1	0	.539	< .0001	.686	< .0001
AS-OCT Auto/ tryb automatyczny	.539	< .0001	1	0	.634	< .0001
Specular Auto/ Mikroskop lustrzany tryb automatyczny	.686	< .0001	.634	< .0001	1	0

Tab. II. CCT measurements obtained using different methods. Spearman correlation coefficients. All values are significantly different from 0 with a significance level $\alpha = .05$.

Tab. II. Pomiary CCT różnymi metodami. Współczynniki korelacji Spearmana. Wartości są istotnie różne od zera dla poziomu istotności $\alpha = 0.05$.

ty of use and high repeatability. There are also other methods of pachymetry e.g. AS-OCT, OLCR (optical low coherence reflectometry – performed using the Lenstar LS 900 device) or specular microscopy (3, 4). Unfortunately, ultrasound pachymetry is a contact method, so it requires topical anaesthesia, which is a disadvantage due to the risk of epithelial damage or infection dependent on the skill level of a clinician performing the exam (3, 4).

The present study was prospectively designed to evaluate for possible interchangeability between AS-OCT (manual and automated mode) and specular microscopy. Our results showed that all three methods yielded correlated results. However, values obtained with automated AS-OCT mode were consistently lower than results obtained with manual AS-OCT mode and specular microscopy.

There have been many comparative studies on this field. Jonuscheit et al. (7) proved that slit-scanning instrument (Orbscan II) yielded higher CCT values than those obtained using US pachymetry. The authors also pointed out that the ultrasound probe displaced the precorneal tear film and might compress the cornea, which could result in a falsely thin reading (7).

In our study, the mean central corneal thickness measured using anterior segment optical coherence tomography in a manual mode and an automated mode, as well as using specular microscopy was 559.0 $\pm$ 53.0 μm, 528.0 $\pm$ 52.0 μm and 547.0 $\pm$ 54.0 μm, respectively. In a similar study by Khaja et al. (5) the mean CCT measured by AS-OCT was 546.36 $\pm$ 44.17 μm. Unfortunately, there was no indication whether the measurements were taken using the automated or manual AS-OCT mode. The same authors measured CCT with specular microscope with the mean value of 557.61 $\pm$ 49.92 μm.

Other investigators (8) compared CCT measurements taken using contact specular microscope, non-contact specular microscope and ultrasound pachymetry. Their results are in accordance with ours. Huang et al. (4) proved that CCT measurements obtained with Scheimpflug-Placido disk corneal analyzer (The Sirius) are in high agreement with ultrasound pachymetry and are interchangeable. Guilbert et al. (9) compared ultrasound pachymetry, the Placido-Scheimpflug system (TMS-5) and Orbscan II (combined Placido-scanning-slit system) obtaining CCT measurements of 556.74 μm $\pm$ 42.45, 543.23 μm $\pm$ 36.73 μm and 564.45 $\pm$ 41.26 μm, respectively. Huang et al. (10) observed diurnal CCT fluctuation ($\pm$ 18 μm), which should be taken into account in long-term follow-up. Sng et al. proved that higher IOP and male gender are correlated with higher CCT values (11). Comparison of various devices may help medical professionals to choose the most accurate method CCT measurement.

We believe that AS-OCT and specular microscopy are useful and convenient methods for assessing central corneal thickness. However, measurements done using automated AS--OCT mode carry a risk of inaccurate estimation. It is, therefore, better to use methods, which offer similar and interchangeable results.

Conclusions

Central corneal thickness is a crucial diagnostic parameter used in e.g. applanation tonometry. All methods of CCT measurement, i.e. automated and manual AS-OCT modes as well as specular microscopy yield correlated results. However, values obtained with automated AS-OCT mode are consistently lower than those obtained using manual mode AS-OCT mode and specular microscopy.

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ISSN 0023-2157 Index 362646