**Original Article**

# Central Corneal Thickness Measurement Using Ultrasonic Pachymetry, Rotating Scheimpflug Camera, and Scanning-slit Topography Exclusively in Thin Non-keratoconic Corneas

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## Abstract

**Purpose:** To evaluate the agreement among Pentacam, Orbscan and ultrasound (US) pachymetry for measurement of central corneal thickness (CCT) in thin corneas with normal topographic pattern.

**Methods:** We included 88 eyes of 44 refractive surgery candidates with thinnest pachymetric readings of 500 micrometers (μm) or less on Orbscan, a normal topographic pattern, no sign of keratoconus, and best corrected visual acuity (BCVA) of 20/20. Pentacam, Orbscan and US were performed in one session by the same examiner. Exclusion criteria were history of ocular surgery, topographic abnormalities suggesting forme fruste keratoconus or keratectasia, and recent contact lens wear.

**Results:** The difference in CCT measurements by US pachymetry and Orbscan II [using an acoustic factor (AF) of 0.92] ranged from −34 to +34 μm. The difference between the thinnest point and central readings measured by US reached 16 μm with Orbscan II (AF: 0.92) and 2 μm with Pentacam. Mean differences between the employed devices were 0.2 μm for Pentacam versus US ($P = 0.727$), 30.1 μm for uncorrected Orbscan versus US ($P < 0.001$), 10.4 μm for Orbscan II (AF = 0.92) versus US ($P < 0.001$), and 0.2 μm for Orbscan II (AF = 0.94) versus US ($P = 0.851$).

**Conclusion:** In normal thin corneas, Pentacam demonstrated better agreement with US pachymetry as compared to corrected Orbscan readings. Results achieved by Orbscan were better consistent with US pachymetry using an AF of 0.94. We speculate that a dynamically graded AF in reverse proportion to CCT constitutes a better approach for correcting Orbscan measurements.

**Keywords:** Central Corneal Thickness; Ultrasonic Pachymetry; Rotating Scheimpflug Imaging; Scanning-Slit Topography; Non-keratoconic Cornea

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## INTRODUCTION

Measurement of corneal thickness (pachymetry) has many diagnostic applications in ophthalmology. To improve the validity of intraocular pressure

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measurements obtained by applanation tonometry, Kohlhaas et al[1] suggested that a correction of one mmHg for every 25 µm deviation from the central corneal thickness (CCT) of 550 µm should be considered. In the field of refractive surgery, accurate measurement of CCT is most importantly employed in the preoperative risk assessment for iatrogenic ectasia. Proposed scoring systems for corneal ectasia often include residual stromal thickness of less than 250-300 µm as a risk factor. Pachymetry is also useful for monitoring endothelial cell function as progressive endothelial cell loss is associated with stromal corneal edema resulting in an increased CCT.

Ultrasound (US) pachymetry, although considered to be the gold standard method, has limitations and drawbacks such as operator-dependency and concerns regarding contact methods which has incited the introduction of non-contact objective methods.[2] Consequently, evaluation of inter-pachymeter agreement has become an area of sustained interest in the contemporary literature. Preliminary studies revealed that Orbscan consistently provided measurements greater than US pachymetry with a mean difference of 28 to 54 µm.[3,4] To reduce this bias, the manufacturer has added an option of "correction factor" named acoustic factor (AF) to the second generation of Orbscan (Orbscan II, Bausch and Lomb, Rochester, New York). Some clinicians may routinely set this value at 0.92. Some studies, however, demonstrated that Orbscan II with AF of 0.92 underestimates the CCT in thin corneas with normal[5] or keratoconic[6,7] topography. Others reported that the application of this correction factor could result in overcorrection of corneal thickness after LASIK and PRK i.e. the Orbscan measures being less than those obtained by US.[8,9] On the other hand, AF of 0.92 has been reported to overestimate CCT in the thickest extreme of corneas.[5,10]

In fact it was predictable that AF of 0.92 would have such limitations. As expected, AFs minimize the mean difference between two methods,[11] but for the extremes of CCT this may lead to over or under estimation (which represents the effect of absolute CCT on degree of inter-device agreement). Indeed, correcting CCT readings in the thin range of CCT with a correction factor which is appropriate for thicker corneas would lead to underestimations. Thus, evaluating the agreement between different pachymeters requires further studies with more samples in the higher and lower ranges of corneal thickness. We attempted to contribute to the existing literature by studying this issue, exclusively in thin corneas (<500-510 µm). This range of corneas has especial considerations in refractive surgery because as corneal thickness decreases, decision making for or against refractive surgery gets more crucial. In other words, deviations from accurate pachymetry may lead to exclusion of potentially eligible cases or on the other hand, exposing patients to probable complications of inadequate residual stromal bed thickness.

## METHODS

A prospective investigation of interdevice agreement was designed and carried out. The Ethics Committee of Tehran University of Medical Sciences approved the study. Among the patients seeking consult for refractive surgery in an academic based clinic (Farabi Hospital, Tehran University of Medical Sciences, Tehran, Iran), those with corneal thinnest point readings of 500 µm or less in Orbscan II (AF: 0.92) were inferred about the study protocol. Fully aware of the design and aim of the study, 44 patients consented to participate in the study and undergo additional examinations (including pachymetry with US and Pentacam). Exclusion criteria consisted of a history of ocular surgery, corneal abnormal topographic patterns consistent or suspected to keratoconus and recent contact lens wear. All CCT measurements were performed at the same session without significant intervals.

### Instruments

The instruments were calibrated and utilized according to the manufacturer recommendations. The Pentacam (Oculus Optikgerate GmbH, Wetzlar, Germany) device is an optical technique which consists of an automatically rotating Scheimpflug camera and a slit illumination system. It generates a series of images based on light scattering from cells within the thin layer illuminated through the slit. Subsequent analysis of the sectional images generates a three-dimensional model of the entire anterior eye segment. This feature enables Pentacam to scan the entire anterior chamber and provide different parameters including corneal pachymetry and tomography, lens densitometry and anterior chamber depth and angle within 2 seconds. As a pachymeter, Pentacam provides a corneal thickness map and determines the thinnest point as well.

Orbscan (Bausch and Lomb, Rochester, New York, USA) is based on a scanning optical slit device which projects light slits at a 45-degree angle. Orbscan measures anterior corneal surface elevation and pachymetry. The posterior elevation data are extrapolated from anterior elevation and pachymetry using triangle methods. Analyzing this mechanism, some authors suggested that the outer-most location of the light reflection may lie at the air–tear interface rather than the tear film–epithelium interface. As a matter of fact, this and other speculations were proposed to explain the numerously reported deviation (overestimation) of corneal thickness readings by Orbscan from those of US. To reduce this bias, some clinicians routinely set the AF at 0.92. In this study, raw

pachymetry data (not multiplied by AF) were initially recorded. Data adjusted with different correction factors were subsequently computed and analyzed as stated by study protocol.

US Pachymetry was scheduled after non-contact methods. The cornea was anesthetized with topical tetracaine 0.5% (Anestocaine; Sina Darou, Iran) and subsequently probe of the ultrasonic pachymeter was manually positioned perpendicularly on the corneal center.

## Statistical Analysis

Statistical analysis was performed using SPSS version 16.0 (SPSS Inc., Chicago, IL, USA). Inter-device difference was examined with paired *t*-test. Significance level was set at 0.05. Inter-device agreement was assessed using the statistical method described by Bland and Altman.[12] This method is based on plotting differences between paired measurements against their means. It would lead to a statistical artifact, if the difference is plotted against values of any of the two (paired) devices and thus the mean of the two measurements is used as an estimate of the true value of CCT. The Bland-Altman plot helps detect any possible relationship between the measurement difference and the true value (i.e. proportional bias). Subsequently, limits of agreement (LoA) are calculated. The 95% limits of agreement, are computed as mean of the differences ±1.96 × standard deviation (SD) of the differences provided that the distribution of the differences is reasonably normal (assessed by a histogram).[13]

It's noteworthy that the limits of agreement calculated for a given sample are solely estimates of the true values pertaining to the whole population. In order to claim that the maximum probable difference between the two devices, in real world of practice, lies within a range between upper and lower LoAs, one should use standard error (SE) and confidence interval to clarify the precision of LoA estimates.

## RESULTS

The study included 88 eyes of 44 patients of whom 28 (64%) were female subjects. Mean patient age was 25.0 ± 5.56 (range, 19-43) years. Mean CCT was 476.2 ± 15.36, 465.8 ± 22.63, and 476.0 ± 15.94 µm with US pachymetry, Orbscan II, and Pentacam, respectively [Table 1]. Histograms of the inter-device differences represented a convincingly normal distribution. Figure 1 represents the degree of concordance among different methods of pachymetry in the spectrum of the thin corneas. Table 2 summarizes the results of comparisons between the US pachymetry and the noncontact methods. The lower section of this table was allocated to Bland-Altman analysis. Data from

**Table 1. Pachymetry with ultrasound, Orbscan and Pentacam in microns**

|  | Minimum | Maximum | Mean±SD |
|---|---|---|---|
| Central thickness |  |  |  |
| ultrasound | 440 | 498 | 476.22±15.36 |
| Pentacam | 435 | 503 | 476±15.94 |
| Orbscan II (AF: 0.92) | 414 | 504 | 465.84±22.63 |
| Thinnest point |  |  |  |
| Pentacam | 433 | 503 | 474.44±16.74 |
| Orbscan II (AF: 0.92) | 398 | 500 | 455.07±23.67 |

SD, standard deviation

this section is demonstrated in Figure 2, as scatterplots of Orbscan II and Pentacam measurements versus US readings. Pentacam demonstrated the smallest mean difference with US pachymetry. In terms of 95% LoA, better agreement with the US pachymetry (narrowest confidence interval) was found for the Pentacam device. Superiority of Pentacam over Orbscan was even further supported by linear regression analysis [Figure 3] i.e. the regression line for Pentacam–US pachymetry correlation was the closest to the line of equality (Y = X). In Table 1, the difference between the thinnest pachymetry readings is also presented. The mean thinest point measured by Pentacam was 0.32% thinner than the central point (a mean difference of 1.6 µm). For Orbscan II, this proportion was 2.31% (mean difference, 10.8 µm). Figure 4 depicts the correlation between Pentacam and Orbscan II readings of thinnest point of the cornea.

In order to evaluate the efficacy of different AFs to correct Orbscan readings, we began data analysis with a simple comparison of the average CCT measured by US pachymetry (476.22 ± 15.4 µm) and the average raw (without correction) Orbscan pachymetry (506.57 ± 24.6 µm). The ratio of these 2 values derives a custom AF which was 0.940 for the group of our patients. After multiplying Orbscan readings adjusted by this custom AF, the average Orbscan pachymetry was 476.18 ± 23.1 µm. There was no significant difference between US pachymetry measurements and the Orbscan II readings adjusted by AF = 0.94 (*P* = 0.851). Using linear regression, Orbscan pachymetry correlated most closely with US ($R^2$ = 0.61) after correction with an AF of 0.94. As shown in Figure 3, AF of 0.94 reduces Orbscan over-and underestimation at the two extremes of CCTs. The last column in Table 2 summarizes the statistical properties of Orbscan II (AF: 0.94) along with the gold standard.

## DISCUSSION

As long as new devices for gauging ocular characteristics emerge rapidly, inter-device agreement evaluation remains an area of sustained interest for ophthalmologists. By definition, two tests are said to be in full agreement

if their readings when plotted along Y (vertical) and X (horizontal) axis, lie exactly over the line of equality. In practice, however, it is most improbable that two measurement methods give identical results for all individuals. Statistical tools of inter-device agreement evaluation, solely determine how much the two methods



**Figure 1.** Box plots of ultrasound, Pentacam, Orbscan II, and corrected Orbscan II CCT[a] readings. CCT, central corneal thickness.

are likely to differ. Subsequently, the clinician should determine whether this amount of difference can be acceptable in clinical contexts or not.[14]

In the present study, we have examined the efficacy of the widely used correction factor of 0.92 in aligning the Orbscan CCT data to that of US pachymetry. In fact shortly after introduction of Orbscan it was demonstrated that it overestimates CCT almost persistently. This incited the manufacturer to provide an option of acoustic (correction) factor in the second generation of Orbscan. According to the manufacturer instruction, the results of pachymetry of 20 patients measured by Orbscan and ultrasonic pachymetry should be compared. Accordingly, AF can be from 0.85 to 0.94. This calibration should be repeated periodically. Some researchers tried to propose different correction methods. Cheng et al[10] suggested a subtraction method where all raw Orbscan readings were subtracted by the mean difference between the raw Orbscan pachymetry and the US pachymetry. They brought up this method on the basic presumption that most of the difference between Orbscan and US readings reflects the tear film thickness. This idea seems appealing since it represents an approach of addressing the exact biophysical cause of discrepancy rather than pure mathematical approach.
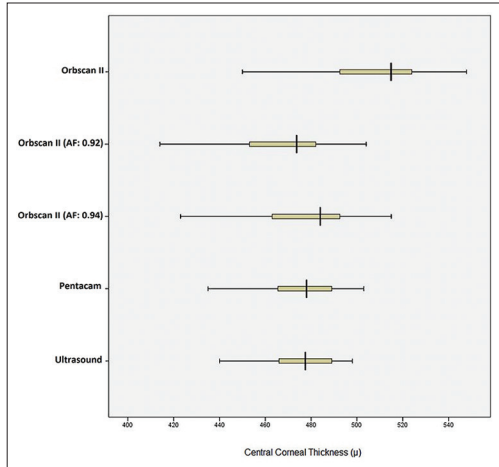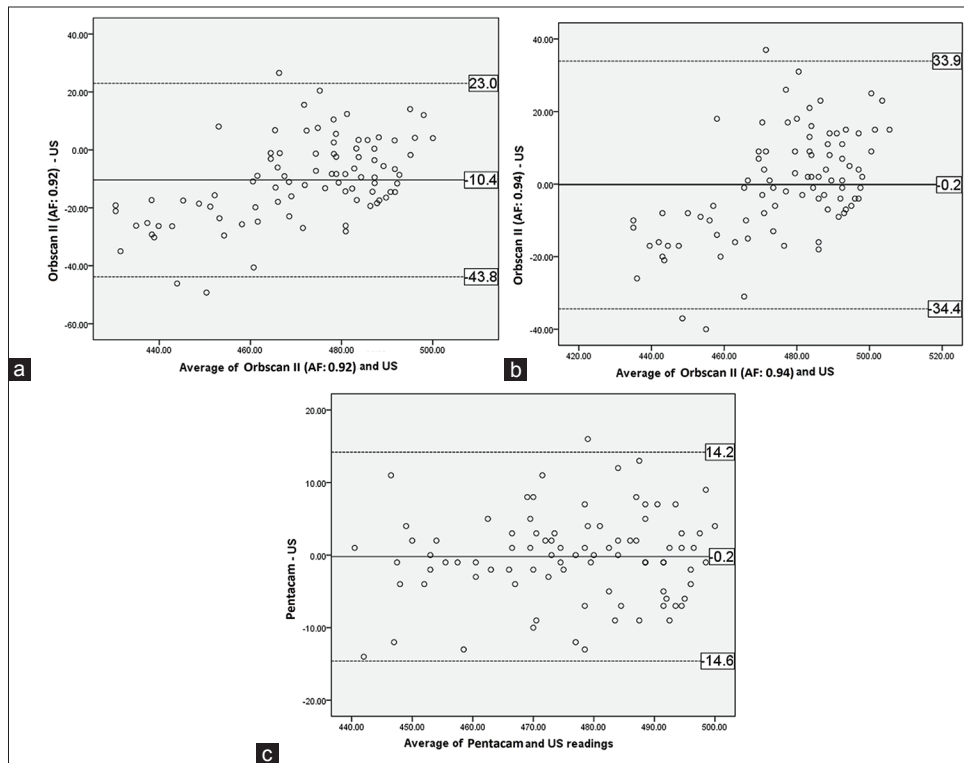


**Figure 2.** Bland-Altman plots of Pentacam, and corrected Orbscan II CCT readings against US. The middle line is the mean and the lines on the side represent the upper and lower limits of confidence intervals for upper and lower limits of agreement respectively. To enhance precision, the upper and lower lines in this figure were moved centrifugally, from the calculated LoAs of our sample of 88 eyes, to the outer limit of their 95% confidence interval. This was done because the calculated LoAs are barely estimates of the values applicable to the whole population. CCT, central corneal thickness.
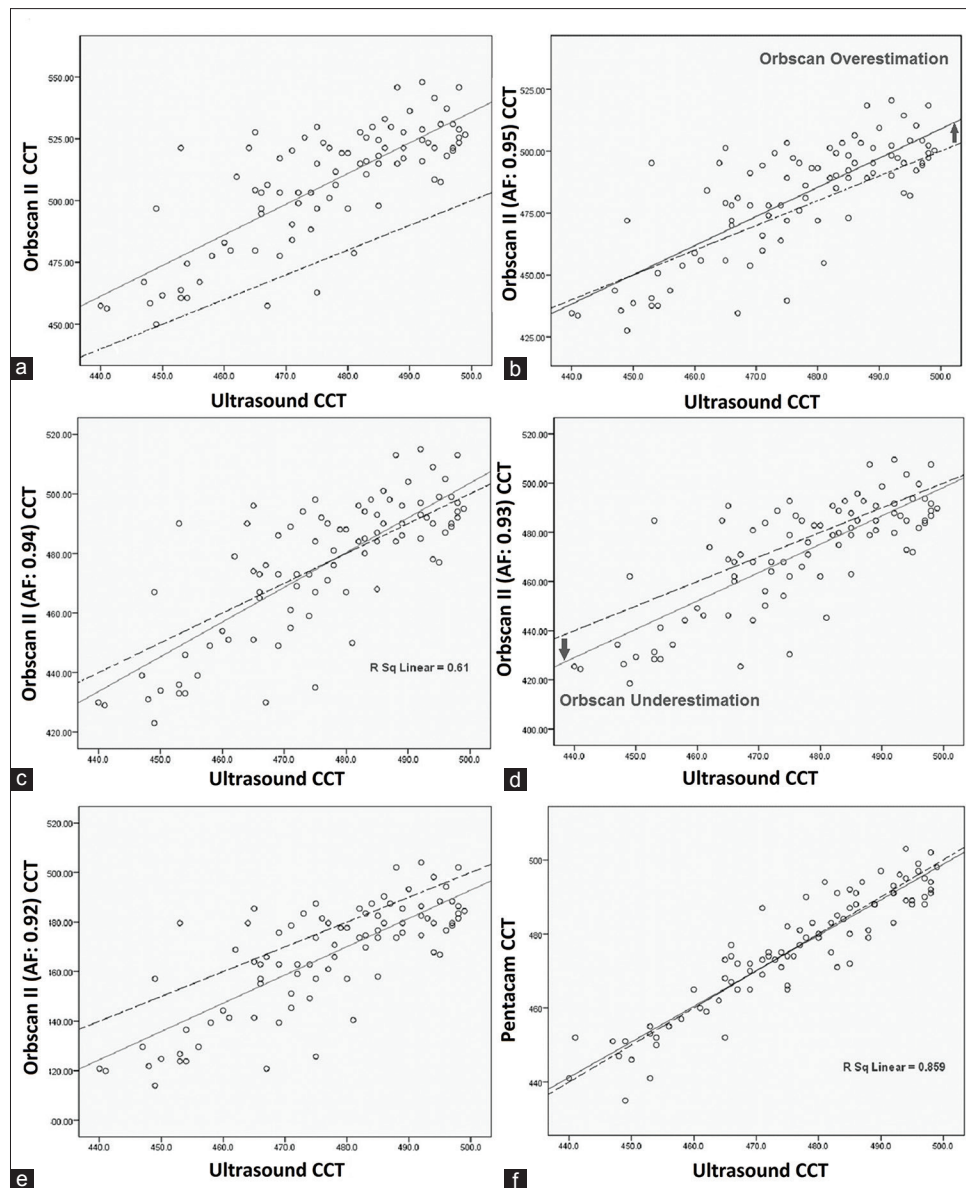
**Figure 3.** Scatterplots of Pentacam, Orbscan II, and corrected Orbscan II CCT readings against Ultrasound measurements. (a) Orbscan, when uncorrected, results in CCT overestimation throughout all ranges of human corneal thickness including thin corneas (<500µ) demonstrated in this diagram. (b and d) AF of 0.93 and 0.95 accompanies a considerable over- and underestimation at extreme CCTs. (c) AF of 0.94 seems to be the nearest to the ideal correction Higher R-Sq-Linear of Pentacam pachymetry is a quantitative indication of superiority to Orbscan readings, even when corrected with the best AF. CCT, central corneal thickness; AF, acoustic factor.

Another method suggested by Hashemi et al[5] was based on employing correction equations extracted from linear regression. These reports essentially raise the question that which correction approach can produce more comparable results to US pachymetry. In our study, we compared these two innovative methods with the popular multiplication method of custom AF. The results proved that the custom AF method (taking correction factor of 0.94) was superior. Another challenge in Orbscan correction arises from the effect of CCT values on the agreement between US and Orbscan. In fact the Bland-Altman plots in our study and most of the relevant

articles demonstrate that the difference between the two pachymeters are proportional to their mean reading (i.e. proportional bias). This effect was well-investigated by Hashemi et al.[5] Noting a proportional relation between value size and agreement calls for incorporation of log transformation in Bland-Altman analysis.[12] Since in this study we have restricted our input data to a narrow range of CCTs (440-500 µ) little is lost if Bland-Altman analysis goes on without log transformation. However, we believe many published reports of agreement evaluation throughout the whole range of corneal thickness suffer from statistical drawbacks of

**Table 2. Comparison between Pentacam, Orbscan II, and ultrasound measurements**

| Pachymeter | Pentacam - US | Orbscan II without AF - US | Orbscan II (AF: 0.92) - US | Orbscan II (AF:0.94) - US |
|---|---|---|---|---|
| Inter-device difference | | | | |
| Mean±SD[Δ] (μm) | 0.2±6.1 | 30.1±15.8 | −10.4±14.4 | −0.2±14.7 |
| Range[Δ] (μm) | -14 to 16 | -12 to 68 | -49 to 27 | -40 to 37 |
| *P* | 0.727 | <0.001 | <0.001 | 0.851 |
| Inter-device agreement | | | | |
| 95% LoA | -11.1 to 12.2 | -0.1 to 61.2 | -38.6 to 17.8 | -29.1 to 28.6 |
| 1.96* SE | 2.2 | 5.7 | 5.2 | 5.3 |
| CI for LoAs | -14.6 to 14.2 | -5.8 to 66.9 | -43.8 to 23 | -34.4 to 33.9 |

[Δ]Inter-device difference. US, ultrasound; AF, acoustic factor; SD, standard deviation; LoA, limits of agreement; SE, standard error for 95% LoA; CI, confidence interval
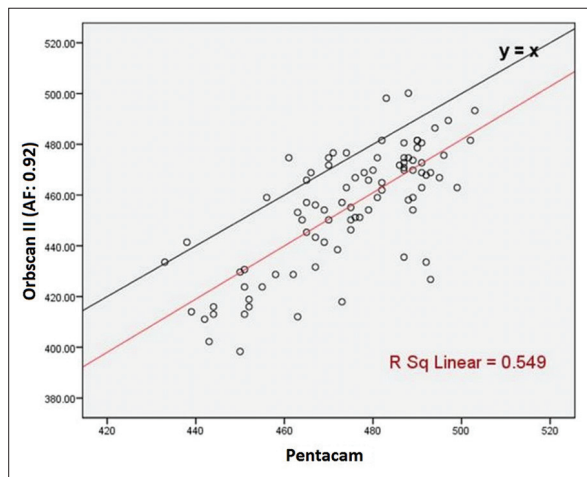


**Figure 4.** Thinnest point correlation between Orbscan II (AF: 0.92) and Pentacam. The red line represents the fit line.

this kind. Another logical consequence of the relation between CCT value and agreement is the fact that correction factors will also be dependent on the CCT values. In other words, a single AF cannot be suitable for the whole normal range of CCTs. This logical deduction was supported by our observation in this study as well as previous reports. In a review of 47 studies, Doughty and Joncheit[11] concluded "the global application of a 0.92 AF does not robustly align the Orbscan CCT data to that of the US pachymetry and; in fact, can easily result in the data being as much as 7% lower."

Our study demonstrated that AF of 0.92, although generally believed to be appropriate for correcting the CCTs in the usual range of 520 to 580 μm, is inferior to AF of 0.94 for thin cornea pachymetry. If we scrutinize the plots of this study [Figure 3], it can be speculated that for CCTs smaller than 460 μm, an AF of even larger than 0.94 (0.95 or 0.96) may be the best adjusting correction factor.

These findings support the need for custom AFs to be utilized in reverse proportion to the CCT values. In other words, we advocate a new mathematical approach of correcting Orbscan readings, where larger AFs are taken for thinner corneas. If enough evidence is generated in support of this approach, a practical implication could be

introduction of a new smart option in future generations of Orbscan in which the processor itself suggests and applies the best-aligning AF for the very specific CCT measured in a single pachymetry. Until that point the best acoustic factor for thicker corneas (>600 μm) remains a missing part of the puzzle which remains to be investigated.

Finally we evaluated the thinnest point of cornea. It is now well-established that the central cornea does not represent the thinnest point of the cornea. The thickness of this thinnest point, usually located temporally inferior, has been reported to be 1.8-2.8% thinner than CCT with Orbscan II (AF: 0.92).[12,15,16] In our study, congruently, this difference amounted to 2.31% (a mean difference of 10.8 μm). Khoramnia et al,[17] reported this difference to be about 0.78% with Pentacam. Our results correspondingly indicate that Pentacam reads a smaller difference between the thinest point and CCT (0.32% with a mean difference of 1.6 μm) in comparison with Orbscan. At the present time, we cannot judge which pachymetry method reads the thinnest point thickness more accurately. Currently it may be suggested that calculation of the residual corneal thickness in laser refractive surgery be based on the thinnest corneal reading which can be as much as 16 μm lower than the CCT [Table 1].

This study shows that Orbscan can produce more comparable results to US pachymetry in thin corneas if AF of 0.94 is taken. The difference between US and Orbscan II (AF: 0.94) lies in the range of −34 to +34 μm. One could argue that the agreement did not improve in regard to AF of 0.92 where discrepancy ranges from −44 to 23 μm. However, a practical advantage of AF of 0.94 is that the range of expected difference straddles the zero axis symmetrically. Although the AF of 0.94 was shown to give the best correlation, it is still overall poor and dynamic over the range of CCT measurements. We speculate that a graded spectrum of AFs in reverse proportion to the CCT size can constitute the best approach of Orbscan correction. This study also demonstrated that the difference between the thinnest point and central readings can amount up to 16 μm with Orbscan II (AF: 0.92) and 2 μm with Pentacam.

This difference should be considered in preoperative planning at refractive surgery clinics. This difference additionally may signal a hint for the puzzle of their different mechanisms. Finally this study demonstrated that Pentacam shows the best agreement with US in thin corneas (i.e. discrepancies as little as −15 to +15 μm).

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Nil.

## Conflicts of Interest

There are no conflicts of interest.

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