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COMPARISON OF CENTRAL CORNEAL THICKNESS MEASUREMENTS USING ANTERIOR SEGMENT OPTICAL COHERENCE TOMOGRAPHY (OCT), CORNEAL TOPOGRAPHY AND SPECULAR MICROSCOPY

Original Research

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ABSTRACT

Background: Central corneal thickness (CCT) is a crucial parameter in ophthalmology, influencing the diagnosis and management of various corneal and glaucomatous conditions. Accurate CCT assessment is essential for clinical decision-making, surgical planning, and disease monitoring. Multiple imaging modalities, including anterior segment optical coherence tomography (AS-OCT), corneal topography (CT), and specular microscopy (SM), are commonly used for CCT measurement. However, variations in measurement accuracy and agreement among these techniques necessitate comparative evaluation to determine their clinical interchangeability.

Objective: To determine the agreement of CCT measurements obtained using AS-OCT, CT, and SM in healthy individuals and assess the correlation between these modalities.

Methods: This prospective, cross-sectional study was conducted at the Armed Forces Institute of Ophthalmology from September 2023 to February 2024. A total of 125 right eyes of healthy volunteers aged 18–50 years with normal corneas (spherical equivalent: -2.00 D to +2.00 D, intraocular pressure <21 mmHg) were included. CCT was measured using Shin-Nippon SPM-700 (SM), TMS-5 Tomey (CT), and TOPCON 3D OCT-2000 (AS-OCT). Each measurement was performed three times by a single examiner, with a five-minute interval between devices. Pearson's correlation coefficient (r) was used to assess agreement among the techniques, with $p \leq 0.001$ considered statistically significant.

Results: The mean age of participants was 35.33±8.32 years (range: 21–50 years), with 55.2% males and 44.8% females. The mean CCT values obtained were 505.74±11.36 µm (SM), 528.79±13.12 µm (CT), and 518.46±19.54 µm (AS-OCT). A strong correlation was observed between CT and AS-OCT ($r = 0.51$, $p \leq 0.001$), followed by a moderate correlation between SM and AS-OCT ($r = 0.39$, $p \leq 0.001$) and a weaker but significant correlation between SM and CT ($r = 0.36$, $p \leq 0.001$).

Conclusion: CCT measurements obtained using AS-OCT, CT, and SM demonstrated reasonably consistent results, with AS-OCT and CT exhibiting the highest agreement. However, variations in correlation strength suggest that these modalities may not be directly interchangeable without adjustment. These findings emphasize the need for careful selection of measurement techniques based on clinical requirements.

Keywords: Anterior segment optical coherence tomography, Central corneal thickness, Corneal topography, Intraocular pressure, Optical coherence tomography, Pachymetry, Specular microscopy.

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INTRODUCTION

Central corneal thickness (CCT) is a fundamental parameter in ophthalmology, playing a pivotal role in diagnosing and managing various ocular conditions. It serves as a critical factor in monitoring progressive diseases such as glaucoma, keratoconus, and corneal dystrophies, where corneal thickness alterations can indicate disease severity and progression. Additionally, precise CCT measurements are essential in assessing the suitability of patients for contact lens wear and planning surgical interventions, including refractive surgery and keratoplasty. Notably, CCT is integral to glaucoma evaluation, influencing intraocular pressure readings and clinical decision-making in its diagnosis and management (1). Multiple imaging modalities have been developed for the accurate assessment of CCT, each with distinct methodologies and advantages. Specular microscopy (SM), one of the earliest techniques, was originally introduced for endothelial cell analysis but has since been adapted for corneal thickness measurement. It functions by capturing mirror-like reflections from the corneal surfaces using an optical reflection microscope. While SM allows simultaneous endothelial assessment and pachymetry measurement, its accuracy is influenced by factors such as corneal clarity, proper alignment, and the expertise of the examiner. Despite its utility, inconsistencies in measurement reliability have been reported (2,3).

Corneal topography (CT) presents a non-contact alternative that evaluates corneal thickness by analyzing light reflection and refraction across the corneal surface. Modern topography systems incorporate advanced imaging technologies, such as Scheimpflug imaging and reflection-based systems, generating detailed three-dimensional corneal maps that include pachymetric data. This method is particularly beneficial in refractive surgery planning and keratoconus screening, given its ability to provide simultaneous curvature mapping and thickness measurements. However, the accuracy of peripheral corneal measurements remains a limitation, and environmental factors may affect reproducibility. Consequently, further validation is necessary to establish its reliability for CCT assessment (4,5). Anterior segment optical coherence tomography (AS-OCT) has emerged as a state-of-the-art imaging modality, adapting the principles of posterior segment optical coherence tomography for anterior segment evaluation. This non-invasive technique employs low-coherence interferometry and infrared light reflection to generate high-resolution cross-sectional images of corneal structures. The advent of Fourier-domain technology has enabled rapid image acquisition, producing high-quality tomograms with remarkable precision. AS-OCT's non-contact nature minimizes the risk of infection and patient discomfort while offering a comprehensive analysis of anterior segment anatomy. However, its accuracy can be influenced by operator expertise, image quality, and patient cooperation. Although AS-OCT devices are relatively expensive and lack portability, their ability to deliver high-quality imaging and swift data acquisition has rendered them indispensable in clinical ophthalmology (6–9).

Each of these modalities—SM, CT, and AS-OCT—employs distinct principles for CCT measurement, and the degree of agreement among them remains an area of ongoing investigation. While previous studies have explored the comparability of various pachymetric techniques, comprehensive evaluations incorporating these three specific modalities are limited. Given the clinical significance of accurate corneal thickness measurement, a direct comparison of these methods is warranted to determine their interchangeability in routine ophthalmic practice (10). This study aims to evaluate and compare CCT measurements obtained using AS-OCT, CT, and SM in a local clinical setting. By assessing the degree of agreement between these techniques, the findings will provide valuable insights for ophthalmologists, aiding in the selection of appropriate measurement tools and enhancing diagnostic precision in clinical practice.

METHODS

This prospective, cross-sectional, comparative study was conducted at the Armed Forces Institute of Ophthalmology, Military Hospital, Rawalpindi, over a six-month period from September 2023 to February 2024. Ethical approval for the study was obtained from the hospital's ethical review committee, and written informed consent was secured from all participants before their inclusion in the study. The sample size was determined using standard statistical calculations, with precision set at 4.00% and an assumed correlation coefficient (r) of 0.946 between MS and CT measurements, based on previously published literature (11). Considering a 95% confidence interval and an infinite population size, the required sample size was estimated to be 123 subjects. To accommodate potential dropouts, a total of 125 right eyes of healthy volunteers aged between 18 and 50 years were included. Eligibility criteria required participants to have normal corneas, a spherical equivalent refractive error between -2.00 D and +2.00 D, and an intraocular pressure (IOP) of less than

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21 mmHg. Exclusion criteria comprised individuals with a spherical equivalent exceeding -6.00 D, recent contact lens use (within two weeks prior to measurement), a history of corneal disorders such as dystrophies, degenerations, keratitis, or ectasia, active ocular diseases, severe cataracts, previous ocular trauma or surgery, and systemic conditions affecting ocular health, including diabetes mellitus.

Each participant underwent a detailed ophthalmic examination, including visual refraction, slit-lamp biomicroscopy, intraocular pressure measurement, and fundus evaluation. Demographic details and relevant medical history were documented using a structured proforma. All measurements were performed between 9:30 AM and 5:30 PM to minimize diurnal variations, with at least one hour of patient awakening before data collection. A single examiner conducted all measurements to maintain consistency, taking three consecutive readings with each instrument. Measurements were obtained while subjects were seated, with a five-minute interval between different devices to prevent potential measurement bias. Room temperature was maintained between 20–22°C, with humidity levels controlled at 30–40%. Central corneal thickness (CCT) was assessed using three different imaging modalities. Specular microscopy (SM) measurements were obtained using the Shin-Nippon SPM-700, which assessed corneal thickness within the range of 400–750 µm by analyzing light reflections from the anterior and posterior corneal surfaces. Corneal topography (CT) measurements were conducted using the TMS-5 corneal topographer (Tomey Corporation, Japan), which utilizes Fourier-domain technology with a scanning speed of 26,000 A-scans per second to generate high-resolution corneal images. Anterior segment optical coherence tomography (AS-OCT) measurements were performed using the TOPCON 3D OCT-2000 (Japan) with a cornea-anterior segment module lens adapter. Subjects were instructed to fixate on a blue target, and scans were centered either on the corneal vertex, identified by a bright vertical flare line, or on the pupil center, ensuring precision in CCT measurement.

The primary objective was to determine the agreement among CCT measurements obtained using AS-OCT, CT, and SM. Statistical analysis was performed using SPSS version 25. Categorical variables such as gender were presented as frequencies and percentages, while continuous variables, including age and CCT measurements, were expressed as mean ± standard deviation (SD). Pearson's correlation coefficient (r) was used to assess the strength of agreement between the three measurement techniques, with r values >0.5 indicating a strong correlation, r between 0.3 and 0.5 considered moderate, and r <0.3 interpreted as weak. Statistical significance was set at $p \leq 0.001$. Scatter plots were generated to visually assess correlations among the different modalities.

RESULTS

The study included 125 participants with a mean age of 35.33±8.32 years (range: 21–50 years). Males constituted 55.2%, while females accounted for 44.8% of the study population. The central corneal thickness (CCT) of the right eye was measured in all participants using specular microscopy (SM), corneal topography (CT), and anterior segment optical coherence tomography (AS-OCT). The mean CCT values obtained with the three techniques demonstrated variation. The mean±SD CCT measured by SM was 505.74±11.36 µm (range: 480–528 µm), by CT was 528.79±13.12 µm (range: 505–571 µm), and by AS-OCT was 518.46±19.54 µm (range: 486–557 µm). The highest mean CCT value was recorded with CT, followed by AS-OCT, while SM yielded the lowest CCT measurements.

Correlation analysis between the three techniques revealed moderate to strong positive correlations. A strong correlation was observed between CT and AS-OCT ($r = 0.51$, $p \leq 0.001$), indicating substantial agreement between these modalities. A moderate correlation was found between SM and AS-OCT ($r = 0.389$, $p \leq 0.001$), while the correlation between SM and CT was relatively weaker but remained statistically significant ($r = 0.349$, $p \leq 0.001$). The statistical significance of all correlations confirmed that these relationships were unlikely to be due to chance. Scatter plot analysis visually reinforced the positive correlations among the measurement techniques, with trend lines indicating a consistent pattern of agreement. The findings highlight that while all three modalities provided comparable CCT measurements, their degree of agreement varied, necessitating careful consideration when selecting a technique for clinical or research purposes.

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Table-I: CCT measurements with Anterior Segment Optical Coherence Tomography (OCT), corneal Topography and Specular Microscopy (n=125)

Measurement technique	CCT (Mean±SD) µm	Minimum CCT µm	Maximum CCT µm
SM	505.74±11.36	480	528
CT	528.79±13.12	505	571
AS-OCT	518.46±19.54	486	557

SM=Specular bimicroscopy, CT=corneal topography, AS-OCT=Anterior segment optical coherence tomography, CCT= central corneal thickness, SD=Standard deviation, µm= micrometer

Table-II: Correlation of CCT measurements among SM, CT and AS-OCT (n=125)

Measurement technique	2-tailed Pearson correlation Significance*		
	SM	**CT**	**AS-OCT**
SM	1	0.349 (0.000)	0.389 (0.000)
CT	0.349 (0.000)	1	0.51 (0.000)
AS-OCT	0.389 (0.000)	0.51 (0.000)	1

Significant at 0.01 SM=Specular bimicroscopy, CT=corneal topography, AS-OCT=Anterior segment optical coherence tomography, CCT= central corneal thickness

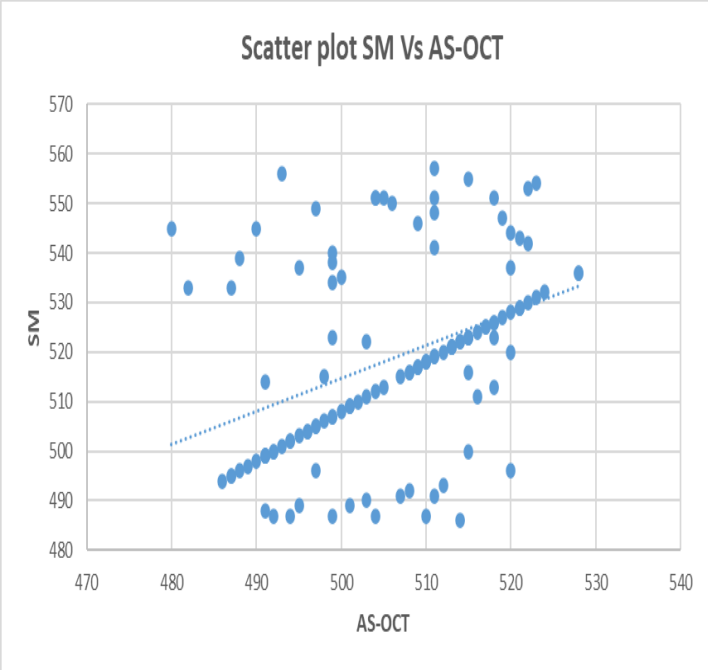


Fig-1: Scatter plot of CCT measurements with trend line indicating a positive correlation between SM and AS-OCT

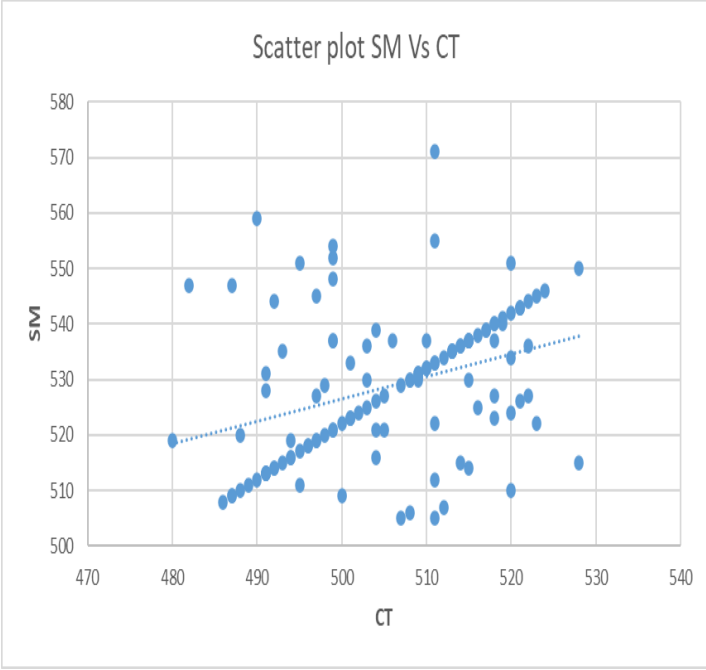


Fig-II: Scatter plot of CCT measurements with trend line indicating a positive correlation between SM and CT

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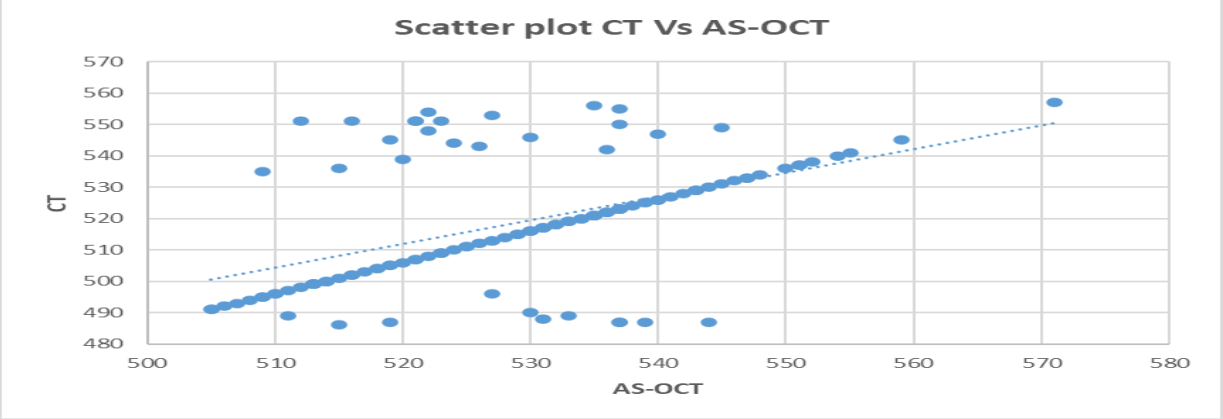


Figure 1 Scatter plot of CCT measurements with trend line indicating a positive correlation between CT and AS-OCT.

DISCUSSION

Central corneal thickness (CCT) measurement is an essential component in ophthalmology, with multiple imaging modalities developed to enhance accuracy and clinical reliability. Various national and international studies have explored the agreement and precision of different techniques; however, direct comparisons among specular microscopy (SM), corneal topography (CT), and anterior segment optical coherence tomography (AS-OCT) remain limited. This study aimed to address this gap by evaluating the correlation among these three techniques and determining their potential interchangeability in clinical practice (12,13). The results demonstrated that the mean CCT measured by SM, CT, and AS-OCT was 505.74±11.36 µm, 528.79±13.12 µm, and 518.46±19.54 µm, respectively. The highest CCT values were obtained using CT, followed by AS-OCT, while SM yielded the lowest measurements. The correlation analysis revealed a strong positive correlation between CT and AS-OCT ($r = 0.51$, $p \leq 0.001$), a moderate correlation between SM and AS-OCT ($r = 0.389$, $p \leq 0.001$), and a relatively weaker but statistically significant correlation between SM and CT ($r = 0.349$, $p \leq 0.001$). These findings suggest that CT and AS-OCT exhibit a higher degree of agreement, whereas SM showed relatively lower concordance with the other two techniques (14,15).

Findings from previous studies have highlighted similar trends, with AS-OCT and CT demonstrating strong agreement in CCT measurements. Studies comparing these modalities with ultrasound pachymetry (USP) also reported statistically significant mean differences, indicating that SM tends to provide lower readings and may have limited repeatability. Some research has suggested that SM-derived CCT measurements are less reliable due to variability in operator-dependent factors and differences in reflection-based imaging techniques. Additionally, investigations assessing non-contact tonometers and optical biometers have indicated that CT and AS-OCT consistently yield comparable results, further reinforcing the present study's observations. While certain studies have advocated for the interchangeability of these techniques in routine clinical practice, others have argued that variations in measurement outcomes warrant careful consideration when using them interchangeably (16,17). The discrepancies observed among different CCT measurement techniques may stem from inherent differences in imaging principles and technological variations in data acquisition. CT relies on Scheimpflug imaging, which captures the corneal structure in a three-dimensional format, whereas AS-OCT utilizes low-coherence interferometry, producing high-resolution cross-sectional images of the anterior segment. SM, on the other hand, employs light reflection principles, which may be more susceptible to external factors such as corneal surface irregularities and operator alignment. These methodological distinctions likely contribute to variations in CCT values, emphasizing the need for standardization and cross-validation when selecting a technique for clinical or research applications (18-20).

The study's strengths include its rigorous methodology, ensuring consistency by using a single examiner for all measurements and implementing strict inclusion criteria to minimize confounding variables. However, certain limitations must be acknowledged. The relatively small sample size and single-center study design may limit the generalizability of findings across broader populations. Future research should incorporate larger, multicenter studies to enhance statistical power and assess the reproducibility of these findings. Additionally, the study did not include a direct comparison with USP, which remains a widely accepted gold standard for CCT measurement. Incorporating a Bland-Altman analysis to evaluate the limits of agreement would provide further insights into the degree

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of interchangeability among these modalities (21). Despite these limitations, the study provides valuable insights into the comparative performance of SM, CT, and AS-OCT in CCT measurement. The strong correlation observed between CT and AS-OCT suggests that these techniques may be used interchangeably in clinical settings, particularly for surgical planning and corneal monitoring. However, the relatively weaker correlation of SM with the other two modalities indicates that its measurements should be interpreted with caution, especially in cases requiring high precision. Further research is needed to establish standardized protocols for CCT measurement and explore the impact of external factors such as ocular surface conditions, patient demographics, and device calibration on measurement accuracy.

CONCLUSION

This study evaluated the agreement among AS-OCT, CT, and SM for central corneal thickness measurement in healthy individuals. The findings demonstrated a positive correlation among the three techniques, with AS-OCT and CT showing stronger agreement, while SM exhibited comparatively lower concordance. Although all methods provided relatively consistent measurements, variations in correlation strength indicate that they may not be directly interchangeable in clinical practice without careful consideration. These results emphasize the importance of selecting the most appropriate modality based on clinical requirements, ensuring accuracy in corneal assessment, and guiding decision-making in ophthalmic care.

AUTHOR CONTRIBUTIONS

Author	Contribution
Shingrif Shabbir*	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Abdul Rauf	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Shabir Ahmed	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Muqaddas Noor	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Nida Hafeez	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Raheela Hafiz	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published

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