Khalil *et al. Beni-Suef Univ J Basic Appl Sci (2022) 11:55*
https://doi.org/10.1186/s43088-022-00235-x

Beni-Suef University Journal of Basic and Applied Sciences

RESEARCH

Open Access

Pentacam versus anterior segment OCT in measuring intended versus achieved ablation depth post-myopic LASIK correction

Hossam-Eldin Mohammed Ahmad Khalil, Khaled Abd-Elaziz Abd-Elhafiz and Abdulaziz Kamal Ibrahim*

Abstract

Background: Accurate quantitative measurements of central corneal thickness (CCT) provide valuable, clinical information for preoperative assessment, surgical planning, and follow-up in myopic patients who have undergone LASIK correction. Typically, an ultrasound is used to measure such parameters. However, noncontact devices such as the Visante anterior segment optical coherence tomographer [AS-optical coherence tomography (OCT)] and Pentacam are becoming more popular to measure ocular parameters. It is important to assess the level of similarity between these two optical devices to compare between the intended and achieved ablation depth after LASIK procedures in cases of myopia and myopic astigmatism.

Methods: This cross-sectional, prospective study included 80 eyes of 40 patients attending Beni-Suef University Hospital between November 2018 and November 2019. All patients underwent LASIK surgery for the correction of myopia with or without myopic astigmatism with spherical equivalent ranging from − 1.5 to − 12 diopters.

Results: No statistically significant difference was observed between the intended ablation depth and the clinically measured ablation depth calculated by Pentacam and AS-OCT 3 months after surgery ($P > 0.05$).

Conclusion: When planning corneal refraction surgery, ablation depth readouts calculated by the computer software of the excimer laser used in this study are reliable. Both Pentacam and AS-OCT are accurate, sensitive, and specific in measuring the CCT and calculating ablation depth. Pentacam provides slightly higher accuracy and sensitivity compared with AS-OCT. LASIK is a safe, predictable, and effective procedure in the treatment of simple myopia and myopic astigmatism.

Keywords: LASIK, Myopia, Pentacam, OCT, Scheimpflug, Ablation

1 Background

It is possible to reduce or eliminate refractive errors in the eyes by undergoing corneal laser refractive surgery [1]. At present, refractive defect reduction is the most effective operation method. Significant advantages include submicron ablation precision and negligible side effects. Typical ablations use a sequence of laser pulses to eliminate enough corneal tissue to achieve the desired result. All phases of refractive correction depend on the thickness of the cornea [2]. The majority of tissue loss results in refractive change [3], and the thickness of the cornea gives structural stability [4]. Overcorrection and inadequate rest of the cornea may lead to increased risk of keratectasia following intervention with deeper than intended ablations [5].

Since iatrogenic keratectasia is now considered to be caused by excessive tissue ablation in the stromal bed, appropriate estimates offer a theoretical resolution to the amount of reliable ablation. This could be especially important for individuals who have experienced laser

*Correspondence: zezo.km@gmail.com
Ophthalmology Department,, Faculty of Medicine, Beni-Suef University, Beni Suef, Egypt

refractive surgery that did not provide the desired outcome, because it would be helpful for future treatments [6]. It is now possible to measure the depth of the cornea using novel methods based on optical coherence pachymetry (OCP) and Scheimpflug [7, 8]. While OCP relies on low-consistency interferometry, Scheimpflug's approach relies on optic corneal segmentation to determine corneal thickness [9].

Using Scheimpflug's technology, Pentacam rotates to take photographs of the retina in front of the subject's eyes. Photographs taken with the Scheimpflug technique are clear and sharp, capturing data from the front of the cornea to the back of the lens. It is also possible to do topographical examinations for the real elevation of corneal faces and surfaces with the Pentacam by moving from one side of the eye to the other [10].

In evaluating the cornea and its form, one of the most critical measurements is the exact thickness, which varies between the front and back surfaces. With its high-precision data on the front and rear corneal areas, the Pentacam is projected to yield at least 25,000 measurements of the corneal width and length [11]. With its lack of contact and excellent axial resolution, optical coherence tomography (OCT) is ideal for cross-sectional imaging of tissues and organs. Direct evaluation of corneal thickness and anatomical sheets in the corneas may also be done using OCT. Using optical light scattering, it is possible to obtain cross-sectional pictures of the cornea, similar to those produced by B-scan ultrasounds. While the early influence of laser in situ keratomileusis (LASIK) on the corneal microstructure may be investigated without influencing postoperative flapping positions and alignments, there is no direct eye contact [12].

It is crucial to have an estimate of ablation depth for two reasons. First, surgeons can determine the "percent tissue changed" (PTA) to limit the danger of ectasia. Second, if the preoperatively estimated ablation depth was incorrect, it may be utilized, postoperatively, to determine whether a residual refractive error is dependent on the ablation depth [6].

Research on the discrepancy between estimated and postoperative ablation depth has revealed mixed findings [11]. The current study compared the intended and achieved ablation depth 3 months after LASIK procedures in cases of myopia and myopic astigmatism using Pentacam and anterior segment OCT. Comparisons were also made between readings of the two approaches.

2 Methods

2.1 Study design

This prospective follow-up study included 80 eyes from 40 myopic individuals over the age of 18 with or without myopic astigmatism with a spherical equivalent ranging from − 1.5 to − 12 diopters. Several aspects of the patients' history were excluded from this study. These included corneal pathology (abnormal corneal topography, corneal dystrophies, and severe dry eye syndrome), anterior segment pathology (cataracts and glaucoma), retinal pathology (retinal tears or detachments), and patient medications that affect corneal healing or the ability to fight infection.

2.2 Methods

A thorough ocular and medical history was taken from all patients prior to surgery, including previous refractive documents and glasses, history of contact lenses, previous medical treatments, previous ocular surgical interference, history of relevant systemic disorders, pregnancy, and lactation. All aspects of eye health were examined, including the corneal surface, anterior segment, and iris. Intraocular pressure (IOP) was measured with applanation tonometry "Goldmann" and the duochrome test. The sphere and cylinder were assessed using the cross-cylinder method for refractive refinement. Corneal imaging using Pentacam HR® Oculus Inc. evaluated the anterior and posterior corneal curvatures and corneal thickness. Central corneal thickness (CCT) was measured using an A-S OCT® SPECTRALIS Heidelberg engineer.

The 80 eyes included in the study underwent LASIK surgery with the excimer laser system. Laser ablation was done with an Allegretto WaveLight EX500 Excimer Laser (WaveLight AG, Germany). The following methods were used to check on all patients 1 day, 1 week, and 3 months post-surgery. Corneal and anterior segment slit lamp inspection was done to determine epithelial recovery and the incidence of any sequelae. The uncorrected visual acuity (UCVA) and best-corrected visual acuity (BCVA) were measured. Apparent refraction with refinement of the sphere was detected using the duochrome test and refinement of the cylinder using the cross-cylinder method. Measurements of CCT were taken using anterior segment OCT and Pentacam HR at 3 months, postoperatively. The true central ablation depth can be identified using comparisons between the pachymetry data collected with the Pentacam and anterior segment OCT both before surgery and 3 months after surgery. According to WaveLight software calculations, the anticipated ablation depth was compared to central ablation depth measured by Pentacam and anterior segment OCT.

2.3 Statistical analysis

Data analysis was performed using SPSS v. 25 (Statistical Package for Social science) for Windows (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, version 25.0. Armonk, NY: IBM Corp.) Means and standard deviations (SDs) were used to describe quantitative variables, whereas numbers (No.) and percentages were used to represent the total number of qualitative variables. The difference between the two groups in terms of scale variables was detected using either an independent *T* test for parametric data or the Mann–Whitney U test for nonparametric data. The Fisher exact Chi-square test was performed to detect a difference in the categorical variables between the two groups. The paired t test was used to compare pre- and postoperative scale parameters. Findings were considered significant when the *P* value ≤ 0.05. The linear correlation between Pentacam and AS-OCT measurements was evaluated using Pearson's correlation analysis. Correlation graphs were drawn for significant correlation, with significance indicated when $P < 0.05$. Correlation is considered positive (direct correlation) when r (correlation coefficient) had a + signal and negative (inverse correlation) in the case of a – signal. Correlation is considered weak when *r* is between 0 and 0.35, moderate when r is between 0.35 and 0.65, and strong when r is greater than 0.65. The receiver operating characteristic (ROC) curve was used to estimate the sensitivity and specificity of Pentacam and AS-OCT measurements of CCT in identifying the desired ablation after LASIK. These results were reported as area under the curve (AUC) and 95% confidence intervals. A cutoff value was defined as that with the highest validity.

3 Results

This current study involved 80 eyes from 40 patients who had simple myopia with or without myopic astigmatism. Of the included patients, 24 were males (60%) and 16 were females (40%). Patients ranged in age from 18 to 42 with an average age of 28.55 ± 7.23. The preoperative sphere equivalent error fluctuated from − 1.50 D to − 12.00 D with a mean of − 6.15 ± 3.14 D.

In the third postoperative month, the spherical equivalent error ranged from 0 D to − 1 D with a mean of − 0.27 ± 0.37 D. A statistically significant difference was observed between preoperative and third month spherical equivalent error assessments ($P = 0.001$). The mean preoperative UCVA was − 0.035 ± 0.05 Log MAR. The mean UCVA in the third postoperative month was 0.035 ± 0.05 Log MAR. This represented a statistically significant difference in UVCA between preoperative and third postoperative month (*P* value < 0.001). The mean preoperative BCVA was 0.025 ± 0.072 Log MAR, whereas the mean BCVA was 0.0075 ± 0.075 Log MAR in the third postoperative month. The difference in BCVA was not statistically significant between preoperative and third postoperative month (*P* value = 0.070) (Table 2).

Preoperative CCT measured by Pentacam ranged from 519 to 631 µm with a mean value of 581.44 ± 31.07 µm. Meanwhile, after LASIK surgery, it ranged from 429 to 552 µm with a mean thickness of 502.68 ± 26.15 µm. This result was statistically significant between preoperative and postoperative CCT ($P < 0.0001$). As for AS-OCT, preoperative CCT ranged from 525 to 650 µm with a mean thickness of 590.85 ± 29.18 µm. Meanwhile, post-LASIK surgery CCT measured by AS-OCT ranged from 430 to 600 µm with a mean thickness of 512.8 ± 29.15 µm. Once again, this was a statistically significant difference between pre- and postoperative CCT ($P < 0.0001$). Overall, there was a statistically significant difference between preoperative CCT measured by both Pentacam and AS-OCT (*P* value = 0.032) (Table 1).

Table 1 Comparison between preoperative CCT measurement using Pentacam and AS-OCT; ($N = 80$)

CCT	Minimum	Maximum	Mean	SD	*P* value
Pentacam	519.00	631.00	581.44	31.07	0.032
AS-OCT	525.00	650.00	590.57	29.18	

Table 2 Comparison between third month postoperative CCT measurement using Pentacam and AS-OCT; ($N = 80$)

CCT	Minimum	Maximum	Mean	SD	*P* value
Pentacam	429.00	552.00	502.68	26.15	0.098
AS-OCT	430.00	600.00	512.18	29.15	

Table 3 Correlation between CCT measurements with Pentacam and AS-OCT pre- and post-LASIK; ($N = 80$)

	CCT by Pentacam	
	Pre-LASIK	Third month post-LASIK
CCT by AS-OCT		
Pearson correlation	0.950	0.916
P value	< 0.001	< 0.001

The third postoperative month CCT measured by Pentacam ranged from 429 to 552 µm with a mean value 502.68 ± 26.15 µm. CCT measured by AS-OCT ranged from 430 to 600 µm with a mean value 512.8 ± 29.15 µm. No statistically significant difference was observed between CCT measured by Pentacam and AS-OCT in the third postoperative month (*P* value = 0.098) (Table 2).

CCTs were compared between AS-OCT and Pentacam readings before and after LASIK. In both situations, OCT measurements correlated very well with Pentacam ($r = 0.950$ and 0.916 before and after LASIK surgery, respectively) (Table 3).

Table 4 Ablation depth in different ablation types; ($N=80$)

Ablation depth	Minimum	Maximum	Mean	SD	*P* values
Intended	22.00	133.00	78.60	34.05	0.864
Pentacam	21.00	143.00	78.75	34.21	0.971
AS-OCT	23.00	160.00	78.38	36.00	

Table 5 Correlation between intended ablation with real ablation calculated by Pentacam and real ablation calculated by AS-OCT; ($N=80$):

	Real ablation calculated by:	
	Pentacam	**AS-OCT**
Intended ablation		
Pearson correlation	0.974	0.863
P value	< 0.001	< 0.001

The calculated (intended) ablation depth ranged from 22 to 133 μm with a mean value of 78.60 ± 34.05 μm. The real ablation calculated 3 months postoperative by Pentacam ranged from 21 to 143 μm with a mean value of 78.75 ± 34.21 μm. As for AS-OCT, the ablation depth ranged from 23 to 160 μm with a mean value of 78.38 ± 36 μm. No statistically significant difference was observed between intended ablation depth and clinically measured ablation depth calculated by the two devices (*P* values > 0.05) (Table 4).

The calculated (intended) ablation depth was compared with the real ablation calculated by Pentacam and AS-OCT. In both situations, the calculated (intended) ablation depth correlated very well with the real ablation calculated by Pentacam and AS-OCT (Pearson correlation r 0.974 before surgery and 0.863 for Pentacam and AS-OCT, respectively) (Table 5).

If the intended ablation depth calculated by the WaveLight EX500 excimer laser (Alcon) computer software is the standard, we compared that to that measured by Pentacam. A ROC curve study was used to evaluate the precision of Pentacam measurements of CCT in detecting the intended ablation post-LASIK. The results of ROC curve analysis showed that a best sensitivity/specificity balance was observed for CCTs measured by Pentacam at a statistically significant level with an 88.9% sensitivity (true positive cases) and 60% specificity (true negative cases).

If the intended ablation depth calculated by the WaveLight EX500 excimer laser (Alcon) computer software is the standard, we compared that to ablation depth measured by AS-OCT. A ROC curve study was used to evaluate the precision of AS-OCT measurements of CCT in detecting the intended ablation post-LASIK. The results of (ROC) curve analysis showed that a best sensitivity/specificity balance was observed for CCTs measured by AS-OCT at a statistically significant level, with a 80% sensitivity (true positive cases) and 60% specificity (true negative cases).

4 Discussion

In the current prospective study on 80 eyes of 40 patients, we compared Pentacam and AS-OCT measurements to determine the real depth of ablation and correlated it to the intended ablation depth as calculated by the WaveLight EX500 excimer laser (Alcon) computer software. After 3 months of follow-up, the mean spherical equivalent was − 6.15 ± 3.14 D. In the present study, the WaveLight EX500 excimer laser (Alcon) computer software system was predictable and accurate. For example, 100% (80 eyes) had a post-operation refraction within 0.50 D of the tried adjustment. Comparatively, in one study by Wallerstein et al., they operated on 114 eyes from 78 cases who experienced LASIK at the Canadian Institute of Refractive Surgery. After 24 months post-surgery, the scatterplot of the tried against actual refractive adjustment showed an expected technique with 51.7%, 71.9%, 84.2%, and 93.8% existing in ± 0.25 D, ± 0.50 D, ± 0.75 D, and ± 1.00 D, of SEQ aim [13]. Kanellopoulos and Asimellis operated on 160 eyes with high myopia ⩾ − 6.00 D, with postoperative average spherical equivalents at − 0.37, − 0.43, and − 0.25 D for the 3, 6, and 12 months, which was also predictable [14].

With respect to corneal thickness measurement, in the present study, the mean value of preoperative CCT was 581.44 ± 31.07 μm when measured by Pentacam and 590.85 ± 29.18 μm when measured by the AS-OCT. A strong positive correlation between the two measurement devices was noted. However, Pentacam measurements were statistically significantly thinner compared to AS-OCT ($P=0.032$). Pentacam measurements underestimated the cornea thickness by 9.13 μm compared with the AS-OCT.

In the third month postoperative results, the mean value of CCT was 502.68 ± 26.15 μm when measured by Pentacam, while the CCT was 512.8 ± 29.15 μm when measured by the AS-OCT. CCT measurements also strongly correlated for the two measurement devices. Pentacam measurements significantly underestimated the cornea thickness by 9.5 μm compared with the AS-OCT ($P=0.098$).

Interestingly, O'Donnell et al. found poor correlation between CCT measurements using Pentacam and Visante AS-OCT with a coefficient of agreement 37.36 μm and limits of agreement 25.61 μm to − 49.11 μm [15]. Conversely, Fu et al. [16] found the opposite of our study. In their study, the mean CCT as measured by the AS-OCT was 519.23 ± 34.37 μm, which was 18.53 μm lower than the Pentacam measurement of 537.76 ± 31.84 μm.

Comparative measurements of CCTs were discovered by Muriel Doors et al. from AS-OCT (Carl Zeiss Meditec), Orbscan II, and Pentacam (Oculus, Wentzler) [17]. CCT measurements using the Cirrus OCT, employing the new anterior segment lens fixtures and the Pentacam HR, were reported by Baghdasaryan et al. [18], with a high P value of < 0.0001. Furthermore, Xuepei Li et al. concluded that the CCT readings were well agreed between Pentacam and CASIA2-OCT. The two instruments can be regarded as interchangeable for monitoring corneal problems or for planning eye surgery for these CCT assessments in healthy patients. No significant changes were found between CAISA2 and Pentacam estimates for CCT or ACD ($P > 0.05$) [19].

In the current study, the mean intended ablation depth was 78.60 ± 34.05 μm. The mean clinically observed ablation depth (calculated by measuring the difference between CCT at the third postoperative month from the preoperative CCT) was 78.75 ± 34.21 μm when measured by Pentacam and 78.38 ± 36 μm when measured by the AS-OCT. No statistically significant disparity was observed between the intended ablation depth and clinically observed ablation depth estimated by the two devices ($P > 0.05$).

The two devices showed an extremely important association between the changes in corneal pachymetry and the anticipated depth of ablation. It was best to correlate with Pentacam (Pearson RC 0.974, $P < 0.001$) and AS-OCT (Pearson RC 0.863 and $P < 0.001$), respectively. Carl-Arnold Lackerbauer et al. evaluated for 3 months post-microscopic laser in the site of keratomileusis (labsic) dissimilarity from measured to intended after operative central corneal depth (CCT). They found that the average variance between measured and intended after operative corneal thickness is between 11.1 μm 6 weeks postoperatively and 13.8 μm 6 weeks postoperatively [20]. Giacomo Savini et al. investigated the conformity of the expected depth of ablation 3 months postoperatively as determined by the EX500 excimer laser with a rotating Scheimpflug camera. No average expected depth of ablation (66.33 ± 24.15 μm) or calculations of the depth of ablation in the smallest core were found to be statistically significant [19]. Anastasios Kanellopoulos et al. evaluated stroma depth decrease in a retrospective of 205 successive eyes of 205 cases experiencing myopic and myopic astigmatism LASIK [14]. Front segment OCT was done preoperationally and 3 months post-operationally. The achieved ablation depth was 86.01 ± 28.28 μm, comparable to the usual programmed greatest ablation deepness of 88.48 ± 26.05 μm. Actual stroma depth decrease following myopic LASIK relates well with the tried versus actual refractive alteration. Febbraro et al. compared the preoperative estimate of greatest ablation depth offered by the laser software with actual extent using Scheimpflug pachmetry (Pentacam HR; Oculus) in myopic laser-aided in-site keratomileusis. They discovered a solid linear association between laser software assessment of greatest ablation depth and Scheimpflug pachmetry ($P < 0.001$). The average ablation depth calculated using Scheimpflug pachmetry was more than that estimated by the laser software, with an average global variance of 2.15 μm ($P < 0.05$) [21]. Arbelaez et al. compared measurements of ultrasound (Pachette pachymeter DGH Technology), Scheimpflug (Pentacam, Oculus), and OCP (Heidelberg Engineering GmbH, Heidelberg, Germany) methods to define ablation depth post-myopic astigmatism cornea laser refractive operation. A high correlation of preoperative pachymetry has been reported for both Scheimpflug and OCP ($r = 0.84$, $P = 0.0001$ for Scheimpflug; $r = 0.83$ and $P = 0.0001$ for OCP) using ultrasound pachymetry as a reference measurement [22].

The central removal depth of ultrasound, Scheimpflug, and OCP measurements ($r^2 = 0.60$, $P = 0.0001$ for ultrasound; $r = 0.75$, $P = 0.0001$ for Scheimpflug; $r = 0.76$, $P = 0.0001$ for OCP) was well correlated with the central ablation depth presented on the laser screen as the reference measurement. The predicted ablation depth did not differ much from the values of Scheimpflug and ultrasonography ($P = 0.47$) [22].

In our study, Pentacam is more sensitive but as specific as AS-OCT on measuring ablation depth. The sensitivity of Pentacam is 88.9%, and the specificity measures around 60%. The sensitivity and specificity of AS-OCT are 80% and about 60%, respectively.

Several papers have studied the sensitivity and specificity of Pentacam and AS-OCT in measuring the anterior chamber angle. Studies have also been conducted to evaluate the sensitivity and specificity in detecting keratoconus and early diagnosis. However, to the best of our knowledge, this is the first report to assess the sensitivity and specificity of these devices in measuring the ablation depth.

The current study was limited by the sample size. Future studies with larger numbers of cases are necessary. Additional Pentacam, OCT, and LASIK devices should also be included with different manufacturers. Furthermore, another aspect of refractive errors, hypermetropia, should be thoroughly investigated and compared with the myopia results. Finally, future studies with longer duration (beyond 3 months) of follow-up would be ideal.

5 Conclusion

The excimer laser's ablation depth readout, estimated by computer software for the purposes of corneal refractive surgery planning, is accurate. Although Pentacam and AS-OCT both measure the CCT and calculate the ablation depth accurately, sensitively, and specifically, Pentacam demonstrates somewhat greater accuracy, sensitivity, and specificity than AS-OCT. Primary myopia and myopic astigmatism may be successfully treated using LASIK, a treatment that is safe, predictable, and effective.

Abbreviations

AS-OCT: Anterior segment optical coherence tomographer; AUC: Area under the curve; BCVA: Best-corrected visual acuity; CCT: Central corneal thickness; IOP: Intraocular pressure; LASIK: Laser in situ keratomileusis; OCP: Optical coherence pachymetry; PTA: Percent tissue changed; ROC: Receiver operating characteristic; SD: Standard deviation; SPSS: Statistical package for social science; UCVA: Uncorrected visual acuity; US: Ultrasound.

Acknowledgements

Not applicable.

Authors' contributions

AK contributed to sampling, performing the experiments, data analysis, preparing the first draft of the manuscript. HM contributed to supervision, data analysis, and revision of the manuscript. KA contributed to conceptualization, supervision, data analysis, and preparing and revising the manuscript. All authors have read and approved the final manuscript.

Funding

None.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The Research Ethical Committee of Faculty of Medicine, Beni-Suef University, has given the approval on conducting the present research (Approval serial No.: FWA00015574). The written informed consent was obtained from all patients prior to the study.

Competing interests

The authors declare that they have no competing interests.

Received: 22 January 2022 Accepted: 29 March 2022
Published online: 13 April 2022

References

1. Munnerlyn CR, Koons SJ, Marshall J (1988) Photorefractive keratectomy: a technique for laser refractive surgery. J Cataract Refract Surg 14:46–52. https://doi.org/10.1016/s0886-3350(88)80063-4 (**PMID: 3339547**)
2. Wang Z, Chen J, Yang B (1999) Posterior corneal surface topographic changes after laser in situ keratomileusis are related to residual corneal bed thickness. Ophthalmology 106:406–409. https://doi.org/10.1016/S0161-6420(99)90083-0 (**discussion 409-410, PMID: 9951499**)
3. Blaker JW, Hersh PS (1994) Theoretical and clinical effect of preoperative corneal curvature on excimer laser photorefractive keratectomy for myopia. J Refract Corneal Surg 10:571–574 (**PMID: 7530108**)
4. DelMonte DW, Kim T (2011) Anatomy and physiology of the cornea. J Cataract Refract Surg 37:588–598. https://doi.org/10.1016/j.jcrs.2010.12.037 (**PMID: 21333881**)
5. Binder PS (2007) Analysis of ectasia after laser in situ keratomileusis: risk factors. J Cataract Refract Surg 33:1530–1538. https://doi.org/10.1016/j.jcrs.2007.04.043 (**PMID: 17720066**)
6. Binder PS (2003) Ectasia after laser in situ keratomileusis. J Cataract Refract Surg 29:2419–2429. https://doi.org/10.1016/j.jcrs.2003.10.012 (**PMID: 14709307**)
7. O'Donnell C, Maldonado-Codina C (2005) Agreement and repeatability of central thickness measurement in normal corneas using ultrasound pachymetry and the oculus Pentacam. Cornea 24:920–924. https://doi.org/10.1097/01.ico.0000157422.01146.e9 (**PMID: 16227833**)
8. Wirbelauer C, Pham DT (2003) Intraoperative optical coherence pachymetry during laser in situ keratomileusis–first clinical experience. J Refract Surg 19:372–377 (**PMID: 12777036**)
9. Kojima M, Wegener A, Hockwin O (1990) Imaging characteristics of three cameras using the Scheimpflug principle. Ophthalmic Res 22(Supplement 1):29–35. https://doi.org/10.1159/000267061 (**PMID: 2388747**)
10. Gherghel D, Hosking SL, Mantry S, Banerjee S, Naroo SA, Shah S (2004) Corneal pachymetry in normal and keratoconic eyes: Orbscan II versus ultrasound. J Cataract Refract Surg 30:1272–1277. https://doi.org/10.1016/j.jcrs.2003.11.049 (**PMID: 15177603**)
11. Khairat YM, Mohamed YH, Moftah IA, Fouad NN (2013) Evaluation of corneal changes after myopic LASIK using the Pentacam®. Clin Ophthalmol 7:1771–1776. https://doi.org/10.2147/OPTH.S48077 (**Epub Sep 9 2013. PMID: 24043925. PMCID: PMC3772758**)
12. Izatt JA, Hee MR, Swanson EA, Lin CP, Huang D, Schuman JS, Puliafito CA, Fujimoto JG (1994) Micrometer-scale resolution imaging of the anterior eye in vivo with optical coherence tomography. Arch Ophthalmol 112:1584–1589. https://doi.org/10.1001/archopht.1994.01090240090031 (**PMID: 7993214**)
13. Wallerstein A, Kam JWK, Gauvin M, Adiguzel E, Bashour M, Kalevar A, Cohen M (2020) Refractive, visual, and subjective quality of vision outcomes for very high myopia LASIK from − 10.00 to − 13.50 diopters. BMC Ophthalmol 20:234. https://doi.org/10.1186/s12886-020-01481-2 (**PMID: 32552787. PMCID: PMC7302155**)
14. Kanellopoulos AJ, Asimellis G (2013) Refractive and keratometric stability in high myopic LASIK with high-frequency femtosecond and excimer lasers. J Refract Surg 29:832–837. https://doi.org/10.3928/1081597X-20130924-02 (**Epub Oct 4 PMID: 24088061**)
15. O'Donnell C, Hartwig A, Radhakrishnan H (2012) Comparison of central corneal thickness and anterior chamber depth measured using LenStar LS900, Pentacam, and Visante AS-OCT. Cornea 31:983–988. https://doi.org/10.1097/ICO.0b013e31823f8e2f (**PMID: 22367044**)
16. Fu J, Wang X, Li S, Wu G, Wang N (2010) Comparative study of anterior segment measurement with Pentacam and anterior segment optical coherence tomography. Can J Ophthalmol 45:627–631. https://doi.org/10.3129/i10-068 (**PMID: 21135897**)
17. Doors M, Cruysberg LP, Berendschot TT, de Brabander J, Verbakel F, Webers CA, Nuijts RM (2009) Comparison of central corneal thickness and anterior chamber depth measurements using three imaging technologies in normal eyes and after phakic intraocular lens implantation. Graefes Arch Clin Exp Ophthalmol 247:1139–1146. https://doi.org/10.1007/s00417-009-1086-6 (**Epub Apr 30. PMID: 19404662. PMCID: PMC2709228**)
18. Baghdasaryan E, Huang X, Marion KM, Tepelus TC, Bagherinia H, Sadda SR, Hsu HY (2018) Reproducibility of central corneal thickness measurements in normal eyes using the Zeiss Cirrus 5000 HD-OCT and Pentacam HR. Open Ophthalmol J 12:72–83. https://doi.org/10.2174/1874364101812010072.PMID:29872486.PMCID:PMC5960748
19. Li X, Zhou Y, Young CA, Chen A, Jin G, Zheng D (2020) Comparison of a new anterior segment optical coherence tomography and oculus Pentacam for measurement of anterior chamber depth and corneal thickness. Ann Transl Med 8:857. https://doi.org/10.21037/atm-20-187 (**PMID: 32793701. PMCID: PMC7396784**)
20. Lackerbauer CA, Grüterich M, Ulbig M, Kampik A, Kojetinsky C (2009) Correlation between estimated and measured corneal ablation and refractive outcomes in laser in situ keratomileusis for myopia. J Cataract Refract Surg 35:1343–1347. https://doi.org/10.1016/j.jcrs.2009.03.030 (**PMID: 19631118**)

21. Febbraro JL, Picard H, Moran S, Grise-Dulac A, Salomon L, Gatinel D (2020) Comparison of laser platform estimation and objective measurement of maximum ablation depth using Scheimpflug pachymetry in myopic femtosecond laser in situ keratomileusis. Cornea 39:316–320. https://doi.org/10.1097/ICO.0000000000002143 (**PMID: 31517724**)
22. Arbelaez MC, Vidal C, Arba Mosquera S (2009) Central ablation depth and postoperative refraction in excimer laser myopic correction measured with ultrasound, Scheimpflug, and optical coherence pachymetry. J Refract Surg 25:699–708. https://doi.org/10.3928/1081597X-20090707-04 (**PMID: 19714794**)

Publisher's Note