• Clinical Research •

Monitoring of central corneal thickness after phacoemulsification—comparison of statical and rotating Scheimpflug pachymetry, and spectral-domain OCT

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Abstract

● **AIM:** To explore the possibility of deploying three contactless devices (static and rotating Scheimpflug technology, spectral domain optical coherence tomography) for measuring central corneal thickness (CCT) in preoperative and postoperative examinations of cataract patients.

● **METHODS:** Totally 72 patients who had undergone surgery without complications were selected. The CCT was measured prior to the operation, as well as on the first, 5th-7th and 28th day following the operation using the Nidek NT 530-P, Sirius®, and Topcon OCT-2000 devices.

● **RESULTS:** A significant postoperative increase and subsequent decrease in CCT was identified with all three devices. The correlations were highly significant and thus reflect a very good degree of comparability at all times with the exception of the rotating Scheimpflug camera. The postoperative results from the latter differed significantly from the other devices. The correlations were Sirius/Topcon (P=0.010) and Sirius/Nidek (P<0.0005). No statistically significant difference could be identified in the comparison between Topcon and Nidek (P=0.056).

● **CONCLUSION:** All three devices are suitable for postoperative monitoring of CCT. The measurement results are only comparable to a limited extent and not interchangeable in the course of treating a single patient. This is due to the different imaging technology used in the devices and the resulting modalities for conducting the measurements.

● **KEYWORDS:** cataract surgery; pachymetry; corneal thickness; Scheimpflug imaging; optical coherence tomography

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INTRODUCTION

The human cornea is composed of multiple layers. The external epithelium is situated on the Bowman's membrane. The corneal stroma, consisting of collagen fibres, has the biggest share of the corneal thickness, followed by another basal membrane (Descemet's membrane), which acts as a base for the endothelium, the barrier to the anterior chamber.

Aqueous humour diffuses the corneal stroma from the anterior chamber. At the same time the endothelium dehydrates the cornea by pumping fluid from the cornea into the anterior chamber to maintain an equilibrium between both components and keep the cornea transparent. If the hydration of the cornea is increased, its symmetrical collagen network gets destroyed and the stroma appears oedematous and opaque. The loss of the corneal transparency leads to deteriorated visual acuity[1].

Corneal Endothelium and Cataract Surgery The ultrasound energy needed to fragment the hard nucleus during cataract surgery strains the corneal epithelium[2-5]. A transient endothelial deterioration reduces the rate of intrastromal dehydration leading to an imbalance between influx of water from the anterior chamber into the corneal stroma and the active transportation of water into the anterior chamber by the corneal endothelium. This results in corneal swelling and thereby an increase in central corneal thickness (CCT) as an expression of endothelial decompensation. Extent and decrease of corneal swelling prove the endothelial recovery and compensation of its function[3,6-14].

A high preoperative endothelial cell count (ECC) does not guarantee an uncomplicated intra- and postoperative course and a low ECC does not make corneal complications not inevitable.

Taking these conditions into account it is any case mandatory to monitor the postoperative course of the cornea. This can be done be measuring the increase and decrease of the CCT as a result of the endothelium's ability to compensate its function. Preoperative measurements will be used as a reference.

Corneal Diagnostics Ultrasound pachymetry posed the gold standard for measuring the CCT for many years. Disadvantages of this method are poor reproducibility and dependency on the examiner in general[15-17]. On the other hand, sonography is a contact process, which can additionally affect the cornea which may be harmed by surgery already. Finally there is the toxicity of topical anaesthetic agents which are necessary for ultrasound pachymetry[18].

Apart from ultrasound pachymetry a number of non-contact-techniques have been developed and established which are able to measure CCT[9,11-12,19-25]. The goal of this study was to evaluate the feasibility of different techniques to measure CCT in the perioperative course of uneventful cataract surgery using phacoemulsification.

Reliable and reproducible measurements which can be delegated to medical assistance personnel are desireable. The examination should be carried out quickly. For economic reasons the inclusion of corneal pachymetry into a multifunctional device is desireable. In this study modern non-contact-techniques for measuring the CCT were evaluated. Besides comparing three different devices, the feasibility of measurements was examined in a real-life-situation.

Economical Aspects Economical aspects are becoming more and more important as many surgical units are performing 20, 30, 50 or even more cataract operations every day and postoperative care must be provided. This is an important issue as the resource "ophthalmologist/physician" is becoming scarce and sought after. So as many parts of the examination as possible have to be delegated to medical assistance personnel.

SUBJECTS AND METHODS

Ethical Approval The study was approved by the Ethical Committee of the University of Bonn, Germany and conducted per the international ethical standards outlined by the Declaration of Helsinki. Informed consent was obtained from the patients.

Totally 71 patients with sight-limiting cataract were included in this study. The patients' age was 79.09±5.84y (54-89y), 30 (42.2%) males, 41 (57.7%) females. Patients were selected after uneventful cataract surgery. Exclusion criteria were previous ocular surgery, corneal disease of any kind or incompliance to therapy or follow-up visits.

All surgical procedures were performed by the same surgeon (Handzel DM) using topical or parabulbar anaesthesia and a divide-and-conquer-technique through a 2.8 mm main incision. A foldable 1-piece-intraocular lens (IOL) was implanted in the capsular bag in all cases. Postoperatively dexamethasone/gentamycin-ointment was applied. The same medication was prescribed as eye drops in a tapered regime for the following 4wk.

All selected patients underwent a comprehensive ophthalmological examination (U1) within 4wk prior surgery. This included objective refraction, best corrected visual acuity, tonometry, anterior segment Scheimpflug imaging, optical coherence tomography (OCT) of the anterior segment and if needed the macula, slit lamp examination and fundoscopy. The CCT was readout after using statical Scheimpflug imaging (NIDEK NT 530-P) which takes place during tonometry, rotating (Sirius) Scheimpflug photography and anterior segment-OCT (Topcon-2000).

Further examinations were performed on the first day postoperatively (U2), 3-6d postoperatively (U3), and 3-5wk postoperatively (U4). Besides a comprehensive postoperative clinical examination, CCT was measured at each visit.

Statical Scheimpflug Photography The Nidek NT-530P is a combination of a non-contact tonometry and pachymetry. The camera is placed diagonally below the cornea, and then sections of cornea are reflected through the lens and projected on the camera. The anterior and posterior position of the cornea are reflected on different positions of the camera. The corneal thickness can be calculated by the distance between these. The result is given by a printout listing the measured values, an image is not available.

Rotating Scheimpflug Photography The Scheimpflug camera Sirius (Fa. Costruzione Strumenti Oftalmici, Scandicci, Italy) is a new multifunctional device, which is also equipped with a Placido-system for corneal topography, infrared meibography, pupillography and tear film analysis.

A rotating Scheimpflug camera is acquiring 25 radial images of the cornea and the anterior chamber in 2-3s. The images are analysed and the results include tangential and sagittal curvature data for the anterior and posterior surface of the cornea, corneal refractive power, biometrical analysis of multiple structures of the anterior segment (anterior chamber volume, chamber angle *etc*.), a calculation of the corneal wavefront and corneal pachymetry. The system is measuring 35 632 points on the anterior and 30 000 points on the posterior surface of the cornea during 5-6s. This data is calculated to a pachymetry map by version 1.0.5.72 of the Phoenix® software (Fa. Costruzione Strumenti Oftalmici, Scandicci, Italy).

Anterior Segment OCT The OCT-2000 (OCT-2000, Topcon Europe Medical B.V., Capelle a/d IJssel, The Netherlands) is a multifunctional OCT for imaging the anterior and posterior segment of the eye. Scanning method for the cornea is a radial scan of 6 mm with a line resolution of 4096 pixel and an axial depth resolution of 5 μm.

Measurement Acquisition All examinations were carried out by well-trained medical technicians according to the

Table 1 Number of measurements taken with the three devices and at different points of time

Device	Point of time, U	*n*	Min, μm	Max, μm	Mean, μm	SD, μm	Variance
SIRIUS	1	70	425	622	539.91	40.57	1646.20
SIRIUS	2	59	77	728	571.83	85.10	7242.04
SIRIUS	3	55	223	714	558.07	77.18	5957.03
SIRIUS	4	47	472	632	543.09	37.05	1372.56
TOPCON	1	65	488	616	549.34	27.91	779.13
TOPCON	2	67	522	655	582.81	27.58	760.89
TOPCON	3	60	525	648	579.37	30.98	960.00
TOPCON	4	59	496	613	556.53	28.34	802.91
NIDEK	1	69	479	636	551.16	32.19	1036.05
NIDEK	2	56	507	707	594.79	44.32	1964.10
NIDEK	3	57	510	701	584.98	37.22	1385.20
NIDEK	4	62	486	625	552.89	32.66	1066.36

manufacturer's advice. The patient was advised to focus on an indicator light and asked to blink prior image acquisition to assure an evenly spread tear film. If image quality was not satisfactory, unpreserved lubricant eye drops were applied and the examination repeated.

Statistical Analysis Statistical analysis was performed using IBM SPSS Statistics, Version 22. The statistical test used are given in the results section. All data was worked up identifying maximum, minimum, mean, standard deviation and variance. Correlations were investigated using Pearson's correlation and checked by Bonferroni-correction.

Purpose and Endpoints of the Study Use of the devices perioperatively by medical assistance personnel under real-life circumstances in order to get useful and valid results; Correlations of CCT for every measurement (U1, U2, U3, U4) and between the different devices.

RESULTS

The results of 71 eyes were analyzed. CCT was measured at four different point of time. Some data could not be gathered due to different reasons all concerning the patients' cooperation. The amount of missing data did not differ significantly between the devices as will be explained in more detail below (Table 1).

As expected, an increase in CCT was noticed on the first postoperative day (U2). This increase was detected as statistically significant with all three devices. At U3 there was a tendency toward a decrease in CCT which was not statistically significant. At U4 CCT was measured within the range of preoperative results which was statistically significant (Figure 1).

An important aspect of this study was the comparability of the three devices under demanding–in this case perioperative-circumstances. Correlations of the results are given in Table 2. All bivariate correlations between the three devices were

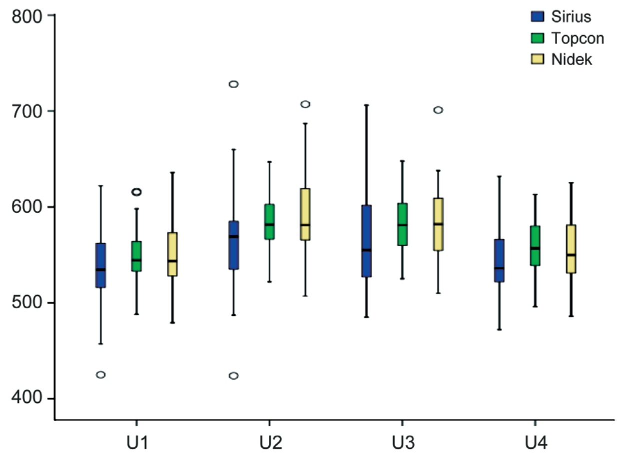

Figure 1 Display of CCT in μm (Y-axis) with the three devices at different points of time (X-axis).

highly significant ($P \leq 0.001$) at (almost) every point of time. This implies good comparability of different devices at different points of time. An important exception can be seen with the Scheimpflug camera: the results of the Sirius device differed significantly from the other two devices at U2, compared to the OCT also with U3 (Tables 3 and 4).

There were significant differences concerning repeated measures with both device and point of time (*t*-test). Significance with interaction in the last line points out that the profiles in the course of time were distinguishable for each device.

Follow up-tests (*P*-values after Bonferroni-correction) for the significant parameters device and point of time brought the following results:

Device: significance for Sirius/Topcon (P=0.010) and Sirius/Nidek (P<0.0005). No difference for Topcon/Nidek (P=0.056)

Point of time: significance for U1/U2, U1/U3, U2/U4, U3/U4 respectively, no significance for U1/U4 an U2/U3. This means CCT increases from U1 to U2, stays on this level until U3 and decreases on U4 to the level of U1 (Table 5).

Table 2 Correlations (Pearson) between different devices at different points of time U1-U4

Device	Topcon correlation; *P*, *n*	Nidek correlation; *P*, *n*
Sirius		
U1	0.745; (<0.0005), 64	0.725; (<0.0005), 68
U2	0.257; (0.052), 58	0.405; (0.004), 49
U3	0.462; (0.001), 53	0.553; (<0.0005), 49
U4	0.742; (<0.0005), 45	0.863; (<0.0005), 47
Topcon		
U1	-	0.919; (<0.0005), 63
U2		0.787; (<0.0005), 55
U3		0.872; (<0.0005), 54
U4		0.908; (<0.0005), 62

Table 3 Correlations (Pearson) between different points of time with each device

Device	U2 correlation; *P*, *n*	U3 correlation; *P*, *n*	U4 correlation; *P*, *n*
U1			
Sirius	0.366; (0.005), 58	0.428; (0.001), 54	0.819; (<0.0005), 47
Topcon	0.522; (<0.0005), 61	0.669; (<0.0005), 54	0.794; (<0.0005), 53
Nidek	0.669; (<0.0005), 56	0.710; (<0.0005), 55	0.823; (<0.0005), 60
U2			
Sirius	-	0.433; (0.002), 48	0.458; (0.003), 40
Topcon		0.448; (<0.0005), 58	0.466; (<0.0005), 56
Nidek		0.678; (<0.0005), 44	0.619; (<0.0005), 49
U3			
Sirius	-	-	0.578; (<0.0005), 38
Topcon			0.719; (<0.0005), 51
Nidek			0.751; (<0.0005), 52

All bivariate correlations of different points of time highly significant for each device ($P \leq 0.0005$).

Table 4 Comparison of the devices and points of time

Parameter	Mean	Standard deviation	95%CI	P^a
Device				
Sirius	549.92	6.10	537.77; 562.07	<0.0005
Topcon	563.68	3.44	556.83; 570.54	
Nidek	567.78	4.18	559.46; 576.11	
Point of time				
1	544.79	4.24	536.35; 553.23	<0.0005
2	581.40	5.56	570.32; 592.46	
3	569.16	5.41	558.37; 579.94	
4	546.50	4.15	538.25; 554.76	
Point of time/device[a] (interaction)				<0.0005

The differences of the parameters of repeated measurements were highly significant (*t*-test).

The estimate of covariance parameters is–apart from two exceptions–highly significant different from zero, another structure is not detectable. So, it will not be moved away from the assumption of an unstructured covariance matrix.

DISCUSSION

The strain on the corneal endothelium by a variety of mechanical and toxic influences which occur during cataract surgery is one of the greatest risk factors for postoperative complications[3,26-29].

Table 5 Corneal swelling could be detected with statistical significance from pre- to postoperative, the same applies to the decrease of CCT postoperatively

U	2	3	4
1	$P<0.0005$	$P<0.0005$	$P=1.000$
2	-	$P=0.085$	$P<0.0005$
3	-	-	$P<0.0005$

P-values after Bonferroni-correction.

Compromising of the corneal endothelium leads to a transitory reduction of its capability to dehydrate the corneal stroma, thus leading to a corneal edema. For this reason, it is important to monitor the rehabilitation of the endothelial capability of postoperative corneal dehydration. Postoperative swelling as well as the following corneal dehydration and the associated detumescence caused by the endothelium's pump function could be shown significantly with all devices used.

The application of different devices and techniques for measuring the CCT have already been evaluated by numerous studies[15,19-22,30-37]. Most of these publications compared the results of measurements taken with the present gold standard, ultrasound pachymetry. Jin *et al*[10] and Jorge *et al*[22] demonstrated excellent accordance in measurements taken by a Scheimpflug camera with ultrasound pachymetry. Especially Jorge *et al*[22] underlined that a feasible compensation of the results remained not possible. Anterior segment OCT was also compared with ultrasound pachymetry when measuring CCT[12,25,34]. The feasibility of anterior segment OCT was shown but also with this device there was no interchangeability with results generated by ultrasound pachymetry, although correlations remained acceptable[15].

Evaluations have been performed between different imaging techniques. Different authors have compared results of Scheimpflug imaging and anterior segment-OCT[12,21,29,38-39]. Most authors emphasize low comparability between different techniques whereas validity within every single technique is very high. Other authors have found correlations that would allow an interchange of results using different techniques[39-40].

The use of these devices postoperatively has not yet been described. Our study was to investigate the comparison of three different devices but for the first time also their practical application apart from study conditions with optimised circumstances.

This was done by examination of untreated eyes (U1) and during the postoperative period (U2-U4). Beside the comparability of the devices, their use under difficult conditions, which can occur postoperatively (periocular swelling, corneal edema, folds of Descemet's membrane *etc*.) was an important outcome of this study.

Comparing the three devices this study could show significant differences in results produced with the Sirius and the Topcon device (P=0.010) and between Sirius/Nidek (P<0.0005). There were no differences in the comparison of the Topcon and the Nidek device (P=0.056). The use of the Sirius camera resulted in fewer reliable results than with the other two devices used in this study. This has to be explained with the more complex acquisition process with the rotating camera, which can be made more difficult by conditions like lid swelling or corneal edema which are not that challenging with a frontal acquisition process as used by the Topcon and the Nidek device.

On the other hand, the Scheimpflug camera offers numerous additional information which can be of interest in a postoperative situation. All this information is available within a single successful image acquisition without additional loss of time. Depending on the particular situation this can be aspects as wound construction[23], anterior chamber configuration[22] or the position of the implanted lens in the anterior chamber, the ciliary sulcus or the capsular bag[41].

The advantage of measurements with the Nidek NT 530-P is without doubt the very fast course of image acquisition, which is generated during pre- and postoperative IOP-measurement nearly without delay. In contrast to that the imaging process with the OCT-2000 presents the most time-consuming procedure as an additional device has to be used.

Postoperative alterations of the cornea can aggravate difficulties of the measurements. High EPT as an indicator of a more complicated operation, which demands more ultrasound energy because of a harder nucleus or prolonged intraocular manipulation, is a common feature. But there are other postoperative changes affecting the quality of the image and so the result. These are corneal edema, Descemet's folds, which can be seen after considerable intraocular manipulation or lid swelling due to perioperative medication or the lid speculum.

The variance in variability of valid data can be partly explained by the examination method. Kurten *et al*[16-17] compared the postoperative increase of CCT measured by sonography, Scheimpflug imaging and OCT. Kuerten *et al*[16-17] showed an increase in CCT to a considerable higher degree as in this study, the mean of CCT was distinctly above 600 µm, which was not reached by any technique in this study. This can be explained by a higher surgical stress leading to more endothelial decompensation or with different devices using the same technique in the two studies. This assumption is supported by the fact that the increase in CCT in the study by Kuerten *et al*[16-17] was greater when measured with the rotating Scheimpflug camera than with the OCT whereas in this study it was diametrically opposite. The study by Kuerten *et al*[16-17] used other devices (Pentacam, Fa. Oculus, Wetzlar, Germany and Spectralis OCT, Fa. Heidelberg Engineering, Heidelberg, Germany). Possibly there are considerable differences between devices of the same imaging technique from different manufacturers[16-17,42].

The use of the devices in anterior segment diagnostics and especially in measuring CCT has already been evaluated extensively[15,19-22,25,30,35,43]. Most studies compared the results with the gold standard, ultrasound pachymetry. Various authors have found excellent correlations of CCT measured with Scheimpflug diagnostics and ultrasound pachymetry[10,12,22,25,38,42]. Similar results were found for OCT[12,15,29,34].

Different measuring techniques have also been investigated and compared[21,33] All authors underlined poor comparability between different techniques while the consistency and reliability were high.

Comparing the three devices in this study significant differences were highlighted between Sirius/Topcon (P=0.010) and between Sirius/Nidek (P<0.0005). No differences were seen when comparing Topcon/Nidek (P=0.056).

Using the Scheimpflug device resulted in fewer reliable results compared to the other two devices.

This might be due to higher efforts when using this technique as the rotating camera takes more time and postoperative changes like lid swelling or corneal edema might be more disturbing than using a frontal position in image/measurement acquisition. On the other hand, multiple information can be gained using the Scheimpflug technique apart from CCT. Depending on the problem this can be wound construction[23], anterior chamber configuration[22] or position of the implanted anterior or posterior chamber lens[41]. The advantage of using the Nidek NT 530-P is very fast data acquisition simultaneously to the obligate measurement of the intraocular pressure. In contrast to this the application of the Topcon OCT-2000 requires the use of an additional device and examination.

Postoperative corneal swelling and the following reduction of CCT could be detected statistically significant with all three devices. The differences in the availability of reliable data can be explained by the examination technique.

Measurements were feasible at all points of time pre- and postoperatively to a satisfying amount. However, there were significant differences between the devices concerning the rate of reliable data.

In conclusion, three different, partly multifunctional devices with the capability of measuring the CCT were evaluated pre- and postoperatively in the course of routine cataract surgery. While feasibility and reliability of these techniques in measuring CCT have been looked into previously in numerous studies, this study explored measurements under more difficult circumstances like immediate postoperative examinations.

Measurements were successful for all points of time with all devices to a satisfying degree. However, there were differences between the three devices used in this study. The Sirius Scheimpflug camera stood out with a significantly lower degree of utilisable images.

The already known phenomenon of postoperative corneal edema and swelling due to transient disturbance of the corneal endothelium could be proven with statistical significance with all three devices.

The analysed devices/techniques were altogether suitable for perioperative monitoring of the corneal thickness. The results are only comparable to a limited extent and not interchangeable during the course of postoperative recovery. The reasons for this can be found in different techniques of image acquisition but also in differences between devices with the same technique of different manufacturers.

This study shows that numerous devices are capable of measuring CCT perioperatively. The choice which device to choose has to be based on the information wanted to extract out of a single examination (*e.g.*, relevance of corneal topography, interest in anterior chamber morphology or location of an implanted lens) but also effort and speed of a single examination.

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REFERENCES

1 Snell RS, Lemp MA. *Clinical anatomy of the eye*. Oxford, UK: Blackwell Science Ltd., 1997.

2 Auerbach FN, Holzer MP, Auffarth GU, Khoramnia R, Thomas BC, Saure D, Rabsilber TM. Influence of corneal pachymetric changes on functional results after cataract surgery. *Ophthalmologe* 2015;112(10):834-839.

3 Green WT, Muir MG. Corneal complications of cataract surgery. *Curr Opin Ophthalmol* 1994;5(4):98-104.

4 Chen Z, Song FQ, Sun LY, Zhao CC, Gao NN, Liu P, Ge HY. Corneal integrity and thickness of central fovea after phacoemulsification surgery in diabetic and nondiabetic cataract patients. *Arch Med Sci* 2018;14(4):818-825.

5 Dzhaber D, Mustafa O, Alsaleh F, Mihailovic A, Daoud YJ. Comparison of changes in corneal endothelial cell density and central corneal thickness between conventional and femtosecond laser-assisted cataract surgery: a randomised, controlled clinical trial. *Br J Ophthalmol* 2020;104(2):225-229.

6 Sandali O, El Sanharawi M, Tahiri Joutei Hassani R, Roux H, Bouheraoua N, Borderie V. Early corneal pachymetry maps after cataract surgery and influence of 3D digital visualization system in minimizing corneal oedema. *Acta Ophthalmol* 2021. Online ahead of print.

7 Mansoori T. Comparison of central corneal thickness measurements using different imaging devices and ultrasound pachymetry. *Indian J Ophthalmol* 2019;67(9):1508.

8 Pillunat KR, Waibel S, Spoerl E, Herber R, Pillunat LE. Comparison of central corneal thickness measurements using optical and ultrasound pachymetry in glaucoma patients and elderly and young controls. *J Glaucoma* 2019;28(6):540-545.

9 Thiagarajan K, Srinivasan K, Gayam K, Rengaraj V. Comparison of central corneal thickness using non-contact tono-pachymeter (Tonopachy) with ultrasound pachymetry in normal children and in children with refractive error. *Indian J Ophthalmol* 2021;69(8):2053-2059.

10 Jin YL, McAlinden C, Sun Y, Wen DZ, Wang YR, Yu JJ, Feng K, Song BH, Wang QM, Chen SH, Huang JH. Sirius Scheimpflug-Placido versus ultrasound pachymetry for central corneal thickness: meta-analysis. *Eye Vis* (*Lond*) 2021;8(1):5.

11 Mayali H, Altinisik M, Diri I, Ilker S, Kurt E, Kayikcioglu O. Comparison of central corneal thickness measurements by contact and non-contact pachymetry devices. *J Curr Glaucoma Pract* 2021;15(1):28-31.

12 Toptan M, Simsek A. A comparison of central corneal thickness measured using noncontact methods and ultrasonic pachymetry. *Niger J Clin Pract* 2021;24(10):1506-1510.

13 Chandler JW, Sugar J, Edelhauser HF. Erkrankungen des äußeren Auges. München: Urban&Fischer; 1999

14 Asfuroglu Y, Kemer OE. Central corneal thickness and corneal volume changes in eyes with and without pseudoexfoliation after uneventful phacoemulsification. *Int Ophthalmol* 2019;39(2):275-280.

15 Northey LC, Gifford P, Boneham GC. Comparison of topcon optical coherence tomography and ultrasound pachymetry. *Optom Vis Sci* 2012;89(12):1708-1714.

16 Kuerten D, Plange N, Koch EC, Koutsonas A, Walter P, Fuest M. Central corneal thickness determination in corneal edema using ultrasound pachymetry, a Scheimpflug camera, and anterior segment OCT. *Graefes Arch Clin Exp Ophthalmol* 2015;253(7):1105-1109.

17 Kuerten D, Plange N, Walter P, Fuest M. Author reply: central corneal thickness determination in corneal edema. *Graefes Arch Clin Exp Ophthalmol* 2017;255(6):1253-1254.

18 Hilsdorf C, Zenklusen G. Corneal damage due to novesine. *Klin Monbl Augenheilkd* 1973;162(4) 525-527.

19 Barkana Y, Gerber Y, Elbaz U, Schwartz S, Ken-Dror G, Avni I, Zadok D. Central corneal thickness measurement with the Pentacam Scheimpflug system, optical low-coherence reflectometry pachymeter, and ultrasound pachymetry. *J Cataract Refract Surg* 2005;31(9): 1729-1735.

20 Beutelspacher SC, Serbecic N, Scheuerle AF. Assessment of central corneal thickness using OCT, ultrasound, optical low coherence reflectometry and Scheimpflug pachymetry. *Eur J Ophthalmol* 2011;21(2):132-137.

21 Ishibazawa A, Igarashi S, Hanada K, Nagaoka T, Ishiko S, Ito H, Yoshida A. Central corneal thickness measurements with Fourier-domain optical coherence tomography versus ultrasonic pachymetry and rotating Scheimpflug camera. *Cornea* 2011;30(6):615-619.

22 Jorge J, Rosado J, Díaz-Rey J, González-Méijome J. Central corneal thickness and anterior chamber depth measurement by Sirius(®) Scheimpflug tomography and ultrasound. *Clin Ophthalmol* 2013;7:417-422.

23 Handzel DM, Meyer CH, Wegener A. Possibilities for use of Scheimpflug technology in cataract surgery. *Ophthalmologe* 2014;111(10):927-934.

24 Gharieb HM, Ashour DM, Saleh MI, Othman IS. Measurement of central corneal thickness using Orbscan 3, Pentacam HR and ultrasound pachymetry in normal eyes. *Int Ophthalmol* 2020;40(7):1759-1764.

25 Üçer MB, Bozkurt E. Comparison of central corneal thickness measurements with three different optical devices. *Ther Adv Ophthalmol* 2021;13:2515841421995633.

26 Rosado-Adames N, Afshari NA. The changing fate of the corneal endothelium in cataract surgery. *Curr Opin Ophthalmol* 2012;23(1):3-6.

27 Ventura AC, Wälti R, Böhnke M. Corneal thickness and endothelial density before and after cataract surgery. *Br J Ophthalmol* 2001;85(1): 18-20.

28 Yamazoe K, Yamaguchi T, Hotta K, Satake Y, Konomi K, Den S, Shimazaki J. Outcomes of cataract surgery in eyes with a low corneal endothelial cell density. *J Cataract Refract Surg* 2011;37(12):2130-2136.

29 Doğan M, Ertan E. Comparison of central corneal thickness measurements with standard ultrasonic pachymetry and optical devices. *Clin Exp Optom* 2019;102(2):126-130.

30 Li HT, Leung CKS, Wong L, Cheung CYL, Pang CP, Weinreb RN, Lam DSC. Comparative study of central corneal thickness measurement with slit-lamp optical coherence tomography and visante optical coherence tomography. *Ophthalmology* 2008;115(5):796-801.e2.

31 Tai LY, Khaw KW, Ng CM, Subrayan V. Central corneal thickness measurements with different imaging devices and ultrasound pachymetry. *Cornea* 2013;32(6):766-771.

32 Dutta D, Rao HL, Addepalli UK, Vaddavalli PK. Corneal thickness in keratoconus: comparing optical, ultrasound, and optical coherence tomography pachymetry. *Ophthalmology* 2013;120(3):457-463.

33 Maloca PM, Studer HP, Ambrósio R Jr, *et al*. Interdevice variability of central corneal thickness measurement. *PLoS One* 2018;13(9):e0203884.

34 Li XP, Zhou YJ, Young CA, Chen AM, Jin GM, Zheng DY. Comparison of a new anterior segment optical coherence tomography and Oculus Pentacam for measurement of anterior chamber depth and corneal thickness. *Ann Transl Med* 2020;8(14):857.

35 Lee JH, Kim JH, Kim SW. Repeatability of central corneal thickness measurement using rotating scheimpflug camera in dry and normal eyes. *Eye Contact Lens* 2018;44(Suppl 2):S29-S32.

36 Kumar KK, Prakash AA, Neeraja TG, Adappa KT, Prabha TSC, Gangasagara SB. To compare central corneal thickness measurements obtained by Pentacam with those obtained by IOLMaster 700, Cirrus anterior segment optical coherence tomography and Tomey specular microscopy in normal healthy eyes. *Indian J Ophthalmol* 2021;69(7):1713-1717.

37 Jiang JY, Ong K. Variability of central corneal thickness measurements-comparing zeiss IOL master and tomey corneal specular microscope. *Asia Pac J Ophthalmol* (*Phila*) 2019;8(4):275-279.

38 David K, Mandana HZ, Niklas P, Peter W, Matthias F. Reproducibility and reliability of central corneal thickness determination in more and less profound corneal edema using ultrasound pachymetry, a Scheimpflug camera and anterior segment OCT. *Graefes Arch Clin Exp Ophthalmol* 2020;258(2):351-358.

39 González-Pérez J, Queiruga Piñeiro J, Sánchez García Á, González Méijome JM. Comparison of central corneal thickness measured by standard ultrasound pachymetry, corneal topography, tono-pachymetry and anterior segment optical coherence tomography. *Curr Eye Res* 2018;43(7):866-872.

40 Bayhan HA, Aslan Bayhan S, Can I. Comparison of central corneal thickness measurements with three new optical devices and a standard ultrasonic pachymeter. *Int J Ophthalmol* 2014;7(2):302-308.

41 Baumeister M, Bühren J, Schnitzler EM, Ohrloff C, Kohnen T. Scheimpflug photographic imaging following implantation of anterior and posterior chamber phakic intraocular lenses: preliminary results. *Klin Monbl Augenheilkd* 2001;218(2):125-130.

42 Rosa N, de Bernardo M, Pepe A, Vitiello L, Marotta G, Imparato R, Capasso L. Corneal thickness evaluation in healthy eyes: comparison between two different Scheimpflug devices. *PLoS One* 2020;15(12):e0243370.

43 de Bernardo M, Salzano FA, Rosa N. Central corneal thickness measurement with Cirrus HD-OCT and Topcon SP-3000P. *J Optom* 2018;11(3):198-199.