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1   **Full title: A comprehensive comparison of central corneal thickness measurement after**

2   **LASIK**

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22

23 **Abstract**

24 **PURPOSE:** To assess the repeatability and reproducibility of central corneal thickness (CCT)

25 measurements by high resolution rotating Scheimpflug imaging (Pentacam, Oculus) and

26 Fourier-domain optical coherence tomography (FD-OCT, RTvue-100, Optovue) after Laser In

27 Situ Keratomileusis (LASIK), and to compare the agreement with ultrasound pachymetry

28 (USP).

29

30 **METHODS:** Forty seven eyes of 47 patients after LASIK were included in the study. The first

31 examiner took two successive Pentacam and RTvue CCT measurements and repeated once

32 again by the second examiner to assess intra- and interobserver repeatability and

33 reproducibility. After performing non-contact examinations, the corneas were measured by

34 USP to compare the level of agreement among the three devices.

35

36 **RESULTS:** All $Pentacam_{center}$, $Pentacam_{apex}$, $Pentacam_{thinnest}$, and RTvue CCT measurements

37 demonstrated high intraobserver repeatability, with respective precision (1.96

38 within-subject standard deviation) and intraclass correlation coefficients (ICC) of 7.52μm,

39 7.43μm, 7.55μm and 3.81μm and 0.985, 0.986, 0.986 and 0.997; interobserver repeatability

40 results were similar. All coefficients of variation were low: <1% for all measures. Compared

41 with Pentacam and USP measurements, the RTvue measurement significantly

42 underestimated CCT by a mean of 10.52 to 15.28μm ($P < 0.001$) and 9.17μm ($P < 0.001$),

43 respectively. The agreement of USP with Pentacam and RTvue by Bland-Altman analysis

44 spanned over 30 μm. The agreement of Pentacam with RTvue spanned approximate 20 μm.

45

46 **CONCLUSIONS:** Both Pentacam imaging and RTvue FD-OCT provide reliable and

47 interchangeable measurement of CCT in post-LASIK corneas. However, they cannot be

48 considered to be clinically interchangeable with USP.

49

50 **Keywords**: Corneal thickness, Optical coherence tomography, Rotating Scheimpflug

51 photography, LASIK

52

53

54   Accurate and reliable determination of central corneal thickness (CCT) is necessary to

55   evaluate patient eligibility for laser in situ keratomileusis (LASIK), planning the procedure,

56   and managing follow-up.[1-2] This is especially important in patients considered for

57   enhancement surgery since their CCTs are more likely to be too thin for safe treatment.[3-4]

58   Although Ultrasound pachymetry (USP) is the gold standard approach to measure CCT, high

59   inter-observer and inter-instrument variation in measurement has been described.[5-6] The

60   measurement error of USP may arise from a lack of meticulous centration of the

61   measurement, oblique incidence of the probe to the cornea, lack of a fixation light for gaze

62   control, variability of sound speed across tissues, or even the effect of the topical anesthetic

63   agent.[7-10] After LASIK, CCT measurement can be confounded by loss of transparency in the

64   postoperative cornea with accompanying corneal refractive index alterations, mistaken

65   detection of the stromal interface as the posterior corneal surface, and alterations in

66   corneal shape rendering reconstruction algorithms inappropriate.[11-13]

67

68   In recent years a number of sophisticated imaging systems have been introduced which

69   measure CCT. These techniques appear to be safe, flexible, and reliable. The original

70   rotating Scheimpflug photography system (Pentacam, Oculus, Wetzlar, Germany) has been

71   shown to provide reliable CCT measurements, which are highly agreeable with USP for

72   normal corneas.[14-20] Repeatability of corneal parameters with the original Pentacam

73   Scheimpflug imaging after LASIK has also been demonstrated, albeit to a limited extent.[21]

74   More extensive evaluation is needed. The latest high resolution (HR) Pentacam Scheimpflug

75   imaging system has a reformed optical design using a high resolution 1.45 megapixel camera

76 and is improved to maximally capture 138,000 data points in less than 2 seconds. To our

77 knowledge no study to date has examined the repeatability and reproducibility of CCT by HR

78 Pentacam Scheimpflug imaging in post-LASIK eyes.

79

80 Optical coherence tomography (OCT) is a noninvasive imaging modality, which uses

81 coherence gating to obtain a cross-sectional microstructure of tissue. Recently,

82 Fourier-domain OCT (FD-OCT) has demonstrated greater speed, shorter acquisition time,

83 higher resolution and a greater signal-to-noise ratio compared to the conventional

84 time-domain OCT (TD-OCT). [22-24] The commercially available FD-OCT (RTvue-100, Optovue

85 Inc, Fremont, California, USA) has a scan rate of 26,000 A-scans per second and an axial

86 resolution of 5 μm; FD-OCT yields highly repeatable and reproducible measurements of

87 retinal nerve fiber layer thickness.[24-25] RTvue FD-OCT is also capable of obtaining high

88 definition cross-sectional images of the cornea by adjusting a corneal adaptor module

89 (CAM); this provides both central and regional pachymetry.

90

91 The present investigation aimed to evaluate the repeatability and reproducibility of CCT

92 measurements using HR Pentacam Scheimpflug imaging and RTvue FD-OCT in post-LASIK

93 eyes. Furthermore, this study also compared the agreement of measurements from HR

94 Pentacam Scheimpflug imaging and RTvue FD-OCT with measurements obtained from USP

95 within the same population.

96

97

98 **PATIENTS AND METHODS**

99

100 Subjects:

101 Subjects were 47 myopic patients who underwent LASIK treatment in the Refractive Surgery

102 Department of the Affiliated Eye Hospital of Wenzhou Medical College between November

103 2008 and February 2009. All LASIK procedures were performed using the 400 Hz Mel-80

104 excimer laser (Carl Zeiss Meditec, Oberkochen, Germany) by the same surgeon (Q.W.). Flaps

105 were created with a mechanical microkeratome (Moria, Antony, France); the intended flap

106 thickness was 130 μm. Exclusion criteria included ocular disease, systemic disease,

107 intraoperative or postoperative complications (eg, free flap, reepithelialization), or

108 retreatment. The research protocol adhered to the tenets of the Declaration of Helsinki and

109 was approved by the local ethics committee. Written informed consent was obtained from

110 all patients. All measurements were performed in the right eye.

111

112 Procedure:

113

114 *Part One:*

115 In the first part of the study, the reliability of CCT measurements obtained by HR Pentacam

116 Scheimpflug imaging and RTvue FD-OCT were investigated. Our definitions of reproducibility

117 and repeatability were based on those adopted by the British Standards Institution, as

118 recommended by Bland and Altman.[26-28]

119

120   The latest Pentacam rotating Scheimpflug camera system was used in this study. The patient

121   was instructed to open both eyes and to fixate on a 475 nm blue light source in the center of

122   the camera during scanning. The automatic release mode was used to reduce

123   operator-dependent variables. The rotating camera captured 25 slit images of the anterior

124   segment in less than 2 seconds. Each slit image consisted of 1,380 true elevation points that

125   were analyzed by Pentacam Software 6.02r23. Only scans with an "Examination Quality

126   Specification" of "OK" were chosen for analysis. The central pupil value of corneal thickness

127   was recorded as CCT (Pentacam$_{center}$), and the corneal thickness at the corneal apex

128   (Pentacam$_{apex}$) and thinnest location (Pentacam$_{thinnest}$) were also recorded. Previous

129   research has demonstrated some unreliability of the Pentacam pupil centre due to changes

130   in pupil size during measurement, therefore inclusion in the study of two alternative

131   Pentacam-derived CCT measures is appropriate.[14]

132

133   The RTvue-100 used a super-luminescence diode as a low coherence light source, emitting

134   light with a 50 nm bandwidth centered at 830 nm, corresponding to 5 μm depth resolution

135   in tissue. The anterior segment imaging could be generated using a CAM, which was a set of

136   lenses added on the probe to focus the OCT beam onto the cornea. Scanning with the

137   FD-OCT was performed by using the corneal pachymetry protocol, which acquires eight

138   evenly spaced 6-mm radial lines oriented 22.5 degrees from one another, consisting of 1024

139   A-scans per line in 0.31 seconds. The subject was asked to look at an internal fixation target.

140   The center of the scan pattern was aligned with the corneal apex reflection visualized on the

141   OCT images. The OCT image was determined when the reflection from the anterior apex of

142   the cornea saturated the imaging system and produced a vertical flare. The average reading

143   displayed in the center was used for the FD-OCT analysis automatically using the recently

144   available software version 3.6.

145

146   The CCT of each patient was measured using Pentacam Scheimpflug imaging and RTvue

147   FD-OCT by two independent and experienced examiners. For each method, the first

148   examiner (HJH) performed testing with both devices, taking two measurements with each.

149   Subjects were then immediately rescanned by the other examiner (WDZ) using the same

150   protocol although taking only one measurement with each device. After each acquisition,

151   the device was moved backwards and realigned for the next scan to eliminate

152   interdependence of successive measurements. The time for the instrument to calculate the

153   data between successive scans was approximately 20 seconds for the Pentacam

154   Scheimpflug imaging and 10 seconds for the RTvue FD-OCT. The total time to acquire all

155   measurements did not exceed 10 minutes. For each method, differences between the 2

156   measurements obtained by the first examiner were used to assess intra-observer

157   repeatability; the differences between the first measurements obtained by the two

158   examiners were used to assess inter-observer reproducibility.

159

160   *Part Two:*

161   In the second part of the study, the interchangeability of CTT measurements using

162   Pentacam Scheimpflug imaging, RTvue FD-OCT and USP in post-LASIK eyes were compared.

163

164   Following the non-contact examinations (Part One), the cornea was anesthetized with 0.5%

165   topical proparacaine (Alcaine; Alcon Laboratories, TX, USA) in preparation for USP. The

166   A-scan USP (SP-3000, Tomey Inc., Nagoya, Japan) was precalibrated for all measurements.

167   The ultrasonic velocity was set at 1640 m/s. The patient was asked to fixate on a target on

168   the ceiling. The pachymeter probe was brought in light contact with the cornea centrally

169   and perpendicularly. Five readings were obtained, and the highest and the lowest values

170   were excluded. The mean of the remaining 3 readings was calculated. In this case averaging

171   of measures was performed as this is a standard approach. [18, 29] This value was then

172   compared with the three mean CCT values for Pentacam Scheimpflug imaging and the mean

173   CCT value for RTvue FD-OCT, which were calculated from the two measurements taken by

174   the first examiner. All measurements were taken between 10 AM and 5 PM to minimize the

175   effect of changes in the physiological condition of the cornea.[30-31]

176

177   **Statistical Analysis**

178

179   All statistical tests were performed using Statistical Package for Social Sciences for Windows

180   version 13.0 (SPSS Inc, Chicago, Illinois, USA). Results are presented as mean ± standard

181   deviation (SD). All data sets were checked for normality using the Kolmogorov-Smirnov

182   statistic. All P values were > 0.05, indicating that the data were normally distributed, and

183   therefore it was appropriate to use parametric statistical tests.

184

185   To assess intra-observer repeatability, the within-subject SD (S_w) of two consecutive

186 measurements by the first examiner was calculated. Precision (repeatability coefficient) was

187 defined as ± 1.96 S_w. The difference between a subject's measurement and the true value

188 from a statistical standpoint would be expected to be less than 1.96 S_w for 95% of the

189 observations.[32] The 95% limits of agreement (LoA) were computed by mean difference ±

190 1.96 SD of the differences which provides an interval within which 95% of the differences

191 between measurements are expected to lie. The within-subject coefficient of variation (CV_w,

192 100 x S_w/overall mean) was also calculated. Further statistical analysis for the intrasession

193 reliability of the measurement method by both instruments was performed with intraclass

194 correlation coefficients (ICC). The ICC was determined on the basis of analysis of variance for

195 two-way mixed-effects model with an absolute agreement for consistency of individual

196 measurements. ICC values can theoretically range from 0 to 1, with a higher value indicating

197 less random or systematic differences in the measurements.[33] To assess inter-observer

198 reproducibility, inter-observer S_w, precision, CV_w, 95% LoA, and ICC were also calculated.

199

200 CCT measurements with the 3 methods were compared using a repeated-measures analysis

201 of variance (ANOVA), with a Bonferroni correction for multiple comparisons, and Bland and

202 Altman plots. Significance was set at $P \leq 0.05$.

203

204 **RESULTS**

205

206 The mean age of the patients was 23.5 ± 4.3 years (range, 18 to 34 years), and 23 patients

207 (49%) were female. The mean post-LASIK period was 207.1 ± 151.2 days (range, 30 to 720

208   days). The mean pre-LASIK refraction was −5.70 ± 1.83 diopters (range, −2.00 to −9.38

209   diopters).

210

211   **Repeatability of CCT Measurements**

212

213   Table 1 presents the intraobserver repeatability statistics S_w, precision, CV_w, and ICC. Both

214   Pentacam Scheimpflug imaging and RTvue FD-OCT demonstrated a high repeatability of CCT.

215   The Bland-Altman plots (Figure 1) illustrate the variability between first and second

216   measurements was smaller with RTvue FD-OCT than with Pentacam Scheimpflug imaging.

217   There was no relationship between variability and mean CCT with either device (all P values

218   were > 0.05).

219

220   **Reproducibility of CCT Measurements**

221

222   Table 2 shows the interobserver reproducibility statistics S_w, precision, CV_w, and ICC. No

223   statistically significant differences in CCT were noted between examiners (P > 0.05).

224   Although both instruments performed well, the RTvue FD-OCT showed better

225   reproducibility (Figure 2). There was no relationship between variability and mean CCT with

226   either device (all P values were > 0.05)

227

228   **Agreement of CCT measurements**

229

230   Table 3 shows that CCT measurements taken using RTvue FD-OCT (447.66 ± 33.57 μm) were

231   significantly lower than Pentacam$_{center}$ (462.94 ± 31.51 μm, P < 0.001), Pentacam$_{apex}$ (459.13

232   ± 31.87 μm, P < 0.001), Pentacam$_{thinnest}$ (458.18 ± 32.29 μm, P < 0.001) and USP (456.83 ±

233   32.66 μm, P < 0.001). No statistically significant difference was found between Pentacam$_{apex}$

234   and USP measurements (P = 0.217), and between Pentacam$_{thinnest}$ and USP measurements (P

235   = 0.864). The Bland–Altman plots showed that the 95% LoA between Pentacam Scheimpflug

236   imaging and RTvue FD-OCT were lower than the values for other 2 pairs of devices (Figure 3)

237   and that there were no relationships between agreement and mean CCT (all P values were >

238   0.05)

239

240   **DISCUSSION**

241

242   The use of validated and reliable measurement instruments is of critical importance for the

243   clinical practice and interpretation of study results.[34] It is crucial, therefore, to evaluate the

244   precision and compare the accuracy of such instruments, particularly before they become

245   widely applied in clinical practice and research settings. The present study demonstrated

246   that HR Pentacam Scheimpflug imaging and RTvue FD-OCT have high repeatability and

247   reproducibility in post-LASIK patients, although the FD-OCT performed slightly better

248   compared with HR Pentacam Scheimpflug imaging. This is probably because the RTvue

249   algorithm includes averaging of multiple points, measures pachymetry with greater speed

250   and shorter acquisition time to reduced eye motion-related artifact, and has higher

251   resolution which aids in distinguishing the anterior and posterior corneal surfaces; these

252 strategies all likely reduce variability. Importantly, we have demonstrated that a reliable CCT

253 measurement can be obtained independent of operators and without numerous

254 acquisitions as illustrated by the comparability of the intra- and inter-observer results. To

255 our knowledge, this is the first study to assess the repeatability and reproducibility of CCT

256 measurement following LASIK using HR Pentacam Scheimpflug imaging and RTvue FD-OCT,

257 and to compare agreement with USP.

258

259 These reliability results are consistent with previous studies that have demonstrated that

260 the original Oculus Pentacam provides reliable CCT measurement in normal corneas,

261 keratoconus and corneal grafts (Table 4).[15-18, 20, 35-36] However, many of the studies that

262 used Pentacam Scheimpflug imaging in post-LASIK corneas were limited because they

263 addressed the accuracy but not the precision of the original Oculus Pentacam in comparison

264 to other pachymeters including optical and USP.[37-40] To our knowledge only Jain et al have

265 investigated the repeatability of CCT in post-LASIK eyes with original Oculus Pentacam,

266 reporting a high degree of repeatability for the central, apical and thinnest pachymetry.[21]

267 However, that study did not correctly present Bland-Altman plots and their results are a

268 little unclear.[32] They assessed repeatability based on five successive scans obtained by the

269 same operator in each patient, and plotted the difference of each reading from an average

270 in each patient on the ordinate against the observation sequence on the abscissa. With such

271 a statistical analysis, the readings are related so cannot be independent from each other.

272 Previous studies have demonstrated that the TD-OCT yielded highly reliable measurements

273 of normal corneal thickness. Muscat et al.[41] assessed the inter-operator variability of CCT by

274   Stratus OCT (Carl Zeiss Meditec, Dublin, CA) and found an excellent reproducibility (95% LoA

275   of -3 to 4 μm, and an ICC of 0.998). Li et al reported high repeatability in anterior segments

276   Visante TD-OCT (Carl Zeiss Meditec, Dublin, CA; the ICC and Sw values ranged between 0.96

277   and 0.98 and 4.9 μm and 7.3 μm, respectively).[42] Kim et al found a small but significant

278   systematic difference between two observers with slit-lamp OCT (Heidelberg Engineering,

279   Dossenheim, Germany; mean, 6.9 μm; SD 10.9 μm).[43] Li et al.[44] reported the reproducibility

280   of CCT by the Visante OCT was 1.7 μm (pooled SD) in post-LASIK corneas. A recent study by

281   Keech et al showed RTvue provides a highly repeatable measure of corneal thickness at

282   various locations in virginal eyes, with ICC ranging between 0.969 and 0.996.[45] The

283   outcomes in this study were similar to or better than TD-OCT studies. The repeatability (2.77

284   × S_w) was less than 5.5 μm (i.e., the difference between any two measurements for the

285   same subject is expected to be less than 5.5 μm for 95% of all pairs of measurements). A

286   change in CCT greater than 5.5 μm would therefore be more likely to represent actual

287   change rather than measurement error. Therefore RTvue FD-OCT enables reliable detection

288   of change of corneal thickness.

289

290   In the present study, HR Pentacam Scheimpflug imaging slightly overestimated CCT

291   compared with USP by an average of 6.11 μm at central pupil but no statistically significant

292   difference was found between Pentacam$_{apex}$ and USP, and between Pentacam$_{thinnest}$ and USP

293   measurements. These differences are clinically insignificant and are consistent with previous

294   studies that compared the original Pentacam system and USP for post-LASIK or PRK corneas

295   (Table 5). However, the range of 95% LoA were 34.6 μm, 33.6 μm and -15.5 to 33.7 μm

296   between Pentacam$_{center}$ vs. USP, Pentacam$_{apex}$ vs. USP and Pentacam$_{thinnest}$ vs. USP,

297   respectively. While the means are comparable, the LoA are large which is due to the

298   variability of both measures, particularly USP which has been shown to be larger than with

299   Scheimpflug imaging.[16,20] Whether this agreement is clinically satisfactory depends upon the

300   clinical situation. This may, for example, alter the decision of whether a patient is suitable

301   for LASIK enhancement or not. Therefore these methods should probably be considered not

302   clinically interchangeable.

303

304   RTvue FD-OCT had a significantly lower mean CCT measurement compared to USP and

305   Pentacam Scheimpflug imaging CCT measurements by a mean of 9.17µm, 15.28 µm, 11.47

306   µm and 10.52 µm at central pupil, apical and thinnest locations respectively, which agrees

307   with findings in previous studies using OCT. Several studies demonstrated that CCT

308   measured by OCT was generally thinner than that measured by USP and Pentacam. Ponce et

309   al., Li et al., and Zhao et al. found the Visante OCT CCT measurement to be thinner than

310   ultrasound by 7.5 µm, 14.6 µm, 16.5 µm, respectively.[42, 46-47] Ho et al report that Visante

311   OCT measurements underestimate Pentacam corneal thickness in post-LASIK patients by a

312   mean of 4.1 µm.[37] More recently, Chen et al.[48] showed that RTvue FD-OCT significantly

313   underestimated CCT measurement compared with the HR Pentacam and USP in healthy,

314   normal corneas, by a mean of 10.9 µm and 5.63 µm, respectively. Both RTvue FD-OCT and

315   Visante TD-OCT use similarity methodology to identify the anterior and posterior corneal

316   surfaces and transform distance between them into corneal thickness by computer analysis.

317   The anterior corneal boundary delineated by the Visante OCT was positioned slightly below

318   the anterior corneal surface, leading to underestimation of corneal thickness.[42] The faster

319   scan speed and higher resolution of FD-OCT can reduce data acquisition time and improve

320   edge detection. This difference may additionally be computational specific algorithm and

321   reflected wave assessment.[42, 49] These factors may largely lead to underestimating the

322   pachymetry with RTVue. The 95% LoA for the agreement between Pentacam Scheimpflug

323   imaging and RTvue FD-OCT are narrow (approximate 20 μm) and were comparable to those

324   found in the reproducibility studies mentioned above. Ciolino et al.[40] compared original

325   Pentacam Scheimpflug imaging and USP CCT in eyes that had undergone laser LASIK and

326   demonstrates that 95% of the eyes differed in CCT measurements by -18.9 to 21.8 μm. Our

327   95% LoA between HR Pentacam Scheimpflug imaging and RTvue FD-OCT are even narrower

328   and comparable to the reported range of -11 μm to 11 μm for the diurnal pachymetric

329   variation of CCT,[30] comparable to the repeatability of Pentacam, and comparable to

330   reproducibility of flap thickness with and Moria LSK-1 and M2 Microkeratomes (the

331   variation range of 19 to 24 μm).[50] Therefore we propose that these systems can be used

332   interchangeably in post-LASIK eyes for most clinical applications. While the mean difference

333   can be adjusted for, the 95% LoA between RTvue and USP spans 32.5 μm. Again this

334   suggests the two measures cannot be used interchangeably. This is especially important for

335   LASIK enhancement surgery assessment where patients may have borderline corneal

336   thickness. Underestimation of corneal pachymetry may lead to exclusion of some of these

337   patients and, in general, to an overly conservative treatment plan. Conversely,

338   overestimation can lead to inadvertent thinning of the stromal bed beyond 250 μm and,

339   theoretically, may increase the risk for keratectasia.[3-4, 51]

340

The current study had several limitations. This type of study is hampered by the different

algorithms each device uses for reporting CCT, yet one can only examine the results that

each device reports. The RTvue reports a CCT which is an average of a number of central

points which enhances its repeatability. The HR Pentacam reports several CCT measures,

which are derived from the centre of the pupil, the corneal apex or the thinnest corneal

point. Fortunately, the choice of CCT makes little difference to the interchangeability with

other measures. Ultrasound pachymetry is theoretically performed over the pupil centre,

suggesting this should be the standard, but it is unlikely that even the most experienced

pachymetrist could discern whether they placed the probe at the corneal apex or the pupil

centre. Indeed the poor repeatability of corneal USP undermines its position as the CCT

measurement of choice. Perhaps it is time the ophthalmic industry moved to consider

imaging systems as the CCT measure of choice. Another shortcoming is that the consecutive

patients had a wide post-LASIK period range from 30 to 720 days. Since both Pentacam and

RTvue FD-OCT rely on measurements of reflected light beams through the corneal tissues,

the accuracy of pachymetry after refractive surgery may be affected when there are loss of

corneal transparency and change of refractive index. Previous reports have demonstrated

Orbscan II CCT measurements tended to be thinner in postoperative corneas and corneas

with haze, while those of Pentacam were statistically stable in postoperative corneas and

corneas with haze[39, 52]. The outcomes cannot be influenced by corneal haze because the

present study only included post-LASIK patients free of surgery complications, corneal haze

and enhancements. Nevertheless, further research is necessary to detect if there are

362   differences in corneal thickness measurements at the one-week, one-month, three-months

363   and one-year postoperatively between these device comparisons.

364

365   In summary, the HR Pentacam Scheimpflug imaging and RTvue FD-OCT demonstrated high

366   repeatability and reproducibility for CCT measurements in post-LASIK eyes. However, it is

367   important to emphasize that in clinical practice, measurement values are not directly

368   interchangeable between both non-contact devices and USP as the LoA are relatively wide.

369

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Figure Legends

Figure 1. Bland-Altman Plots of the mean difference between the first and second measurements against the mean CCT readings taken with the Pentacam High Resolution Rotating Scheimpflug Photography (A, B, C) and RTvue Fourier-domain Optical Coherence Tomography OCT(D). The 95% limits of agreement are shown with dashed lines, and the solid line represents the mean difference between these measurements.

Figure 2. Bland-Altman Plots of the mean difference between examiners' measurements against the mean CCT readings taken with the Pentacam High Resolution Rotating Scheimpflug Photography (A, B, C) and RTvue Fourier-domain Optical Coherence Tomography OCT (D). The 95% limits of agreement are shown with dashed lines, and the solid line represents the mean difference between these measurements.

Figure 3. Bland-Altman plots comparing CCT between Pentacam$_{center}$ and USP (A), Pentacam$_{center}$ and RTvue (B), Pentacam$_{apex}$ and USP (C), Pentacam$_{apex}$ and RTvue (D), Pentacam$_{thinnest}$ and USP (E), Pentacam$_{thinnest}$ and RTvue (F), and RTvue and USP (G). The 95% limits of agreement are shown with dashed lines, and the solid line represents the mean difference between these measurements.

TABLE 1.Intraobserver Repeatability of Pentacam High Resolution Rotating Scheimpflug Photography and RTVue Fourier-domain Optical Coherence Tomography OCT in Measuring Central Corneal Thickness (n = 47)

Device	Mean Difference (µm) ± SD	S_w (µm)	Precision (µm)	CV_w (%)	ICC (95% CI)
Pentacam$_{center}$	-0.77 ± 5.43	3.83	7.52	0.83	0.985 (0.974 to 0.992)
Pentacam$_{apex}$	-0.81 ± 5.36	3.79	7.43	0.83	0.986 (0.975 to 0.992)
Pentacam$_{thinnest}$	-0.83 ± 5.44	3.85	7.55	0.84	0.986 (0.975 to 0.992)
RTvue	0.94 ± 2.62	1.95	3.81	0.43	0.997 (0.994 to 0.998)

Pentacam$_{center}$ = central corneal thickness measured by the Pentacam, Pentacam$_{apex}$ = apical corneal thickness measured by the Pentacam, Pentacam$_{thinnest}$ = thinnest corneal thickness measured by the Pentacam, SD = standard deviation, S_w = within-subject standard deviation, Precision = 1.96 x S_w, CV_w = within-subject coefficient of variation, ICC = intraclass correlation coefficient, CI = confidence interval, LoA = limits of agreement according to Bland-Altman method.

TABLE 2. Interobserver reproducibility of Pentacam High Resolution Rotating Scheimpflug Photography and RTVue Fourier-domain Optical Coherence Tomography OCT in Measuring Central Corneal Thickness (n = 47)

Device	Mean Difference (μm) ± SD	S_w (μm)	Precision (μm)	CV_w (%)	ICC (95% CI)
Pentacam$_{center}$	0.47 ± 5.85	4.11	8.05	0.89	0.984 (0.971 to 0.991)
Pentacam$_{apex}$	-0.62 ± 5.44	3.83	7.50	0.83	0.986 (0.992 to 0.992)
Pentacam$_{thinnest}$	-0.38 ± 4.83	3.39	6.65	0.74	0.989 (0.981 to 0.994)
RTvue	1.04 ± 2.40	1.84	3.60	0.41	0.997 (0.994 to 0.998)

Pentacam$_{center}$ = central corneal thickness measured by the Pentacam, Pentacam$_{apex}$ = apical corneal thickness measured by the Pentacam, Pentacam$_{thinnest}$ = thinnest corneal thickness measured by the Pentacam, SD = standard deviation, S_w = within-subject standard deviation, Precision = 1.96 x S_w, CV_w = within-subject coefficient of variation, ICC = intraclass correlation coefficient, CI = confidence interval, LoA = limits of agreement according to Bland-Altman method.

Table 3. Paired t test, Correlation Values and Limits of Agreement (LoA) among 3 different Devices.

Device Pairings	Mean Difference (µm) ± SD	95% LoA (µm)	P Value		
Pentacam$_{center}$ – USP	6.11 ± 8.84	-11.2 to 23.4	< 0.001		
Pentacam$_{center}$ – RTvue	15.28 ± 5.43	4.6 to 25.9	< 0.001		
Pentacam$_{apex}$ – USP	2.30 ± 8.56	-14.5 to 19.1	0.217		
Pentacam$_{apex}$ – RTvue	11.47 ± 5.12	1.4 to 21.5	< 0.001		
Pentacam$_{thinnest}$ – USP	1.35 ± 8.62	-15.5 to 18.2	0.864		
Pentacam$_{thinnest}$ – RTvue	10.52 ± 5.28	0.2 to 20.9	< 0.001		
RTvue – USP	-9.17 ± 8.28	-25.4 to 7.1	< 0.001		

Pentacam$_{center}$ = central corneal thickness measured by the Pentacam, Pentacam$_{apex}$ = apical corneal thickness measured by the Pentacam, Pentacam$_{thinnest}$ = thinnest corneal thickness measured by the Pentacam, USP = Ultrasound pachymetry, SD = Standard deviation.

* 2 tailed.

Table 4.Summary of Previous Studies for the Repeatability and Reproducibility of Central Corneal Thickness Measurements by Pentacam Rotating Scheimpflug Photography.

First Author	Study Population	Eyes (Patients) (n)	Repeatability		Reproducibility	
			ICC (95% CI)	95% LoA (µm)	ICC (95% CI)	95% LoA (µm)
de Sanctis	Normal	20 (20)	0.99 (0.98 to 0.99)	-12.5 to 12.5	0.98 (0.97 to 0.99)	-17.8 to 12.6
Lackner *	Normal	24 (24)	†	†	†	-10.2 to 11.9
O'Donnell**	Normal	21 (21)	†	†	†	-24.1 to +21.1[a]
Miranda **	Normal	23 (23)	†	†	†	-10.91 to 13.00[b]
Miranda **	Normal	23 (23)	†	†	†	-13.43 to 11.23[c]
Miranda **	Normal	23 (23)	†	†	†	-11.99 to 10.02[d]
Ucakhan	Normal	45 (45)	0.994 (0.991 to 0.997)	†	†	-10.91 to 13.00
Shankar	Normal	67(67)	†	†	†	-15.29 to 13.07[e]
Shankar	Normal	67(67)	†	†	†	-15.10 to 13.02[f]
de Sanctis *	Keratoconus	33 (33)	0.98 (0.95 to 0.99)	-14.5 to 14.2	0.98 (0.96 to 0.99)	-14.8 to 13.8
Ucakhan	Mild Keratoconus	19 (19)	0.988 (0.981 to 0.992)	†	†	†
Ucakhan	Moderate Keratoconus	28 (28)	0.998 (0.978 to 0.994)	†	†	†
Ucakhan	Severe Keratoconus	15 (15)	0.982 (0.945 to 0.996)	†	†	†
de Sanctis *	Corneal Grafts	20 (20)	0.96 (0.92 to 0.99)	-12.8 to 22.2	0.95 (0.91 to 0.99)	-18.2 to 21.8

ICC = intraclass correlation coefficient, CI = confidence interval, LoA = limits of agreement according to Bland-Altman method.

* Represents that the measurements between two examiners, ** Represents that the measurements between two session.

† Represents that the information was not provided within the article.

[a] Represents the repeatability measurements 48 hours later, [b] Represents the repeatability measurements within a few seconds, [c] Represents the repeatability measurements 1 hour later, [d] Represents the repeatability measurements 1 week later, [e] Represents pupil centre, [f] Represents corneal apex.

Table 5. Findings of Studies Comparing Ultrasound Pachymetry (UP) and Pentacam Rotating Scheimpflug Photography in Eyes That Have Undergone Laser In Situ Keratomileusis (LASIK) or Photorefractive Keratectomy (PRK).

First Author	Study Population	Eyes (Patients) (n)	Mean CCT (µm) ± SD		Mean Difference (µm)		Pearson Correlation
			UP	Pentacam	±SD	95% LOA	Coefficient
Ciolino	Post LASIK	104 (53)	506 ± 22	505 ± 32	-1.4 ± 10	-20 to 20	0.945
Ho	Post LASIK	103 (52)	430.66 ± 40.23	438.2 ± 41.18	-7.54 ± 15.06	-37.06 to 21.98	0.932
Hashemi*	Post LASIK	60 (30)	468 ± 48	478 ± 51	-9 ± 15	-39 to 19	†
Kim(1 to 3 months)	Post PRK	24 (15)	476 ± 46.4	468 ± 39.9	+7.54 ± 12.2	-16.4 to 31.4	0.980
Kim(> 4 months)	Post PRK	21 (14)	494 ± 33.1	481 ± 33.1	+12.6 ± 10.1	-7.2 to 32.4	0.954

CCT = central corneal thickness, SD = standard deviation; LoA = limits of agreement according to Bland-Altman method.

* Represents that the surgical procedure for myopic correction was LASIK in 38 eyes, PRK in 14 eyes, and PRK plus mitomycin-C in 8 eyes.

† Represents that the information was not provided within the article.