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1 **Title: The effects of ocular magnification on Spectralis spectral domain**
2 **optical coherence tomography scan length**

3

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21

22 **Abstract (180 words)**

23 **Purpose:** To assess the effects of incorporating individual ocular biometry
24 measures of corneal curvature, refractive error and axial length on scan
25 length obtained using Spectralis spectral domain optical coherence
26 tomography (SD-OCT).

27 **Methods:** Two SD-OCT scans were acquired for 50 eyes of 50 healthy
28 participants, first using the Spectralis default keratometry (K) setting, then
29 incorporating individual mean-K values. Resulting scan lengths were
30 compared to predicted scan lengths produced by image simulation software
31 based on individual ocular biometry measures including axial length.

32 **Results:** Axial length varied from 21.41 to 29.04mm. Spectralis SD-OCT scan
33 lengths obtained with default-K ranged from 5.7 to 7.3mm and with mean-K
34 5.6 to 7.6mm. We report a stronger correlation of simulated scan lengths
35 incorporating the subject's mean-K value ($\rho = 0.926$, $P < 0.0005$) compared to
36 Spectralis default settings ($\rho = 0.663$, $P < 0.0005$).

37 **Conclusions:** Ocular magnification appears to be better accounted for when
38 individual mean-K values are incorporated into Spectralis SD-OCT scan
39 acquisition compared to using the device's default-K setting. This must be
40 considered when taking area measurements and lateral measurements
41 parallel to the retinal surface.

42

43 **Key Words:** Optical Coherence Tomography; axial length; scan length;
44 Spectralis; keratometry.

45

46 **Introduction**

47 Optical Coherence Tomography (OCT) allows a direct cross-sectional
48 view of the human retina [1] correlating well with retinal histology [2]. SD-OCT
49 provides increased acquisition speed and higher image resolution compared
50 to older time-domain OCT techniques [3,4]. OCT technology is increasingly
51 employed in the clinical diagnosis of ocular pathology such as age-related
52 macular degeneration [5], macular holes [6], vitreo-macular traction [7], and
53 glaucoma [8]. Quantitative evaluation of retinal thickness using both automatic
54 and manual measuring techniques is used to aid clinical diagnosis and design
55 treatment protocols [9-11]. It is known that segmentation algorithms employed
56 by individual OCT instruments result in variability in retinal thickness
57 measurement complicating comparison across different platforms [12,13]. In
58 addition, ocular magnification of retinal images is affected by refractive error,
59 corneal curvature, refractive index, axial length and anterior chamber depth
60 [14,15]. The distance of the eye to the measuring device can also influence
61 the magnification effect [16]. In the case of OCT scan images, ocular
62 magnification may affect lateral measurements i.e. those made parallel to the
63 retinal plane [17]. The optical set-up of the OCT instrument as well as the
64 software program for calculating image size will govern image size calculation
65 in computerized fundus imaging [18]. If lateral measurements such as drusen
66 diameter, geographical atrophy area in dry age-related macular degeneration
67 or foveal width measurements for example are to be used for establishing
68 diagnosis and treatment protocols, the potential impact of ocular magnification
69 on lateral measurements must be considered.

70 An inverse correlation between retinal nerve fibre layer thickness, optic
71 nerve head parameters and axial length has been reported [19-22]. However,
72 these correlations became negligible when corrections accounting for axial
73 length were applied to the measured values [19,22,23]. This suggests that
74 axial length should be taken into account when assessing the reliability of
75 OCT data [24]. However, not all OCT platforms account for axial length
76 induced ocular magnification, and various attempts have been made to
77 correct for the magnification of an individual nominal scan length produced by
78 the OCT instrument [22]. In a study by Wagner-Schuman et al., a ratio of the
79 individual's axial length to that assumed by the instrument was applied to
80 lateral measurements [25]. Others have addressed the issue of lateral scaling
81 by applying a correction based on the SD-OCT instrument manufacturer's
82 formula using modified Littman's method [14], which incorporates individual
83 refractive error, corneal radius and axial length [22,26]. An alternative
84 approach used in studies of retinal morphology has been to exclude subjects
85 with refractive error greater than ± 5.00 or ± 6.00 DS to minimize potential
86 errors [27,28]. In contrast to these other SD-OCT platforms, the Spectralis
87 (Heidelberg Engineering, Heidelberg, Germany) applies an automatic
88 modification process to cancel out the effect of ocular magnification,
89 generating individual scan lengths based on three parameters. It assumes a
90 non-modifiable pre-set axial length of 24.385mm based on the Gullstrand
91 schematic eye [29] (personal communication with Heidelberg Engineering,
92 Germany; July 2013). Secondly, by allowing the operator to focus the retinal
93 image, the subject's refractive error is taken into account. Thirdly, a default
94 corneal curvature i.e. keratometry (K) setting of 7.70mm equal to the K-value

95 of Gullstrand's model eye [29] is assumed by the device, as described in its
96 technical specifications. Alternatively, an option to use the subject's actual
97 mean-K is provided. The present study was carried out to investigate the
98 effect of individual mean spherical error (MSE), mean-K and axial length on B-
99 scan length obtained using the Spectralis SD-OCT.

100

101 **Methods**

102 *Study protocol*

103 The study was conducted from October to December 2013 at the
104 Division of Optometry and Visual Science, City University London. A total of
105 50 volunteers took part; all presented Log MAR visual acuity better than 0.3
106 log units in the eye being tested. Exclusion criteria were: ocular pathology,
107 medication that may affect retinal function and previous laser eye surgery. By
108 default, measurements were taken for the right eye unless it did not meet the
109 inclusion criteria, in which case the left eye was used. Each participant had
110 measures of MSE (based on an average of five autorefractor readings) and
111 mean-K (average of three horizontal and vertical K readings) taken with the
112 Auto Kerato-Refracto-Tonometer TRK-1P instrument (Topcon, Tokyo, Japan).

113 The Spectralis SD-OCT was used to scan the undilated test eye of
114 each participant in a dark room [30,31]. Two high resolution 20° x 10° volume
115 scans (97 B-scans 30 microns apart, ART 16 frames including 1024 A scans)
116 were acquired for each participant. The first scan was obtained using the
117 default corneal curvature setting of 7.70mm; while the second had the
118 subject's mean-K entered into the software prior to scan acquisition. The
119 participant was instructed to look at the central fixation target while the

120 infrared fundus image was focused with a dial corresponding to their MSE.
121 During scan acquisition, the investigator independently monitored the
122 participant's fixation via the live fundus image. All scans had a minimum
123 quality level of 25 decibels, as recommended by the manufacturer guidelines.
124 The resulting "default-K" and "mean-K" scan length was recorded from the
125 Spectralis mapping software, Heidelberg Eye Explorer (Version 1.7.0.0 ©
126 2011). Axial length was measured using the IOLMaster (Carl Zeiss Meditec,
127 Dublin, CA, USA). This is a well-known non-contact device based on partial
128 coherence interferometry shown to have good axial length measurement
129 repeatability [32,33]. Zemax optical design software (Zemax, LLC, Redmond,
130 WA, USA) was used for simulation of an image from a 20° SD-OCT
131 incorporating individual subject's MSE, mean-K and axial length data. The
132 Gullstrand's exact model eye [29] was applied to the simulation since
133 Spectralis software image size calculations are based on this model. Within
134 the Zemax model, mean-K values and axial length were modified for each
135 subject by changing the radius of curvature of the anterior corneal surface and
136 the axial distance between posterior lens surface and retinal plane
137 respectively. MSE was modelled as a paraxial lens immediately before the
138 model eye. An object with a field of 10° (with respect to the optical axis,
139 resulting in 20° overall field) was set and the size of the image at the retinal
140 plane calculated by the software was used to represent the simulated scan
141 length. This was compared to the default-K and mean-K scan lengths.

142

143 *Ethical approval and consent*

144 The study was approved by Optometry Research & Ethics Committee
145 City University London. Written informed consent was obtained from all
146 subjects conforming to the tenets of the Declaration of Helsinki.

147

148 *Statistical analysis*

149 All statistical analyses were performed using SPSS version 21.0 for
150 Windows (SPSS Inc., Chicago, USA). Values in the text and tables are
151 presented as the mean \pm standard deviation (SD). Preliminary analyses were
152 performed to ensure no violation of the assumptions of normality, linearity and
153 homoscedasticity. Since Kolmogorov-Smirnov test revealed a significant
154 deviation from a normal distribution for scan length and MSE, Spearman's
155 Rank Correlation Coefficient ρ was calculated to explore the correlation
156 between default-K and mean-K with simulated scan lengths. Statistical
157 significance was accepted at $P < 0.05$.

158

159 **Results**

160 A total of 22 males and 28 females were included in the study. The
161 mean age was 21 ± 2.9 years. Mean, minimum and maximum values of
162 mean-K, MSE, axial length, and scan lengths are summarised in Table 1.

163 *[insert Table 1 approximately here]*

164 A Wilcoxon Signed Rank Test revealed a statistically significant difference in
165 scan lengths obtained using default-K, mean-K and from simulations (Figure
166 1). There was a significant correlation between mean-K ($\rho = 0.926$, $P <$
167 0.0005) and default-K scan length with the simulated scan length ($\rho = 0.663$,
168 $P < 0.0005$), shown in Figure 2. We explored the effect of axial length and

169 MSE on these relationships and found that the correlation between mean-K
170 and simulated scan length remained strong and significant when controlling
171 for axial length ($\rho = 0.822$, $P < 0.0005$) and for MSE ($\rho = 0.875$, $P < 0.0005$).
172 The correlation was weakened for default-K measurements when controlling
173 for axial length ($\rho = 0.473$, $P < 0.001$) and became non-significant when
174 controlling for MSE ($\rho = 0.221$, $P = 0.128$).

175 *[insert Figure 1 and Figure 2 approximately here]*

176

177 **Discussion**

178 The Spectralis SD-OCT generates individual scan lengths based on
179 refractive error, corneal curvature and a non-modifiable pre-set axial length of
180 24.385mm according to the Gullstrand schematic eye. We explored the
181 correlation of Spectralis SD-OCT scan length acquired using the instrument's
182 default-K setting of 7.70mm versus using the subject's mean-K, when
183 compared to Zemax software simulated scan length. The aim was to ascertain
184 whether the effect of ocular magnification on SD-OCT scan length was
185 represented more accurately using an individual's mean-K value as opposed
186 to the Spectralis default-K setting in comparison to simulated output based on
187 Gullstrand exact eye model [20]. We included individuals with axial length of
188 21.41mm to 29.04mm resulting in mean-K scan lengths ranging from 5.6 to
189 7.7mm (Figure 1). Whilst direct comparisons cannot be drawn from other
190 studies with different subject demographics, individual scan lengths ranging
191 from 5.3 to 7.0mm have been reported whereby the nominal 6mm scan was
192 corrected using each subject's axial length (varying from 21.56 to 28.36mm)

193 based on the Cirrus eye model [20]. Of note, the most accurate model eye to
194 calculate ocular magnification has yet to be determined [18], although
195 differences between modified Littman's technique [14] and the Gullstrand eye
196 model are less than 2% for axial lengths from 22 to 26.5mm [34].

197 While there was significant correlation of mean-K ($\rho = 0.926$, $P <$
198 0.0005) and default-K scan length with the simulated scan length ($\rho = 0.663$,
199 $P < 0.0005$), the correlation was much stronger for mean-K scan length. The
200 within-subject SD of K measurements have been shown to range from
201 0.05mm to 0.18mm depending on the instrument used [35]. According to the
202 Spectralis technical guidelines, a 0.1mm error in K will result in an error in
203 lateral measurement of 0.8%. This translates to a 0.1mm change in scan
204 length for every 0.2mm deviation from the individual's mean-K. The TRK-1P
205 gives repeated measurements within $\pm 0.12DS$ on test eyes (personal
206 communication with Topcon; June 2014) that may explain the lack of perfect
207 agreement between the mean-K and simulated scan lengths in the current
208 study. Another consideration is that subjective refraction was not carried out
209 to estimate MSE. However, it has been shown that using an autorefractor is
210 an accepted method to approximate refractive error [36]. Nonetheless,
211 accuracy of ocular biometry measurements is potentially a limitation of the
212 study. We incorporated individual's mean-K and MSE values into Spectralis
213 scan acquisition as well as the Zemax simulation. Any error in these values
214 would therefore have the same effect on both occasions. We postulate that
215 the discrepancy from perfect correlation is more likely to be caused by some
216 other assumption built into the OCT software. Furthermore, Tan et al.
217 explored the effect of different lens powers and varying eye-scanner distance

218 on image magnification while maintaining a constant axial length [37]. This
219 was repeated keeping a constant lens power while varying eye-scanner and
220 axial length. The results showed that even with accurate axial length
221 measurement, in eyes not complying with standard assumptions (for example
222 cataract) or in eyes that over-accommodate during imaging, the magnification
223 is still not sufficiently corrected. In addition, there was no option to include
224 separate horizontal and vertical K values in the Spectralis software. The
225 mean-K value underestimates or overestimates the horizontal K value
226 depending on whether the individual has with- or against-the-rule astigmatism.
227 The latter may explain the lack of perfect agreement between the mean-K and
228 simulated scan lengths in the current study. However, as the mean-K value
229 has to be inserted prior to scan acquisition and cannot be changed
230 retrospectively, using mean-K allows subsequent analyses of vertical frames
231 or measurements of area.

232 There was a strong and significant correlation between scans taken
233 with mean-K and the simulated scan length when controlling for the effect of
234 MSE ($\rho = 0.875$, $P < 0.0005$) and axial length ($\rho = 0.822$, $P < 0.0005$). This
235 was not the case for scans taken using the default setting of $K = 7.70\text{mm}$. A
236 recent study aimed to address the issue of the influence of axial length on
237 OCT data acquired from Spectralis SD-OCT scans [38]. The study involved a
238 novel method of measuring the known distance of a sub-retinal visual implant
239 *in vivo*. The results confirmed the accuracy of lateral measurements taken
240 from Spectralis SD-OCT measurements of emmetropic medium (22.51 to
241 25.5mm) length eyes. The authors did recommend that caution should be
242 exercised when comparing measurements obtained from very short (<

243 22.5mm) or very long (> 25.51mm) eyes. Contrary to this, when the data was
244 examined in the current study, the largest deviation of either mean- or default-
245 K scan length from the simulated scan length did not belong to those with the
246 higher MSE or those with axial length that deviated most from the Gullstrand
247 exact eye model value of 24.385mm (Figure 2). Moreover, optic nerve head
248 area measurement from Spectralis SD-OCT scans has been found to be
249 independent of axial length when transverse scaling is applied using
250 measures of ocular biometry including K and axial length [39]. It therefore
251 does not seem to be necessary to measure axial length to minimise potential
252 lateral measurement errors resulting from not correcting for ocular
253 magnification [20].

254 The simulated scan length consistently overestimated the mean-K and
255 default-K scan length output. Nonetheless, we observed a stronger correlation
256 between scan length obtained with mean-K compared to default-K. Scan
257 lengths above 5.9mm produced by the default-K setting were increasingly
258 under-estimated compared to those obtained with mean-K (Figure 2). This
259 implies that lateral measurements of drusen size and foveal width for example
260 are likely to be underestimated if SD-OCT scans larger than 5.9mm are
261 obtained with the default-K setting. We recommend incorporating the
262 individual's mean-K and MSE during lateral retinal measurements when using
263 the Spectralis SD-OCT. In addition, it is important to consistently use the
264 individual's mean-K value for subsequent scans of the same patient for long-
265 term monitoring in a clinical setting, for example measuring progression of
266 non-exudative pigment epithelial atrophy.

267

268 **CONCLUSION**

269 **This study provides useful information on the effect of ocular biometry**
270 **measures on Spectralis SD-OCT scan length. The effect of ocular**
271 **magnification on scan length appears to be better accounted for when**
272 **an individual's mean corneal curvature value is incorporated into**
273 **Spectralis SD-OCT scan acquisition as opposed to using the device's**
274 **default setting. We recommend performing scan acquisition**
275 **incorporating a measured mean keratometry value, with the fundus**
276 **image focussed according to the individual's refractive error. This**
277 **should be considered when taking area measurements and lateral**
278 **measurements parallel to the retinal surface. These results may be of**
279 **interest for clinical trials using SD-OCT for area or lateral**
280 **measurements.**

281

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284

285 **Conflict of Interest Statement**

286 All authors certify that they have NO affiliations with or involvement in any
287 organization or entity with any financial interest (such as honoraria;
288 educational grants; participation in speakers' bureaus; membership,
289 employment, consultancies, stock ownership, or other equity interest; and
290 expert testimony or patent-licensing arrangements), or non-financial interest

291 (such as personal or professional relationships, affiliations, knowledge or
292 beliefs) in the subject matter or materials discussed in this manuscript.

293

294 **Legends**

295 **Table 1** Summary of variations in mean keratometry, axial length and mean
296 spherical error within the study sample

297

298 **Figure 1** Box and whisker plot to show scan lengths obtained from SD-OCT
299 scans obtained with default-K settings; mean-K values; and from software
300 simulations incorporating axial length values. The length of each box is the
301 interquartile range and the band inside the box represents the median. The
302 whiskers show the smallest and largest values, with outliers indicated by the
303 circles and extreme outliers by the asterisks. The mean and median scan
304 length for scans using the default-K was $6.04 \pm 0.28\text{mm}$, $Md = 5.95\text{mm}$; for
305 the mean-K group $6.10 \pm 0.33\text{mm}$, $Md = 6.00$; and for the simulated-K group
306 was $6.23 \pm 0.38\text{mm}$, $Md = 6.21\text{mm}$

307

308 **Figure 2** Scatterplot of mean-K (black squares) and default-K (grey triangles)
309 scan lengths against Zemax simulated scan length (x-axis). There is a
310 statistically significant correlation of mean-K ($\rho = 0.926$, $P < 0.0005$) and
311 default-K ($\rho = 0.663$, $P < 0.0005$) with the simulated scan length. Dashed grey
312 line represents perfect agreement, $r = 1.00$

313

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