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1 Introduction

2 The increasing incidence of myopia across the globe [1], and in East Asia in particular [2-5],
3 has caused great interest in the optometric community, not least because of the emergence
4 of treatment options such as soft dual-focus design contact lenses [6,7], orthokeratology
5 contact lenses [8-11] and pharmaceutical agents [12].
6

7 Whilst myopia can certainly be a general inconvenience, requiring the use of refractive
8 correction usually in the form of spectacles and contact lenses, the main focus of recent
9 concern is the pathological consequence of an eye which is fundamentally too long for its
10 refractive capability, with higher levels of retinopathy [13], retinal detachment [14], glaucoma
11 [15] and cataract [16] seen in myopic eyes.
12

13 In optometric circles, the degree of myopia is typically described in refractive error
14 terminology. This is entirely logical when the primary consideration is vision correction and
15 refraction. Myopes are described in terms of the lens power required to correct refractive
16 error and indeed, refractive error is described as being associated with myopic pathology
17 [17]; however, when the key clinical consideration is the pathological consequences of
18 increased eye size (rather than refractive concerns), it seems more appropriate to describe
19 ocular dimensions than refractive error.
20

21 Various dimensional terms are potentially available (e.g. global volume) for such a
22 description but the most commonly used, primarily due to its relatively straightforward
23 measurement, is *axial length*. Related to this, Cheng, Brennan and co-workers have recently
24 argued that the impact of any form of myopia management is best described as its effect on
25 eye growth rather than the slowing of refractive error change [18].
26

27 Of course, there is a close relationship between refractive error and axial length but an
28 inspection of myopia-related pathology suggests axial length is the more important factor. In
29 an assessment of over 9,000 patients, Tideman et al. included both axial length and
30 refractive error in a statistical model exploring the likelihood of visual impairment [19] and
31 reported that axial length demonstrated a significant relationship with visual impairment but
32 refractive error did not.
33

34 Traditionally, ocular axial length was assessed using A-scan ultrasound methods but over
35 the past 20 years, more sophisticated, non-contact, rapid instrumentation has become
36 available. Such devices include the IOLMaster (v3, v5 and 500) (Carl Zeiss) and the newer
37 IOLMaster 700 (Carl Zeiss) which employ partial coherence interferometry for biometric
38 estimates, the Lenstar LS 900 (Haag-Streit) which employs low coherence reflectometry [20]
39 and the Aladdin (Topcon) [20] which utilises a similar approach [21]. Such devices were
40 initially developed to assist with the selection of intra-ocular lens power for patients
41 presenting for cataract surgery. They are relatively expensive, typically costing around
42 £20,000 to £40,000. Such a cost is justifiable in a surgical setting or in a research centre
43 working on myopia treatment, but for optometrists and opticians interested in myopia control
44 (especially in the early stages of this new form of refractive management) such devices have
45 very limited use for other types of patients and as such, the cost is likely to be prohibitive.
46 Anecdotal reports suggest that there are fewer than 20 infrared biometers in optometric
47 practices in the United Kingdom.
48

49 An alternative approach is to explore the potential of estimating axial length from refractive
50 error alone or from a combination of refractive error and corneal curvature. To a first order of
51 approximation, it seems reasonable to suppose that these three optometric measures should
52 be associated and as refractive error estimation and corneal shape measurements are
53 fundamental competencies of all optometrists, such analysis harbours the potential for a
54 simple and inexpensive route to axial length measurement as an aid for eyecare practitioners
55 wishing to consider myopia management in children.

56

57 **Methods**

58

59 **Generation of relationship**

60 Data from a multi-centre study of novel dual focus soft, daily disposable contact lenses were
61 used to generate the best fit relationship between axial length versus refractive error and
62 corneal curvature. This study has recently been reported in detail [7] but in brief, 144
63 subjects aged 8-12 years were examined annually for 36 months, having been fitted after a
64 baseline assessment with a dual focus contact lens (Misight(R) 1 day, CooperVision, Inc) or
65 a conventional design, spherical lens (Proclear(R) 1 day, CooperVision, Inc). Topography
66 and axial length measures were evaluated at each visit with an IOL Master 500 (Carl Zeiss,
67 Oberkochen, Germany) and cycloplegic and non-cycloplegic refractive errors were
68 determined with a WR-5100K or WAM-5500 autorefractor device (Grand Seiko Co.,
69 Hiroshima, Japan).

70

71 Using data for all visits over three years of the study, a linear mixed model was
72 constructed to evaluate the potential for calculating the reciprocal of axial length from the
73 reciprocal of mean anterior corneal radius of curvature and spherical equivalent refractive
74 error at the corneal plane. Also included in the model were 'eye', nested within 'subject',
75 which was treated as a random effect. The performance of using the regression model to
76 calculate axial length in comparison to the measured biometer values (i.e. calculated axial
77 length vs. measured axial length) was assessed by constructing Bland-Altman charts and by
78 determining the 95% limits of agreement [22].

79

80 **Assessment with a separate dataset**

81 To evaluate the efficacy of the determined relationship, a comparison between measured
82 and calculated axial length values was performed on a separate dataset. Here, values were
83 used from the Northern Ireland Childhood Errors of Refraction (NICER) study of Saunders
84 and colleagues [23-25]. Data were available for 1,046 young people (age six to 22 years,
85 99% of whom were white) on whom auto-refraction (SRW-5000 or NVision-K 5001, Shin-
86 Nippon, Tokyo, Japan), anterior cornea radius of curvature and axial length determination
87 (IOL Master v3 Carl Zeiss, Oberkochen, Germany) were assessed. Again, a Bland-Altman
88 assessment was conducted to calculate the 95% limits of agreement.

89

90 **Results**

91 Using cycloplegic refraction data from the Chamberlain et al. study [7], the model found the
92 following predictive relationship:

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$$94 \quad \frac{1}{A} = \frac{0.22273}{k} + 0.00070S + 0.01368$$

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Where A = axial length (mm), k = mean anterior corneal radius of curvature (mm) and S = spherical equivalent refractive error at the corneal plane (D). Here, both $\frac{1}{k}$ (F = 1636, p < 0.0001) and S (F = 1334, p < 0.0001) were significant factors, with $r^2 = 0.83$. Reorganisation of this equation to calculate axial length gives:

$$A = \frac{1}{\frac{0.2273}{k} + 0.00070S + 0.01368}$$

Figure 1 shows the Bland Altman chart for the relationship between measured and calculated axial length. The 95% limits of agreement for the two measures are ± 0.73 mm ($\pm 3.0\%$ of the mean axial length measurement).

When this exercise ~~is was~~ repeated for non-cycloplegic measures, the 95% confidence limits ~~are were~~ ± 0.75 mm ($\pm 3.0\%$). These limits of agreement were larger if only the refractive error was included in the model and corneal radius of curvature was ignored (± 1.26 mm [$\pm 5.1\%$] and $r^2 = 0.57$ for both cycloplegic and non-cycloplegic measures).

When this formula was employed for the NICER database, there was a small offset error between the two methods, with values 0.13mm longer on average with the calculated values than those measured (Figure 2). The 95% limits of agreement were -0.73 to +0.99mm (an average of $\pm 3.7\%$).

Discussion

Using refraction and keratometry data from the analysed dataset was able to provide reasonable predictive capability for determining absolute axial length. Incorporation of keratometry measures into the calculation offers much better agreement than refraction alone. Interestingly, similar findings were observed whether the refraction data were collected via a cycloplegic or non-cycloplegic refraction.

The limits of agreement of around ± 0.73 mm or $\pm 3\%$ are small in absolute terms and allows for a good estimate of axial length. For example, Tideman et al. outlined the risk of visual impairment for five sub-groups of axial length: less than 24mm, 24-26mm, 26-28mm, 28-30mm and greater than 30mm [19]. The derived formula can readily assign patients to these 'risk groups' and assist practitioners in deciding whether some form of myopia management is warranted.

The predictive formula performed similarly with the data from the NICER study, with a modest offset error and 95% confidence limits of $\pm 3.7\%$. This result is perhaps surprisingly good given the different instrumentation and protocols employed across the two studies. It would certainly be possible to modify this relationship for different clinical scenarios (e.g. different age ranges) and equipment - and certainly further work is required to understand this better - but this first overview suggests that the formula may be resilient to diverse clinical situations.

139 It is important to note that whilst the predictive capability of this formula seems reasonable for
140 absolute measures of axial length, it is unlikely to be helpful in tracking changes in axial
141 length over time or with different treatment modalities. A 3% change in axial length (the 95%
142 confidence limits of the formula) is towards the upper end of the magnitude of change seen
143 in the dual focus lens study of Chamberlain *et al.* [7] over a three year period. As such, the
144 predictions provided by the formula are too 'noisy' to be employed for precise tracking of
145 myopic changes over time. In contrast, commercial biometers offer inter-observer or intra-
146 observer repeatability (95% confidence limits) of $\pm 0.06\text{mm}$ ($\sim 0.25\%$) or better, [26,27],
147 indicative of a precise capability for tracking axial length change.

148

149 **Conclusion**

150 This work indicates that considering corneal curvature readings alongside refractive error
151 measurement offers a good estimate of absolute axial length, and this estimate becomes
152 less accurate if refractive error alone is used as a sole proxy for axial length. The formula
153 developed provides extra clinical information to optometrists and opticians in the community
154 [\(particularly those without access to dedicated biometry instrumentation\)](#) considering myopia
155 management options for their patients and can be used in conjunction with published axial
156 length risk parameters. However, practitioners wishing to precisely monitor change in axial
157 length should utilise a commercial biometric device.

158

159 **Acknowledgement**

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164 **References**

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243 **Figure legends**

244

245 Figure 1: Bland-Altman chart showing the relationship between the difference in axial length
246 (measured - calculated) versus mean axial length for the dataset of Chamberlain et al. [7]

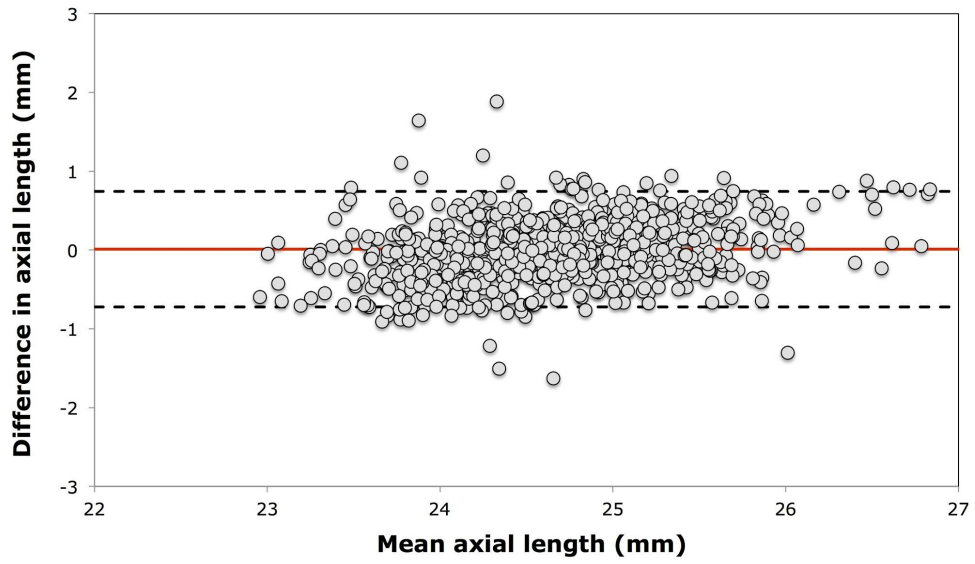
247 The red line indicates the mean difference between the two methods and the dotted lines
248 show the 95% limits of agreement as described by Bland and Altman (1986). [22]

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250 Figure 2: Bland-Altman chart showing the relationship between the difference in axial length
251 (measured - calculated) versus mean axial length for the NICER dataset [23] The red line

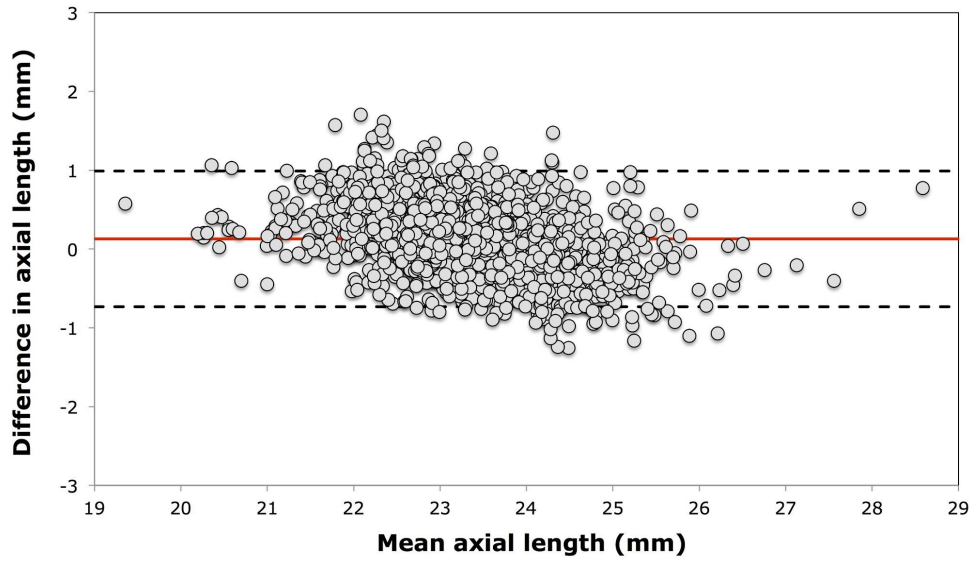
252 indicates the mean difference between the two methods and the dotted lines show the 95%
253 limits of agreement as described by Bland and Altman (1986). [22]

254 Figure 1.
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259 Figure 2.



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Short communication

Estimation of ocular axial length from conventional optometric measures

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Key words

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