Estimation of ocular axial length from conventional optometric measures

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Introduction

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

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

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

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

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

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

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

Methods

Generation of relationship

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

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

Assessment with a separate dataset

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

Results

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

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

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 ±0.73mm (±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 (±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 (±1.26mm [±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 ± 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 ±0.73mm or ±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 ±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.

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

Conclusion

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

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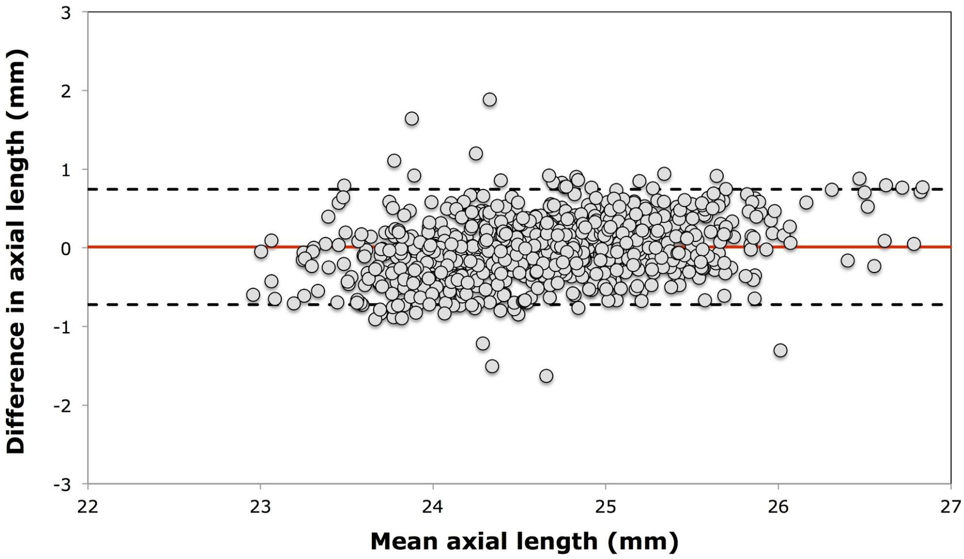
Figure legends

Figure 1: Bland-Altman chart showing the relationship between the difference in axial length (measured - calculated) versus mean axial length for the dataset of Chamberlain et al. [7] The red line indicates the mean difference between the two methods and the dotted lines show the 95% limits of agreement as described by Bland and Altman (1986). [22]

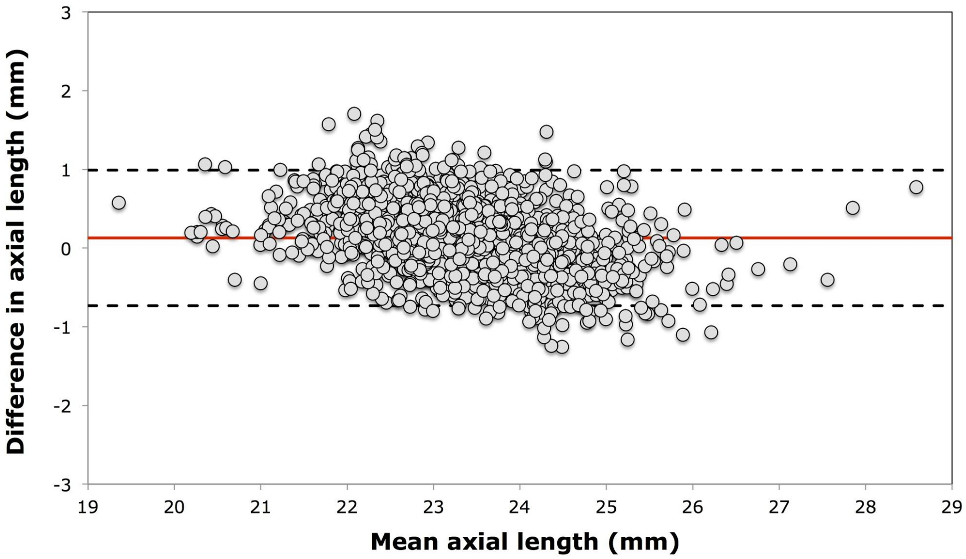
Figure 2: Bland-Altman chart showing the relationship between the difference in axial length (measured - calculated) versus mean axial length for the NICER dataset [23] The red line indicates the mean difference between the two methods and the dotted lines show the 95% limits of agreement as described by Bland and Altman (1986). [22]

Figure 1.



Difference in axial length (mm)
3
2
1
0
-1
-2
-3
22
23
24
25
26
27
Mean axial length (mm)

Figure 2.



Difference in axial length (mm)
Mean axial length (mm)
3
2
1
0
-1
-2
-3
19
20
21
22
23
24
25
26
27
28
29

Short communication

Estimation of ocular axial length from conventional optometric measures

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Key words
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