Experimental Eye Research 102 (2012) 70–75

Contents lists available at SciVerse ScienceDirect

Experimental Eye Research

journal homepage: www.elsevier.com/locate/yexer

Human ocular biometry☆

Robert C. Augusteyn [a,b,c,*], Derek Nankivil [c], Ashik Mohamed [a,b,d], Bianca Maceo [c,e], Faradia Pierre [c], Jean-Marie Parel [a,c,e]

[a] Vision Cooperative Research Centre, Brien Holden Vision Institute, Sydney, Australia
[b] School of Optometry and Vision Science, University of NSW, Sydney, Australia
[c] Ophthalmic Biophysics Center, Bascom Palmer Eye Institute, University of Miami Miller School of Medicine, Miami, FL 33136, USA
[d] Prof. Brien Holden Eye Research Centre, L V Prasad Eye Institute, Hyderabad, India
[e] Biomedical Optics and Laser Laboratory, Department of Biomedical Engineering, University of Miami College of Engineering, Coral Gables, FL 33146, USA

ARTICLE INFO

Article history:
Received 7 April 2012
Accepted in revised form 28 June 2012
Available online 20 July 2012

Keywords:
human
ocular growth
corneal dimensions
globe dimensions
gender

ABSTRACT

The aim of this study was to examine growth of the human eye globe and cornea from early in gestation to late in adult life. Globe antero-posterior length, horizontal and vertical diameters, corneal horizontal and vertical (white to white) diameters and posterior pole to limbus distances were measured using digital calipers (±0.01 mm) in 541 postmortem eyes. Additional pre- and postnatal data for some of the dimensions were obtained from the literature. All dimensions examined increase rapidly during prenatal development but postnatal growth differs. Growth of globe antero-posterior length, vertical and horizontal diameters as well as corneal vertical and horizontal diameters stops within 1 year after birth. Logistic analysis is consistent with an asymptotic prenatal growth mode and no further growth after its completion around 1 year after birth. Horizontal and vertical globe diameters are the same at all ages but the corneal horizontal diameter is always larger than the vertical diameter. No differences could be detected between males and females in any of the ocular dimensions. Globe and corneal growth take place primarily during the prenatal growth mode and dimensions reach their maxima, shortly after birth. It is suggested that cessation of a growth stimulating signal at birth marks the end of the prenatal growth mode and that the small increases over the next year are due to cells already stimulated. Male and female eyes of the same age have the same globe and cornea dimensions.

1. Introduction

Detailed knowledge of ocular dimensions (globe, cornea and lens) and how they change with age are of considerable value in understanding ocular growth and the development of pathologies such as myopia and presbyopia. Surgical procedures for improving vision, such as intraocular lens (IOL) implantation and refilling of lens capsular bags (Phaco-Ersatz) (Nishi et al., 1993; Koopmans et al., 2006; Parel et al., 1986) would also benefit from such information.

There have been numerous studies in which some ocular dimensions, such as lens thickness, or axial length were measured. Such measurements have generally been made *in vivo*, with the slit lamp or ultrasound, and have required correction for optical or sonic distortion (e.g. Atchison et al., 2008; Dubbelman et al., 2001). Differences in the corrections and measurement techniques have led to variations in the reported dimensions. Furthermore, many of the previous studies were concerned with specific issues and considered only a limited age group, such as myopia development in young children. Very few considered the relationship between different dimensions such as the cornea, lens and globe. As a result there is a paucity of data, variability in those that are available and some questions regarding extrapolation of limited age data to the whole of the life span.

Measurement of global dimensions and, until recently, lens diameter can only be performed *in vitro*. Many of the measurements of other ocular dimensions would be easier and more accurate if also conducted *in vitro*. However, because of the limited availability of *ex vivo* human tissues, very few data have been obtained on the globe and lens. As part of a long-term study on factors contributing to the development of presbyopia (Augusteyn et al., 2011), we have collected a large body of *in vitro* data on human

☆ A preliminary report on some of the data was presented at the annual meetings of the Association for Research in Vision and Ophthalmology, Fort Lauderdale in May 2010 and 2012.

* Corresponding author. Vision CRC, 30 Melcombe Rd, Ivanhoe, Victoria 3079, Australia. Tel.: +61 3 9499 1838.
E-mail addresses: B.Augusteyn@ier.org.au, raugustn@bigpond.net.au (R.C. Augusteyn).

0014-4835/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.exer.2012.06.009

globe, cornea and lens dimensions. Although the vast majority of these were from adults, data for prenatal and juvenile eyes are available in the literature. The combination has provided us with a comprehensive data set which offers the possibility of exploring various aspects of ocular growth over the whole of the human life span.

2. Methods

Post-mortem human eyes from donors, ranging in age from 1 day to 104 years, were provided by the Florida Lions Eye Bank, Miami, USA and the Ramayamma International Eye Bank, Hyderabad, India. The eyes were obtained and used in compliance with the guidelines of the Declaration of Helsinki for research involving the use of human tissue. The cause and time of death, time to enucleation, donor age and gender were available for most eyes. Following a common protocol described previously (Augusteyn et al., 2011), diseased eyes and eyes with obvious anomalies were excluded, leaving 541 eyes. In a small number of cases, where the donor globe was flaccid, the globe was re-inflated by injecting balanced salt solution (BSS, Alcon Inc, Fort Worth, TX) into the vitreous cavity, via an oblique self-sealing insertion of a 30 ga needle through the posterior sclera, until IOP, assessed by palpitation (Birnbach and Leen, 1998) reached about 20 mmHg. The assessment of tonus and injection of salt solution were performed by an experienced ophthalmic surgeon. Small variations in the final pressure in a fully extended globes would be unlikely to affect the measurements since preliminary tests for a study on scleral buckling, conducted in our laboratory (Nakagawa et al., 2000), had shown that equatorial diameter was unchanged with pressures ranging from 6 to >90 mm.

Measurements of global and corneal (white to white) dimensions were performed, after removing surrounding fat and extraocular muscle stumps, using digital calipers (0.01 mm readout, INOX IP54 Caliper, Micro Precision Calibration Inc., California and 500-195-20, Mitutoyo America Co, Aurora IL) as first described by Nakagawa et al. (2000). Each eye was examined and pairs were not averaged when both eyes from one donor were available. The repeatability of the measurements was tested in a separate study (Taneja M., et al., Invest Ophthalmol Vis Sci. 2012; 53:E-Abstract 4908). The dimensions measured are shown in Fig. 1.

Additional data, predominantly foetal and early childhood, were obtained from the literature for some of the dimensions. Globe dimensions were found in articles by Ehlers (1968), Harayama et al. (1980), Huang (1987) and Lim et al. (1998). Corneal dimensions came from al-Umran and Pandolfi (1992), Denis et al. (1998), Ehlers (1968), Harayama et al. (1980), Huang (1987), Kirwan et al. (2005), Ko et al. (2001), Kwak et al. (1988), Liu (1992), Rufer et al. (2005)

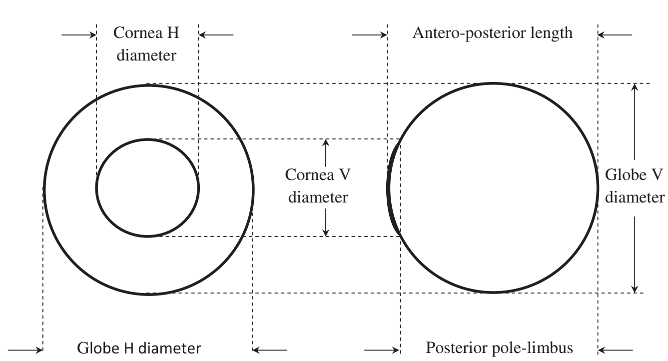

Fig. 1. Diagrammatic representation of the ocular dimensions measured; coronal view on LHS and sagittal view on the RHS. Corneal curvature has been exaggerated in order to better show the measurement positions.

and Savini et al. (2011). With the exception of the Orbscan corneal measurements of Rufer et al. (2005) all published dimensions were obtained with Castroviejo (±0.5 mm), Jameson-type (±0.25 mm) or Vernier (±0.05 mm) calipers.

Plots of data copied from the literature were magnified at least ten-fold and the coordinates for the points were measured to the nearest 0.5 mm, before being converted to the axis units. The maximum error associated with these measurements was estimated to be <1%.

Data were examined using various algorithms commonly in use for analysing growth processes. The logistic equation in its linearized form [log (Dimension) = log (Maximum dimension) − k/Age] was found most suitable, where 'k' is the growth constant. Student's t-statistics were used to compare different biometric parameters and to test for significance of regression coefficients.

3. Results

Postnatal globe and cornea dimensions (Fig. 1) were obtained from 541 eyes in the present study. Up to 200 additional data for some of the parameters of interest, including all of those from prenatal donors, were gleaned from the literature. To simplify presentation and interpretation, the data from eyes younger than 2 years post-conception are displayed differently from those over 2 years from conception.

3.1. Globe

The antero-posterior (AP) lengths and the horizontal (H) diameters of isolated globes, as a function of age since conception, are presented in Fig. 2. The AP lengths and the horizontal diameters all increase rapidly through foetal life and more slowly until about 1 year postnatal (1.74 years since conception), but, thereafter, appear to be constant. Linear regression analysis of the older (>2 years) eye data suggests that the AP length might increase at 0.0019 ± 0.0037 mm/year (p = 0.304) and H at 0.0016 ± 0.0038 mm/year (p = 0.420) while the vertical diameter (V) might decrease at −0.0016 ± 0.0039 mm/year (p = 0.431). However, these rates were statistically not significantly different from zero, leading to the conclusion that none of the globe dimensions change after completion of the asymptotic growth within 1 year of birth (1.74 years post-conception). For all eyes between 2 and 100 years after conception, the means for the horizontal and vertical diameters are 24.26 ± 0.96 mm (n = 518) and 24.16 ± 0.97 mm (n = 510), respectively. The external AP globe length is slightly but significantly greater than the globe diameter (p < 0.027), with a mean of 24.44 ± 1.03 mm (n = 509). There was no significant difference between the horizontal and vertical globe diameters (p > 0.54). Where both measurements were available for the same eye, the ratio of H/V for 507 eyes, older than 2 years, was 1.003 ± 0.032. Each of the adult globe dimensions measured in the present study is around 2.5% greater than previous estimates (Park and Karesh, 2006).

The early growth in globe dimensions can be well described with a logistic function, consistent with asymptotic growth. A linearized logistic plot of the AP lengths (log AP length vs 1/age) is shown in Fig. 3. All of the prenatal data and those from postnatal eyes less than two years after conception fall on a single straight line with a slope of 0.165 years (the growth constant), indicating these are the outcomes of a single growth mode.

Backwards extrapolation of the logistic lines of best fit, such as that in Fig. 3, was used to determine where the young trend lines met the adult trend lines (constant). The intersection points indicated that the above maximum globe dimensions were all reached shortly after 1 year post conception.