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The postnatal growth of the capsule of the human crystalline lens

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INTRODUCTION

The capsule of the human crystalline lens is a delicate membrane surrounding the lens fibres. It is composed of a number of extremely fine layers which form an inner region or capsule proper, while an outer region, termed the zonular lamella, is amorphous in structure (Fig. 1). The capsular thickness is not uniform: an annular zone of increased thickness occurs both in front and behind the lens at the insertion of the zonule (Salzmann, 1912).

Certain factors relating to the dimensions of the capsule have been known for a long time. Tscherning (1904) found that the anterior lens profile was flattened at the periphery during accommodation, a factor which Fincham (1937) attributed to these variations in thickness of the lens capsule. Also Dub (1891) showed that the volume of the lens increases very rapidly in the first decade of life, while Fisher (1969) found that pressure between capsule and lens fibre substance does not increase with age. Thus, in order that the capsule may encompass the rapid increase in volume of the lens fibres which continues after birth an increase in length of the capsule lamellae must occur.

As no marked flattening occurs at the periphery of the young extirpated and accommodated human lens (Fisher, 1969), it was desirable to measure the thickness of different parts of the lens capsule throughout the life span and to reassess the structural influences of the capsule which mould the lens fibres.

MATERIALS AND METHODS

Lenses were obtained from human cadavers not more than 24 hours, and in some cases as early as 8 hours, after death. After the cornea had been removed and the iris reflected, the lens was removed from the eye by cutting the zonule with microscissors under magnification. Neonatal lenses from four cadavers were examined, and four in each decade from birth to seventy years of age.

To avoid shrinkage by fixatives, all measurements were made on fresh specimens immersed in isotonic saline. The capsule was cut around the equator of the lens with fine scissors and carefully separated from the lens substance with a small brush of marten's hair while the lens was submerged in saline. The two portions of the lens capsule were then examined under a phase contrast microscope to ensure that all traces of epithelium or lens fibre fragments had been removed.

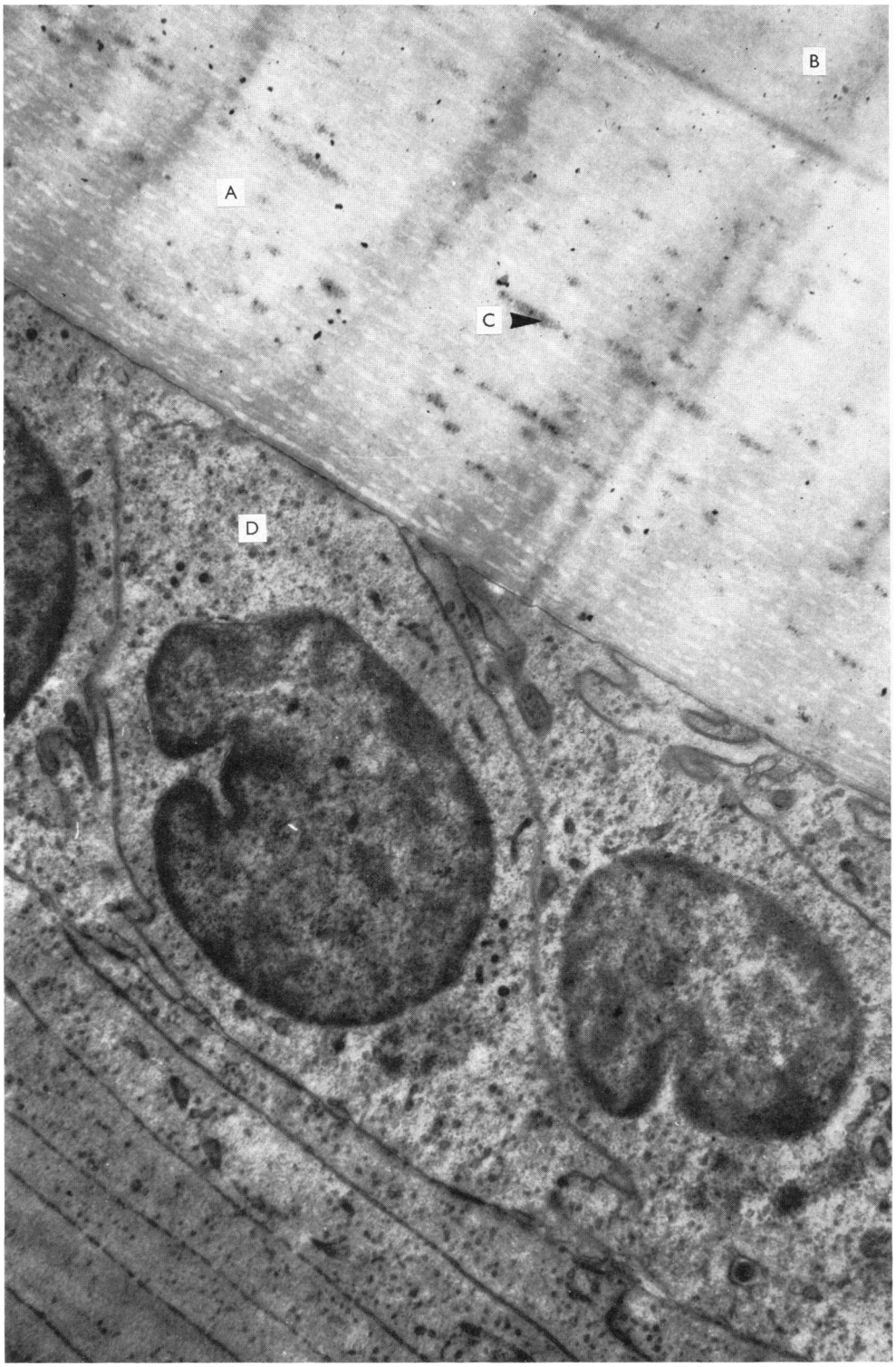

Fig. 1. An electron micrograph of the lens capsule and underlying lens epithelium (×25000). Lens capsule (A). Zonular lamella (B). Dense staining fibres (C). Lens epithelium (D).

Table 1. *Values of capsular thickness* (μ)

Lens	Anterior portion of capsule					
	Anterior pole		Insertion of zonule		Equator	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Neonatal	8·1	±0·36	10·9	±0·54	10·5	±0·57
Young adult (11–20)	12·7	±0·95	16·8	±0·45	19·9	±1·32
Old adult (61–70)	14·9	±0·97	23·8	±1·05	18·7	±1·10

Procedure

A drop of isotonic saline (NaCl 0·9 g/100 ml) mixed with a suspension of latex spherules (0·8 μm diameter) was placed on a glass slide and either the anterior or posterior portion of the capsule carefully spread out; radial cuts in the peripheral part of the specimen were made so that it could be mounted flat. The upper surface of the capsule was again moistened with a further drop of saline and latex suspension and a cover-slip was lightly placed in position.

The capsular specimen was then accurately centred by means of the mechanical stage of the microscope (Wild M-20). From this central reference point radial distances were measured with the aid of the mechanical stage micrometer (accuracy ±0·1 mm). Thickness measurements were made at 0·5 mm intervals along a radius. Latex spherules adhering to the lens capsule could be identified since they were not undergoing Brownian movement when viewed under high power. They were focused under phase contrast and the difference in focus between spherules on the under and upper surfaces of the capsule was determined. Three determinations of thickness were made at each of two points equidistant from the centre (accuracy of each determination ±0·4 μm). The mean of these six values was taken as the average thickness of the capsule at a given radial distance from the anterior or posterior poles respectively. Since the refractive indices of the capsule (1·39) and saline (1·33) were so small, the apparent thickness differed from the true thickness within the range of experimental error, and no correction was made for this.

However, when measurements were attempted in the region of the zonular attachment, the attached zonular fibres could not be completely removed, and this impeded the measurements. Since α-chymotrypsin is employed to partially digest the zonular fibres during a cataract extraction and so to facilitate the removal of the lens, the effect of this enzyme on the lens capsule was examined. The capsule was immersed for two minutes in an enzyme solution (0·1 mg/ml) maintained at a temperature of 37 °C; it was then removed and washed in saline, remounted, and the thickness was again measured. No appreciable decrease in thickness of the capsule could be detected following enzymic treatment in any region of the capsule, so the method was employed to study the zonular region of the capsule.

Measurement of capsular arc length

Since the pressure on the lens fibres by the enclosed capsule decreases from birth (Fisher, 1969), capsular stretching due to the growing lens fibres does not occur. Therefore, a simple measure of the extent of the lens capsule can be obtained by

calculating the arc length (c) of a sagittal section of the lens between corresponding points on the equator. The determination of this length requires accurate measurements of the lens profile by a method described previously (Fisher, 1969). Since the profile of the excised lens is approximately ellipsoidal,

$$c = 2a\int_0^{\frac{1}{2}\pi} \sqrt{(1-k^2 \sin^2 x)}.dx$$

where

$k = \sqrt{\{1-(b/a)^2\}}$

c = arc length of a sagittal section of the lens (mm).

a = equatorial radius of lens (mm).

b = perpendicular distance of anterior pole from equatorial plane of lens (mm).

RESULTS

Changes with age in thickness of the lens capsule

Table 1 shows the numerical values of thickness with standard deviations for different regions of the anterior portion of the capsule.

These are best illustrated by typical examples which show the general trend of average values (Fig. 2). Comparison of these figures shows that capsular thickness changes more or less in different regions of the lens as age advances.

(i) Anterior and posterior poles of lens.

At the anterior pole of the lens the thickness of the capsule increases steadily as age advances, whereas at the posterior pole it remains constant.

(ii) The equator of the lens.

In this region the capsule shows a slight increase in thickness until about the age of 50 years, after which a decrease in thickness occurs.

(iii) Anterior and posterior zonular attachments of the lens.

The thickness of the capsule underlying the anterior attachment of the zonule increases steadily throughout life but the region of the capsule underlying the posterior portion of the zonule does not show a significant increase in thickness.

Significant increases in capsular thickness with age are therefore confined to the anterior portion of the capsule. Accordingly they have been averaged from birth onwards over the four lenses in each decade and compared with the average thickness values of the neonatal lens capsule (Fig. 3). The capsule increases in thickness about twice as much at the insertion of the zonule as at the anterior pole of the lens.

Changes with age in the extent and thickness of the capsule

Fig. 4 shows histograms of increases in thickness and arc length of the capsule with age. An increase in thickness occurs steadily throughout life at the insertion of the anterior zonular fibres and to a lesser extent at the anterior pole. In contrast to this two thirds of the increase in arc length of the capsule occurs in the first decade of life.

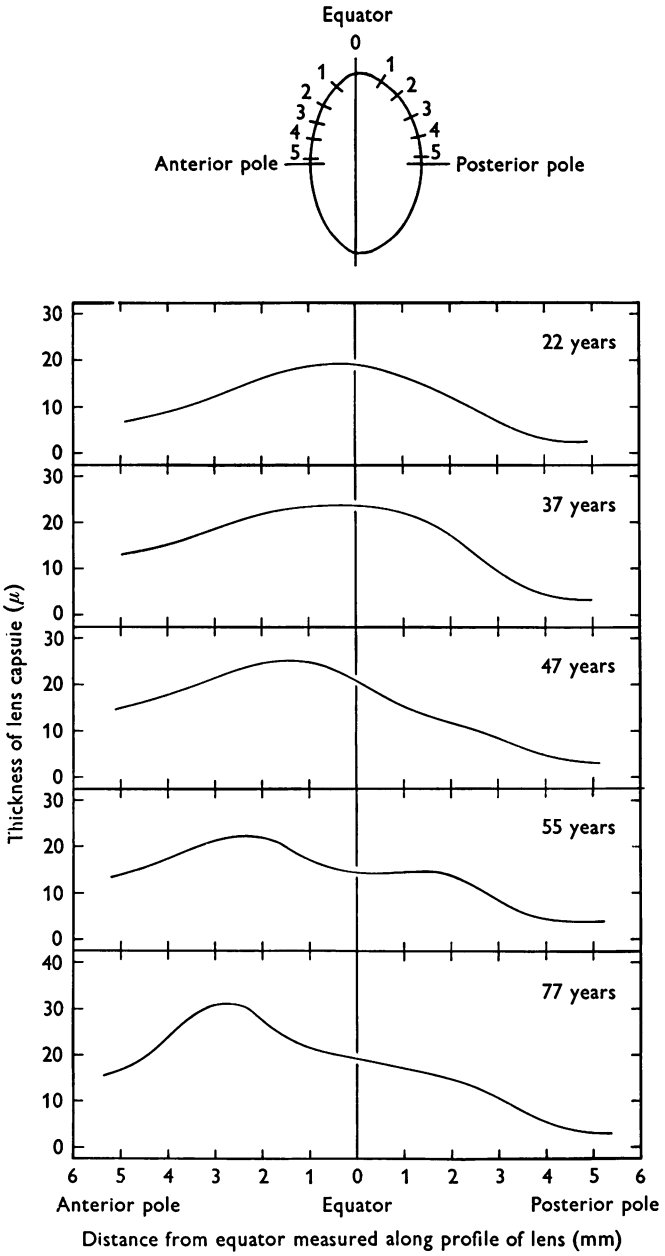

Fig. 2. Changes of capsular thickness with age in typical human lenses.

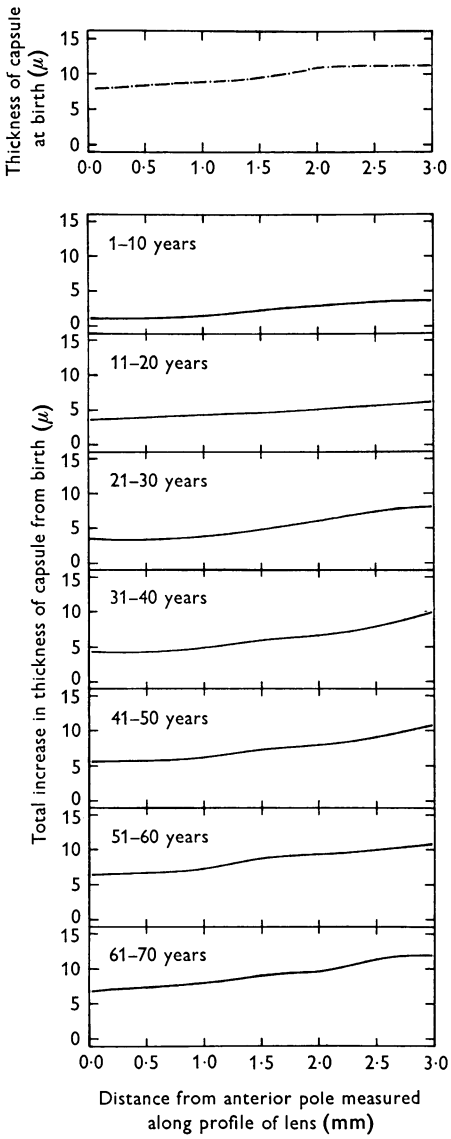

Fig. 3

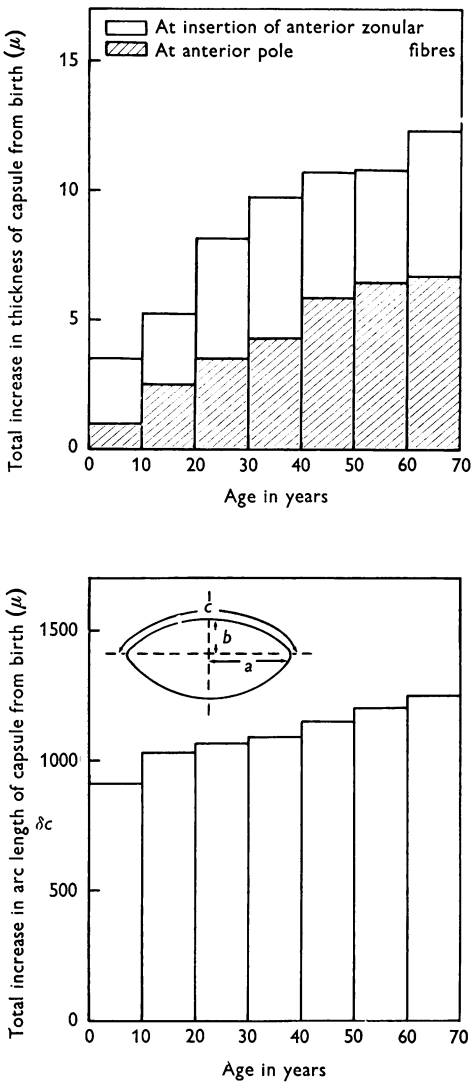

Fig. 4

Fig. 3. Average increases in thickness of the human lens capsule from birth (N = 4 lenses for each group).

Fig. 4. The thickness and longitudinal growth of the human lens capsule (N = 32 lenses).

DISCUSSION

Young & Occampaugh (1966) have shown that the capsule is formed by the addition, to its inner surface, of molecules laid down by the epithelial cells. A further property of these cells is that they lose the powers of D.N.A. synthesis as soon as they become elongated and move to the posterior region of the lens (Papaconstantinou,

1967). The present study confirms the measurements of Salzmann (1912) that capsular thickness is almost independent of age in the posterior portion of the lens capsule, so the ability of the fibres to form capsular protein appears to parallel D.N.A. synthesis.

The thickness of the capsule and accommodation

A previous study of capsular thickness (Fincham, 1937) showed that the capsule is thicker at the zonular insertions than elsewhere. The present study (Fig. 2) shows that this is so only late in life when accommodation has ceased, and that in early life the equator of the capsule is as thick or slightly thicker than elsewhere, including the region of zonular attachment. Furthermore, at this time the anterior portion is about half as thick, and the posterior portion only one-sixth as thick, as the equatorial region. Consideration of mechanics suggests that local modifications of the lens fibre substance by the capsule are impossible (Fisher, 1969). The present capsular thickness measurements suggest that when the eye focuses on a near object it is the thicker equatorial portion of the unrestrained capsule that chiefly deforms the lens substance. Conversely, when the eye focuses on a distant object the influence of the equatorial capsule is reduced and the much thinner anterior polar portion of the capsule may assist in the backward movement of the lens substance: the posterior polar portion can hardly exercise any lenticular constraint because of its extreme thinness.

The change in the rate of growth of the capsule with age

Fig. 4 shows that the changes in growth of the capsule with age can be divided into two distinct periods. Initially the capsule rapidly increases in area because after birth the increase in the volume of the lens is the dominant feature. This period lasts throughout the first decade of life. The second period, lasting long after accommodation fails, is marked by an increase in the thickness of the capsule at the anterior zonular insertion. This could be due to hypertrophy caused by maximum capsular accommodative stress occurring at this site, coupled with the undiminished activity of the ciliary muscle during accommodative life (Swegmark, 1969). The relation between thickness and longitudinal growth reflects these differences in the two periods. In the former, thickness and longitudinal growth are about equal and average 2 to 3 % per annum of the neonatal thickness and arc length of the capsule respectively. In adult life, however, longitudinal growth averages only about 0·1 % per annum, while thickness growth still continues at about 1 % per annum beneath the anterior portion of the zonular insertion. Thus the complex variations in capsular thickness seen in the elderly adult lens, as compared with a neonatal capsule of almost uniform thickness, are due to growth occurring over a prolonged period of time.

SUMMARY

The variation of thickness and size of the human lens capsule with age has been measured on fresh specimens immersed in isotonic saline. The greater part of superficial growth occurs in the first decade of life. The thickest portion of the capsule at birth is in the region of the lens equator. Despite the increase with age in the thickness of other parts of the capsule this region remains as thick or thicker than elsewhere until late adult life. Eventually, however, the capsule beneath the insertion

of the anterior zonular fibres becomes the thickest region. The influence of the capsule in changing the shape of the lens during accommodation is discussed in the light of these findings.

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