The stretching capability of the zonules was studied in 40 human eyes obtained postmortem from 27 patients. A continuous circular capsulorhexis (CCC) (2.2–6.8 mm) was performed, and the lenses were removed by either phacoemulsification (26 eyes) or planned extracapsular cataract extraction (ECCE) (14 eyes). Maximal zonular stretch was calculated as the difference in distance between the ciliary processes and the zonular insertion at rest and after maximal stretch. This zonular stretch test showed that zonules can stretch to a mean distance of 3.82 mm before rupturing. Capsular elasticity was measured in 35 of the eyes by gradually opening a modified caliper until the capsular opening was torn. The ratio between the circumference at rupture and the circumference at rest was used as an index of capsular elasticity. Circumference of the intact capsulorhexis could be enlarged an additional 62% before a radial tear occurred. In most cases, no significant correlation was seen between the capsular and zonular capability to stretch. Maximal zonular stretch decreased significantly with age by approximately 0.5 mm for every 5 yr, whereas capsular elasticity did not show a significant correlation with age. Two eyes with pseudoexfoliation had relatively friable zonules but the capsular elasticity was within normal limits. Patient age is probably the best indicator of the stretching capability of the zonules. Invest Ophthalmol Vis Sci 32:2835–2839, 1991

The lens capsule and zonular fibers are elastic structures that can stretch when external force is applied.1 The stretching ability of the anterior capsule is clinically important during the removal of lens substance or implantation of an intraocular lens (IOL) through an anterior capsulectomy. Manipulations of the lens during cataract surgery challenge the integrity of the zonules and may cause zonular rupture. Tearing of zonules is a serious complication of cataract surgery. If the anterior hyaloid membrane is also ruptured, vitreous loss may occur. This is sometimes associated with significant postoperative complications, such as retinal detachment. Loss of zonular support may cause unstable fixation of a posterior chamber (PC) IOL, with subsequent malposition. Because the zonules are obscured by the iris, it is often difficult for the surgeon to determine their integrity. Wilson et al showed that large disinsertion of the zonules is common (5 of 20 eyes in their series).2 Surgical techniques are constantly improved to minimize stress on the zonules during capsulotomy, lens removal, and IOL implantation.

Elasticity of the anterior capsule can be determined during anterior capsulotomy, especially while continuous circular capsulorhexis (CCC) is being performed. A fragile capsule will tear more easily, and often with less control, than an elastic capsule. We studied the maximal capability of the zonules and the capsule to stretch before rupture. We also studied the degree of correlation between the stretching capacity of the two structures.

Materials and Methods

Forty eyes obtained postmortem from 27 patients were used in this study. Eleven patients were men, 13 women, and 3 of unknown sex. Mean age was 72.2 ± 8.8 yr (range: 52–85 yr). After the cornea and iris were removed, a CCC, ranging in length from 2.2 to 6.8 mm, was performed with a 26-gauge needle. In 26 eyes, the lens was removed by phacoemulsification (Site Model TXR; Microsurgical Systems, Inc., Horsham, PA), and in 14 eyes, the lens was removed by manual hydroexpression. Care was taken to minimize trauma to the zonules during surgery.

Zonular Stretch Test

The anterior insertion of the zonules was identified in each eye by high-power magnification; the distance...
of the zonular insertion from the anterior tips of the ciliary processes was measured with a Castroviejo caliper (Storz Instruments, St. Louis, MO). The anterior capsule was then pulled radially toward the center of

![Fig. 1. Zonular stretch test. The cornea and the iris were removed to allow clear visualization of the lens and the anterior tips of the ciliary processes. Lens material was removed before the stretch tests. (A) Distance between the anterior zonular attachment and the ciliary processes before stretch was 1.6 mm. (B) Moderate stretch of the anterior zonules. The zonules can stretch without being torn. (C) Super maximal zonular stretch caused tearing of some zonular fibers. The last reading of the distance between the central zonular attachment and the ciliary processes, immediately before rupture, was taken. The distance was 5.7 mm, corresponding to 4.1 mm stretch (5.7 - 1.6 = 4.1 mm).](image1)

![Fig. 2. Capsular stretch test. The pins attached to the caliper are introduced into the capsular bag and the caliper is gradually opened. The last reading before capsular tear was used to calculate capsular circumference at rupture (Cr).](image2)

the lens with forceps that were applied approximately 1 mm anterior to the zonular attachment (Figs. 1A–C). Maximal zonular stretch was calculated as the difference in distance between the anterior attachment of the zonules and the ciliary processes at rest and after maximal stretching. Maximal stretching was defined as the status just before zonular rupture.

**Capsular Stretch Test**

The maximal ability of the anterior capsulectomy to stretch was measured in 35 of the eyes using a modified Vernier caliper. Two pins were firmly attached to the tips of the caliper so that the distance between the outer portion of the pins correlated with the reading on the metric scale (accuracy 0.1 mm). The ratio between the circumference of the capsulectomy immediately before rupture (Cr) and the circumference of the original capsulectomy (Cc) was used as an index of the maximal stretching ability of the capsule. In 22 eyes, the zonular stretch test was performed before capsular examination (Fig. 2). Measurements were taken at four primary locations: 3:00, 6:00, 9:00, and 12:00 o'clock positions—and then in four secondary locations—1:30, 4:30, 7:30, and 10:30 positions. In 13 eyes, the zonule stretch test was performed after the capsule was stretched and torn. In these cases, measurements were taken at least 1.5 clock hours from the tear.

Two additional eyes from a 75-year-old patient with pseudoexfoliation syndrome were excluded from statistical analysis. However, separate measurements were done on these eyes and were compared with the other eyes.

**Results**

The zonules showed a high stretching capability before they were torn. The distance between the anterior
encroachment of the zonules on the capsule and the ciliary processes, before stretch, was 1.6 ± 0.16 mm (range: 1.5–2.1 mm) (Fig. 1A). The zonules in eyes with an intact capsulectomy stretched to a total distance of 5.31 ± 0.91 from the ciliary processes (Figs. 1B and 1C). In eyes with a peripheral tear in the anterior capsule (capsular stretch test done before zonular stretch test), zonules located 1.5–3.0 clock hours from the tear were stretched to a distance similar to that of zonules located more than 3 clock hours from the tear (5.23 ± 0.79 mm and 5.28 ± 0.84 mm, respectively, \( P = 0.818 \)). These results of the zonular stretch test in all eyes were grouped together for higher statistical significance. Rupture of zonules occurred after they were pulled to a mean distance of 5.42 ± 0.98 mm corresponding to a stretch of 3.82 ± 0.98 mm, (difference between distance at rest and immediately before rupture). The breaking point of the zonules was influenced by the patient's age, even though 85% of the patients were older than 65 yr. Mean maximal stretch was 4.55 mm in patients younger than 70 yr, and gradually decreased to 3.02 mm in patients older than 80 yr, a decrease of approximately 0.5 mm for every 5 yr of age (analysis of variance – \( P = 0.00429 \), Fig. 3). Zonules in the male group showed a greater capability to stretch compared with the female group (4.25 mm and 3.48 mm, respectively, \( P = 0.0231 \)), even though the patients’ mean age (72.1 and 71.4, respectively) and age distribution were similar. There was a large variability, however, and the significance of this finding in such small groups is uncertain.

The capsular stretch test showed a mean stretching capacity of 62% (\( Cr/Cc = 1.617 \pm 0.21 \)). The circumference at rupture was higher than the circumference at rest by 15–100%, indicating that the capsules were capable of stretching in all cases. Capsular elasticity did not show a statistically significant correlation with age; however, patients younger than 70 yr had a somewhat more elastic capsule (\( Cr/Cc = 1.69 \)) than did older patients (\( Cr/Cc = 1.60 \)). No statistically significant correlation existed between the capsular and zonular capability to stretch (Fig. 4). However, the two eyes from a 79-year-old patient had the lowest zonular stretch (1.9 mm) and also had low capsular elasticity (\( Cr/Cc = 1.34 \)). The six eyes with the highest maximal zonular stretch (5.22 mm) had high capsular elasticity (\( Cr/Cc = 1.74 \)); these patients were relatively young (mean age: 62 yr). In comparison, the values of the other 27 patients were mean zonular stretch 3.49 mm and \( Cr/Cc \) of 1.61, with no significant correlation between zonular stretch and capsular elasticity.

The ratio obtained with the capsular stretch test of the patient with pseudoexfoliation was \( Cr/Cc = 1.56 \). This value is well within the normal limits. The zonules, however, were relatively fragile and were torn after a stretching of only 2.6 mm.

The diameter of the initial capsulectomy and the type of operation (phacoemulsification or manual nucleus extraction) had no apparent effect on ability of the capsules or zonules to stretch.

**Discussion**

The zonular apparatus is a complex system of multiple fibers that originate at the pars plana and are inserted into the lens capsule. As the zonules course toward the lens capsule, they have strong anchorage to the major and minor ciliary processes and to the valleys between them. With contraction of the ciliary muscle, the zonules that bridge the ciliary body and the capsule relax. The ciliary processes, therefore, serve as the functional origin of zonules. The zonules then insert onto the posterior, equatorial, and anterior surfaces of the lens. Some zonules are also
attached to the anterior hyaloid membrane. The presence of circular zonular belts also has been reported.5-7 When the anterior capsule is pulled centrally, the centripetal stress is probably distributed among all of these structures. The pars plana and the ciliary processes are also stretched, although to a lesser extent than the zonules. In this study, the anterior zonules were generally the first to rupture. Some investigators have suggested that the width of the anterior zonular insertion increases with age, thus decreasing the zonule-free area.8-10 In our series, the distance between the ciliary processes and zonular insertion did not seem to be affected by age, and varied within a relatively small range (1.5-2.1 mm).

The zonules showed a considerable ability to stretch before they ruptured (mean: 3.8 mm). They can usually tolerate most of the stress generated during cataract surgery. Manipulation and displacement of the lens to 3 mm occurs only rarely during the routine case. Nevertheless, the zonules are sometimes severely challenged during an aggressive anterior capsulectomy, during an attempt to remove the nucleus through a too-small capsular or limbal opening, or during aspiration of cortical fibers. Vigorous and uncontrolled IOL implantation also can stretch zonules beyond their capacity. This finding explains why zonular dialysis probably occurs more commonly than usually thought.2 The popularity of the CCC is increasing. An intact CCC can better maintain the integrity of the capsular bag and fixation of an intraocular lens.11 When the nucleus is extracted manually (planned ECCE), pressure needed to deliver the nucleus through a small elastic opening may create considerable stress on the zonules and cause zonular rupture.12

Because zonules are obscured from the surgeon in most clinical situations, the surgeon cannot ascertain zonular status and integrity. In this study, we attempted to determine whether there is a clinically useful correlation between zonular and capsular breaking points. However, this study shows that no such correlation exists. This finding is best explained by noting that the maximal zonular stretch correlates well with the patient's age, whereas the elasticity of the capsule is only minimally affected by age (Fig. 5). The patients who showed some correlation between capsule and zonular elasticity also differed significantly in age. Age plays a major role in determining zonular properties. Fisher showed a significant reduction in the modulus of elasticity of the capsule with increasing age.13,14 In our series, 76% of the subjects were older than 70 yr, and a wide variation was not seen in this elderly population. In a larger series that also included a greater number of younger patients,3 we found a significantly higher capsular elasticity in patients younger than 55 yr compared with patients 65 yr or older.

Pseudoexfoliation is a well known risk factor for zonular breakage or dialysis and lens dislocation.14,15 Involvement of the lens capsule in the pathologic process is often suspected because the exfoliative material is most evident on the surface of the anterior capsule. The normal capsular elasticity in our case is in agreement with the findings of Ruotsalainen and Takkanen that showed no differences in thickness between eyes with pseudoexfoliation and control eyes.16 The high incidence of complication in these cases is related to the more friable zonules rather than to capsular-related problems. Although the results of an analysis of two eyes of one patient are not enough to draw definite conclusions, the findings correlate with the clinical experience.

In summary, this study suggests that patient age is probably the best indicator for the expected breaking point of the zonules. Behavior of the anterior capsule, as determined by the surgeon, should not be used to evaluate the elastic properties of the zonules. Care should be taken to prevent placing stress on the lens zonules during cataract surgery, especially in older patients and in eyes with diseases such as pseudoexfoliation.

Key words capsulectomy, capsule elasticity, zonular elasticity, pseudoexfoliation syndrome, stretch test

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