The mechanical response of the porcine lens to a spinning test

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Abstract

The pig lens has been used as a model for presbyopia as pigs lack accommodative ability. Previous studies using microindentation have indicated that the shear modulus distribution is qualitatively similar to that of the aged human lens and that the lens does not alter its refractive power due to equatorial stretching. A lens spinning test was used to determine whether prior lens stiffness data obtained from a sectioned porcine lens were reliable and whether the testing conditions significantly influence the lens' mechanical properties. The elastic modulus distribution determined for fresh lenses closely matched that measured previously using a microindentation test. Confocal scanning laser microscopy was used to evaluate changes to the lens' structure arising from mechanical stress and following storage for up to one week.

Keywords: Eye, lens properties, presbyopia, accommodation, lens storage, lens spinning

Spinning-Experimente zum mechanischen Verhalten von Schweinelinsen

Zusammenfassung

Die Linse des Schweins wurde in verschiedenen Studien als Modell für Presbyopieuntersuchungen genutzt, wobei das Schweineauge allerdings kein Akkommodationsvermögen besitzt. Eigene Studien an Schweinelinsen mittels Mikroindentierung zeigten ein der humanen Linse ähnliches Schubmodul und dass sich die Brechkraft dieses Linsentypus während einer äquatorialen Dehnung nicht ändert. Im Rahmen dieser Studie werden sogenannte „Lens spinning"-Tests genutzt, um Steifigkeitsuntersuchungen an geschnittenen Linsenpräparaten zu validieren und zu untersuchen, welchen Einfluss Lager- und Testbedingungen auf die mechanischen Eigenschaften der Linse haben. Die Verteilung des Elastizitätsmoduls entspricht den in früheren Untersuchungen mittels Mikroindentierung ermittelten Werten. Konfokale Laser-Scanning-Mikroskopie wurde genutzt um mechanisch induzierte bzw. lagerungsbedingte Veränderungen der Linsenstruktur zu untersuchen.

Schlüsselwörter: Auge, Linseneigenschaften, Presbyopie, Akkommodation, Lagerung, lens spinning

1 Introduction

Ocular accommodation is the process by which the eye changes focus from far to near due to increasing curvature and thickness of the lens induced by changes in zonular tension arising from ciliary muscle contraction [1,2]. Presbyopia is the progressive decrease in accommodation amplitude with age. While many potential causes have been studied [3–9],

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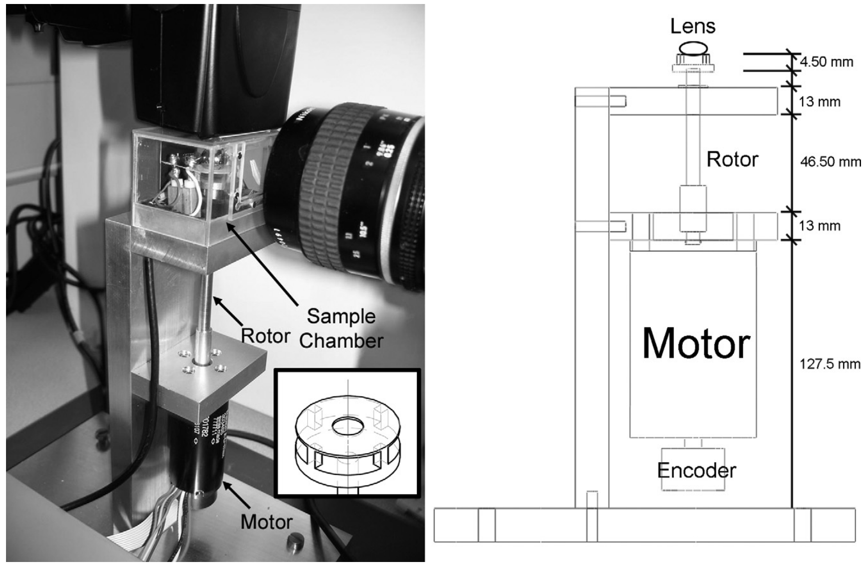

Figure 1. Left: Photograph of the spinning rig with inset detail of sample support. Right: Side view of spinning apparatus drawn to scale.

this condition is closely correlated with changes in the lens' mechanical properties [10–17]. The results of these studies generally agree that the lens becomes stiffer with age, especially within the nucleus region while the outermost cortical regions remain relatively compliant throughout life.

An accurate knowledge of the age-related variation in the mechanical properties of the human lens will enable the development of improved finite element models of accommodation in the aging lens (e.g. [18]) and improve understanding of the pathogenesis of presbyopia. Such a model would also be useful for testing the efficacy of candidate treatments for presbyopia, such as lens refilling [19–22]. Successful restoration of accommodation using this technique depends on identifying a polymer (or composite) system which will yield a useful level of accommodation.

In practice, human lenses used for ex vivo mechanical testing are typically obtained 24-72 hours post mortem. This may give rise to anisotonic conditions within the eye as the production of aqueous humor ceases post mortem upon cessation of ciliary blood flow [23]. Recent work has demonstrated the influence of anisotonic conditions on lens dimensions [24,25], though no study has yet been published which examines the influence that storage conditions might have on the measured mechanical properties of the lens. We hypothesized that storage of lenses under such conditions for prolonged periods (e.g. post mortem time prior to experimentation on human lenses) might significantly alter the mechanical response of the lens. We also considered that temperature may influence the mechanical response of the lens though no relevant data exist in the literature.

We therefore constructed a lens spinning rig similar to that described by Burd et al. [26] with the notable addition of temperature and humidity controls [27]. Lenses from six-month-old pigs were then tested using the inverse finite element analysis approach employed by [17] to confirm the reliability of the spinning test in quantitatively measuring the lens' mechanical property distribution. Additional experiments were then performed to evaluate whether temperature, humidity, or post mortem storage influenced the encapsulated lens stiffness. These tests utilized a simpler metric for the apparent stiffness of the lens and capsule as a unit to capture changes in the lens and/or the capsule due to temperature, humidity, or storage effects. All animal tissues were treated in accordance with the Statement for the Use of Animals in Ophthalmic and Visual Research of the Association for Research in Vision and Ophthalmology.

2 Methods

2.1 Lens Spinning Apparatus

A spinning rig based on the design of Burd et al. [26] was constructed with certain improvements to allow the test process to be controlled automatically and to provide temperature and humidity control within the test chamber. A motor (EC max 60; Maxon Motor AG; Sexau, Germany) was fitted to the lower of two horizontal plates, while the rotor passed through a bearing fitted into the center of the upper plate (Fig. 1). The horizontal plates were bolted to a larger vertical plate, which was in turn bolted to a large base plate. The upper plate was machined such that it formed a watertight well to hold a brine solution (saturated sodium chloride) to control humidity. A Perspex (Lucite International, Southampton, UK) box was used to enclose the sample chamber on the top plate when humidity control was used; in this case, resistive heaters were used to raise the temperature of the air to 37 °C when elevating the temperature. When humidity was not controlled, the lid was not used and the entire rig was placed in a