Biomechanical evaluation of the anterior lens capsule following manual capsulorhexis and femtosecond laser capsulotomy

PhD thesis

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Introduction

Performing an anterior capsulorhexis is a key part of cataract surgery. An ideal rhexis is well-centered, has a proper size, circular, and its edge is continuous. These factors help to maintain the correct intraocular lens (IOL) position within the capsular bag as well as help minimize the incidence of radial tears of the anterior capsule. The ideal capsulorhexis from a mechanical viewpoint is strong; the opening must withstand the stress of maneuvers during surgery.

An anterior capsule tear disrupts the integrity of the capsular bag; thus the appropriate position of the IOL may be compromised.

One of the most feared complications of cataract surgery is posterior capsule rupture. Extension of a tear through the posterior capsule occurred in almost half of eyes with an anterior capsule tear. This fact highlights the importance of a resistant anterior capsule opening.

The most commonly used technique to open the anterior capsule is Continuous Curvilinear Capsulorhexis (CCC). Although CCC seems perfect from a mechanical viewpoint, it is performed manually; thus accuracy and reproducibility are inherently limited by surgeon's experience and dexterity. With the intraocular application of femtosecond laser, a highly-controlled and reproducible Femtosecond Laser Capsulotomy (FLC) became feasible.

However the findings in the literature of the mechanical resistance of the FLC are controversial.

Earlier laboratory studies reported that FLC rendered greater resistance to capsule tearing than CCC in porcine eyes. However, a multi-center clinical study showed that there was a higher incidence of radial tears following FLC than CCC.

However the resistance of FLCs with different pulse energy settings was evaluated, those mechanical behaviour is unknown.

Purpose

Due to the controversial and deficient data in the literature, the purpose of our study group was

- to evaluate and compare the biomechanical behaviour and ultrastructure of the anterior lens capsule following CCC and FLC, furthermore

- to evaluate and compare the biomechanical behaviour and ultrastructure of the anterior lens capsule following FLC with different pulse energy settings.

Methods

Specimens

Fresh porcine eyes were obtained immediately following slaughter from a local abattoir. They were randomly selected for the study groups. In the CCC group, the cornea and iris were removed, permitting free access to the anterior capsule. CCC was performed with a cystotome and forceps. The goal was to perform a well-centered, circular capsular opening with an intended diameter of 5 mm.

In the laser groups a femtosecond laser system (Alcon Laboratories Inc., Forth Worth, TX, USA) was used with the SoftFit™ patient interface. Depending on the applied laser pulse energy 3 different group was created: FLC 1 group (2 µJ, low energy), FLC 2 group (5 µJ, intermediate energy), FLC 3 group (10 µJ, high energy). Following the laser procedure, the cornea and iris were removed. In all groups the anterior capsule was cut using microscissors around the aequator, resulting in a ring-shaped capsule specimen.

All specimens were inspected via light microscopy (BX 51M, Olympus Co., Tokyo, Japan) without any staining to ensure geometrical uniformity of the samples. Specimens with unacceptable shape or size were excluded from the study. Specimens with visible irregularity at the rim of the opening were also discarded. In total, 125 eyes met the stated criteria to be included in the study (CCC group, n=50, FLC 1-3 groups, n=25).

Mechanical test

Mechanical testing was carried out with universal testing equipment (Zwick Z005, Zwick GmbH & Co. KG, Ulm, Germany). The specimen support consisted of two polished metal pins (r=0.4 mm). The ring-shaped specimen was carefully slipped over the two pins, which were lubricated with methylcellulose to reduce friction. During the test, the specimen support was submerged in BSS (Balanced Salt Solution) at room temperature to prevent the dehydration of tissue. The lower pin was fixed. The upper pin, connected to a force transducer (sensitivity 0.01 mN), was separated from the fixed one by a stepping motor at a speed of 10 mm/min until the capsule ring tore. The force required for stretching as well as the displacement of the moving pin were recorded continuously with the manufacturer's software (testXpert, Zwick GmbH & Co. KG, Ulm, Germany)

The unstretched circumference (C_{us}) of the opening was calculated as follows:

$$C_{us}=4r+2r\pi+2L_0$$

where r represents the radius of the tip, and L_0 represents the distance between the lower and upper pin when the strain reached a small preload of 1.5 mN. In this state, the ring-shaped specimen was distorted to a narrow oval shape without stretching of the opening (the increase in circumference was negligible).

The stretched circumference (C_s) of the opening was calculated as follows:

$$C_s=4r+2r\pi+2L_0+2L_1$$

where L_1 represents the displacement of the moving pin from the position of L_0 to the position at which the ring tore.

The circumference stretching ratio (CSR) between the stretched and unstretched circumference was expressed as a percentage by

$$CSR=(C_s/C_{un})\times100\%$$

The rupture force, the CRS and the force-displacement characteristic were evaluated.

Scanning Electron Microscopy

The disk-shaped anterior lens capsule specimens obtained during sample preparation were fixed for scanning electron microscopy in freshly-prepared 1% glutaraldehyde and 1% paraformaldehyde in 0.1 mol/L sodium cacodylate buffer (pH 7.2). The fixed samples were dehydrated in a series of ethanol dilutions (20%-96% vol/vol), 1:1 mixture of 96% (vol/vol) ethanol/acetone, and pure acetone followed by vacuum-drying. The specimens were mounted on adhesive carbon discs, sputter coated with gold, and images taken with scanning electron microscope JSM 6380LA (JEOL, Ltd., Tokyo, Japan).

Statistical Analysis

Statistical analyses were performed with Statistica 8.0 (Statsoft Inc., Tulsa, OK USA). For group comparisons of variables one-way ANOVA was used. Post hoc analysis was performed using the Dunnett and Tukey tests. In all analyses, a p value of less than .05 was considered statistically significant.

Results

Mechanical test

The rupture force was 164±56 mN in the CCC group, 119±11 mN in the FLC 1 group, 118±10 mN in the FLC 2 group, and 108±14 mN in the FLC 3 group. The difference was statistically significant ($p<0.01$, one-way ANOVA). Post hoc analysis (Tukey test) revealed that the FLC 3 group had significantly lower rupture force compared to the FLC 2 group ($p<0,01$), and FLC 1 group ($p<0,01$), but he difference between the FLC 2 group and FLC 1 group was not significant ($p=0,9479$). Post hoc analysis (Dunnett test) revealed that the rupture force was significantly greater than in the FLC 1 group ($p<0,01$), in the FLC 2 group ($p<0,01$), and in the FLC 3 group ($p<0,01$).

The CSR was 151±6% in the CCC group, 148±3% in the FLC 1 group 148±3% in the FLC 2 group, and 144±3% mN in the FLC 3 group. The difference was statistically significant ($p<0.01$, one-way ANOVA). Post hoc analysis (Tukey test) revealed that the FLC 3 group had significantly lower rupture force compared to the FLC 2 group ($p<0,01$), and FLC 1 group ($p<0,01$), but he difference between the FLC 2 group and FLC 1 group was not significant ($p=0,9985$). Post hoc analysis (Dunnett test) revealed that the rupture force was significantly greater than in the FLC 1 group ($p<0,01$), in the FLC 2 group ($p<0,01$), and in the FLC 3 group ($p<0,01$).

Below 71 mN, no capsular tear occurred in either group. Below 82 mN, no capsular tear occurred in the FLC groups, whereas at 82 mN the probability of capsular tears was 4% in the CCC group.

The force-displacement curves were similar in all groups: they ended suddenly prior to steep rise in force.

Scanning electron microscopy

In the CCC group the regular lamellar arrangement of collagen fibrils was clearly visible. In the FLC 1 and FLC 2 groups microgrooves (caused by the laser beam) were visible. The edge was gently serrated - not torn - but sign of thermal damage was not visible. In the FLC 3 group the morphological characteristics were changed: the serrated edge was hardly visible. Furthermore the collagen fibers were coagulated at the cutting edge.

Conclusions

- We could not confirm the findings of earlier laboratory studies.
- According to our results
  - the anterior lens capsule opening following FLC has less average resistance to capsule tear than following CCC,
  - the anterior lens capsule opening following FLC yield better mechanical reliability, than followng CCC,
  - the anterior lens capsule opening following FLC created at a high energy level has less average resistance to capsule tear than those created at a low or intermediate level,
  - the ultrastructure of the cut capsule provides an explanation for the observed differences in mechanical properties.

List of publications

List of publications releated to the thesis

Sándor GL, Kiss Z, Bocskai ZI, Bojtár I, Takács ÁI, Nagy ZZ. Mechanical Behavior of Capsulotomy Performed With Femtosecond Laser. In: Nagy ZZ (editor), Femtosecond laser-assisted cataract surgery: Facts and results. Slack Incorporated, Thorofare, NJ, 2014: 29-31.

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