·Basic Research·

Stress and continuous relaxation spectrum of porcine cornea after LASIK

Xue-Jun Fang[1], Yan-Chun Xu[1], Tian-Yu Shi[2], Li Zhang[2], Zi-Fan Li[2]

[1]Department of Ophthalmology, the First Affiliated Hospital of China Medical University, Shenyang 110001, Liaoning Province, China
[2]Aier Eye and Optometry Hospital of Shenyang City, Shenyang 110003, Liaoning Province, China
Correspondence to: Yan-Chun Xu. Department of Ophthalmology, the First Affiliated Hospital of China Medical University, Shenyang 110001, Liaoning Province, China. eyexyc@163.com
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Abstract

• AIM: To explore the characteristic of relaxation of porcine cornea after LASIK.

• METHODS: Usual LASIK was performed on fresh porcine corneas with stable intraoculer pressure (IOP) maintained through optic nerve irrigation . The ablation depth on stroma is 30%, 50% and 70% respectively. Then the dumbbell-shaped corneal strip specimens were cut and stored in 20% Human Albumin solution for use (4oC).Sip up the Albumin solution on specimens, and fixed them on homemade jig. Stress relaxation tests were performed on Tytron250 Dynamics Experiment System. The loading speed was 385mm/min, extending rate was 1.5, and relaxation time was 1 000s. The data were collected electronically and automatically.

• RESULTS: In LASIK procedure, though a single flap-cutting can cause a little reduction of corneal stress relaxation ($P<0.05$, $P=0.49$), the cornea may still remain its property of visco-elasticity. When ablation depth was 30% or more, corneal stress relaxation decreased to almost one half ($P<0.01$).The change of corneal stress relaxation degree in vertical meridian specimen was lower than that in horizontal specimen, especially when ablation depth was 70%, and it's statistically significant ($P<0.001$). In LASIK operation, the more depth the ablation, the more reduce the stress relaxation degree, and it's easy to cause deformation and creep deformation.

• CONCLUSION: The changes of the stress relaxation in vertical and longitudinal meridian specimens are similar, and slightly obvious in longitudinal specimen, especially in 70% ablation group.

• KEYWORDS: LASIK; stress relaxation; relaxation spectrum

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INTRODUCTION

The importance of biomechanical researches in eye surgery occupies the first place. But regretfully, a few mechanic researchers note this, and the progress in this aspect is based on "gradual probes" [1] . Both domestic and foreign literatures has the correlated reports on biomechanical performance of cornea [2-5], but there are very few reports about these characteristics after corneal refractive surgery. Nearly all biological solid materials are viscoelasticitic bodies[6]. Collagen fiber is the basic structural element of soft and hard tissues in human body.

Collagen fiber has obvious viscoelastic properties, and has hysteresis loop and stress relaxation phenomenon. Cornea is a kind of biological tissue, and is a viscoelastic material. Creep deformation and stress relaxation are the responses of material in two different aspects. The hysteresis curve is insensitive to rate of strain in cornea as well as the most biological soft tissues. This kind of insensitivity shows a minority of adaptation to viscoelastic models made up of spring and damp. That is, it is not suitable to describe cornea material with discrete relaxation time spectrum. Therefore, a continuous relaxation spectrum must be used in description, and when measuring corneal maximal intensity and rupture strain, the aeolotropic characteristic must be considered .

MATERIALS AND METHODS

Porcine Cornea LASIK Modeling Fresh porcine eyes stored in humid-room for less than 24 hours. were connected with irrigation system by needle puncture through optic nerve. The IOP was maintained with compound salt solution filled in the irrigation system. The irrigation height was 1m.

Refractometery, corneal curvature, IOP, central pechimetery and axial length were measured. Hansatome excellus Z16 microblade (Bausch & Lomb) was used to create corneal flap with vertical hinge assisted by 9.5 ring of vacuum; Corneal stromal ablation was performed with 217Z100 Eximer laser (Bausch & Lom), with optical diameter of 7.0mm, transitional area of 10.2mm ×10.1mm, depth of 30%, 50%,70% respectively.

Ten eyes were in each group (30%, 50%, 70% according to ablation depth, 5 for horizontal specimen, 5 for vertical specimen); 10 eyes were in single flap-cutting group. 6 eyes were in control group (3 for horizontal specimen, 3 for vertical specimen). A dumbbell-shaped former (centre 5mm×3mm, both ends 9mm×5mm) was adhibited on cornea surface, specimen was cut with sharp blade (Figure 1). A few viscoat was spread on endothelial side, and specimen was stored in Eppendorf tube filled with 200mL/L Human Albumin solution 2.0mL(4℃) for next day use .

Stress –strain Test of Porcine Cornea Sip up the Albumin solution on specimens, and fixed both ends on homemade jig. The effectual specimen was 5.0mm×3.0mm. Stress relaxation tests were performed on Tytron250 dynamics experiment system. The loading speed was 385mm/min，extending rate λ was 1.5, and relaxation time was 1 000s. The data were collected electronically and automatically.

RESULTS

Horizontal Specimen Stress Relaxation After LASIK on porcine cornea with 30% thickness of ablation, when extending rate λ is 1.5, the maximal axial stress Pmax= 5.51 ±1.98N (Figure 1A). When ablation depth reached 50% after LASIK, and extending rate λ was 1.5, the maximal axial stress, P max=5.28 ±0.28N (Figure 1B). When the corneal depth ablated by LASIK was 70% , and extending rate λ was 1.5, the maximal axial stress, P max= 2.18 ±0.56N (Figure 1C). With extending rate λ=1.5, horizontal specimen stress relaxation degree was shown in Table 1. In Table 1, P max was the maximal axial stress with extending rate λ=1.5; △ P was the relaxation value within 1 000s, that is the change of axial stress within 1 000s. In flap-cut-only group, stress relaxation degree reduced, compared with normal group.It's statistically significant. P< 0.05; In groups with ablation depth of 30%, 50% and 70%, the stress relaxation degree all reduced obviously, compared with normal group (P<0.01).

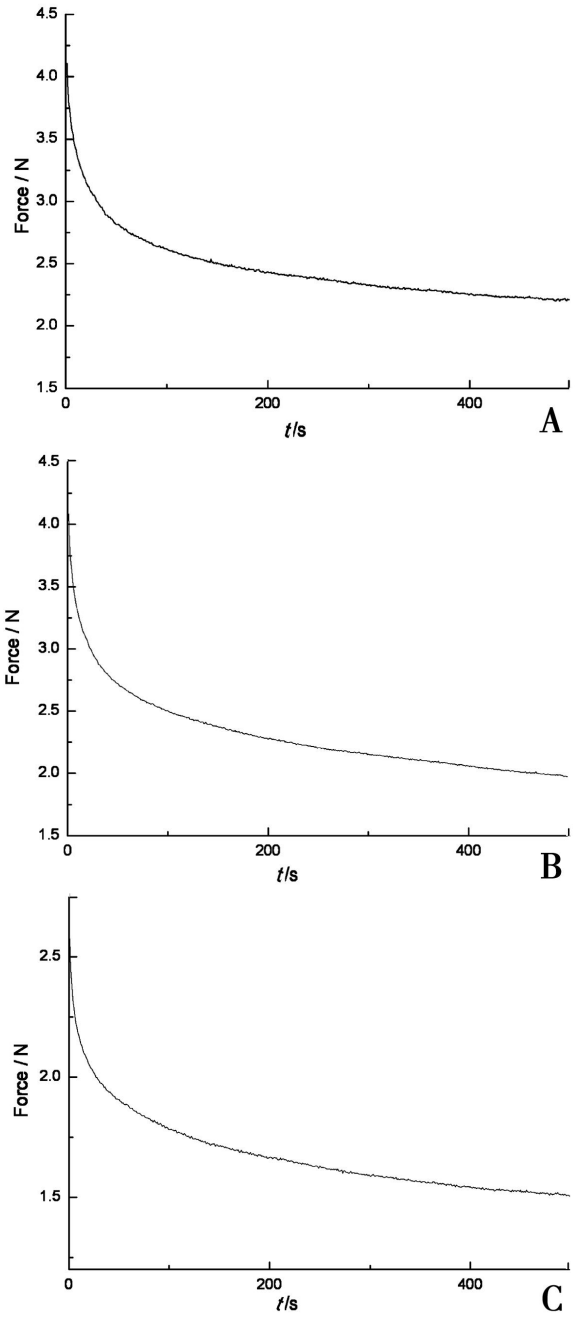

Figure 1 Stress relaxation curve with 30%, 50% or 70% ablation depth A: 30%; B: 50%; C: 70%

Vertical Specimen Stress Relaxation When the ablation depth was 30% , and extending rate λ was 1.5, the maximal vertical stress, Pmax=3.32±0.38N. When the ablation depth was 50%, maximal vertical stress, Pmax=3.49±0.34N, and when the ablation depth was 70%, Pmax=0.5±0.02N. Stress relaxation curve in vertical and horizontal specimens were similar. After LASIK in porcine cornea, vertical specimen stress relaxation degree with extending rate λ=1.5, was shown in Table 2. In Table 2, P max was the maximal axial stress with λ=1.5 , △ P was the relaxation value within

Table 1 Horizontal stress relaxation degree (mean±SD,*n*)

Specimen	*P*max (*n*)	△*P* (*n*)	△*P*/*P*max
30%	5.51±1.98	3.00±1.55	0.53±0.09
50%	5.28±0.28	2.14±0.39	0.50±0.23
70%	2.18±0.56	0.94±0.19	0.44±0.26
Normal	15.04±2.58	14.98±2.58	0.99±0.01
Flap	6.60±2.17	5.08±3.22	0.73±0.25

Table 2 Longitudinal specimen stress relaxation degree (mean±SD,*n*)

Specimen	*P*max (*n*)	△*P* (*n*)	△*P*/*P*max
30%	3.32±0.38	2.29±0.14	0.69±0.03
50%	3.49±0.34	2.40±0.19	0.69±0.01
70%	0.55±0.02	0.33±0.01	0.61±0.04
Normal	9.37±0.01	8.80±0.08	0.94±0.01
Flap	8.94±0.13	7.77±0.43	0.87±0.04

1 000s, that is the change of axial stress within 1 000s. Analysis of this data showed that, the flap-cut-only group had the reduced stress relaxation degree, compared with normal group (P<0.05). In groups with ablation depth of 30%, 50% and 70% , the stress relaxation degrees reduced compared with normal group (P<0.05).

DISCUSSION

The important characteristic of cornea is transparent and without blood vessels, it's basic function is to refract light. Deeply understanding the biomechanical properties of cornea is important for evaluation of modern refractive surgery. Feng [7] pointed out in "mechanical properties of live tissues" that the soft tissues have visco-elastic property which is characterized by the behavior of relaxation, creep deformation and lag . Relaxation means that when a strain happened in an object, if this strain keeps constant, that is , the corresponding deformation is constant, then, the stress within the object will reduce as time passing. Moreover, the phenomenon of creep deformation means that the strain within the object is constant and will cause further deformation.

In the studies on properties of rubber, plastics, paint, glass, concrete, metal, rock, soil, oil, muscle and many other materials, researchers found that, it's difficult to explain the complexity of these materials with classical elasticity theory, plasticity theory, and Newton's fluid theory. So comes the thinking rheology. Rheology concerns about the creep deformation, stress relaxation, yield value of materials, and about the rheological modeling and constitutive equations.

Maxwell found in 1869 that a material should be of both elasticity and viscosity. For viscous material, the stress can not keep constant, and will decrease in a certain rate to zero. The decreasing rate depends on both originally applied stress and the property of material. This phenomenon is called stress-relaxation. Researchers also found that, though the stress keeps constant, the material can deform further, and this is known as creep deformation, or distortion. Cornea as well as other soft tissues has the property of elasticity, viscosity and plasticity. When a sudden load is on it, deformation and recovering is its biomechanical property. That is also an important factor that can influence the effect of refractive surgery.

This experiment showed that the horizontal and vertical stress relaxation degree on intact cornea is 99% and 94% respectively , there is no statistical significance (P>0.05). This showed that though the porcine cornea is an anisotropic material, as a whole performance, the difference of mechanical properties measured in two orthogonal direction is minimal, and the cornea should be concerned as isotropic material under a certain accuracy requisition. This is similar to corresponding reports [8,9]. When the integrity of cornea had been broken, the corneal stress relaxation degree reduced. In flap-cut-only group, and groups of ablation depth of 30%, 50% and 70%, the stress relaxation degree all reduced. It was obviously shown in group of 70% depth ablation. That was, in LASIK operation, the more depth the ablation, the more reduce the stress relaxation, and it's easy to cause deformation and creep deformation.

LASIK had been used widely. About how the cornea changed, many researchers took up with the mechanical influence on cornea, to explore mechanism of surgery. Refractive surgery mainly change the curvature of cornea, correct the effect of refraction system. Generally, the mechanism of correction is that, by cutting the anterior layer of cornea, the peripheral corneal tissue may slightly steepen with the action of IOP, thus, the refractive power can be reduced. The ablation can change the rigidity of cornea which can deform under some factors.

In our experiment, it's found that changes of the stress relaxation in horizontal and vertical specimen were similar, and the change was slightly obvious in vertical specimen, especially in 70% ablation group, it's statistically significant (P <0.001). Some researchers performed visco-elastic experiments on cornea[10], and proved that human cornea had property of visco-elasticity. Our experiment was performed on porcine cornea, because it's difficult to obtain human cornea, and the porcine cornea is similar to human cornea for study [11], and is suitable to describe the stress relaxation with continuous spectrum. This experiment is to prove the

change of visco-elastic material of cornea, and provide the basic material properties for further finite element modelling.

In conclusion we found that changes of the stress relaxation in horizontal and vertical specimen were similar, and the change was slightly obvious in vertical specimen, especially in 70% ablation group, it's statistically significant (P<0.001). In LASIK operation, the more depth the ablation, the more reduce the stress relaxation, and it's easy to cause deformation and creep deformation.

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