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Biomechanical properties after pre-twist of canine patellar tendon

Accepted: 29 November 2000 / Published online: 24 February 2001
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Abstract We studied what effect a rotational pre-twist of the patellar tendon had on its mechanical properties. We used the central strip of canine patellar tendons. The length, width and thickness of each specimen were measured and the specimens were mounted in custom-made aluminum pots. Five groups of 10 specimens each were measured with neutral rotation, 90° external rotation, 180° external rotation, 270° external rotation and 360° external rotation. The ultimate stress, ultimate strain, average elastic modulus, and strain energy density were measured. There were no statistically significant differences among the five groups. Twisting the graft up to 360° did not decrease the biomechanical properties of the graft.

Résumé Le but de cette étude est d'apprécier l'effet d'une rotation de 360° du tendon patellaire sur ses propriétés mécaniques: contrainte et déformation à la rupture, module d'élasticité et densité d'énergie de déformation. Des chiens adultes bâtards ont été utilisés. La bande centrale du tendon patellaire a été prélevé en mesurant la longueur, la largeur et l'épaisseur des spécimens. Cinq 5 groupes de 10 spécimens ont été séparés: groupe 1 (rotation neutre), groupe 2 (rotation de 90°), groupe 3 (rotation de 180°), groupe 4 (rotation de 270°), et groupe 5 (rotation de 360°). Entre les différents groupes, la contrainte à la rupture, la déformation à la rupture, le module moyen d'élasticité et la densité d'énergie de déformation n'étaient pas statistiquement différents. La torsion de la greffe à 360 degrés n'a pas diminué les propriétés biomécaniques de la greffe dans notre étude.

Introduction

For reconstruction of the anterior cruciate ligament (ACL) some authors have advocated pre-twisting of the patellar tendon graft. Jackson and Reimar [8] have recommended a 90° pre-twist to decrease the possibility of abrasive wear on the tunnel edge and to facilitate fixation. As much as 180° pre-twist has been recommended [5]. Munns et al. [9] have described that pre-twist of 90° external rotation of patellar tendon graft increase the failure stress, average elastic modulus and strain energy density.

However, little work has been done on the effect of such pre-twisting on the biomechanical behavior of the patellar tendon grafts. The purpose of this study was to determine the effects of a pre-twist to 360° external rotation on the tensile mechanical properties of a canine patella-patellar tendon-tibial complex of ultimate stress, ultimate strain, average elastic modulus and strain energy density.

Materials and methods

The hind limbs of adult Mongrel dogs (obtained from the college of Veterinary Medicine, Kyungpook National University, Korea) were removed at time of death and frozen to -30°C. Use of the dogs was approved by the Institutional Animal Care and Use Committee. After the initial freeze, the specimens were thawed at 5°C overnight and dissected to patella-patellar tendon-tibial complexes. A central 3.5 mm strip was cut with a custom-made two-bladed scalpel calibrated to within 0.1 mm with vernier calipers. This width represented approximately the central third of the tendon.

Length was determined by vernier calipers on the posterior surface of the tendon positioned centrally on the patellar and tibial attachments. Thickness was measured at 5 mm distal to the patella and 5 mm proximal to the tibia. A mean of three measurements at each level was used. The cross-sectional shape of the patellar tendon was assumed to be rectangular and the area of cross-section was calculated by using the averages of measured thickness and width of the patellar tendon.

An Instron 4200 (series IX Automated Material Testing System v4.05a, Instron Corporation, Canton, Mass., USA) was

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Fig. 1 A potting mold custom-designed to embed the cross-pinned tibia in the lower rotatable cylinder and screw-held patella in the upper cylinder

Fig. 2 A typical load-displacement curve for patella-patellar tendon-tibia complex

used for data acquisition. The specimens were mounted vertically to allow a straight-line pull without impingement on the tendon (Fig. 1). Force was measured in Newtons directly from the load cell. Elongation was calibrated by grip-to-grip displacement measured directly from the unit (Fig. 2). Applied strain rate was 250 mm/min to failure of the patellar tendon. Only specimens failing in substance were used for data analysis.

The 50 specimens were randomly assigned to five groups (10 specimens per group) with different degrees of external rotation: neutral rotation, 90° external rotation, 180° external rotation, 270° external rotation and 360° external rotation.

The data obtained were evaluated for the following mechanical properties.

1. Ultimate stress: Ultimate load is referred to as the load at the point of in-substance rupture of the patellar tendon. Ultimate stress is then defined as the ratio of the ultimate load to the cross-sectional area of the initially untwisted patellar tendon measured in MPa.
2. Ultimate strain: Ultimate displacement is referred to as the grip-to-grip displacement at the point of in-substance rupture of the patellar tendon. The ultimate strain is then defined as the ratio in percentage of the ultimate displacement to the initial length of the untwisted patellar tendon.
3. Average elastic modulus: The ratio of the ultimate stress to the ultimate strain is defined as the average elastic modulus of the patellar tendon measured in MPa.
4. Strain energy density: The total energy absorbed at failure is given by the area under the load elongation curve up to the in-substance rupture of the patellar tendon. The strain energy density is defined as the ratio of the total energy absorbed at failure to the initial volume of the untwisted patellar tendon measured in MJ/m³. Parameters were normalized based on the measured dimensions of the specimens to mitigate variations between animals with respect to patellar tendon size.

The effects of pre-twist on the tensile mechanical properties of patellar tendon were analyzed by using two parametric one-way analysis of variance ($P1$) and non-parametric Kruskal-Wallis one-way analysis of variance ($P2$), with repeated measures followed by Schéffé multiple comparison test. A P -value of 0.05 or less was considered statistically significant.

Results

Table 1 shows the effects of pre-twist on the mechanical properties of patellar tendon. Ultimate stress had a tendency to decrease with increasing of external rotation, but there were no statistically significant differences among five groups ($P1=0.059$, $P2=0.095$). Ultimate strain also had a tendency to decrease with increasing external rotation. But there were no statistically significant differences among five groups ($P1=0.154$, $P2=0.165$). For the aver-

age elastic modulus and the strain energy density there were no statistically significant differences among the groups ($P1=0.061$, $P2=0.059$).

Discussion

This study focuses on the factors that affect the tensile mechanical properties of the graft itself in external rotation pre-twist.

Munns et al. [9] found an average 3–5° external rotation from patellar to tibia in canine patellar tendons. Butler et al. [3] and Amiel et al. [2] described the path of collagen fiber bundles in tendons as having a helical pattern rather than a linear pattern. Evans and Barbenel [7] and Yahia and Drouin [13] observed a helical course of collagen fiber bundles in the canine patellar tendon.

Alm et al. [1] reported a significant, progressive decrease in the failure load of canine patellar tendon from 0° to 180° rotation, irrespective of direction. Cooper et al. [6], by contrast, found a significant 30% increase in failure stress for 90° rotation. Munns et al. [9] reported that failure stress increased by 8% in 90° external rotation and decreased by 9% in 90° internal rotation. We found that ultimate stress decreased with increasing external rotation. In neutral rotation ultimate stress was 135.1 MPa and decreased with 22% to 105.2 MPa in 360° external rotation. The difference was not statistically significant ($P1=0.059$, $P2=0.095$).

Cooper et al. [6] reported that elongation of human bone-patellar tendon-bone composite grafts with 10 mm wide patellar tendon increased from 15.8% at 0° to 18.5% at 90° rotation. Alm et al. [1] documented a decrease in the failure elongation of canine patellar tendon from 5.4 mm at 0° to 5 mm at 90° rotation. In the study of Munns et al. [9] using canine patellar tendons, there was a small decrease in the failure strain from 23.3% at 0° to 22.8% at 90° rotation. In our study, ultimate strains were 28.8% at 0° rotation, 30.8% at 90°, 29.9% at 180°, 25.5% at 270°, and 24.6% at 360° rotation. Ultimate strain had a tendency to decrease with increasing external rotation of the patellar tendon. But the differences were not significant ($P1=0.154$, $P2=0.165$).

Munns et al. [9] reported that average elastic modulus increased by 6% in the 90° external rotation group, decreased by 6% in 90° internal rotation group from

Table 1 Results of tensile mechanical properties

	Ultimate stress (MPa)	Ultimate strain (%)	Average elastic modulus (MPa)	Strain energy density (MJ/m ³)
Neutral rotation ($n=10$)	135.14±14.44	28.80±4.33	477.02±88.12	25.01±4.85
90° external rotation ($n=10$)	130.75±12.86	30.82±3.08	426.86±54.92	27.47±4.66
180° external rotation ($n=10$)	131.22±16.90	29.97±5.16	448.11±98.28	25.98±6.00
270° external rotation ($n=10$)	115.55±7.58	25.53±4.96	465.79±89.74	21.00±2.54
360° external rotation ($n=10$)	105.20±26.69	24.60±3.20	424.07±62.44	19.39±3.72
$P1$	0.059	0.154	0.814	0.061
$P2$	0.095	0.165	0.818	0.059

$P1$, P -value of parametric one-way analysis of variance; $p2$, P -value of non-parametric Kruskal-Wallis one-way analysis of variance

the untwisted patellar tendon. In our study, there were no statistically significant differences among groups ($P1=0.154$, $P2=0.165$).

Strain energy density measurements for the ACL and bone-patellar tendon-bone has been reported by several authors [4, 10, 11, 12]. Significant differences were observed in the strain energy density due to variations in the tissue structure, orientation of the tissue during the application of loading, and age of the tissue. Munns et al. [9] reported that strain energy density was increased more in the 90° external rotation group than in the 90° internal rotation group. In our study, strain energy density showed a tendency to decrease with increasing external rotation. But the differences were not statistically significant ($P1=0.061$, $P2=0.059$).

We have identified some possible shortcomings in our methodology. First, no effort was made to estimate the age of the dogs, nor to document their weight. Finally, our specimen population was less homogenous and only included a small number of specimens. We performed a purely biomechanical study on the pre-twist of the patellar tendon without considering the angular course of the graft.

As a result, we observed that the ultimate stress, ultimate strain and strain energy density had a tendency to decrease with increasing of external rotation. Twisting the graft to 360° however, did not decrease the biomechanical properties of the graft. In the setting of an ACL reconstruction, the graft is passed through tunnels and courses around angles. The stress risers on an intra-articular central third patellar tendon graft would certainly affect its ultimate tensile strength in vivo. In addition, the changing biomechanical properties of the graft through revascularization and remodeling are unknown.

Acknowledgements We thank Dr. K.-H. Kim of the Department of Dental Material, School of Dentistry, Kyungpook National University for his kind technical assistance.

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