The Remained Patellar Tendon Strength after Central One Third Removal : A Biomechanical Study

WITOON LAIRUNGRUANG, MD*,
SOMSAK KUPTNIRATSAIKUL, MD**,
PIBUL ITIRAVIVONG, MD**

Abstract

The study was aimed at comparing the ultimate load bearing capabilities between normal patellar tendons (control group) and tendons after central one-third removal (removal group). Eleven fresh Thai cadavers provided study specimens. The average age of the cadavers was 24.86 ± 7.13 years. Five tendons were used as control specimens and another six tendons underwent central one-third removal. The Instron 5583 testing machine and Cooper's technique of measurements were used to test the ultimate load. Rate of elongation of tendon was set at 500 mm/sec.

The results showed that the removal group cross-sectional area was 48.67 mm^2 or 49.64 per cent of the control group (98.04 mm^2). The mean ultimate load of the control group was 4,365.59 N. The mean ultimate load of the removal group was 2,226.58 N or about 51 per cent. The energy level to breaking point in the control group was 72.17 J and 32.58 (45.14%) in the removal group. The average width of the central one-third portion was measured at 8.68 ± 0.56 cm.

Generally in a clinical situation, when the ultimate load is reduced to about half in the donor knee, care must be taken before allowing full weight to bear. Caution should also be emphasized in cases where a routinely 10 mm wide graft has been taken, as the donor tendon may be weakened by more than half and may rupture prematurely.

Key word : Patellar Tendon Graft, ACL Reconstruction, Tensile Strength of Patellar Tendon

**LAIRUNGRUANG W,
KUPTNIRATSAIKUL S, ITIRAVIVONG P
J Med Assoc Thai 2003; 86: 1101-1105**

* Department of Orthopaedic Surgery, Chai Nat Hospital, Chai Nat 17000,
** Department of Orthopedics, Faculty of Medicine, Chulalongkorn University, Bangkok 10330, Thailand.

Bone-patellar tendon-bone (B-PT-B) graft is a well-known graft for anterior cruciate ligament (ACL) reconstruction. Noyes et al had tested tensile strength of central one-third (14 mm) patellar tendon grafts and reported that their strength was about 168 per cent of normal ACL[1]. Cooper et al tested the same kind of graft of various widths and found that the tensile strength of the graft was related to the width and the cross-sectional area of the graft[2]. It is probable that the patellar tendon graft is now the most suitable graft for ACL reconstruction. But it should be considered further. Donor site morbidity is one of the major problems occurring. The donor tendon will be weakened and has the risk of rupturing, but it is unknown how high the relative risk is.

Shelbourne reported an accelerated rehabilitation program after ACL reconstruction in 1990[3]. Although it was successful as reported in his paper, some surgeons remain in doubt about the strength of the donor and the graft. This study was aimed to compare the ultimate load of the normal tendon and the tendon after central one-third-graft removal. The results may give clues for the surgeons' confidence level, concerning the early rehabilitation program.

MATERIAL AND METHOD

The entire patella-patellar tendon-tibial tubercle composite grafts were taken from fresh cadaveric knees. The cadavers, at the time of death, had an age range from 15-45 years old and had no history of knee injury. The grafts were processed by embedding in saline soaked gauze covered with aluminum foil and a plastic bag, then kept frozen at -60°C until the time of testing.

The authors obtained 11 grafts from 7 Thai cadavers (6 males and 1 female). The average age of the donors was 24.86 ± 7.13 years. At the time of testing, the grafts were thawed at room temperature, and moistened with normal saline solution while thawing. Then the grafts were prepared for biomechanical testing. The cross-sectional area of the graft was measured using wet gravitation direct measurements. The tissue was kept moistened throughout the preparative process. The measurements were taken at the proximal, middle and distal parts of the tendons, three times at each level. The average value was recorded as the dimensions of the grafts.

The grafts were then divided into 2 groups by randomization. Group 1 consisted of the entire tendon. The donor tendons, after central one-third-graft removal, were placed in group 2. In group 2, the dimensions were measured again from the donated tendons and the grafts. Both patella and tibial portion were potted in a stainless steel mold using epoxy glue to hold firmly in place. The potting a modified version of Cooper's technique of potting was used (Fig. 1).

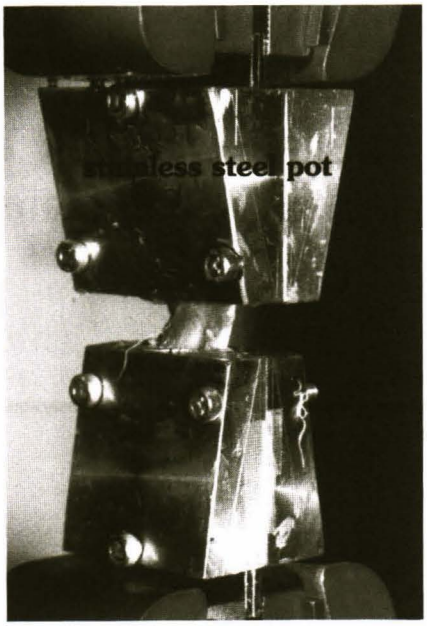

Fig. 1. The bony portions were fixed in the stainless steel pot with epoxy glue.

Biomechanic testing was performed using an Instron 5583 testing machine with a 150 KN load cells. The pots were clamped with the machine grips (Fig. 2). The elongation rate was set at 500 mm/sec to approximate the fast rate used by previous authors [1,2] (It is the fastest rate of the machine.) The specimens, those that had major bony avulsion because of stress risers in the fixation system, were discarded. Tissue elongation was measured by distance between the pots. The biomechnical values (ultimate load, stress, strain, Young modulus, energy to failure and toughness) were reported by the Instron 5583 machine. The statistical analysis was performed using arithmetic means and two-tailed Student's *t*-test.

RESULTS

The tendons tested mostly ruptured at the tendon mass, near their insertion to the patella bone, as occurring in clinical normal patellar tendon rupture (Fig. 3). The measurements of ultimate load, cross-sectional area, stress, strain energy to failure and toughness were shown in Table 1. The ultimate load

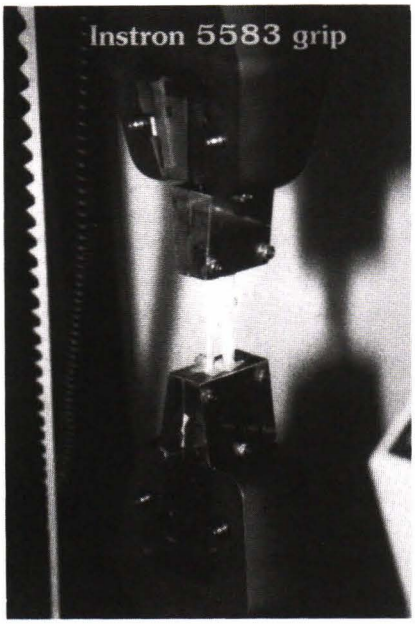

Fig. 2. The pots were clamped with the Instron machine grips.

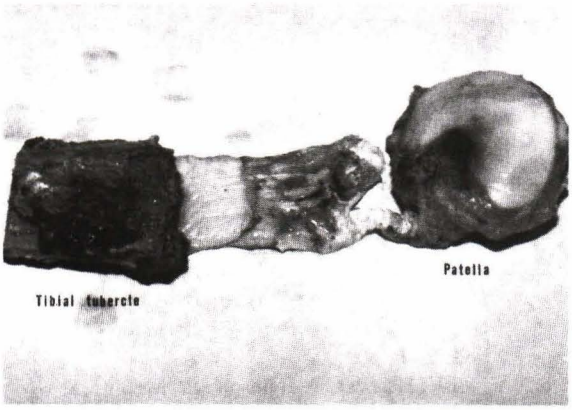

Fig. 3. Patellar tendon tested ruptured near the insertion to patellar bone.

and energy to failure between group 1 and group 2 were statistically significant ($p < 0.001$). Average width of central one-third of the patellar tendons tested (group 2) was 8.68 ± 0.56 mm. The mean cross-sectional area of group 2 was 49.64 per cent that of group 1. The mean ultimate load and the energy to failure of group 2 were 51 per cent and 45.14 per cent those of group 1 respectively.

The dimensions of all 11 patellar tendons were 3.45 ± 0.31 mm thickness, 26.75 ± 1.90 mm width, and 92.72 ± 13.56 mm^2 cross-sectional area. The means width of the central one-third of patellar tendons was 8.92 ± 0.63 mm (not significantly different from the central one-third of patellar tendons in group 2).

DISCUSSION

The viscoelastic properties of the tendon will be affected by the slow rate of elongation[4,8]. The creep property of the tendons will cause the slow rate of elongation to decrease the ultimate load[4,5]. So the authors chose the fast rate as previous authors did [1,2]. Woo SL-Y et al reported that the frozen - state did not affect the tensile properties of ligaments[6,8]. As the specimens were kept frozen, the tensile properties of the tendons should not have been adversely affected.

From measurements of the dimension of the patellar tendons, the authors found that the average width of the tendon grafts was narrower than expected. Average central one-third width was only 8.68 mm. In ACL reconstruction, some surgeons routinely use central 10 mm graft. If the authors extrapolate the results to Thai people, it may be assumed that the 10 mm graft of Thai people may be bigger than the central one-third graft. After graft removal the authors found that the cross-sectional area was decreased to about half, which may be due to the inequality of the thickness of the central and the peripheral portion of the patellar tendon.

Cooper et al reported that the ultimate load of the tendon was related to the cross-sectional area [2]. The present study found that taking the central one-third graft reduced the cross-sectional area to one half and ultimate load was also reduced to one half. So if a graft more than central one-third is taken, the donor tendon might weaken even more than half. This figure may appear unacceptable dreadful. However, Curwin and Stanish estimated that the tensile load on the patellar tendon when walking was about 500 N, when landing from a jump it was about 8,000 N, and when running fast it was about 9,000 N[7]. The data may be misinterpreted because the figures from a different method of evaluation can't be compared directly. Curwin's data was obviously bigger than the present study (in the present study, the normal patella tendon ultimate load was only about 4,000 N). So if we compared relatively, it suggested that although the

Table 1. Biomechanical variables of the patellar tendon tested.

Group	Area (mm^2)	Ultimate Load (N)	Stress (Mpa)	Strain	Young modulus	Energy to Failure (J)	Toughness (Mpa)
1 (n = 5) control group	98.04 ±15.04	4,365.59 ± 683.36	44.77 ± 5.19	132.78 ± 60.61	67.32 ± 32.18	72.17 ± 10.61	39.94 ± 12.50
2 (n = 6) removal group	48.67* ± 5.91	2,226.58* ± 399.52	46.31 ± 9.65	94.19 ± 57.91	113.31 ± 104.81	32.58* ± 4.67	34.92 ± 12.25

*significant statistical difference $p < 0.001$

central one-third patellar tendon graft removal gives rise to the weakness of the quadriceps mechanism of the donor tendon, the donor tendon still has the required strength enough for walking though not for running and jumping[9].

SUMMARY

The donor patellar tendon was tested for ultimate load before and after central one-third graft removal. The study showed that the donor tendons were decreased in their ultimate load and energy to failure properties to about a half. The central one-third width was only 8.68 mm which is narrower than the usual use of 10 mm graft. So if we routinely take 10 mm graft as recommended in the literature it means that the Thai donor tendon will be weakened for more than half. The rehabilitation program for the patients must be aware of this weakness of the quadriceps mechanism.

(Received for publication on February 26, 2003)

REFERENCES

1. Noyes FR, Butler DL, Grood ES, Zernicke RF, Hefzy MS. Biomechnical analysis of human ligament grafts used in knee ligament repairs and reconstructions. J Bone Joint Surg 1984; 66-A: 344-52.
2. Cooper DE, Deng XH, Burstein AL. Warren RF. The strength of the central third patellar tendon graft, a biomechanical study. Am J Sports Med 1993; 21: 818-23; discussion 823-4.
3. Shelbourne KD, Nitz P. Accelerated rehabilitation after anterior cruciate ligament reconstruction. Am J Sports Med 1990; 18: 292-9.
4. Grood ES, Noyes FR. Cruciate ligaments prosthesis: Strength, creep, and fatigue properties. J Bone Joint Surg 1976; 58-A: 1083-8.
5. Mow VC, Flatow EL, Foster RJ. Biomechanics. In Simon SR, ed. Orthopaedic Basic Science. The American Academy of Orthopaedic Surgeons, 1994: 397-446.
6. Woo SL-Y, Orlando CA, Camp JF, et al. Effects of postmortem storage by freezing on ligament tensile behavior. J Biomech 1986; 19: 399-404.
7. Aglietti P, Buzzi R, Insall JN Disorders of the patellofemoral joint. In. Insall JN, Windsor RE, Kelly MA, et al, eds. Surgery of the knee. Vol. 1.2nd ed. New York: Churchill Livingstone; 1993: 241-385.
8. Fu FH, Harner CD, Johnson DL, Miller MD, Woo SL-Y. Biomechanics of knee ligaments: Basic concepts and clinical application. Instr Course Lect 1994; 43: 137-48.
9. Zernicke RF, Garhammer J, Jobe FW. Human patellar-tendon rupture, a kinetic analysis. J Bone Joint Surg 1977; 59-A: 179-83.

การวิเคราะห์ทางชีวกลศาสตร์ : ความแข็งแรงของเอ็นสะบ้า ภายหลังการนำ graft ไปใช้ในการสร้างเอ็นแอนทีเรีย ครูซิเอ็ท

วิฑูรย์ ไหลรุ่งเรือง, พบ,*
*สมศักดิ์ คุปต์นิรัติศัยกุล, พบ**, พิบูลย์ อิทธิระวิวงศ์, พบ***

การศึกษานี้มุ่งหวังที่จะเปรียบเทียบความแข็งแรง (ultimate load) ระหว่างเอ็นสะบ้าปกติและเอ็นสะบ้าภายหลังการนำ graft central one-third ไปใช้ในการทำ ACL reconstruction

เอ็นสะบ้า 11 ชิ้น ถูกนำจาก fresh cadaver คนไทย 7 คน อายุเฉลี่ยของ cadaver 24.86 ± 7.13 ปี ใช้วัด ultimate load ของเอ็นสะบ้าปกติจำนวน 5 ชิ้น และ นำไปตัด graft central one-third ออกจำนวน 6 ชิ้น ใช้เครื่องมือ Instron 5583 และใช้วิธีการของ Cooper's ในการทดสอบ ultimate load อัตราการยืดของ tendon ตั้งไว้ที่ 500 มม/วินาที (ความเร็วสูงสุด)

ผลการทดลองพบว่า tendon ที่ถูกนำ graft ไปแล้ว จะเหลือพื้นที่หน้าตัด 48.67 มม^2 เทียบเป็น 49.64% ของเอ็นปกติ (98.04 มม^2) ค่า ultimate load ของเอ็นปกติ 4,365.59 N แต่เอ็นที่นำ graft ไปแล้วเหลือ 2,226.58 N (51%) พลังงานที่ใช้เพื่อทำให้ขาด 72.17 J และ 32.58 J (45.14%) ในเอ็นปกติ และเอ็นภายหลังนำ graft ตามลำดับ ความกว้างเฉลี่ยของ graft ที่นำออกไปเท่ากับ 8.68 ± 0.56 มม

ในทางคลินิก เนื่องจาก ultimate load ลดลงประมาณครึ่งหนึ่งในเข่าที่เป็น donor จึงต้องระมัดระวังก่อนที่จะให้ผู้ป่วยได้เริ่มเดินลงน้ำหนักเต็มที่ และควรจะต้องระมัดระวังเพิ่มขึ้น ในรายที่นำ graft กว้าง 10 มม ซึ่งอาจมากกว่า 1/3 ของความกว้างของเอ็นในคนไทย เพราะ tendon ที่เหลืออาจจะลดความแข็งแรงไปเกินครึ่ง และอาจขาดได้ถ้าทำกิจกรรมที่แรงเกินไป

คำสำคัญ : เอ็นสะบ้า, การสร้างเอ็นแอนทีเรีย ครูซิเอ็ท, ความแข็งแรงของเอ็น

วิฑูรย์ ไหลรุ่งเรือง, สมศักดิ์ คุปต์นิรัติศัยกุล, พิบูลย์ อิทธิระวิวงศ์
จดหมายเหตุทางแพทย์ ฯ 2546; 86: 1101-1105

* กลุ่มงานศัลยกรรมออร์โธปิดิกส์, โรงพยาบาลชัยนาท, ชัยนาท 17000
** ภาควิชาศัลยศาสตร์ออร์โธปิดิกส์, คณะแพทยศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย, กรุงเทพ ฯ 10330