ACTA
ORTHOPAEDICA
et
TRAUMATOLOGICA
TURCICA

Author’s translation
Acta Orthop Traumatol Turc 2005;39(4):356-360

The effect of the tibial tunnel fixation level on the results of cyclic loading in anterior cruciate ligament reconstruction

Ön çapraz bağ rekonstrüksiyonunda tibial tünel tespit seviyesinin tekrarlayıcı yüklenme testi sonuçlarına etkisi

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Amaç: Bu çalışmada, ön çapraz bağ (ÖÇB) rekonstrüksiyonunda yumuşak doku tendon greftinin, tibial tünelde yumuşak doku interferans vidası ile anatomik olmayan (eklemden uzak) ve anatomik (ekleme yakın) seviyede tespiti biyomekanik olarak karşılaştırıldı.

Çalışma planı: On iki adet dana tibiası ve dana ekstansör digitorum süperfisialis tendonu, yumuşak dokulardan temizlenerek altışarlı iki homojen gruba ayrıldı. Kırk beş dereceye ayarlanmış ÖÇB kılavuzu yardımıyla tibialara 7 mm çapında tüneller açıldı. Her bir tünel, genişleticilerin çapı 0.5 mm artırılarak 9 mm'ye kadar genişletildi. Tendonlar 9x30 mm'lik yumuşak doku interferans vidası ile tibial tünele anatomik olmayan (grup I) ve anatomik (grup II) seviyede tespit edildi. Tüm örneklere, servo-hidrolik test cihazında önce 500 kez 50-250 N arasında değişen sinüzoidal kuvvetle 1 Hz frekansı ile tekrarlı yük verildi, sonra 20 mm/dk hızla en yüksek dayanma kuvveti (load to failure) belirlenmek üzere gerilme testi uygulandı. İstatistiksel analizler Mann-Whitney U-testi ile yapıldı.

Sonuçlar: Ortalama vida ilerleme torku I. ve II. gruplarda sırasıyla 8.2±2.4 Nm ve 7.8±2.3 Nm bulundu ($p=0.88$). Tekrarlayıcı yüklenme testi uygulandıktan sonra greftlerde ortalama yer değiştirme sırasıyla 1.9±0.75 mm ve 2.2±1.2 mm ($p=0.63$), sertlik (stiffness) ise sırasıyla 132.72±10.93 N/mm ve 125.14±15.93 N/mm ($p=0.63$) bulundu.

Çıkarımlar: Ön çapraz bağ rekonstrüksiyonunda kullanılan yumuşak doku tendon greftinin tibial tünelde interferans vidası ile anatomik olmayan ve anatomik seviyede tespitinin biyomekanik olarak farklılık oluşturmadığı sonucuna varıldı.

Anahtar sözcükler: Emilebilir implant; ön çapraz bağ/cerrahi; biyomekanik; kemik yoğunluğu; kemik vidası; dana; tendon/transplantasyon; gerilme kuvveti; tibia/cerrahi; tork.

Objectives: This study was designed to compare the biomechanical characteristics of non-anatomic (far from joint) and anatomic (close to joint) levels of tibial tunnel fixation with soft tissue graft using a soft tissue interference screw in anterior cruciate ligament (ACL) reconstruction.

Methods: Twelve bovine tibiae and digital extensor tendons were divided into two homogeneously equal groups after removing soft tissues. Tibial tunnels were prepared with a 7-mm drill with the use of an ACL guide adjusted to 45°. Each tunnel was then dilated to 9 mm in 0.5 mm increments. Digital extensor tendons were fixed at non-anatomic (group I) or anatomic (group II) tibial tunnel levels with a soft tissue metal interference screw, 9x30 mm in size. All the specimens were cycled 500 times from 50 to 250 N with 1 Hz frequency in a servo-hydraulic testing machine followed by ultimate load at-failure testing at a rate of 20 mm/min. Statistical analyses were made using the Mann-Whitney U-test.

Results: The mean screw insertion torque values were 8.2±2.4 Nm and 7.8±2.3 Nm in groups I and II, respectively ($p=0.88$). The mean values of graft displacement (1.9±0.75 mm versus 2.2±1.2 mm, $p=0.63$) and stiffness (132.72±10.93 N/mm versus 125.14±15.93 N/mm, $p=0.63$) did not differ significantly, either.

Conclusion: The biomechanical properties of ACL reconstruction with soft tissue graft fixation using a soft tissue interference screw are not influenced by the level of tibial tunnel fixation.

Key words: Absorbable implants; anterior cruciate ligament/surgery; biomechanics; bone density; bone screws; cattle; tendons/transplantation; tensile strength; tibia/surgery; torque.

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Received: 30.12.2004 **Accepted:** 31.05.2005

Reconstruction of the ligament is a common treatment method in the acute and chronic ruptures of the anterior cruciate ligament (ACL). Various types of grafts and fixation methods have been employed in such surgeries. Recently, soft tissue tendon grafts have been widely used due to lesser donor site morbidity,[1] no extreme functional insufficiency,[2] abundant endurance of the graft and a biomechanical function similar to ACL. On the other hand, disadvantages of such grafts are that the graft requires longer union period as it has no bone blocks,[3] and the fixation on the tibial side provides a weaker link. Although many methods have been attempted to overcome these disadvantages, still no agreement exists particularly on the fixation of the soft tissue tendon graft.[4-7]

The fixation strength of grafts is significantly influenced by the regional bone mineral density. Weiler et al.[8] hypothesized that non-anatomic fixation has a higher graft fixation strength when it is fixed with the tibial tunnel entry as this region consists of cortical bones, and it is where the screw is contacted most tightly with the graft. Same authors indicated that fixation strength of the graft is as important as the size of the graft for the stability of the knee following an ACL reconstruction.

The objective of this study was to compare the effect of fixating the soft tissue tendon grafts with a soft tissue interference screw at non-anatomic and anatomic levels of the tibial tunnel on the biomechanical parameters. As biomechanical parameters, we evaluated the insertion torque (described as the strength confronted while the screw advances within the tunnel), the stiffness (described as the difference occurred at the length of the free graft between the two fixation points when an unit power is applied) and the maximum load to failure (described as the limit where the endurance against the applied power disappears).

Material and method

We used 12 fresh bovine knees. All tibia samples were harvested from one-year old healthy animals, and placed in a deep freezer within one hour in plastic bags. The bovine tibiae were divided into two equal groups.

The frozen samples were allowed to thaw at room temperature (24 °C) 24 hours before testing. Tibiae were used within one week after harvesting. Following the removal of soft tissues, bone mineral density of each tibia was measured using the DEXA (dual energy X-ray absorptiometry) screening system (Hologic QDR-4500, Hologic Inc., Waltham, MA, USA). During these measurements, the tibiae were kept in 15x25 cm plastic buckets containing physiologic saline solution. Twelve bovine extensor digitorum superficial grafts (70 mm long and 8 mm wide) were debrided of soft tissues, and prepared as double-pedicled (pediculated) using the interlocking whipstitch method with an Ethibond No. 2 suture (Ethicon Inc., Somerville, NJ, USA) (Figure 1). A graft table was used during the preparation and before the fixation for stretching. Before the fixation, a 3 kg load was applied on the graft table for 15 minutes in order to attenuate its effect on the displacement and stiffness. Then, the tibial tunnel was prepared by a 7 mm drill with a 45 degrees angle to the tibial plateau as described by Howell et al.[9] and, dilated with 7.5, 8, 8.5 and 9 mm dilators.

After the tibial tunnels were ready, soft tissue grafts were placed into each tunnel, followed by fixations at non-anatomic (far from joint) level in Group I, and anatomic (close to joint) level in Group II by 9x30 mm soft tissue interference screws. The screw insertion torque was measured by a torque meter (P3 Strain Indicator, 4 Channel, Vishay Measurements Group, USA). Then, the bovine tibiae cut into similar pieces were embedded in polyester steel plaster, and a worst-case-scenario was established, positioning them with a 45° angle to the fixation table as to transfer the tensile load directly onto the tibial tunnel (Figure 2). The specimens were duly placed into the custom designed Servo-Hydraulic Universal Test Machine (Mechanics Department of Engineering Faculty, ITU - 2003, 200 psi).

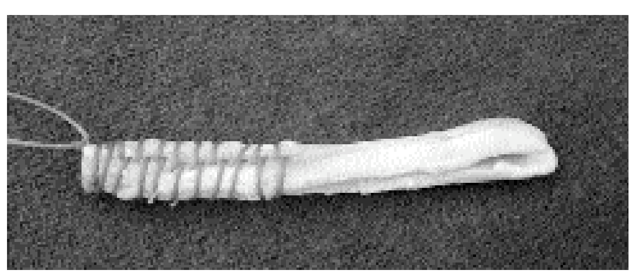

Figure 1. Double-pedicle bovine extensor digitorum superficial tendon prepared by interlocking whipstitch method with No.2 Ethibond.

The specimens were prepared for tension procedure in this position. The grafts which were fixed to the bone were tied to the load cell (ESIT, SPA 300 kg, S/N 223) connected to the servo-hydraulic test machine by inserting a steel needle between the two legs of the free ends). A dynamic stress was applied on the grafts by a repetitive load of 1 Hz frequency, with a sinusoidal force ranging from 50 to 250 Newton (N) for 500 times by the testing machine.

Each specimen was, statically and as initiated from zero N, loaded in a tension test at a speed of 20 mm/min until the damage occurs. During these procedures, changes in the size of grafts were concomitantly and dynamically transferred to the computer by means of a potentiometric displacement transducer (Micro-Epsilon WDS 300 P60 CR P, S/N 4600). The data were directly recorded in the computer by a data collection system called “ESAM Traveller” (ESA Messtechnik, GmbH, Olching, Germany; Type 1032-S, S/N 0060502) at a speed of 100 Hz/sec.

Statistical analyses were performed using the Mann-Whitney U-test, and SPSS for Windows version 11.0 software program; $p<0.05$ was considered significant.

Results

The mean bone mineral density was similar in both groups (Group I 0.898±0.22 g/cm2, Group II 0.910±0.32 gr/cm2, $p=0.96$). The mean screw insertion torque values were 8.2±2.4 Nm and 7.8±2.3 Nm in groups I and II, respectively with no significant difference ($p=0.88$). All specimens completed the

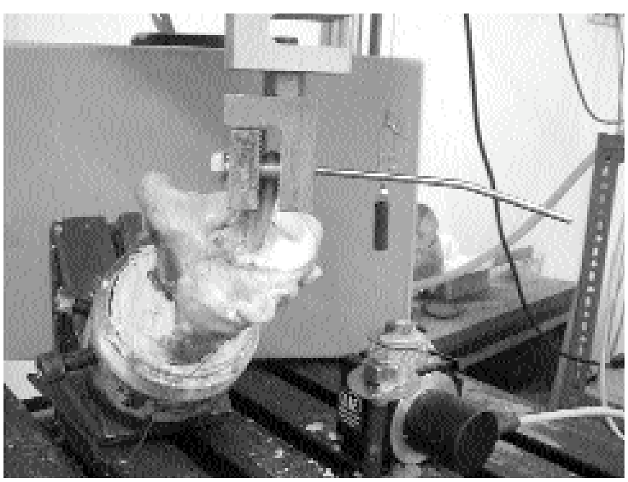

Figure 2. Servo-hydraulic testing system.

Table 1. The maximum load to failure strength values (N)

Specimens	Group I	Group II
1	450	685
2	725	850
3	645	715
4	375	320
5	790	610
6	740	695

cycling loading test without any damage. The mean graft displacement was 1.9±0.75 mm in Group I, and 2.2±1.2 mm in Group II, No significant difference was found between the two groups ($p=0.63$). Furthermore, stiffness did not differ significantly in either group (132.72±10.93 N/mm versus 125.14±15.93 N/mm, $p=0.63$). In Group I, two grafts (450 N and 375 N), and in Group II one graft (320 N) left the screw inside the tunnel, and reached the maximum load to failure strength. All the remaining specimens reached the maximum load to failure strength when the screw cut out of the graft (bunun başka türlü bir ifade edilme biçimi olabilir, emin değilim). Selby et al.[10] defined the slippage of graft past the tunnel leaving the screw as the actual inadequate fixation strength during the cycling loading tests. Therefore, actual graft-screw-tunnel complex fixation strength was not measured. The maximum load to failure strength for specimens is provided in Table 1.

Discussion

The knee stability can be enhanced by increasing the graft fixation strength and taking the advantages of biomechanical characteristics of the graft selected in the anterior cruciate ligament reconstruction. In a study by Nyland et al.[11] using synthetic bones, it was found that there was a positive correlation between the bone mineral density, screw insertion torque and graft fixation strength; and also that bone mineral density significantly increased the tibial tunnel fixation strength. Similarly, the screw geometry has an effect on the graft’s fixation strength. Weiler et al.[12] found that as the diameter and size of the screw are increased, the screw-graft contact area is also increased, which in turn results in increased screw fixation strength. In the same study, it was also reported that the length of the screw had more effect on the graft fixation strength compared to the diameter of screw; therefore, if any absorbable screw is to be used for fixation, it is required to use a longer screw.

Fineberg et al.[13] also indicated that any angulation between screw and graft exceeding 15 degrees significantly reduces the fixation strength, and also that graft and screw should be in parallel in graft fixations.

Another variable, which has an impact on the graft fixation strength, is the fixation depth of the screw at the tibial tunnel. As the screw cannot be as long as the tunnel itself, it cannot completely cover the tunnel, and it can remain at any level of the tunnel during fixation. Selby et al.[10] suggested that for a more strengthful fixation, the screw should be in contact with the cortical bone. However, in the anatomic fixation, the graft is tightened with the body of the screw, and the cancellous bone of the tibia is in this region.. Ishibashi et al.[14] indicated that the graft fixation level at the tibial side has a great impact on the knee kinematics and a more stable knee was achieved with anatomic fixation. On the other hand, in non-anatomic tunnel fixations, the windshield wiper effect is increased, which in turn leads to expansion of the tunnel and delay in the bone-graft union.[14,15]

The stiffness of the graft and fixation complex is an indication of the knee stability in the anterior cruciate ligament reconstruction. The graft size has an effect on the stiffness. The more the size of the graft remaining after fixated to the tibial and femoral tunnels, the lower the stiffness. Magen et al.[5] reported that graft size and fixation complex have an impact on the stiffness, and the graft-screw-tunnel fixation stiffness contributed more compared to the graft's stiffness; therefore, any fixation level which increases the fixation strength may increase the stiffness of the fixation level, resulting in a more stable knee.

Phillips et al.[16] compared the screw insertion torque for fixations in the distal third, middle third, and proximal third of the tibial tunnel using human cadavers and absorbable screws; but, they didn't evaluate biomechanical parameters like displacement, stiffness and fixation strength. Their distal third and proximal third correspond to our non-anatomic and anatomic fixations, respectively.

There is a remarkable difference between the two studies in the insertion torque. They found that the insertion torque was significantly different in the distal third and proximal third of the tibial tunnel (8.7 Nm and 4.3 Nm, respectively).

However, in our study the screw insertion torques were similar for both regions, and the difference was not significant. In the above-mentioned study, the diameter of the tunnel was drilled 2 mm smaller than the diameter of graft, and equaled to the diameter of graft by dilators and absorbable screws of the same size were used. The course of the screw in the fixation of the tibial proximal third is longer; so, the abrasion in the grooves of screw would be higher. Therefore, we believe that fixation at proximal third or anatomic level may lead to more abrasion in the screw, resulting in a decreased screw insertion torque. Lack of any measurement on the bone mineral density and any definition for describing the parameters to divide the groups are the weak points of the above-mentioned study. Lack of any parallel results from the two studies, as we believe it, can be attributed to the fact that in our study the bone mineral density in both groups was very similar, and we used soft tissue interference screws.

The bone mineral density has a great effect on the outcome in the graft-screw fixations. If it is not standard, we cannot study the effect of other variables on the fixation. Therefore, before starting the study, we measured the bone mineral density of all bones to be analyzed so that we eliminated the effect of such variable on the outcomes.

We used bovine knees in our study as it is easily available and the quality of bone is similar to the quality of human bone. Shapiro et a.[17] indicated that the bovine bone is very similar to the human bone in biomechanical studies. It has also been reported that no significant difference is evident between the young adult human bone and the bovine bone.[12,18] As graft, bovine extensor digitorum superficial tendons were used.

The bovine bone was preferred because it is more easily available compared to the cadaver tendons and it has a similar stiffness and viscoelastic behavior against the high strength applied onto the human semitendinous-gracilis tendons.[18,19] We used dilation method while preparing the tibial tunnel in order to enhance the fixation strength by increasing the density of cancellous bone. As the cycling loading test used in our study is an animation of the effect of a post-operative rehabilitation program, results of such a test is very helpful in guiding the orthopedists.

During the cycling loading tests, we found that the screw fixation level has no effect on the stiffness and displacement. Based on this, we assume that a more stable knee can be achieved by shortening the size of graft, which is the second variable, to enhance the stiffness of graft by an anatomic fixation as suggested by Ishibashi et al.[14]

Acknowledgement

We would like to extend our thanks to Ayşe Öztürk, the radiology technician who performed the bone mineral intensity measurements, and to Erol Erdoğan, MD, PhD, who contributed to the writing of this article.

References

1. Brown CH Jr, Steiner ME, Carson EW. The use of hamstring tendons for anterior cruciate ligament reconstruction. Technique and results. Clin Sports Med 1993;12:723-56.
2. Yasuda K, Tsujino J, Ohkoshi Y, Tanabe Y, Kaneda K. Graft site morbidity with autogenous semitendinosus and gracilis tendons. Am J Sports Med 1995;23:706-14.
3. Hoffmann RF, Peine R, Bail HJ, Sudkamp NP, Weiler A. Initial fixation strength of modified patellar tendon grafts for anatomic fixation in anterior cruciate ligament reconstruction. Arthroscopy 1999;15:392-9.
4. Aglietti P, Buzzi R, Zaccherotti G, De Biase P. Patellar tendon versus doubled semitendinosus and gracilis tendons for anterior cruciate ligament reconstruction. Am J Sports Med 1994;22:211-7.
5. Magen HE, Howell SM, Hull ML. Structural properties of six tibial fixation methods for anterior cruciate ligament soft tissue grafts. Am J Sports Med 1999;27:35-43.
6. Kocabey Y, Nawab A, Caborn DN, Nyland J. Endopearl augmentation of bioabsorbable interference screw fixation of a soft tissue tendon graft in a tibial tunnel. Arthroscopy 2004;20:658-61.
7. Scheffler SU, Sudkamp NP, Gockenjan A, Hoffmann RF, Weiler A. Biomechanical comparison of hamstring and patellar tendon graft anterior cruciate ligament reconstruction techniques: The impact of fixation level and fixation method under cyclic loading. Arthroscopy 2002;18:304-15.
8. Weiler A, Richter M, Schmidmaier G, Kandziora F, Sudkamp NP. The EndoPearl device increases fixation strength and eliminates construct slippage of hamstring tendon grafts with interference screw fixation. Arthroscopy 2001;17:353-9.
9. Howell SM, Wallace MP, Hull ML, Deutsch ML. Evaluation of the single-incision arthroscopic technique for anterior cruciate ligament replacement. A study of tibial tunnel placement, intraoperative graft tension, and stability. Am J Sports Med 1999;27:284-93.
10. Selby JB, Johnson DL, Hester P, Caborn DN. Effect of screw length on bioabsorbable interference screw fixation in a tibial bone tunnel. Am J Sports Med 2001;29:614-9.
11. Nyland J, Kocabey Y, Caborn DN. Insertion torque pullout strength relationship of soft tissue tendon graft tibia tunnel fixation with a bioabsorbable interference screw. Arthroscopy 2004;20:379-84.
12. Weiler A, Hoffmann RF, Siepe CJ, Kolbeck SF, Sudkamp NP. The influence of screw geometry on hamstring tendon interference fit fixation. Am J Sports Med 2000;28:356-9.
13. Fineberg MS, Zarins B, Sherman OH. Practical considerations in anterior cruciate ligament replacement surgery. Arthroscopy 2000;16:715-24.
14. Ishibashi Y, Rudy TW, Livesay GA, Stone JD, Fu FH, Woo SL. The effect of anterior cruciate ligament graft fixation site at the tibia on knee stability: evaluation using a robotic testing system. Arthroscopy 1997;13:177-82.
15. Morgan CD, Kalmam VR, Grawl DM. Isometry testing for anterior cruciate ligament reconstruction revisited. Arthroscopy 1995;11:647-59.
16. Phillips BB, Cain EL, Dlabach JA, Azar FM. Correlation of interference screw insertion torque with depth of placement in the tibial tunnel using a quadrupled semitendinosus-gracilis graft in anterior cruciate ligament reconstruction. Arthroscopy 2004;20:1026-9.
17. Shapiro JD, Jackson DW, Aberman HM, Lee TQ, Simon TM. Comparison of pullout strength for seven- and nine-millimeter diameter interference screw size as used in anterior cruciate ligament reconstruction. Arthroscopy 1995;11:596-9.
18. Giurea M, Zorilla P, Amis AA, Aichroth P. Comparative pull-out and cyclic-loading strength tests of anchorage of hamstring tendon grafts in anterior cruciate ligament reconstruction. Am J Sports Med 1999;27:621-5.
19. Ferretti A, Conteduca F, Labianca L, Monaco E, De Carli A. Evolgate fixation of doubled flexor graft in anterior cruciate ligament reconstruction: biomechanical evaluation with cyclic loading. Am J Sports Med 2005;33:574-82.