Biomechanical Study of Bone-Patellar Tendon-Bone and Bone-ACL-Bone Grafts

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Abstract

Twenty Rottweier dogs were included to investigate the biomechanical behaviors of bone-patellar tendon-bone and bone-ACL-bone grafts for ACL reconstruction. Those dogs were further divided into three experimental groups and one control group. The group I was sacrificed three months after ACL reconstruction, the group II, six months and the group III, twelve months. For bone-patellar tendon-bone graft, the mean maximum tensile strength was 117.1 N in the group I, 232.8 N in the group II and 777.4 N in the group III. For bone-ACL-bone autograft, the mean maximum tensile strength was 458.7 N in the group I, 814.4 N in the group II and 1064.1 N in the group III. The mean maximum tensile strength was 1461.7 N in the control group. This study revealed the bone-ACL-bone graft has a better result than bone-patellar tendon-bone graft for ACL reconstruction in the dog model.

Keywords: ACL reconstruction, Bone-patellar tendon-Bone, Bone-ACL-Bone, Biomechanical evaluation.

Introduction

The major mechanical role of ligaments is to maintain smooth movement of joints and to restrain excessive joint displacements under high loads. The anterior cruciate ligament (ACL) of the knee is frequently injured primarily during sport activities, such activities accounting for as much as 90% of all knee ligament injuries in young and active individuals [1]. The mechanical role of ACL is to restrain excessive anterior translation of the knee. Surgical reconstruction of ACL is generally considered in active young adult with instability of knee, or multiple ligament injuries [2].

Reconstruction of the ACL using a variety of autologous grafts is a common procedure in reconstructive knee surgery [3-5]. The hamstring-tendon grafts as well as the bone-patellar tendon-bone (BPTB) grafts had good clinical and functional results [6-9]. However, those grafts still have some disadvantages. The disadvantages of hamstring tendons include their strength, potential elongation of the graft during the postoperative period, less secure graft fixation, and a longer time needed for incorporation into bone tunnels [10]. The biomechanical testing also demonstrated that the BPTB graft had a higher ultimate tensile strength than the hamstring graft [9,11]. Therefore, the BPTB autograft is regarded as the standard choice of graft due to its strength and shorter incorporation period. However, the disadvantages of BPTB graft include graft-site morbidity due to patellofemoral joint problems, patellar fracture, quadriceps weakness and rupture of the patellar tendon [11].

There has been a growing interest by using allografts as ACL substitutes. Shelton et al. [12] compared the efficacy of allograft versus autograft central one-third bone-patellar tendon-bone reconstruction of ACL in 60 patients. Their result showed that no statistical differences were found between those two groups at 3, 6, 12, or 24 months for swelling, side-by-side arthrometer difference, range of motion, and patellofemoral pain. Harner et al. [13] reported 3- to 5-year outcome of allograft and autograft for ACL reconstruction. They concluded that allograft tissue provides an acceptable alternative to autograft tissue for reconstruction of the ACL. Shino et al. [8] measured the anteroposterior ligamentous laxity and thigh muscle power in 92 subjects who were rated as successes after undergone arthroscopic ACL reconstruction for unilateral ACL insufficiency 18 to 36 months previously. Those subjects were divided into two groups according the type of graft: fresh-frozen allogenic tendon or central one-third autogenic patellar tendon. They concluded that the allograft procedure is advantageous over the patellar tendon autograft in terms of better restoration of anterior stability. From those above studies, the allograft had been demonstrated as an alternative source for ACL reconstruction.

Recently, the bone-anterior cruciate ligament-bone allograft transplantation has been recognized as a potential...
solution to reconstruction of the ACL [14]. However, the comparison of biomechanical behaviors between the bone-ACL-bone allograft and the transitional autogenic BPB graft has not been studied extensively. The purpose of this study was to investigate the biomechanical behaviors of bone-patellar tendon-bone and bone-ACL-bone grafts for ACL reconstruction.

Material and Methods

Twenty male Rottweiler dogs with mean body weight of 30.59 (±3.47) Kg were included in this study. Those dogs were randomly divided into two groups, the experimental group (N=18) and the control group (N=2). Each dog in the experimental group had its right knee gotten bone-ACL-bone graft and left knee gotten bone-patellar tendon–bone graft for ACL reconstruction. The experimental group was further divided into three groups depended on the time for biomechanical evaluation. The group I was sacrificed three months after ACL reconstruction, the group II, six months and the group III, twelve months.

To perform the bone-patellar tendon-bone autograft for ACL reconstruction, the ACL in the left knee of those experimental dogs was excised firstly. The Clancy procedure was used to reconstruct the ACL by using central third of patellar-tendon with patellar and tibial tubercle bone block [15]. The 3.5 mm AO cancellous screw were used for fixation. To eliminate the surgical uncertainty, all reconstruction surgeries were performed by one surgeon. After reconstruction of ACL, all experimental and control dogs were free to move in the cage.

Three (group I), six (group II) and twelve (group III) months after the ACL reconstruction, those experimental dogs were sacrificed for biomechanical and histological evaluations. Each group had six specimens, five specimens were used for biomechanical test and one specimen was for histological evaluation. The control group was also tested at the same period with the group III (twelve months).

In biomechanical testing, the testing specimen including lower half of femur and the upper half of tibia was harvested. All soft tissues in the knee joint were removed except the ACL. Two stainless-steel rods were used to fix the femur and tibia. Those two rods were held by hook-like fixators which were attached to the gripper of material testing system (MTS Bionix 858, Eden, Pairie, USA) (Figure 1). Those specimens were subjected to a tensile load at a strain rate=1.2%/ sec [16] and 0 degree of knee flexion. The tensile force and crosshead displacement graphs were plotted and the maximum tensile strength was recorded. The student t test was used for statistic analysis and the significant level p=0.05 was set.

The ACL grafts of both right and left knees in the experimental group and the ACL in the control group were harvested. Those specimens were stained by haematoxylin and eosin to investigate the orientation of the fibers and the numbers of cell by scanning electron microscope (SEM, Hitachi S-3500 N, Tokyo, Japan).

Results

Four dogs were failed for biomechanical test. Among them, two dogs were died before its expected time for sacrificing and the other two dogs were with slim or tear of transplanted patellar tendon. In biomechanical testing, all specimens torn at the intraarticular portion of the graft, the graft fixation within the bone tunnels remained intact. For bone-patellar tendon-bone graft, the mean maximum tensile strength was 117.1 N in the group I, 232.8 N in the group II and 777.4 N in the group III. For bone-ACL-bone graft, the mean maximum tensile strength was 458.7 N in the group I, 814.4 N in the group II and 1064.1 N in the group III. For the intact ACL in the control group, the mean maximum tensile strength was 1461.7 N (Table 1). The maximum tensile strengths in bone-patellar tendon-bone grafts were only 8.0%, 15.9% and 53.1% of the intact ACL after surgery for 3, 6 and 12 months, respectively. In bone-ACL-bone graft, the maximum tensile strengths were 31.4%, 55.7% and 76.8% of the intact ACL after surgery for 3, 6 and 12 months, respectively. The maximum tensile strength was greater in the bone-ACL-bone...
Biomechanical Behavior of Bone-ACL-Bone Grafts

In the histological study, the cell numbers in bone-ACL-bone autograft was almost equal to the control group. However, poorer orientation of the collagen fiber was found in the experimental group. The hyaline degeneration and chondroid metamorphosis in the bone-ACL-bone autograft was similar to the control group. In the bone-patellar tendon-bone autograft, the hyaline degeneration and chondroid metamorphosis were also found, however, the cell numbers were less than the control group. The nucleus was almost disappeared and the orientation of the fiber was poorly organized. Even after 12 months of reconstruction surgery, the expected metamorphosis of the patellar tendon due to the stress was not found.

**Discussion**

ACL reconstruction was more and more popular to treat the acute or chronic ACL injuries. In the last decade, arthroscopic ACL reconstruction has become a common technique for many orthopaedic surgeons. Autografts such as patellar tendon and hamstring and allografts such as Achilles tendon and patellar tendon are the grafts most often used. However, those grafts still have some disadvantages. From the biomechanical point of view, the reconstruction of the ACL is not only to restore its anatomical structure, but also to restore its function and strength. Noyes et al. [17] reported the biomechanical properties of human graft tissues which showed the patellar tendon to be the strongest available autograft. Many surgeons have used these data to determine graft proficiency. Although some acceptable clinical results by using the bone-patellar tendon-bone autograft have been reported [6,9]. The anterior knee pain or donor site morbidity was still a problem for bone-patellar tendon-bone autograft.

Thorson et al. [18] compared the efficacy of bone-ligament-bone allograft versus iliobial band autograft replacement of the ACL in the dog model. They found that the maximum tensile strength of the allografts reached only 17% of the control value versus 41% for the autografts after surgery for one month. Blickenstaff et al. [19] analyzed the biomechanical properties of a semitendinosus autograft in a rabbit model. They found that the average maximum tensile strength was a function of time after surgery and showed a trend of increasing strength over time. The greatest strength was approximately 25% of the normal ACL at 52 weeks after surgery. In our studies, the maximum tensile strength of the bone-patellar tendon-bone and bone-ACL-bone grafts were also investigated. The maximum tensile strength was also resulted as a function of time after surgery. The maximum tensile strength of bone-ACL-bone graft was always greater than the bone-patellar tendon-bone graft. However, the greatest value was only 76.8 percent of the normal ACL even after one-year surgery.

The decrease in tensile properties after sterilization and preservation as well as risk of inflammatory reaction has been a concern for using allografts. Allografts are usually preserved by deep freezing or freeze-drying. Deep freezing without drying has little or no effect on the biomechanical properties of ligaments, with no significant differences in the stiffness, ultimate load or modulus noted between treated and control ligaments [20,21]. Gamma irradiation can reduce the risk of disease transmission, however, a trend toward decreased structural and mechanical properties of the tissue has been observed [22]. Those effects would influence the material properties of actual bone-ACL-bone allograft.

Noyes et al. [23] found that the cell in the patellar tendon was still survival after implantation for ACL reconstruction in a monkey model. In our study, the cell numbers decreased significantly and the nucleus was almost disappeared in the autogenic patellar tendon after surgery for twelve months. The organization of the fibrous tissue was also poorly. During six months after surgery, the autogenic patellar tendon was sustained degeneration in the early period, then recovered in the last period. The maximum tensile strength was only 8% to 15% of the control group. However, this effect was less in the bone-ACL-bone graft, its maximum tensile strength was 31% to 55% of the control group. After twelve months recovery, the changes in patellar tendon or ACL tissues were similar to that after six months recovery. However, the maximum tensile strength was changed significantly. The maximum tensile strengths in bone-patellar tendon-bone and bone-ACL-bone were 53% and 77% of the control group respectively. Change of intrinsic mechanical properties or change of tissue structure which dominates the remodeling procedure of those grafts need to further investigate.

One dog was found the transplanted patellar tendon torn after surgery for twelve months. The osteophyte was also

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**Table 1. The maximum tensile strength of experimental and control groups (Unit: Newton)**

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<thead>
<tr>
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<th>Experimental Group I</th>
<th>Experimental Group II</th>
<th>Experimental Group III</th>
<th>Control group</th>
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<tr>
<td>Bone-Patellar tendon-Bone</td>
<td>117.1 (N=6) (62.9 to 178)</td>
<td>232.8 (N=4) (168.4 to 294.4)</td>
<td>777.4 (N=4) (762.8 to 784.8)</td>
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<tr>
<td>Bone-ACL-Bone</td>
<td>458.7 (N=6) (362.4 to 617.3)</td>
<td>814.4 (N=4) (797.6 to 849.6)</td>
<td>1064.1 (N=4) (1035.2 to 1092.9)</td>
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<td>Intact ACL</td>
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<td>1461.7 (N=4) (1249.6 to 1839.6)</td>
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observed around the femoral condyle. However, no significant change was found in the articular cartilage. It meant that the degeneration of knee joint was correlated to the absent of anterior cruciate ligament. This finding was similar to human knee joint’s degeneration. It is indicated that the reconstruction of ACL can prevent the early degenerative change in human knee joint.

In this study, the dog model was selected based on the similarities in structural and functional aspects between canine and human knee joint [24]. The dog and human knees showed that both of them exhibit a biocondylar of tibiofemoral joint. However, the dog’s condyle is higher and the patellar tendon is slimmer. Those effects would influence the strength of reconstructed ACL.

Conclusion

This study revealed that the maximum tensile strength in bone-ACL-bone graft was greater than the bone-patellar tendon-bone graft. The bone-ACL-bone graft has a better result than bone-patellar tendon bone graft for ACL reconstruction in the dog model.

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Reference