The Biomechanical Study on the Quadriceps Tendon Used for Double-bundle Reconstruction of the Anterior Cruciate Ligament

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ABSTRACT Objective: To investigate the biomechanics of the quadriceps tendon and to provide theoretical basis for double-bundle reconstruction of anterior cruciate ligament(ACL). Methods: 32 quadriceps tendons (width 1cm) taken from fresh cadaver were dissected into 2 bundles according to the anatomy, one bundle including rectus femoris, vastus medialis and vastus lateralis was named A bundle and the other was named B bundle. The width and thickness of the A and B bundle were detected respectively with a Vernier caliper and the biomechanics were determined by WDW-30 election universal testing machine. Results: The thickness, width, ultimate load and ultimate tensile strength of bundle A were 4.39± 1.72mm, 8.19± 1.18mm, 685.67± 227.09 N and 17.00± 3.48 Mpa respectively, while for bundle B,which were 3.06± 1.47 mm, 7.10± 2.03mm, 435.04± 205.80 N and 13.16± 4.02 Mpa. There was difference between bundle A and the ACL (p<0.05). Conclusion: The ultimate load of bundle A was much lower than the the ACL and bundle Bwas also lower than the ACL.

Key Words: biomechanics; quadriceps tendon; anterior cruciate ligament; transplant; graft

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Introduction

The anterior cruciate ligament (ACL) is one of the most frequently injured structures of the knee joint [1]. Because of its crucial function as the primary restraint against anterior tibial translation, ACL disruption inevitably causes alterations in knee kinematics which are most probable to result in secondary degenerative changes and long-term functional impairment [2, 3]. As the ACL fails to heal in a manner that would restore normal knee kinematics, reconstructive techniques have been emphasised for patients who desire restoration of knee function and stability as well as return to high-level physical performance [4]. To improve the status of patients, new reconstructive techniques have been developed over the years, such as the anatomic double-bundle ACL reconstruction [5-8]. Although current concepts in knee ligament repair are reported to be clinically successful in most trials, ACL reconstruction has failed from a biomechanical point of view to both fully restore normal knee kinematics and to anatomically imitate the native ACL. Therefore, it may be presumed that surgical ACL reconstruction would not adequately prevent secondary lesions or early degenerative changes of the injured knee joint.

ACL graft choices are numerous for reconstruction [9]; They include ipsilateral and contralateral autograft patellar tendon, hamstrings, and quadriceps tendon. Moreover, allograft Achilles tendon, patellar tendon, quadriceps tendon, and hamstrings are available through tissue banks. There was different strengths and weaknesses for each. But, no single graft option is clearly superior to other. Some surgeons prefer to using the quadriceps tendon as an alternative graft source for ACL reconstruction for several reasons. Firstly, it is thicker and wider than the patellar tendon, providing 50% greater mass than a patellar tendon-bone-tendon graft of similar width [10]; Secondly, harvesting the central quadriceps tendon is easy to perform under direct visualization through an anterior incision, regardless of its open or arthroscopic fixation method. Ease of harvesting reduces surgery time; Last, this graft has a natural cleavage in the coronal plane, which allows for the creation of 2 bundles to satisfy the double-bundle reconstruction of the ACL. One bundle named A was consisted of the rectus femoris (RF), vastus medialis (VM) and vastus lateralis (VL) and the other named B was vastus intermedius (VI) . The A bundle was used to reconstruct the anteromedial bundle (AMB) of the ACL and the B bundle for the posterolateral bundle(PLB).

The objectives of this study were to analyze the biomechanics of bundle A and bundle B taken from the full-thickness, 10mm wide central section of the quadriceps tendon and to measure the length and width of the A and B. And then we made comparison of the biomechnaics in groups: bundle A vs. the ACL; bundle B vs. the ACL in order to discuss whether the quadriceps tendon could be the appropriate graft for the double-bundle reconstruction of the ACL.

1 Material and method

1.1 Harvesting technique

Thirty-two fresh cadavers with the mean age of 64.2± 10.2 years were used in this study. The quadriceps tendon graft was harvested through an incision beginning at the superior pole of the patella and extending 5 to 6 cm proximally. A 10-mm wide central

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quadriceps tendon graft was harvested, care being taken to incise all 3 layers perpendicularly (rectus tendon, VLO-VMO tendon, and vastus intermedius tendon) and to avoid entering the underlying synovium and suprapatellar pouch . The overall length of the graft was approximately 10 mm. The quadriceps tendons were gingerly divided into two bundles A and B on the basis of the anatomy. The distal end of each bundle was carefully sutured using 4 No. 2 nonabsorbable sutures with a whip stitch [11]. The specimens were wrapped in saline-soaked gauze and stored at -80℃. All of the 32 specimens were harvested by the the same person in order to standardize the specimens and minimize the errors.

1.2 Morphology measure

The specimens were first thawed at room temperature for one hour, and then the specimens were wiped dry with a sterile gauze. Five points were selected equally in the specimens and marked up with a marker pen. Then, the width and thickness of each point were measured with a Vernier caliper and the mean of the five times' measurement results were calculated. The cross section area of the specimens was calculated by the formula of the ellipse according to the width and thickness. After the measurement, we repacked the specimens withsaline-soaked gauze and stored at -80℃ again.

1.3 Biomechanics test

One hour before the test, the specimens were thawed at room temperature. They were kept moist with saline spray during the preparation and testing period. Each specimen was mounted in an election universal testing machine (model WDW-30, Instron Corporation, Ke xin, Chang chun, China). Each end of the tendon was then fixed in a grasping clamp with an equal length of 40 mm between the clamps. The specimen was equilibrated in the bath for 30 min before a preload of 2N was applied and the gauge length was reset. This was followed by preconditioning between 0 and 1.5mm of elongation for 3 cycles and a load to a failure test. All tests were conducted at an elongation rate of 10mm/min. the load-elongation curve was obtained. The ultimate load and ultimate tensile strength were received from the curve.

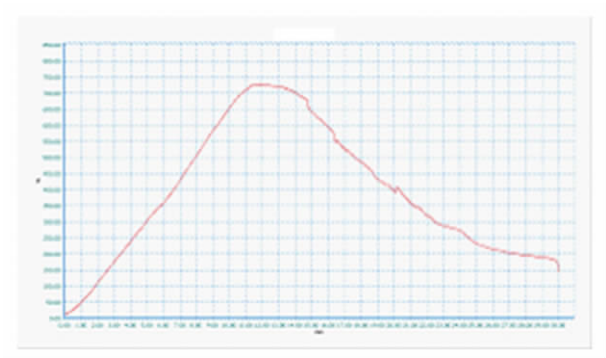

Fig 1 The load-elongation curve

Data expressed as mean ± S.D. The comparison of the ultimate load respectively between bundle A and the ACL, bundle B and the ACL were conducted using the Student-test.

2 Results

The ultimate load of the ACL is approximately 2160± 157 N [12]. The difference in reaching the ultimate load was statistically significant between the A bundle and the ACL(t=17.08, $p<0.05$) , as well as between the B bundle and the ACL (t=11.96,$p<0.05$).

Table 1 The morphology of bundle A and B

	thickness (mm)	width (mm)	cross section area (mm²)
A	4.39± 1.72	8.19± 1.18	39.52± 7.53
B	3.06± 1.47	7.10± 2.03	31.91± 9.87

Table 2 The biomechanics of bundle A and B

	Ultimate load (N)	Ultimate tensile strength (Mpa)
A	685.67± 227.09	17.00± 3.48
B	435.04± 205.80	13.16± 4.02

3 Discussion

ACL is one of the most frequently injured structures in the knee[13] and its function has extensively been studied during the last decade [14,15]. Bone-patellar tendon-bone (BPTB) grafts are generally accepted as a standard graft choice for ACL reconstructive surgery. While patellar tendon graft harvest was reported to be associated with anterior knee pain and donor-site morbidity [16], the use of quadriceps tendon-patella bone (QTPB) grafts, introduced by Blauth in 1984 [17], had been recognized to be a reasonable alternative choice for primary or revision ACL reconstruction, providing comparable graft properties [18, 19].

The quadriceps tendon is interposed between the myofascial junctions of the superficial layer of the rectus femoris muscle, the middle layers of the vastus medialis and vastus lateralismuscles, and the deep layer of the vastus intermedius muscle [20]. The layers converge to the broad insertion of the quadriceps tendon at the base of the patella. The most anterior fibers of the quadriceps tendon blend over the anterior aspect of the patella [21,22] as structural components of the vertical and horizontal tensile bracing system[23]. Biomechanically, the quadriceps tendon and the patella are integral parts of the active and passive extensor mechanisms of the knee joint [24,25].

The RF, the most superficial muscle of the quadriceps group, inserts into the anterior portion of the base and the superior third of the anterior surface of the patella in one of three possible ways. The superficial fibers of this common tendinous attachment (unilaminar or trilaminar) continue over the patella and become continuous with the patellar ligament.

Centrally, the VL and VM unite to constitute a continuous aponeurosis, which inserts into the base of the patella, just posterior to the insertion of RF, and also continues laterally and medially to insert into the sides of the patella. The lateral expansion of VL then blends with the capsule of the knee, thereby forming part of the lateral patellar retinaculum. Most fibers of the VM end in an aponeurosis that blends with the medial side of the suprapatellar tendon or the RF tendon.

The VI has an intimate origin with VL proximally and the lateral intermuscular septum distally. It inserts through a broad, thin tendon into the base of the patella posterior to the VL and VM or merged with them. Medially and laterally, this insertion reinforces the patellofemoral ligaments.

The four muscular elements of the quadriceps fuse to form the quadriceps tendon 2 cm proximal to the patella. Some authors have suggested that the three layers of the quadriceps tendon remain disparate to their insertion into the patella [26,27]. However, Standring [28] did not describe the quadriceps tendon as having any laminations, but rather said the components come together to form one structure attached to the sides and base of the patella. Zeiss et al [27] reported each layer of the quadriceps tendon is composed of fibers from more than one of the quadriceps muscles.

Staubli HU[29] reported that the ultimate load of the quadriceps tendon was 2352N. In our study, we divided the quadriceps tendon into two limbs, A and B. Each one of the ultimate loads became much smaller than the whole quadriceps tendon. Thus, we were in doubt whether the ACL double-bundle reconstruction achieved a suitable graft or not. We investigated and found that this might be due to the deviation, which destroyed the integrity of the quadriceps tendon and lead the ultimate load decreased sharply. In addition, there was a marked difference between the cadaver and living body. Thus the biomechanics of the quadriceps tendon were possible to change after breaking away from the living body. Also it should be noted that, freezing the specimens for period of time at -80℃ altered significantly the ultimate tensile failure.

Up until now, nothing was reported about morphology and biomechanics of A bundle and B bundle divided from the quadriceps tendon even though the quadriceps tendon has been used as graft of the ACL double-bundle reconstruction for many years. Everyone knows that the ultimate load and ultimate tensile strength are quite crucial for the healing efficacy after the operation of the ACL double-bundle reconstruction. As a result, researching on the morphology and biomechanics of the A bundle and B bundle makes sense to the graft selection of the ACL double-bundle reconstruction. It provides the theoretical basis for whether the quadriceps tendon could be the appropriate graft for the ACL double-bundle reconstruction.

There were some limits in our study. Firstly, the measuring tool we used-the Vernier caliper was not perfect enough for measuring the soft tissue such as the quadriceps tendon. The data obtained from the Vernier caliper could affect the ultimate tensile strength that was relevant with the cross section area. Secondly, the age of the cadavers we harvested the quadriceps tendons from, was a little old so that the results we received were probably lower than the normal. Lastly, after we harvested the quadriceps tendons, we should test the biomechanics as soon as possible rather than storing at -80℃. As a result of the laboratory limit, we had no option but to store at -80℃ firstly and test the biomechanics in the right time later. As everybody knows , freeze-thawing is able to affect the biomechanics of the tendons.

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股四头肌腱双束重建前交叉韧带的生物力学特性研究

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摘要 目的： 探讨股四头肌腱的生物力学特性，为其能否应用于临床前交叉韧带(ACL)重建提供实验依据。**方法：** 取 32 例新鲜尸体的 1cm 宽股四头肌腱，按其解剖结构分为两束：股直肌、股内、外侧肌腱合为 A 束，股中间肌腱为 B 束，用游标卡尺测量两束的宽度及厚度，然后将两束置于电子万能试验机上分别测其生物力学指标。**结果：** A 束厚度为 4.39± 1.72mm,宽度为 8.19± 1.18mm，生物力学强度为 685.67± 227.09N，抗拉强度为 17.00± 3.48Mpa；B 束厚度为 3.06± 1.47mm，宽度为 7.10± 2.03mm，生物力学强度为 435.04± 205.80N，抗拉强度为 13.16± 4.02Mpa。A 束生物力学强度与 ACL 比较，差异有统计学意义 ($p<0.05$)；B 束生物力学强度与 ACL 比较，差异有统计学意义 ($p<0.05$)。**结论：** 股四头肌腱的生物力学性能不能满足 ACL 双束重建的要求，其在临床上应用于 ACL 双束重建的价值有待于进一步的深入研究。

关键词： 股四头肌腱；前交叉韧带；移植；生物力学；移植物

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