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Biomechanics of anterior cruciate ligament reconstruction using twisted doubled hamstring tendons

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Abstract We studied the biomechanical properties of a twisted doubled semitendinosus and gracilis graft. We applied an un-axial load in order to reproduce the kinematics of a reconstructed anterior cruciate ligament (ACL). A modified cryo-jaw clamp system was used to minimize soft tissue slippage. The lower grip, after fixation of the free ends of the tendons, was rotated 45°, translated 1 cm, and bent 40°, simulating a knee sprain. The graft was tested to failure using a servohydraulic machine. The specimen from one knee of seven unembalmed cadavers was assigned to the untwisted (parallel) bundles group, while its pair was assigned to the twisted group. For the parallel bundles group, the mean maximum load was 1709.3±581.9 N, for the twisted group 2428.3±475.4 N ($P<0.05$). The mean stiffness was respectively 213.6±72.4 N/mm and 310.3±97.3 N/mm ($P=0.08$). Although caution should be used in extrapolating the results to clinical estimates of the strength of hamstring grafts, the results of the present study could justify the use of twisted semitendinosus and gracilis bundles in ACL reconstruction.

Résumé Nous avons étudié les propriétés biomécaniques d'un greffe du semitendineux torsadé et doublé du droit interne. Nous avons appliqué une charge non-axiale pour reproduire la cinématique d'un ligament croisé antérieur (ACL) reconstruit. Un clamp de Cryo modifié a été utilisé pour minimiser le glissement des tissus mous. La prise inférieure, après fixation de la partie libre des tendons a été tourné de 45°, translaté de 1 cm et courbé à 40°, en simulant une entorse du genou. La greffe a été testée à la rupture avec une machine servohydraulique. Le spécimen d'un genou de sept cadavres non embaumé a été assigné aux essais en faisceaux parallèles pendant que sa paire a été assignée au groupe avec torsion. Pour le groupe travaillant en parallèle la charge maximale moyenne était 1709.3±581.9 N, pour le groupe en torsion de 2428.3±475.4 N ($P<0.05$). La raideur moyenne était 213.6±72.4 N/mm et 310.3±97.3 N/mm respectivement ($P=0.08$). Bien que la prudence doit être utilisée dans l'extrapolation des résultats à la clinique, les résultats de la présente étude pourraient justifier l'usage d'un faisceau torsadé de semitendineux et droit interne dans la reconstruction du ligament croisé antérieur.

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Introduction

Because of the high incidence of donor site complications following harvest of the central-third patellar tendon autografts [1, 13, 16, 22], hamstring tendon grafts have been advocated as an alternative graft in anterior cruciate ligament (ACL) replacement [6, 15]. Multiple stranded semitendinosus and gracilis tendon grafts currently are recommended, since it has been demonstrated that ultimate failure load and stiffness of equally tensioned four-stranded hamstring tendon grafts are significantly higher than values reported for the 10 mm patellar tendon grafts [11]. However, in order to achieve the expected mechanical benefits from combining multiple stranded tendon grafts, it is important to maintain equal tension in all bundles of the graft. This condition might be easily obtained at surgery but is unlikely to be maintained during physiological and pathological knee motions [25].

In order to allow the four bundles to be equally loaded in all conditions, it has been suggested to braid and twist the four bundles as in a rope [8, 23]. Some authors demonstrated that braiding and twisting decreases the strength and stiffness of a four-stranded tendon graft [5, 19]. However, in all investigations of the graft's biomechanical

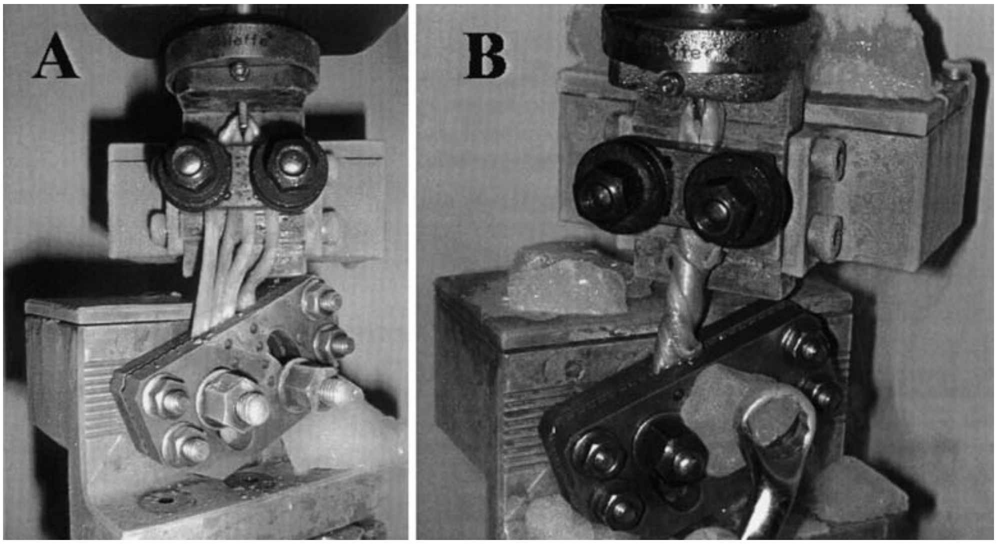

Fig. 1 After fixation of the free ends of the tendons, the lower grip can be rotated, translated, and bent, simulating the situation in a knee sprain. Parallel (*A*) and twisted (*B*) bundles

properties, an axial load applied. This condition is unlikely to mimic the physiological stresses applied to the reconstructed ACL during normal and pathological knee movements.

The purpose of this paper was to study the biomechanical properties of a twisted doubled semitendinosus and gracilis graft by applying an un-axial load in order to reproduce the kinematics of a reconstructed ligament after a knee sprain.

Material and methods

Specially designed soft tissue grips that incorporated dry ice to freeze the tendon ends were used to minimize soft tissue slippage. The upper grip received the looped tendon and the lower grip, after fixation of the free ends of the tendons, could be rotated, translated, and bent, simulating a knee sprain (Fig. 1).

Seven pairs of semitendinosus and gracilis tendons were harvested in an open fashion from unembalmed cadaver knees (mean age at death 67.2, range 61–73 years). The specimen from one knee was assigned to the untwisted (parallel) bundles group while its pair was assigned to the twisted group.

In tests performed on parallel bundles, a suture was placed at the ends of semitendinosus and gracilis tendons; the tendons were placed over the post in the upper clamp,and a 2 kg weight was attached to the sutures in order to obtain equal tension on all bundles. The clamps were then tightened and the lower grip rotated 45° counterclockwise, translated 1 cm, and bent 40°. Definitive clamping was obtained by placing dry ice in the ice containers. The tendons were preconditioned to a distraction of 1 mm for 10 cycles. Marks were made at each clamp-tendon interface with India link to evaluate the tendons for possible slippage in the clamp. After preconditioning, the clamp length was measured in the middle portion of the lower grip while maintaining a load of 50 N. A temperature probe was placed on the tendons at the midpoint between the two clamps. When the temperature dropped to 13°C, the tendons were tested to failure at a strain rate of 540 mm/sec. The site and mode of failure were recorded for all tests. Maximum load and stiffness were determined from load-elongation curves with use of data acquisition software.

In tests performed on twisted bundles, after an equal tension on all bundles was obtained by applying a 2-kg weight on each end of the tendons, the lower grip was rotated 720° counterclockwise before primary clamping. The lower grip was then rotated, displaced, and bent as for the parallel bundles and, after definitive ice clamping, failure test was performed following the same protocol. Statistical analysis of the results was performed using a paired *t*-test.

Results

Of the seven pairs of grafts tested, one case of rupture at the clamp tendon interface was observed: this case was excluded, leaving six pairs of tendons that failed at mid-substance available for statistical analysis. The mean maximum load (and standard deviation) was 1709.3±581.9 N for the parallel bundles group and 2428.3±475.4 N for the twisted group ($P<0.05$). The mean stiffness and standard deviation was 213.6±72.4 N/mm for the parallel bundles group and 310.3±97.3 N/mm for the twisted group ($P=0.08$).

Discussion

Several factors can affect the results in ACL reconstruction: pretensioning of the graft, tensioning and angle of tensioning. and fixation devices [2, 3, 9, 14, 24, 26]. However, a critical factor in success of such reconstruction is the graft choice, as biomechanical properties of the graft material could influence surgeon preference [4, 10, 12, 21]. The two most commonly used grafts are the central third of the patellar tendon and the hamstring tendons. The most popular papers dealing with biomechanical properties of ACL substitutes are Noyes et al. [20] and a more recent study by Hamner et al. [11]. They agree that a four-strand semitendinosus and gracilis graft might be more than 250% stronger than a normal ACL. However, in order to allow the composite graft to obtain the optimal biomechanical properties, all strands must be under equal tension. This is the situation in which mechanical properties of graft strands are additive [6, 15], resulting in the best biomechanical performance of the composite graft.

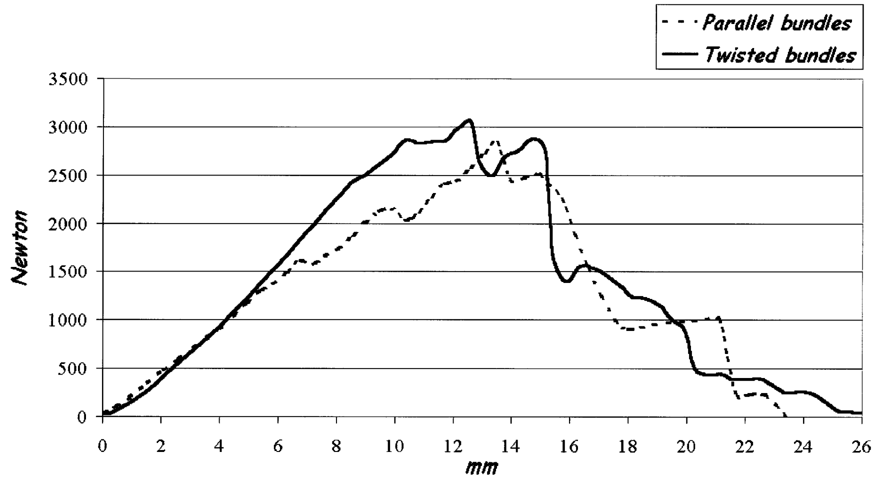

Fig. 2 Load versus displacement of the parallel and twisted bundles

This ideal situation could be easily obtained at surgery before the definitive fixation of the graft with the knee locked at a fixed flexion angle. It is, however, unlikely to be maintained after fixation, as the tibia is allowed to move in respect to the femur. Wallace and coworkers [25] demonstrated a different load in the bundles of a double-looped semitendinosus and gracilis graft in only a few grades of flexion-extension of the knee. Therefore, it is reasonable to believe that during physiological, and even more so in pathological conditions (knee sprains), an equal tension of the bundles is unlikely to be maintained, resulting in a loss of strength of the graft. In an effort to improve the strength of ACL reconstruction, Cooper et al. [7] examined the effect of twisting the patellar tendon graft. They reported that a 90° twist significantly increased the tensile strength of the patellar tendon. Munns and coworkers [18] agreed with the findings of Cooper, while other groups have reported no significant difference in graft strength with twisting [17]. In the last few years, some authors have proposed that braiding or twisting hamstrings tendons will increase the graft strength [8, 23]. Brown et al. [6]. and, more recently Nicklin et al. [19], demonstrated that twisting and braiding semitendinosus and gracilis tendons result in a loss of strength and stiffness as compared with a parallel four-stranded tendon graft. They concluded that braiding and twisting are used extensively in the manufacture of ropes to improve flexibility and handling properties, not strength. However, in these tests, an axial load was applied to the graft, which probably doesn't represent the physiological situation inside the knee joint. Twisting and braiding are used in manufacturing of ropes to allow all the bundles to undergo approximately the same load under all conditions. Brown and coworkers [11] showed that losing the equal tension of the bundles produces a significant decrease in strength and stiffness of the composite graft. By analyzing the load displacement curve of our tests, we assume that – as the ends of the parallel bundle graft move after fixation – a significant difference in the tension applied to each bundle is observed, modifying the biomechanical properties of the graft. Simple twisting of the bundles as in a "false" rope allow the bundles to be loaded more uniformly when an un-axial load is applied, resulting in a better performance of the graft (Fig. 2).

In the present study, we observed the behavior of parallel and twisted semitendinosus and gracilis graft by mimicking a knee sprain biomechanically. Although the device we used seems to improve the quality of the mechanical tests, we caution not to extrapolate the results to the clinical situation. Many factors influence the biomechanical properties of a composite graft. However, our results justify the use of twisted semitendinosus and gracilis graft in ACL reconstruction.

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