Original article

Semitendinosus muscle architecture during maximum isometric contractions in individuals with anterior cruciate ligament reconstruction and controls

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Summary

***Background*: The most widely used graft as a replacement in anterior cruciate ligament (ACL) reconstruction is the semitendinosus (ST) tendon graft. After harvesting for ACL reconstruction, the hamstring tendon regenerates in most people and becomes similar to normal. The effect of graft harvest on muscle morphology and function remains unclear. The present study aimed to examine the morphology of the ST during isometric contraction after harvesting the ST tendon for ACL reconstruction.**

***Methods*: Maximal isometric contractions of the knee flexors from two angular positions were performed by 8 participants, at least 1 year after ACL reconstruction with an ST tendon graft and 8 matched controls. Ultrasonographic images were used to measure the pennation angle and muscle thickness of the ST muscle.**

***Results*: There was not a statistically significant difference in pennation angle values between the control group and the group who underwent ACL reconstruction (p >0.05). Muscle thickness was significantly higher in the ACLR group compared with controls (p< 0.05).**

***Conclusions*: Individuals who underwent ACL reconstruction display a higher ST muscle thickness but similar pennation angle compared with controls. This indicates that ACL reconstruction has an effect on ST muscle belly but effect on force generation capacity is rather limited.**

Level of evidence: IIb.

KEY WORDS: ACL, knee injury, morphology, reconstruction, ultrasound.

Introduction

The semitendinosus (ST) tendon graft is widely used as a replacement in anterior cruciate ligament reconstruction. There are advantages in using the ST tendon such us ease harvesting during surgery, suitable morphology as ACL graft and lower donor-site morbidity[1]. After harvesting for ACL reconstruction, the hamstring tendon regenerates in most people and becomes similar to normal[2, 3].

Many studies have been published on the anatomy and the composition of the regenerated tendons using MRI scans, ultrasonography and CT scans[4-6]. Morphological changes including atrophy[4] and shortening[7] of the ST muscle belly have been confirmed in patients with ACL reconstruction using the ST tendon. Further, the tendon undergoes morphological changes such as regeneration and hypertrophy [2, 4, 5, 8-10] up to 32 months after surgery. In addition, ST muscle volume decreases by an average of 30% and appeared to correlate well with the degree of tendon regeneration after ACL reconstruction[7]. The majority of cases demonstrated some but not complete regrowth of tendon remnants 3 years after surgery[8].

Previous research findings are controversial indicating considerable decrease of knee flexion torque and strength after harvesting the ST for ACL reconstruction[11] by some studies but no reduction in hamstring strength by others[12]. The current consensus is that the strength of the knee flexors is not significantly decreased postoperatively based although on isokinetic tests[8]. Nomura et al.[13] reported that regenerated ST tendon was confirmed in 21 of the 24 patients who underwent ACL reconstruction, but muscle volume (87.6%) and muscle length (74.5%) of the ST in the operated limb were significantly smaller than those in the normal limb. The percentage of the knee flexion torque of the operated limb compared with that of the normal was apparently lower at 105° (69.1%) and 90° (68.6%) than at 60° (84.4%). Tendon regeneration, ST muscle shortening, and ST muscle atrophy correlated with decreased knee flexion torque. These results indicated that preserving the morphology of the ST muscle-tendon complex is important. Nevertheless, important architectural parameters of the harvested muscle, such as pennation angle and muscle thickness, have been examined. Further, although previous studies[4,14,15] documented the presence of tissue in the harvest gap, little information is available on the morphology of the ST muscle during isometric knee flexion in the harvested limb.

The present study aimed to compare the morphology of the ST muscle during isometric contraction in a group of individuals who underwent ACL reconstruction with ST tendon graft and controls.

Materials and methods

A total of 16 subjects (12 males and 4 females; age 28,56 ± 7,7144 years, mass 75,93 ± 11,59 kg, height 1.75 ± 7,26 cm) volunteered to participate in this study after signing written informed consent. Eight participants (6 males and 2 female) were healthy and they had no injury of the lower limbs including history of hamstring strain or any other muscle or ligamentous injury of the knee and 8 participants (6 males and 2 females) underwent ACL reconstruction with semitendinosus tendon graft. The selection criteria were as follows: a. isolated ACL rupture with absence of any injury of other structures, b. ACL reconstruction with a semitendinosus tendon autograft technique, c. surgery occurred more than 12 months prior to this study, d. followed the same postoperative rehabilitation by the same medical team and e. no history of neurological disease, or vestibular or visual disturbance, f. any other episode of instability after ACL reconstruction surgery[16]. The study was approved by the University's Institutional Review Board. This research project was conducted according to international standards[17]**.**

Maximum isometric tests were performed on a Cybex isokinetic dynamometer (Humac Norm, Cybex CSMI, Stoughton, MA, U.S.A. A twin - axis goniometer (Model TSD 130B, Biopac Systems, Inc., Goleta, CA, USA) was used to record knee angular position (0°= full knee extension). Muscle morphology was recorded using ultrasonic[18] device (SSD-3500, ALOKA, Japan) with a linear array probe of 10 MHz wave frequency and a probe length of 6 cm. The US signals were collected using an ADVC-100 (Canopus Co. Ltd. Japan) analogue to digital convertor directly to a PC (via fire wire) at 30 Hz. The video-capturing module of the Acknowledge (version 3.9.1., Biopac Systems) software allowed simultaneous recording of the US video images at a rate of 30 Hz. US images were digitized using a video-based software (Max Traq Lite version 2.09, Innovision Systems, Inc., Columbiaville, Michigan, USA).

The subjects were positioned in a prone position on the chair with hip and knee flexion angle initially at 0º (hip knee full extension) and then in 45º. The thigh, pelvis, and trunk were stabilized with straps. The axis of knee rotation was aligned with the lateral femoral condyle. A twin - axis goniometer (Model TSD 130B, Biopac Systems, Inc., Goleta, CA) was used to record knee angular position (0º=full knee extension).

The scanning head of the probe was coated with transmission gel to obtain acoustic coupling. The US probe was placed over the most distal 1/3 of the ST, along the distal muscle-tendon junction (Fig. 1). Echo-absorptive markers were placed between the probe and the skin to serve as a fixed reference.

The position of the probe was recorded by measuring the distance from a fixed point on the probe to the tibial condyle. Once the probe was appropriately placed and its position recorded, ultrasound video of the ST was taken and stored. The familiarization and warm-up contained several sub-maximal and three maximal efforts at each angular position of the main protocol.

During testing, the subjects performed 3 maximal isometric efforts of the knee flexors at full knee extension (0°) and 45° of knee flexion. The duration of the isometric trial was 5 sec. An interval of 2 min between tests was used to minimize fatigue effect and all tests were performed by the same investigator.

The US images were digitized using a video-based

Figure 1. Example image from the experimental set up.

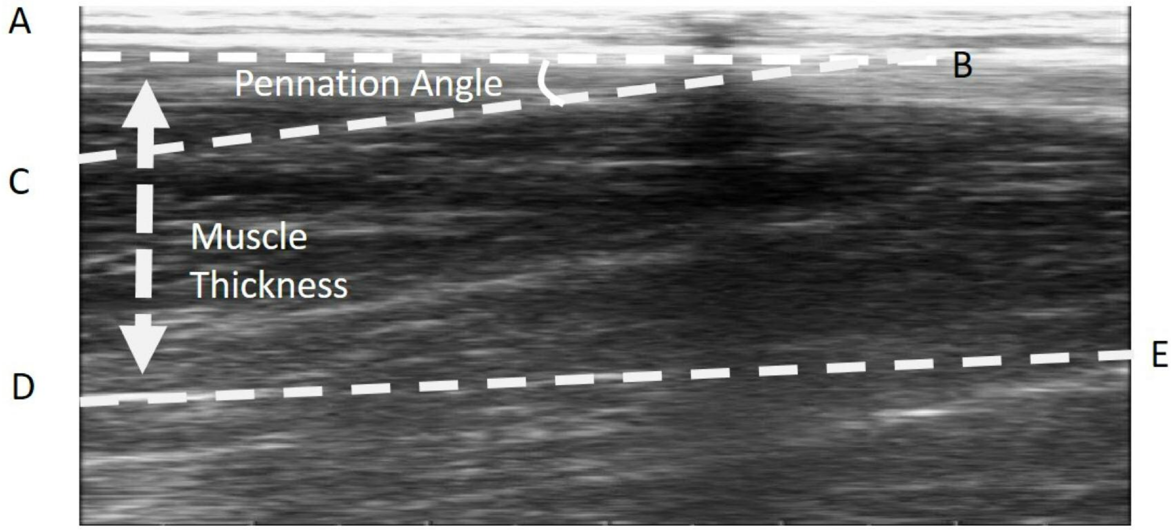

Figure 2. Pennation angle (PA) and muscle thickness (MT) of the semitendinosus (ST).

software (Max Traq Lite version 2.09, Innovision Systems, Inc., Columbiaville, Michigan, USA). For each image, several points were digitized (Fig. 2) as described by Blazevich et al.[19]. Following digitization of the US images, ST thickness was estimated as the distance between the superficial and deep aponeurosis. The angle between the line marking the outlined fascicle and the deep aponeurosis was then measured giving the pennation angle (PA). The reliability and validity of the present protocol are presented elsewhere[20].

Statistical analysis was performed using Statistical Package for the Social Sciences (SPSS 23.0 Inc., Chicago, IL). Data were expressed as means and standard deviations (SD) for anthropometrical data and means with standard errors (SE) for all other data. All data of ST muscle were averaged for each angle.

Three-way analysis of variance (2x2x2) designs were used to examine group differences in each outcome variable, at each of 2 angular positions (0º, 45º), 2 groups (ACLR and controls) and 2 testing conditions (rest and flexion). The level of significance was set at $p < 0.05$.

Results

Pennation angle

The mean and standard deviation of the pennation angle values per group are presented in Table I and Table II. The pennation angle ranged from 19.40 (2.19º) to 29.11 (6.2°) for the ACLR group and from 18.07 (2.75º) to 24.24 (6.05º) for the control group. The ANOVA showed that there was not a statistically significant Group X Angle, contraction interaction on pennation angle values during MVC ($F_{1,14=}0.157$; p=0.69).

Table I. Pennation angle (PA) and muscle thickness (MT) of the semitendinosus (ST) obtained at 0º at rest and at MVC for ACLR and controls.

Group		Pennation angle	Muscle thickness
ACLR	Rest	19,4º (2.19)	2,73(0.65)
	Flexion	29,11º (6.2)	5,1 (4.7)
Controls	Rest	18,07º (2.75)	1,88 (0.49)
	Flexion	24,24º (6.05)	2,36(0.46)

Table II. Pennation angle (PA) and muscle thickness (MT) of the semitendinosus (ST) obtained at 45º at rest and at MVC for ACLR and controls.

Group		Pennation angle	Muscle thickness
ACLR	Rest	19,37 (2.2)	2,71(0.67)
	Flexion	28,31º(4.91)	4,08(1.01)
Controls	Rest	18,16º (2.69)	2,39(0.27)
	Flexion	24,20º (3.81)	3,33(0.80)

The mean and standard deviation of the muscle thickness values per group are presented in Table I and Table II. The muscle thickness ranged from 2.73 (0.65) to 5.18 (4.7) for the ACLR group and from 1.88 (0.49) to 3.33 (0.17) for the control group. The ANOVA showed that there was not a statistically significant Group X Angle, contraction interaction on muscle thickness values ($F_{1,14}$=0.97; p=0.34). On the other hand, a significant main effect between groups was found, as ACLR group showed higher values than controls ($F_{1,14}$=5.27; p=0.03).

Discussion

The results of this study showed that the ST pennation angle did not significantly differ between individuals who underwent ACLR and controls while muscle thickness was higher in ACLR group.
The ACL group showed a higher muscle thickness than the controls (Tab. II). This is an indication of a muscle hypertrophy adaptation due to ACL reconstruction. Results on muscle adaptations after ACL reconstruction are conflicting. Particularly, our results seem to be in line with several studies which have shown that the hamstring tendon regenerates after harvesting for ACL reconstruction in most people and becomes similar to normal[2,3]. Ferretti et al.[14] reported a histological study of the regenerated tissue and concluded that it is very similar to that of normal adult tendon. Eriksson et al.[4] demonstrated that the ST muscles showed no abnormalities in muscle fiber area, fiber type distribution or oxidative potential after harvesting their tendons.
In contrast to the above findings, other studies have reported significant atrophy[4] and shortening[7] of the ST tendon or/and muscle belly in patients with ACL reconstruction using the ST tendon. Makihara et al.[21] found a lower muscle volume of the ST after its tendon has been harvested while the difference of flexion torque between the normal and ACL reconstructed limbs significantly increased as the knee flexion angle increased. Similarly, Nomura et al.[11] reported that muscle volume and muscle length of the ST in the operated limb were significantly smaller than those in the normal limb. The percentage of the knee flexion torque of the operated limb compared with that of the normal was also lower. Direct comparisons of these findings with our results are difficult. Particularly, evaluation of muscle architecture in our study was performed using ultrasonography whilst the aforementioned studies utilized MRI. Further, our findings are based on muscle properties during contraction while MRI findings mainly refer to muscle properties at rest. Nevertheless, if ACL reconstruction is accompanied by shortening of the ST tendon, as the tendon re-attaches to a more proximal position 4, then this might cause a further shortening of the muscle belly. In theory, this would not be accompanied by a change in whole muscle volume, but there might be an increase of muscle thickness and cross sectional area. Further studies are required to verify this suggestion.
The absence of pennation angle differences between the two groups could be a result of the rehabilitation training program[22] followed by the ACLR group which increased muscle thickness and probably resulted in hypertrophy[23] as opposed to control group which did not selectively strengthened their hamstrings. A possible additional factor affecting the thickening behavior of the ST muscle is the interaction of contraction behavior of the neighboring pennate muscles: the biceps femoris muscle and semimembranosus muscle because a flexion task generally activates more than one muscle[24]. However, it should be stated that ST muscle fiber morphology is almost parallel and long and therefore muscle-tendon adaptations are more complicated to identify than other muscles[25].
Evaluation of the ST muscle contraction behaviors is necessary for rehabilitation processes and is helpful to change the plan of rehabilitation programs. The relationship between the muscle architectural changes in ACLR people are not simple because affecting causes include various factors. Advances of knowledge related to force generation capacity and morphology of the affected muscles would contribute to our understanding of musculoskeletal systems and would facilitate rehabilitation.
In conclusion, patients who performed ACL reconstruction with the ST tendon display a higher muscle thickness and a similar pennation angle of the ST muscle compared with controls. This indicates that ST morphology recovers after harvesting in most people one year after ACL reconstruction.

Strengths and weaknesses of the study

This study is one of the very few that investigated ST morphology under maximum isometric conditions after harvesting for ACLR, although has limitations, including a relatively small sample size, which is however similar to other studies. Another limitation is that our measurements refer to planar and superficial muscle where the US technique is only as good as the operator who is performing the examination and the quality of the apparatus that is used.

Conflict of interest

The Author has no financial or personal relationships with other people or organizations that could inappropriately influence their work.

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