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Correlation between semitendinosus and gracilis tendon cross-sectional area determined using ultrasound, magnetic resonance imaging and intraoperative tendon measurements

Nikiforos Galanis [a], Matthaios Savvidis [b], Ioannis Tsifountoudis [c], George Gkouvas [b], Ilias Alafropatis [a], John Kirkos [a], Eleftherios Kellis [d,*]

[a] Division of Sports Medicine, Department of Orthopaedics, Papageorgiou General Hospital, Medical School, Aristotle University of Thessaloniki, Thessaloniki, Greece
[b] First Orthopaedic Department, 424 General Military Hospital, Thessaloniki, Greece
[c] Radiology Department, 424 General Military Hospital, Thessaloniki, Greece
[d] Laboratory of Neuromechanics, Department of Physical Education and Sport Sciences at Serres, Aristotle University of Thessaloniki, Serres, Greece

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ABSTRACT

The purpose of this study was to examine the correlation in semitendinosus (ST) and gracilis (GT) tendon cross-sectional area (CSA) evaluated directly during anterior cruciate ligament (ACL) surgery and pre-operatively using ultrasound (US) and magnetic resonance imaging (MRI). A total of 14 patients undergoing ACL reconstruction with a quadruple ST–GT graft by the same orthopaedic surgeon participated in this study. Pre-operative evaluation included determination of ST and GT CSA area using US and MRI. Intraoperative measurement of the diameters of the ST, GT and the final ACL graft using a closed-hole sizing block with 0.5-mm increments was made and this diameter was used to estimate tendon CSA. The correlation between graft diameter and CSA were 0.563 (GT) and 0.807 (ST) for MRI and 0.498 (GT) and 0.612 (ST) for US. The final ACL graft diameter displayed a correlation coefficient of 0.813 with MRI CSA and 0.518 with US CSA. No differences in CSA were observed between intraoperative, MRI and US methods ($p > 0.05$). The intraclass correlation coefficients between the US, MRI and intraoperative graft methods for the ST and GT data ranged from 0.502 to 0.903 with an estimation error ranging from 1.41% to 2.26%. These results indicate that in clinical situations where MRI is contra-indicated or not accessible, US can provide measurable values which could predict sufficient diameter of the ACL graft. In addition, determination of tendon CSA using US displays errors less than 2% which is similar to that observed using MRI. This suggests that the application of US can be applied to in vivo examination of the ST and GT CSA.

1. Introduction

The use of musculoskeletal ultrasound (US) has allowed the description of muscle and tendon properties in vivo (Fukunaga et al., 2002; Maganaris and Baltzopoulos, 2000). The advantages of US over other methods include the rapid, non-invasive and real time evaluation at rest and contraction state conditions, relatively low cost, lack of ionizing radiation and high axial resolution (Bey and Derwin, 2012).

Quantification of hamstring tendon morphology is important in both research and clinical settings. From a clinical perspective, hamstring autografts are at the present commonly used for anterior cruciate ligament (ACL) reconstruction, with the semitendinosus (ST) and the gracilis (GT) muscles being the main donors in a variety of reconstructive methods in terms of graft configuration and bone-to-tendon fixation (Aglietti et al., 2004; Drogset et al., 2010; Jarvela, 2007; Yasuda et al., 2006). From a biomechanical perspective, in vivo assessment of hamstring physical properties such as tendon length and cross-sectional area allow the quantification of its mechanical behavior such as stiffness or modulus, when combined with estimates of tendon force (Bey and Derwin, 2012).

* Corresponding author at: Laboratory of Neuromechanics, Aristotle University of Thessaloniki, TEFAA Serres, Serres 62100, Greece.

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Evaluation of hamstring tendon physical properties is crucial for ACL operation outcome with a minimum graft diameter of 7 mm being demanded for a 2-stranded ST and 2-stranded GT single-bundle ACL reconstruction (Yasuda et al., 2006). The ST and GT autografts may vary anatomically in diameter and length (Pagnani et al., 1993; Pichler et al., 2008), rendering their choice problematic if they do not meet sufficient size to provide the surgeon with a graft suitable for fixation and capable of withstanding high forces.

Prediction of the grafts diameter pre-operatively could be highly beneficial, as other donor sites may be chosen in case of inadequate hamstring proportions. Anthropometric measurements have correlation with the size of the hamstring autograft allowing the surgeon to alter the operation plan if graft is predicted as undersized (Pinheiro et al., 2011; Treme et al., 2008; Tuman et al., 2007; Xie et al., 2012). Magnetic resonance imaging (MRI) of ST and GT cross-sectional area (CSA) has also moderate to high correlation with autograft diameter with correlation coefficients ranging from 0.419 to 0.697 (Beyzadeoglu et al., 2012; Hamada et al., 1998; Wernecke et al., 2011). To our knowledge only one study examined whether US measurements of the ST and the GT diameter display a high correlation with the intraoperative hamstring autograft diameter (Erquicia et al., 2013). Particularly, Erquicia et al. (2013) have reported that graft size displayed a moderate correlation between cross-sectional area (CSA) determined pre-operatively using the US ($r = 0.51$) and MRI (0.54) in a sample of 33 patients. Despite this moderate relationship, these authors have positively commented on the pre-operative use of US and MRI for final graft prediction.

Failure rates of a 4-stranded GT-ST autograft has been shown to increase with graft diameter of less than 8 mm (Conte et al., 2014). Therefore, previous research studies have examined the prediction ability of MRI or US measurements by identifying a certain cutoff point which discriminates a sufficient diameter of the final graft (Erquicia et al., 2013; Wernecke et al., 2011). For MRI, the identified cutoff could predict a minimum graft size in 80.8% (Erquicia et al., 2013) or 93% (Wernecke et al., 2011) of the cases, while for US, the chosen cutoff could discriminate 80.8% of the patients. Given the limited amount of published data and the relatively low correlation coefficients between pre-operative CSAs and final ACL graft, clearly, more research is necessary to verify previous findings. US measurements can be conducted easily and with minimal cost compared to MRI and could predict the grafts size more objectively than simple anthropometric measurements.

A recent review (Kwah et al., 2013) reported that a few studies examined the validity of US measurements for examination of muscle architecture in vivo. However, the validity of examination of tendon morphology, such as CSA, using US has not been previously examined. Numerous recent studies have raised questions on the reliability of US examination of tendon morphology (Brushoj et al., 2006; Ekizos et al., 2013; Gellhorn et al., 2012; Gellhorn and Carlson, 2013) but only a few examined the validity of this technique (Gellhorn et al., 2012). Gellhorn et al. (2012) reported a high correlation of patellar tendon length between US and direct dissection measures. In a recent review, Bey and Derwin concluded that the accuracy of US technique for examination of in vivo tendon function is currently unknown (Bey and Derwin, 2012). These studies are, however, mainly on patellar tendon measurements and may not apply to other tendons.

The purpose of this study was double-fold: first, to examine the relationship between pre-operative US and MRI CSA with the final quadruple ACL graft diameter and second, to examine the validity of US for in vivo examination of the ST and GT CSA. Two hypotheses were tested: first, that US thickness would display a moderate correlation with MRI and the final ACL graft and, second, that there would be no differences in CSA determined using the three methods (US, MRI and dissection).

2. Method

2.1. Subjects

This was a prospective study. A total of 60 patients scheduled for ACL reconstruction with a hamstring autograft performed by the same orthopaedic surgeon (M.S.) at the 424 General Military Hospital of the Thessaloniki were selected to participate in this study during a 4-month period. Patients were excluded if they had previous ACL surgery, partial ACL injuries, multiligament knee injuries, other soft-tissue injuries, and intraoperative graft amputation, injured contralateral extremity, back, and neck, no history of neurological disease, or vestibular or visual disturbance. A total of 14 males (age 31.14 ± 3.11 yrs, mass 86.71 ± 9.53 kg, height 178.32 ± 4.30 cm) met the inclusion criteria and they participated in this study after signing informed consent forms. Approval for the experiment was obtained from the local Hospital University Ethics Committee on Human Research in accordance with the declaration of Helsinki.

2.2. Surgical procedure

One surgeon (M.S.), who routinely performs hamstrings autograft ACL reconstruction, was involved in the procedure. A short oblique incision was performed over the pes anserinus bursa of the injured leg. The GT and ST tendons were harvested, with the tendon stripper and all the muscle fibers were removed. Each tendon was attached to the graft preparation station (Graftmaster, Acufex™) and its thickness was measured with a metric 'caliper' style micrometer (Fig. 1).

The two tendons were paired to form a 9–10 cm long quadrupled construct. The quadrupled graft was measured again with the micrometer and it was then passed through an open-hole sizing block (of 0.05 mm incremental diameter from 5 mm to 11 mm). We recorded the combined diameter of the 4-strand graft. The femoral fixation was accomplished with a flip-tack button (Karl Storz Endoscopie™) and the tibial fixation with PLLA screws (Megafix®-P) and Co–Cr staples. All patients underwent a medial portal anatomic SB ACL reconstruction.

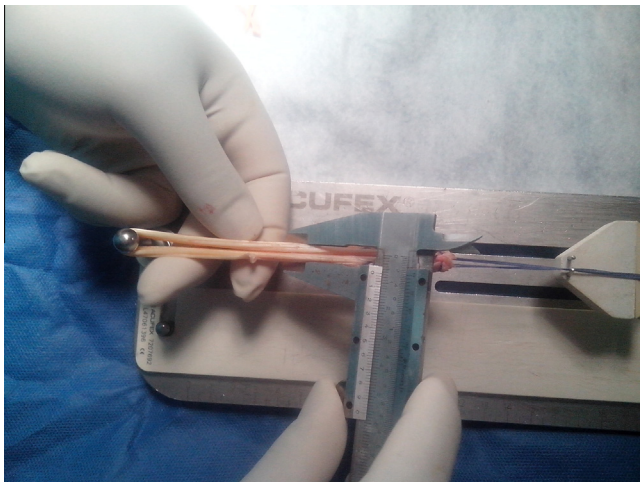

Fig. 1. Evaluation of graft thickness using a metric "caliper" style micrometer.