Stress Concentration with Quadriceps Tendon Graft Harvest

Anja Wackerle[1,2], William Gamble[3], Armin Runer[1,2], Svenja Hoeger[1,2], Michael P. Smolinski[3], Mark C. Miller[3], Volker Musahl[1], Patrick Smolinski[3]
[1]Department of Orthopaedic Surgery, University of Pittsburgh, Pittsburgh, PA, USA
[2]Department for Orthopaedic Sports Medicine, Klinikum Rechts der Isar, Technical University of Munich, Munich, Germany
[3] Department of Mechanical Engineering and Material Science, University of Pittsburgh, Pittsburgh, PA, USA

patsmol@pitt.edu

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INTRODUCTION: Graft choice is critical in anterior cruciate ligament (ACL) reconstruction (ACLR), with the quadriceps tendon (QT) gaining popularity as an autograft [1]. For an anatomic, individualized ACLR, it is essential to choose a graft size to match the morphological characteristics of each individual [2,3]. It remains unknown how much of the QT can be harvested without reducing the strength of the remaining tendon too much, potentially risking donor-site complications. Native QT size varies and can be measured by MRI and ultrasound [4-5]. Harvesting a QT autograft will cause a reduction in the remaining tendon strength and could result in tendon rupture. Thus, a thorough understanding of graft size-dependent strength reduction is important for decision-making in clinical practice. The goal of this study is to evaluate the effect of the graft harvest on the stress concentration induced in the tendon.

METHODS: Institutional approval was received for this study (Corid ID 1186). The extensor mechanisms were harvested from twenty paired, fresh-frozen cadaveric knees from 10 individuals (mean age 49.1±14.7, age range 25 to 63 years; 1 female). One side of each pair was randomly assigned to either 1) the intact QT or 2) the donor QT group. All tendons were laser scanned (Faro Arm, Faro Inc.) to measure their cross-sectional area (CSA) at 4 cm proximal of the patella. For the donor QT group, a partial thickness soft tissue graft (5x10x70 mm) was harvested from the center of the QT. The change in CSA area of the donor QT was defined as the difference in CSA between pre- and post-graft harvest. For both groups, the patella was embedded in a resin block. For tensile testing, each resin block was clamped to a uniaxial testing machine (MTI 5K, Measurements Technology Inc., Marietta, GA, USA) base. The proximal end of the tendon was clamped by a freeze clamp, leaving 80mm of tendon length between the potted patella and clamp. All tendons were cycled 20 times (20 to 50 N), preloaded with 10 N, and then loaded to failure at a rate of 10 mm/min. The change in failure load was defined as the difference in failure load between the intact and donor QT within each pair.

RESULTS SECTION: Mean CSA of the intact tendons (213.4±49 mm^2) was not significantly different from that of the native donor tendons before harvest (221.4±38.7 mm^2). The CSA of the intact donor QT was reduced by 31.7% ± 7.4% after graft harvest. The failure location was at the mid-substance in four donor tendons, at the insertion in one donor tendon, and in one intact tendon. Four intact tendons failed at or close to the insertion. The intact QTs failed under higher ultimate load (5209.9±999.3 N) than the donor QTs (2553.1±701.4 N). The failure load was significantly reduced in the donor QT when compared to the intact paired QT of each individual, with a mean reduction of 51.0 %. A plot of the percent reduction in failure strength versus the percent reduction in tendon CSA is given in Figure 2, with the slope of the linear regression (passing through the origin) of 1.56, and corresponding Pearson's r = 0.498.

DISCUSSION: Harvesting a QT graft corresponding to 31.7±7.4% of the donor tendon CSA resulted in a 51.0±15.6% reduction in residual tendon failure strength. The moderate correlation between CSA reduction and load reduction (Pearson's r = 0.498), and the regression slope of 1.56 indicate that the loss in strength is substantially greater than would be predicted from CSA change alone. A regression slope > 1 suggests the presence of a stress concetration effect, where local stresses increase disproportionately, which becomes more pronounced with greater CSA removal. In other words, harvesting larger grafts is likely to produce even larger reductions in donor tendon strength. This finding suggests that there may be a functional upper limit of QT graft size, beyond which the mechanical integrity of the donor tendon could be compromised. Despite the 50% reduction in ex vivo failure strength observed in this study, clinical reports of QT rupture after ACLR are rare [6]. This apparent discrepancy may be explained by several factors: postoperative loading of the QT in vivo may not approach its maximum capacity; biological healing processes could restore tendon strength over time; and neuromuscular adaptations might redistribute load away from the donor site. These possibilities suggest that in vivo tendon safety margins are larger than indicated by failure testing alone. It is important to note that the current analysis is based on a graft size roughly equivalent to an 8 mm diameter ACL graft, which is typical in clinical practice. The regression model derived here can be used to estimate potential strength loss for larger grafts, though extrapolation should be made cautiously. In vivo remodeling, patient activity level, and rehabilitation protocols may all influence the long-term mechanical consequences of harvest.

SIGNIFICANCE/CLINICAL RELEVANCE: Autograft harvest produces a disproportionately large reduction in residual QT strength relative to CSA removed, suggesting a stress concentration effect that increases with graft size. These findings highlight the need to harvest a sufficiently large graft while preserving as much of the donor tendon's integrity as possible.

REFERENCES: 1) Sheean et al., BJSM, 2018. 2) Fu et al., KSSTA, 2014. 3) Geib et al., Arthroscopy, 2009. 4) Offerhaus et al., AJSM, 2018. 5) Todd et al., AJSM, 2015. 6) Singhet al., KSSTA, 2023.

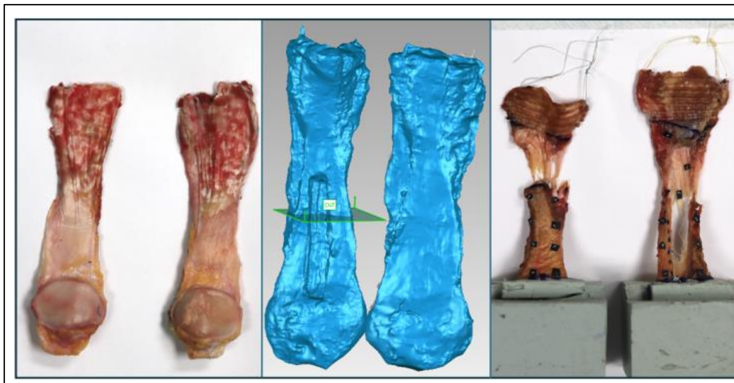

Figure 1: Preparation of paired QTs (left), CSA measurement 4 cm proximal of patella using scan (middle), tendon pair after being loaded to failure (right).

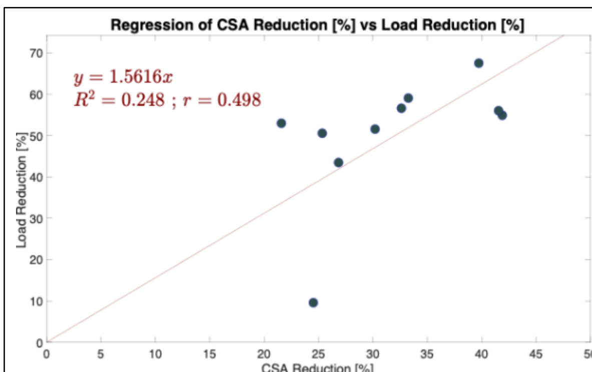

Figure 2: Linear regression of the percentage reduction in failure load with percentage reduction in tendon cross-sectional area.