

# Relationship of Musculotendinous Junction Location to Harvested Semitendinosus and Gracilis Tendon Length

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**Background:** Harvested hamstring tendon length has received scant attention in published anterior cruciate ligament (ACL) reconstruction literature, yet length can limit the ability to increase graft diameter by folding the tendon over more than once. Indeed, some ultrashort tendons may be too short to yield a clinically useful graft after being folded over just once. Ultimately, the total length of a harvested hamstring tendon may depend on the length of the tendon distal to its musculotendinous (MT) junction.

**Purpose:** To compare the lengths of harvested hamstring tendons to the location of the MT junction to help predict abnormally short tendon harvest.

**Study Design:** Cross-sectional study; Level of evidence, 3.

**Methods:** Eighty-four consecutive patients undergoing primary ACL reconstruction using hamstring tendon autografts underwent intraoperative measurement of the total length of each harvested semitendinosus (ST) and gracilis (G) tendon, as well as the distance from the MT junction to that tendon's distal end (ie, the "tendon-only" length).

**Results:** The ratio of the tendon-only portion to total harvested tendon length averaged 0.52 (range, 0.39-0.71) for the ST and 0.52 (range, 0.43-0.71) for the G, suggesting a 95% chance of harvesting a tendon <15 cm in length for the tendon-only portion is <6.45 cm for ST or <6.75 cm for G tendons. There was moderate correlation between the lengths of harvested ST and G tendons with patient height as well as with the diameter of the combined, quadruple-stranded graft.

**Conclusion:** The ratio of the tendon-only length to total harvested length for both the ST and G appear to range from approximately 0.4 to 0.7. Patients with abnormally distal MT junctions of either their ST or G are likely to have an abnormally short harvest of that tendon, even in the absence of technical harvesting error.

**Keywords:** ACL; hamstring; semitendinosus; gracilis; length

Hamstring tendon autografts continue to be a popular graft choice for anterior cruciate ligament (ACL) reconstruction surgery.<sup>13</sup> For single-bundle reconstructions, both the semitendinosus (ST) and gracilis (G) tendons are typically harvested, cleaned of muscle fibers and other nontendinous tissue attachments, and then doubled over themselves,

creating a 4-stranded graft used to replace the damaged native ACL.

To be clinically useful, the harvested tendons need to be of sufficient length and thickness to substitute for the torn native ligament, and a recent biomechanical investigation has confirmed significant correlation with quadrupled human hamstring diameter and graft strength.<sup>4</sup> Furthermore, clinical studies have suggested higher failure rates with smaller-diameter grafts.<sup>11,12</sup> On the other hand, there is clinical evidence showing no such linkage.<sup>10</sup> Nevertheless, concern about small-diameter grafts has led some surgeons to recommend thickening ACL grafts deemed to be "too thin" by constructing a 5-stranded or 6-stranded graft from the 2 harvested hamstring tendons by folding over the tendons more than once.<sup>4,6</sup>

However, one occasionally encounters an abnormally short hamstring tendon associated with an unusually distal musculotendinous (MT) junction. Indeed, the lead author (O.A.I.) has noted that when muscle fibers of either tendon

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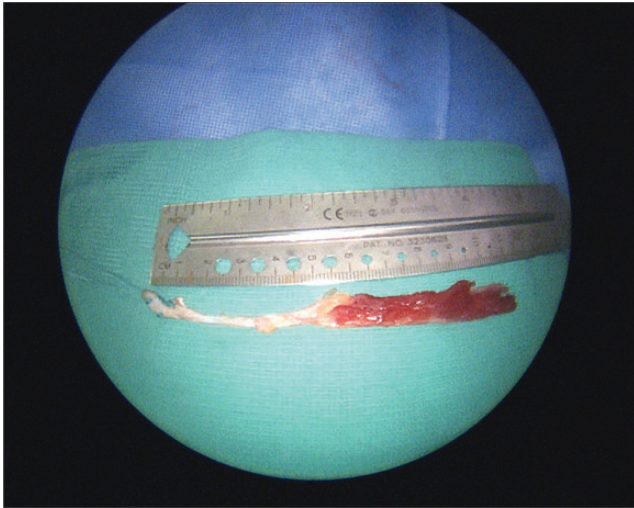
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Ethical approval for this study was obtained from the UTMB Health Institutional Review Board (IRB No. 15-0304).

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**Figure 1.** Example of an abnormally distal musculotendinous junction of the semitendinosus in a 17-year-old male along with a very short harvested tendon, which prompted the current investigation.

can be visualized prior to employing a tendon stripper from an incision near the pes anserinus insertion, that particular harvested tendon is abnormally short (Figure 1). This can preclude using the harvested tendon in the usual fashion, much less creating a graft with 5 or more strands. Recognizing such a situation as early as possible during surgery may facilitate minimizing prolonging the operative time necessitated by alteration in the surgical plan, thereby limiting increased cost and anesthetic time. Although the lengths of harvested ST and G tendons have heretofore received some attention in the published literature, there has been no prior investigation reporting how the length of either harvested tendon correlates with how close the MT junction is to the distal insertion site.

The purpose of this study was to determine whether the presence of muscle fibers more distal than usual on either the semitendinosus or gracilis would be predictive of an abnormally short harvested tendon. The starting hypothesis was that the distance from the most distal muscle fibers to the tendon insertion (ie, the “tendon-only” length) would be more than 30% of the total length of the harvested tendon.

## METHODS

Length measurements of harvested ST and G tendons were taken and recorded intraoperatively from 84 consecutive patients undergoing primary ACL reconstruction surgery using hamstring autografts by the lead author (O.A.I.) from December 2011 through December 2014. Those requiring additional ligament surgery were not included.

Hamstring harvesting was performed through an approximately 2-cm longitudinal incision made over the pes anserinus insertion, with blunt dissection establishing a plane (from superior to inferior) between the pes tendons and the underlying medial collateral ligament. The pes

tendons were then sharply transected at their tibial insertion and the G and ST identified on the undersurface of the pes before being separated from each other and the overlying sartorial layer by a combination of sharp and blunt dissection. A No. 2 braided, nonabsorbable suture was placed in the distal end of the mobilized G and another in the distal end of the ST in modified Krakow fashion. After mobilization, including releasing all adhesions to the surrounding fascia, each tendon was harvested using a 6-mm diameter, closed-end tendon stripper (Mitek). Gradual tapering of the tendon in the proximal aspect helped confirm the harvesting process was free of premature truncation, which would result in a falsely short tendon length measurement. The distance from the distal end of each harvested tendon to where that tendon’s muscle fibers were first seen was recorded to the nearest centimeter as the “tendon-only” portion. Then, the muscle fibers and other nontendinous attached soft tissues were removed from each tendon, and a No. 2 braided, nonabsorbable suture was placed in modified Krakow fashion in the proximal end, with the aim to obtain as long a tendon graft length as possible. Tension was then applied to the proximal and distal sutures to remove any slack, and the total length of the prepared tendon graft was recorded to the nearest centimeter. Both tendons were then folded over a suture, and the diameter of the resulting 4-stranded graft was measured to the nearest 0.5 mm using cylindrical sizing blocks. If an abnormally short tendon was harvested, that patient’s data were not included in the results of the 4-stranded graft diameter, but all other data were still included in the analysis. All data were recorded prospectively, as was each patient’s age, sex, height, weight, and whether the surgery involved the right knee or the left.

The length of each harvested ST was compared with that of its G counterpart. The length of the tendon-only portion of each hamstring (ie, the distance from the MT junction to the tendon insertion) was divided by the total usable length of the harvested tendon. These results were used to calculate (using twice the standard deviation) the 95% likelihood of harvesting an abnormally short ST or G tendon (defined arbitrarily as <15 cm) based on the length of each muscle’s tendon-only portion.

Spearman correlation coefficients were calculated to determine further correlations between measurements of the harvested tendons and patient height, weight, or age. The strength of the correlation was classified as follows: strong ( $R > 0.66$ ), moderate ( $0.33 \leq R \leq 0.66$ ), or weak ( $R < 0.33$ ). The association of sex with quadrupled graft diameter was evaluated using the Mann-Whitney-Wilcoxon test. Multivariate analysis was performed to exclude the possibility of confounding variables. A priori study collection goals were a minimum of 50 subjects to improve statistical reliability as well as inclusion of at least 1 unusually short tendon. Consequently, institutional review board approval was obtained for up to 100 subjects.

## RESULTS

Of the 84 primary hamstring ACL reconstructions in this investigation, 37 were performed on males and 47 on

TABLE 1

Hamstring ACL Reconstruction Study Population (n = 84)<sup>a</sup>

Parameter	Mean	Minimum	Maximum
Patient age at surgery, y	23.1	14	55
Patient height, cm	168.6	135	188
Patient weight, kg	76.6	49	143
Total ST length, cm	26.1	20	33
Tendon-only ST length, cm	13.5	9	20
Total G length, cm	22.9	10	29
Tendon-only G length, cm	12.0	5	16
Four-stranded graft diameter, mm <sup>b</sup>	7.9	6	10

<sup>a</sup>ACL, anterior cruciate ligament; G, gracilis; ST, semitendinosus.<sup>b</sup>One patient not included due to abnormally short gracilis tendon.

females; 36 were performed on the right knee and 48 on the left. Patient demographic and tendon measurement data are summarized in Table 1. The length of the harvested ST in any subject ranged from 92% to 220% that of the harvested G, and averaged 115%. In fact, the harvested ST was shorter than its corresponding G in only 3 cases (3.6%) and was of a length equal to the G in only 1 case (1.2%). There was no case of technical error causing obvious premature truncation of the harvested tendon.

The ratio of the tendon-only portion to total tendon length for the ST averaged 0.52 (range, 0.39-0.71) and that of the G also averaged 0.52 (range, 0.43-0.71). This included 1 abnormally short (10 cm long) G harvested from a 30-year-old female (height, 157 cm; weight, 82 kg) for whom an allograft hamstring tendon was substituted for the too short gracilis. The tendon-only portion of that abnormally short G measured just 5 cm, so muscle fibers on this tendon were readily apparent prior to utilizing the tendon stripper, in sharp contrast to every other harvested hamstring tendon in this investigation.

Overall, the 95% CI of the chance of harvesting a G with a total length of <15 cm ranged from 0.03% to 6.46%, whereas that of harvesting a ST with a total length of <15 cm ranged from 0% to 4.3%. The study data suggest that there is a 95% chance of having a total harvested ST length of at least 15 cm if its tendon-only length is a minimum of 9.45 cm and a 95% chance of the total harvested G length being at least 15 cm if its tendon-only length is a minimum of 9.0 cm. More concerning, however, is that there is a 95% chance of the total harvested ST length being <15 cm if its tendon-only portion is <6.45 cm and of harvesting a G with total length <15 cm if its tendon-only portion is <6.75 cm.

Total length of harvested ST correlated moderately with patient height ( $R = 0.60$ ;  $P < .0001$ ) and weight ( $R = 0.46$ ;  $P < .0001$ ) but did not quite reach statistical significance for correlating with patient age ( $R = 0.21$ ;  $P = .05$ ). Likewise, total length of harvested G correlated moderately with patient height ( $R = 0.57$ ;  $P < .0001$ ) and weight ( $R = 0.47$ ;  $P < .0001$ ) but did not significantly correlate with patient age ( $R = 0.14$ ;  $P = .20$ ).

Similarly, the 4-stranded quadrupled graft diameter demonstrated moderate correlation with patient height ( $R = 0.57$ ;  $P < .0001$ ) and weight ( $R = 0.64$ ;  $P < .0001$ ) but

did not significantly correlate with patient age ( $R = 0.18$ ;  $P = .11$ ). Furthermore, the quadrupled tendon graft diameter showed moderate correlation with total ST length ( $R = 0.56$ ;  $P < .0001$ ) and weak correlation with tendon-only ST length ( $R = .30$ ;  $P = .0055$ ), whereas its correlation was of a moderate degree with both total harvested G length ( $R = 0.61$ ;  $P < .0001$ ) and tendon-only G length ( $R = 0.51$ ;  $P = .0001$ ). Unsurprisingly, males demonstrated a significantly greater median quadrupled graft diameter than females (8.5 vs 7.5 mm, respectively;  $P < .0001$ ).

## DISCUSSION

A recognized potential complicating factor of ACL reconstruction using hamstring autograft is inadequate harvested graft size in terms of graft length, diameter, or both. Although this can be due to surgical technical error, some patients simply have diminutive G and/or ST tendons. The results of this investigation confirm our clinical impression-based hypothesis that the tendon-only length of both these muscles is greater than 30% of the length of the total harvested tendon, and in fact, averages approximately half their useful surgical length. More specifically, this study's analysis demonstrates that the chance of harvesting an abnormally short (<15 cm) tendon is very high if the tendon-only length is less than 7 cm, and conversely, is very low if the tendon-only length is at least 10 cm. The harvested tendon length becomes of even greater importance if the strategy to cope with inadequate graft diameter involves not just doubling a tendon by folding it once but tripling or quadrupling it by folding it more than once to generate a 5- or more stranded graft, as suggested by some authors.<sup>4,6</sup> However, the current study shows moderate correlation between the diameter of the quadrupled 4-stranded graft and the lengths of the harvested ST and G. This suggests that smaller-diameter tendons also tend to have shorter lengths, limiting prospects of quadrupling or even just tripling a tendon to increase graft diameter.

Other authors have advocated routinely quadrupling the ST and using suspensory femoral and tibial fixation.<sup>5</sup> Indeed, this may have been a viable option for many patients in the current investigation. However, the example of a very short ST given in Figure 1—which was the impetus for launching the current study—appears to have been too short for even that approach. Furthermore, there is some evidence suggesting that purely soft tissue grafts may have inferior clinical outcomes when fixed outside both the femoral and tibial tunnels compared with such grafts being fixed close to the interarticular aperture of those tunnels.<sup>9</sup>

Attempts to correlate anthropometric measurements to the size of harvested hamstring tendons have consistently yielded statistically significant positive correlations but only to a moderate degree, making prediction unreliable.<sup>3,14-17,19</sup> Indeed, the current investigation also found moderate correlation at best between harvested tendon length or quadrupled graft diameter and patient height or weight, but not age. Our results are very close to those

reported by Xie et al<sup>19</sup> in the largest anthropometric study of harvesting ST and G tendon size to date (235 patients). Those authors report correlation coefficients between harvested ST length and patient height of 0.61 (compared with our 0.60) and patient weight of 0.42 (compared with our 0.46). Similarly, they also report correlation coefficients of harvested G length with patient height of 0.48 (compared with our 0.57) and patient weight of 0.37 (compared with our 0.47). Interestingly, although these correlations are quite similar between the 2 investigations, Xie et al<sup>19</sup> studied a population consisting almost exclusively of Han Chinese, whereas the current investigation was conducted in a major US metropolitan area with a mixed population of primarily European, African, and Latin American ancestry, as well as some East Asian, South Asian, and West Asian ancestry. This suggests that correlation between anthropometric measurements and length of ST and G tendons is similar across human races.

The correlation between patient age and ST length almost reached the threshold of statistical significance at  $P = .05$ , but there was no similar approach toward statistical significance between patient age and G length. Speculating, it may be that the location of the musculotendinous junction can recede from the insertion site of certain muscles with age.

In contrast to correlation with anthropometric measurements, the relationship of how distal the MT junction is to the total usable length of the harvested hamstring has not been investigated previously. Although the MT junction cannot be determined clinically prior to surgery, it may be possible to visualize with magnetic resonance imaging (MRI), although the feasibility and reliability of this remains to be determined by future investigations. Indeed, prior attempts to use MRI for predicting adequacy of ST and G tendons for ACL reconstruction have largely focused on hamstring tendon diameter, not length.<sup>1,2,7,18</sup> An exception to this is the investigation of Hamada et al,<sup>8</sup> who found weak correlation between the cross-sectional area of the ST measured on knee MRI to the harvested length of that tendon, whereas the correlation between the imaged cross-sectional area and that of the harvested tendon was strong. In contrast, Yasumoto et al,<sup>20</sup> using 3-dimensional computed tomography (CT), found moderate correlation between the imaged and harvested ST tendon length but no significant correlation between the imaged and harvested ST tendon cross section. However, although obtaining MRI prior to ACL reconstruction is fairly routine practice, obtaining CT scans, with added cost and radiation exposure, is not.

Even if an abnormally short ST or G tendon cannot currently be reliably determined with routine preoperative imaging, visualizing muscle fibers after mobilization of either tendon, but prior to utilizing a tendon stripper from an incision close to the pes insertion site, should alert the surgeon to the high likelihood of that particular tendon being very short. Realizing this allows earlier preparation for alternate graft options and also gives the option of not proceeding with harvesting, as the resulting tendon may be of little surgical value.

One of the limitations of this investigation is that this represents the experience of a single surgeon, although that also increases the reproducibility of the surgical

technique reported herein. Conceding that harvested tendon length may be technique dependent, the correlational findings of this study being quite similar to those of previous investigations suggest that the technique utilized, which is fairly standard, resulted in tendon harvesting similar to what has been previously reported in the literature. Another study limitation is that the length of an abnormally short harvested tendon was arbitrarily defined at 15 cm. Indeed, the adequacy of graft size for hamstring ACL reconstruction remains to be defined definitively.<sup>10,19</sup> The current investigation used a 15-cm cutoff for an abnormally short harvested tendon based on the standard surgical technique of hamstring autograft single-bundle ACL reconstruction performed by the lead author, which is to use a 4-stranded quadrupled graft consisting of ST and G tendons, utilizing suspensory femoral fixation and interference tibial fixation, and creating the femoral tunnel through an accessory anteromedial portal.

## CONCLUSION

The ratio of the tendon-only length to total harvested length for both the ST and G appear to be in the range of 0.4 to 0.7. Patients with abnormally distal MT junctions of either their ST or G are likely to have abnormally short harvest of that tendon even in the absence of technical harvesting error.

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