Side-by-Side Comparison of 4-Strand Versus 5-Strand Hamstring Graft Diameters in Patients Undergoing Anterior Cruciate Ligament Reconstruction

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ABSTRACT

Background: Hamstring (HS) graft size is an independent risk factor in determining outcomes related to anterior cruciate ligament reconstruction (ACLR). Although anthropometric correlations with HS tendon size have been studied, a predictable association with resultant graft size has not been established. This study directly compares the difference in diameter between a 4-strand (4S) and 5-strand (5S) HS autograft in the same patient.

Methods: A total of 31 consecutive patients undergoing ACLR with HS autograft were included in the study. The gracilis and semitendinosus tendons were harvested for each patient. The diameters and lengths of a standard 4S HS graft followed by that of 5S HS graft with a tripled semitendinosus tendon were measured and recorded for each patient.

Results: There were a total of 17 males included in the study, with an average age of 32.7 years. The average 4S HS graft measured 7.2 mm in diameter versus the 5S graft that averaged 9.0 mm in the same patient, with an average increase of 1.8 mm ($P < 0.001$). The calculated cross sectional area for a 4S HS graft was 40.7 mm^2 versus 63.6 mm^2 for a 5S graft ($P < 0.001$).

Conclusion: This is the first study to directly compare the difference in diameter between a 4S and 5S HS autograft in the same patient. A 5S graft reliably increases the diameter of a HS autograft in the same patient by at least 1 mm without sacrificing graft or tunnel length to a degree that may be detrimental to the overall quality of the reconstruction.

Keywords: Anterior Cruciate Ligament, Anterior Cruciate Ligament Reconstruction, Autograft, Hamstring

INTRODUCTION

The incidence of primary anterior cruciate ligament reconstruction (ACLR) in the United States rose from an estimated 87,000 to 130,000 cases from 1994 to 2006.[1] Multiple graft options exist for reconstruction, including bone-patellar tendon-bone (BPTB) autograft, hamstring (HS) tendon autograft, quadriceps tendon (QT) autograft, and allograft tissue. Many factors influence graft selection such as surgeon training, experience, and patient factors.[2,3] Although several studies have shown no difference in outcomes between BPTB and HS autografts, some recent literature suggests that HS autografts may be associated with higher rates of failure.[4,5,6,7]

HS graft size has been shown to be an independent risk factor in determining outcomes related to ACLR. In 2012, Magnussen et al[8] reported that use of HS autografts with a diameter greater than 8.0 mm was associated with a lower rate of revision ACLR. Several other studies have confirmed these results, and it has become well established that a graft diameter of 8 mm or greater can play a role in minimizing the risk for graft rupture.[9,10,11]

For HS autografts, it can be difficult to make an accurate preoperative prediction of the size of the harvested tendons and diameter of the eventual graft. Although some studies have correlated certain anthropometric indices to the diameter of the gracilis and semitendinosus tendons, a reliable model to predict the eventual size of the autograft has not been well established.[12] Given these limitations in predicting graft diameter, there has been interest in investigating techniques and methods to increase the overall diameter of the HS graft without compromising its structural integrity.

To our knowledge, no direct comparison has been made of the diameter, cross sectional area, and graft length in the femoral tunnel and tibial tunnels between a 4-strand (4S) and 5-strand (5S) HS graft in the same patient. We hypothesized that a 5S HS autograft, when compared to a 4S HS autograft in the same patient, will increase the diameter significantly to a value of at least 8 mm while providing adequate graft within both the femoral and tibial tunnels for fixation.

METHODS

Patient Selection

A total of 31 consecutive patients undergoing ACLR with HS autograft were included in the study. Inclusion criteria included any patient older than 18 years undergoing a primary ACLR with HS autograft. Exclusion criteria included multi-ligament knee injury and history of previous ACLR. The local Institutional Review Board granted exempt status for the study.

Surgical Technique

All grafts were obtained by a single orthopaedic surgeon proficient in HS tendon graft harvest (GT). The HS tendons were harvested in a standard fashion using a 3 cm oblique incision centered over the pes anserine tendon insertion. The gracilis and semitendinosus tendons were released from their distal attachment on the tibia and sequentially harvested using a closed tendon stripping device. All measurements were obtained after blunt removal of attached muscle and fat, but this was completed before any further postharvest alteration or graft trimming. The 4S HS graft was prepared by folding over (doubling) both the gracilis and semitendinosus tendons. Graft size was measured with a standard non-slotted sizing block (Smith & Nephew, Memphis, TN) that allows measuring differences of 0.5 mm in diameter. The 4S graft diameter was determined when the entire quadrupled graft, including the most distal portions of the HS tendons, fit through the sizing block and would not fit through the next 0.5 mm smaller size.

After sizing of the 4S graft was complete, the 5S graft was constructed. Based on a target graft length of 85 mm for females and 95 mm for males, the musculotendinous junction of the semitendinosus tendon was cut to a length 3 times the desired graft length. Similarly, the gracilis was cut to a length twice the desired graft length. After the tendons were prepared, the semitendinosus tendon was divided into thirds with a marking pen (Figure 1). The proximal one-third of the semitendinosus tendon was then folded back onto itself and secured with #2 Fiberwire (Arthrex, Naples, FL) suture (Figure 2). The graft was then placed under tension to ensure that all tissue was under uniform tension. The looped end of the semitendinosus tendon was secured with a #2 Fiberwire whipstitch. The gracilis and semitendinosus tendons were combined and folded in half, creating the 5S construct (doubled gracilis and tripled semitendinosus) (Figures

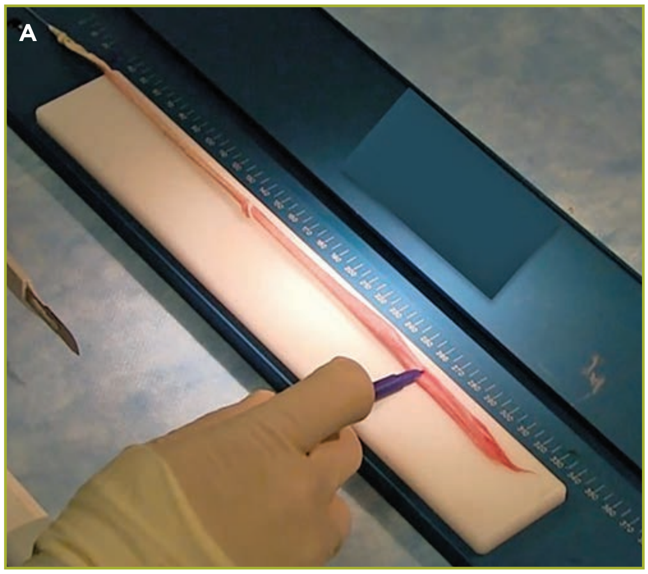

Figure 1. *Using a marking pen, the semitendinosus tendon is divided into thirds based on overall measured*

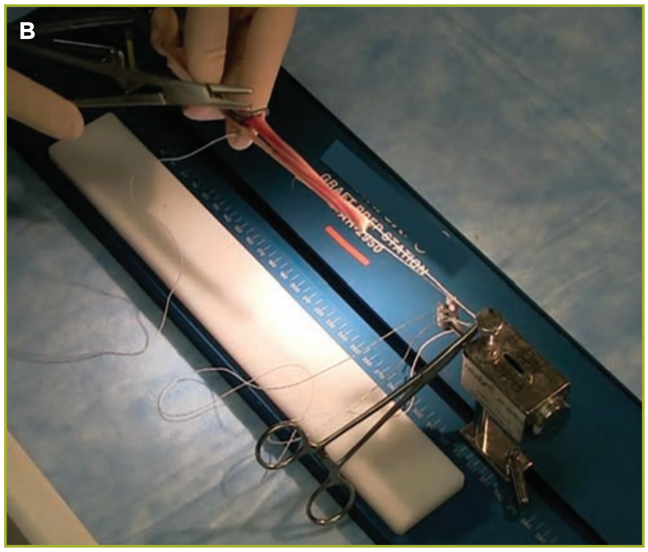

Figure 2. *Folding one-third of the semitendinosus tendon onto itself, and securing it with a non-absorbable suture.*

3A and B). The 5S graft was then measured using the same technique described for the 4S graft.

All patients had an ACLR performed with independent femoral tunnel drilling. The femoral socket was drilled from inside-out with a cannulated drill (Arthrex, Naples, FL). The tibial tunnel was made with a cannulated drill. Both tunnels were made according to the measured graft diameter. Using a modification to the technique previously described by Lavery et al,[13] the graft was then fixed with an ACL femoral Tight Rope (Arthrex, Naples, FL) (Figures 4A and B). Tibial fixation was performed with a Graftbolt PEEK sheath and screw (Arthrex, Naples, FL) for every case.

Statistical Analysis

A student *t* test was used to compare the averages of the diameter and calculated cross sectional area for

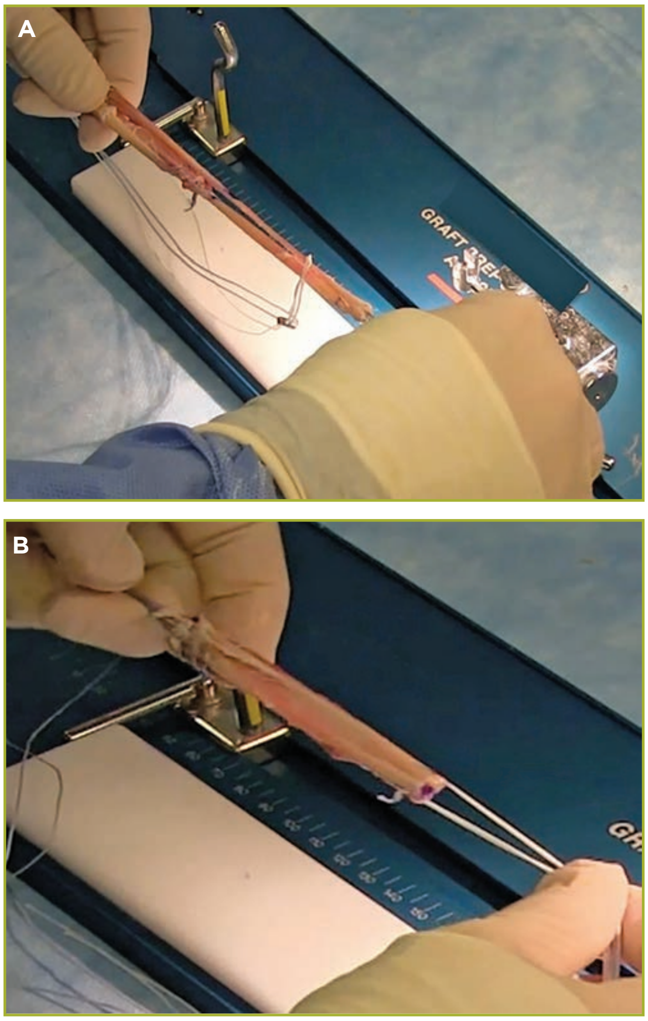

Figure 3. *A, B) The gracilis and semitendinosus tendons are then combined and folded in half, creating the 5-strand graft (doubled gracilis and tripled semitendinosus).*

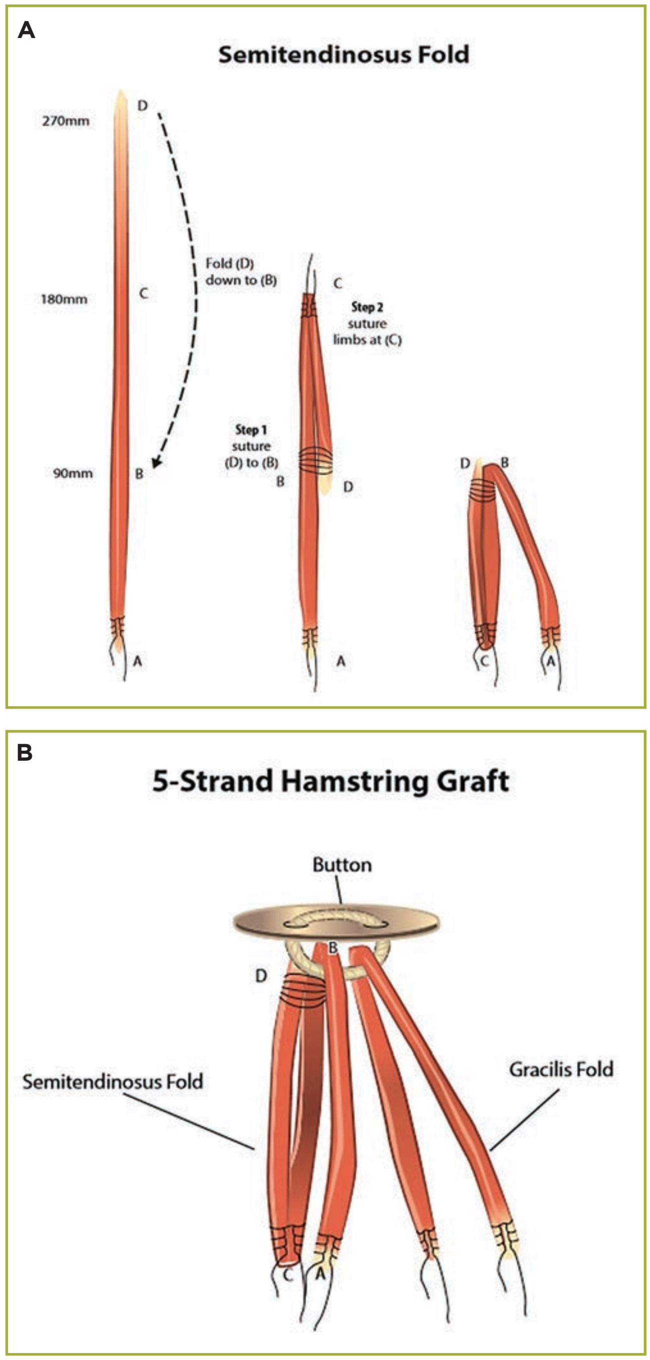

Figure 4. *A) Diagram depicting the technique to triple the semitendinosus tendon. B) The three equal-length tendon strands of the tripled semitendinosus and the doubled gracilis are fixed through the Tight Rope (Arthrex, Naples, FL) to complete the 5-strand HS graft.*

both the 4S and 5S grafts. Statistical significance was based on an assumed value for the Type I error of 0.05. A linear regression model was utilized to determine if any relationship existed between patient height and weight measurements and patient-specific 4S and 5S graft diameters.

RESULTS

A total of 31 HS autograft tendon pairs were harvested and analyzed. The average age of the patients was 32.7 years, with 55% of the patients male. The average subject height was 171 cm, with an average body mass index of 28.6 kg/cm^2 (Table 1). The average 4S HS graft measured 7.2 mm (range, 6.5 - 8.0 mm) in diameter versus the 5S HS that averaged 9.0 mm (range, 7.5 - 9.5 mm) in the same patient, with a total of 5 of the 31 5S HS grafts measuring between 7.5 and 8.0 mm. This was a statistically significant increase of 1.8 mm in graft diameter ($P < 0.001$). Similarly, there was a statistically significant increase in calculated cross sectional area from 40.7 mm^2 to 63.6 mm^2 when going from a 4S HS to 5S HS graft, respectively ($P < 0.001$) (Table 2). The average graft length in the tunnel was 26 mm (range, 20 - 30 mm) and all grafts ended at the external tibial aperture distally. There was no association between patient weight and diameter of the 4S or 5S graft. However, there was a weak association noted between patient height and the 4S graft diameter [$P = 0.002$, 95% confidence interval (CI) (0.0085, 0.033)] as well as the 5S graft diameter [$P = 0.0001$, 95% CI (0.017, 0.047)].

Table 1. Patient characteristics

Mean age at time of surgery Years (range)	32.7 (15-68)
Sex	
Males (%)	17 (55)
Females (%)	14 (45)
Anthropometric Measures	
Mean Height, cm (range)	171.0 (152.4-188.0)
Mean Weight, kg (range)	83.2 (58.8-123.6)
Mean body mass index, kg/cm2	28.6

Table 2. Intraoperative 4-strand and 5-strand graft dimensions

	4-Strand	5-Strand
Graft diameter, mm (range)	7.2 (6.5 – 8.0)	9.0* (7.5-9.5)
Graft calculated cross-sectional area, mm^2	40.7	63.6*
Graft length, mm		
Male	Not available[a]	96.5
Female	Not available[a]	84.3
Graft in femoral tunnel, mm (range)	Not available[b]	26 (20-30)

*Indicates significance with *P*-value of <0.001

[a]Graft length was not measured for the 4-strand graft as this has not historically been a concern after 4-strand graft preparation

[b]All anterior cruciate ligament reconstructions were completed with the 5-strand hamstring graft, thus 4-strand graft in femoral tunnel was not measured and similarly has not been a historical concern.

DISCUSSION

ACL HS autograft size has been established as an important variable in improving biomechanical properties and clinical outcomes related to ACLR. This study shows that despite known physiologic variability in HS tendon size and length, there is a significant increase in HS autograft diameter of at least 1 mm when utilizing a 5S versus a 4S HS tendon graft in the same patient. Perhaps more importantly, the average cross sectional area of the graft increased by 56.2%, from 40.7 to 63.6 mm^2. This illustrates the exponential relationship of cross sectional area to the radius of the graft and correlates to an increased strength of the graft. For solid cylindrical materials, the strength is proportional to the radius to the 3rd power, and stiffness is proportional to the radius to the 4th power. The average graft length in the femoral tunnel for the 5S HS graft was 26 mm, with an absolute minimum of 20 mm for the 31 patients evaluated.

Inadequate ACL graft size has been implicated as a cause of ACLR failure. Some failures have been attributed to insufficient graft diameter, with several studies providing convincing evidence that a diameter greater than 8 mm may be optimal.[8] The Multicenter Orthopaedic Outcomes Network (MOON) study group retrospectively reviewed 263 consecutive patients and found that a younger patient age and smaller HS autograft size was a predictor of poorer subjective patient outcomes.[9] However, when young patients (< 20 years old) underwent reconstruction with grafts larger than 8 mm diameter, the failure rate in the MOON study reduced from 18.3% to 0%, a finding similar to outcomes in the study by Magnussen. In a recent systematic review, there was a 6.8 times greater relative risk of failure of HS autograft ACL reconstructions for graft diameters equal to or less than 8 mm.[10] Furthermore, Spragg et al[11] found that grafts ranging from 7 to 9 mm in diameter have a 0.82 times lower likelihood of requiring revision surgery with every 0.5-mm incremental increase in diameter.

It has been shown that a quadrupled HS tendon has greater initial biomechanical strength than a matched patellar tendon and is sufficient for use in ACLR.[14] However, there is recent evidence suggesting that tensile strength is highly dependent on graft diameter.[15] Boniello et al[15] showed that there was a statistically significant increase in tensile strength with increasing graft diameter for quadrupled HS tendon grafts measuring between 6 and 9 mm in diameter. They also noted that increasing HS graft diameters by 1 mm may dramatically affect graft strength. Calvo et al[16] showed that converting to a 5S graft in patients with diameters less than 8 mm resulted in re-rupture rates no different than those patients with 4S grafts greater than 8 mm.

Although several studies have attempted to predict HS tendon autograft size prior to harvest,[12,17,18] a reliable model to predict the eventual size of the quadrupled HS autograft tendon does not exist. Patient height and weight have been proposed as surrogate markers for HS tendon length and size; however, this is not a universally accepted model. The current study showed that 1) no relationship existed between HS graft diameter and patient weight, and 2) there was only a weak correlation for graft diameter and patient height. Graft configurations that exceed the 8 mm threshold decrease the need for such predictions. Several approaches have been examined for grafts measuring less than 8 mm in diameter, including allograft supplementation, contralateral HS harvest, and graft preparation configurations that triple or quadruple one or both of the tendons. Techniques for 5S HS graft reconstruction have been discussed in the literature.[13] Tutkus et al[19] collected data on 122 adult patients undergoing ACLR and found that preparation of a 5- or 6-strand HS graft yielded graft diameters larger than 8 mm in 98.4% of cases.

Furthermore, it has been recognized that graft preparation can change tendon size and dimensions. In a recent study, Cruz Jr. et al[20] investigated how the size of HS tendon allograft changes as they are prepared for ACLR. They found that the average diameter of HS ACL grafts decreases by almost 1 mm after being subjected to both tension and circumferential compression within a standard cylindrical sizing block. The measurements found in the current study likely fall on the lower end when compared to retrospective studies in the literature. The tendons were first passed and compressed through the sizers for the 4S measurements prior to preparation of the 5S construct and then further compressed and tensioned. Further, grafts were passed through sequentially smaller sizers until they would not fit, resulting in the lowest possible number being reported for each graft. Despite this, the current study grafts averaged 9.0 mm in diameter, which we believe compares favorably with the existing data from retrospective studies. Additionally, most patients increased their graft diameters by more than 1.0 mm when going from a 4S to 5S construct. We did have one patient with a 5S graft diameter of 7.5 mm. This patient had a 4S graft diameter of 6.5 mm, and a 5S graft was used for this patient. However, a 6S graft can be created with tripling of the gracilis tendon in the same fashion described for the semitendinosus, further increasing the graft diameter.

Other than graft diameter, the available graft length for fixation in the femoral tunnel has been cited as a potential source of failure. Some critics have noted that the overall HS graft length is decreased by increasing the HS graft diameter, thus the amount of graft in the femoral and/or tibial tunnels may be compromised. Qi et al[21] published a series of 40 adult canines that underwent ACL reconstruction with Achilles tendon grafts with varying graft lengths in the tibial bone tunnels. They found that the histologic maturity and biomechanical strength of the bone-tendon junction after ACL reconstruction were delayed if the intra-tunnel graft length was less than 15 mm. Mariscalco et al,[22] studied this question and showed no difference in 2-year patient-reported outcome scores between patients with graft length in the femoral tunnel less than 25 mm and those with graft length in the femoral tunnel of at least 25 mm. They concluded that as little as 15 mm of intra-tunnel length in the femur can be used without adverse consequences. All patients in the current study had 5S grafts that averaged over 25 mm in the femoral tunnel, with a minimum intra-tunnel length of 20 mm, and had adequate length to reach the external tibial aperture distally.

Limitations

One limitation of this cross-sectional cohort study is that only graft diameter, length, and calculated cross-sectional area were evaluated. Although previous research has illustrated crucial concepts that could be inferred and extrapolated to this study, the design of the study is such that long-term clinical outcomes still need to be performed and thus no clinical conclusions can be drawn. Standard surgical measuring methods with a simple surgical hand ruler and standard graft-sizing block were used for all measurements rather than digital calipers with micrometer increments; therefore, the measurements are subject to some variability. In addition, a single fellowship-trained orthopaedic surgeon performed all graft measurements, thus inter- and intra-rater reliability was not performed. However, previous studies show excellent to near-perfect inter-rater reliability when measuring these variables.[20,23] Although gender was recorded, the analysis of different subgroups with respect to gender should be based on large samples to objectively reveal reliable differences. Since this study was based on consecutive patient encounters, it was difficult to control for potential confounding variables that may influence the final data interpretation.

To our knowledge, this is the first study to directly compare the difference in diameter between a 4S and 5S HS autograft in the same patient. Assuming that larger graft diameters and surface area leads to improved clinical outcomes and biomechanical properties, a 5S graft can reliably increase the diameter of a HS autograft in the same patient by at least 1 mm without sacrificing graft or tunnel length to a degree that may be detrimental to the overall quality of the reconstruction. Further studies are needed to determine if this translates into improved clinical outcomes with lower risk of graft failure and need for subsequent revision.

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