Impact of Hamstring Graft Diameter on Tendon Strength: A Biomechanical Study

Michael R. Boniello, M.S., Paul M. Schwingler, M.D., Justin M. Bonner, Samuel P. Robinson, M.D., Andrew Cotter, B.S., and Kevin F. Bonner, M.D.

Purpose: The purpose of this study was to compare the tensile strength of hamstring grafts of varying combined pull-through diameters within the clinically relevant range of 6 to 9 mm. **Methods:** We tested 44 non-irradiated allograft hamstring grafts (11 per group). Combined looped semitendinosus and gracilis grafts were allocated to the 6-, 7-, 8-, or 9-mm group based on the smallest-diameter lumen that the graft could be "pulled through" using a surgical sizing instrument. Testing was performed on an Instron materials testing machine (Instron, Norwood, MA). Samples were secured with cryoclamps, prestressed, and pulled to failure at a rate of 10% gauge length per second. **Results:** The mean load to failure was 2,359 ± 474 N, 3,263 ± 677 N, 3,908 ± 556 N, and 4,360 ± 606 N for the 6-, 7-, 8-, and 9-mm grafts, respectively. Minimum failure loads were as low as 1,567 N, 2,288 N, 2,874 N, and 3,720 N for each group, respectively. There were statistically significant differences between the 6- and 7-mm, 6- and 8-mm, 6- and 9-mm, and 7- and 9-mm groups ($P = .01$). **Conclusions:** Statistically different increasing tensile strength was seen as graft diameter increased. Significant variability exists in the strength of multi-stranded hamstring allografts within the diameter range of 6 to 9 mm that often falls well below the commonly accepted value of 4,000 N for a hamstring graft. **Clinical Relevance:** Recent evidence suggests a higher early failure rate of hamstring autografts in subsets of patients with graft diameters of 8 mm or less. This study may increase awareness that hamstring grafts may not be nearly as strong as previously appreciated and that increasing tendon diameters by 1 to 2 mm may dramatically affect graft strength. These data may be helpful in preoperative discussions regarding variable hamstring size, strength, and potential intraoperative augmentation options.

Over the past several decades, few anatomic structures have been the focus of such extensive study as the anterior cruciate ligament (ACL). Despite this plethora of data, considerable debate remains regarding the optimal surgical technique for ACL reconstruction. Surgeons have successfully used a number of graft options including both autograft and allograft sources. Historically, patellar tendon autograft has been the most popular because of its rapid bone-to-bone healing and its strength, thought to be comparable with the native ACL.[1,2] Although this is still the preferred graft of many surgeons, increased appreciation of donor-site morbidity, combined with the evolution of improved soft-tissue fixation devices over the past 2 decades and comparable published outcomes, has led autologous hamstring grafts to become a more popular graft choice among many surgeons.[3-9] Clinically, an autograft diameter variation of between 6 and 9 mm is usually encountered, with 7 to 8 mm being most common for quadruple-stranded grafts,[10] and recent literature suggests that hamstring autograft size may influence not only the risk of revision but also patient-reported outcomes.[10,11]

Despite the rise in popularity of hamstring grafts, their use for ACL reconstruction is not without its challenges and controversies. Several studies suggest no difference in short-term (2-year) or long-term (10-year) clinical outcomes between hamstring and patellar tendon grafts.[12,13] However, others suggest a trend toward greater stability and lower failure rates with patellar tendon grafts.[8,9,14-16] Unlike "middle-third" patellar tendon autografts, which can be reliably harvested to obtain a specific surgeon-determined size, hamstring autografts feature greater donor-size variability.[17,18]

From Eastern Virginia Medical School (M.R.B., P.M.S.), Norfolk; Jordan-Young Institute for Orthopedic Surgery & Sports Medicine (J.M.B., S.P.R., K.F.B.), Virginia Beach; and LifeNet Health (A.C.), Virginia Beach, Virginia, U.S.A.

The authors report the following potential conflict of interest or source of funding: K.F.B. is a consultant for and receives royalties from Zimmer. The grafts for this study provided by LifeNet. A.C is an employee of LifeNet Health.

Received July 7, 2014; accepted December 11, 2014.

Address correspondence to Kevin F. Bonner, M.D., Jordan-Young Institute for Orthopedic Surgery & Sports Medicine, 5716 Cleveland St, Ste 200, Virginia Beach, VA 23462, U.S.A. E-mail: kfbonner@cox.net

0749-8063/14571/$36.00

http://dx.doi.org/10.1016/j.arthro.2014.12.023

Table 1. Method of Pairing Each Tendon Tested

6 cm			7 cm			8 cm			9 cm		
T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3
G	G		G	ST	ST	G	ST		ST	ST	
ST			G	G		G	ST		G	ST	
ST			ST			G	G	G	G	G	G
ST			G	G		ST	ST		ST	ST	
ST			G	ST		G	ST		G	ST	
ST			G	ST		G	ST		G	ST	
ST			G	ST		G	ST		G	ST	
ST			G	ST		G	ST		G	ST	
ST			G	ST		G	G		G	ST	
G			G	G		G	ST		G	ST	
G			G	G		G	ST		G	ST	

G, gracilis; ST, semitendinosus; T, tendon.

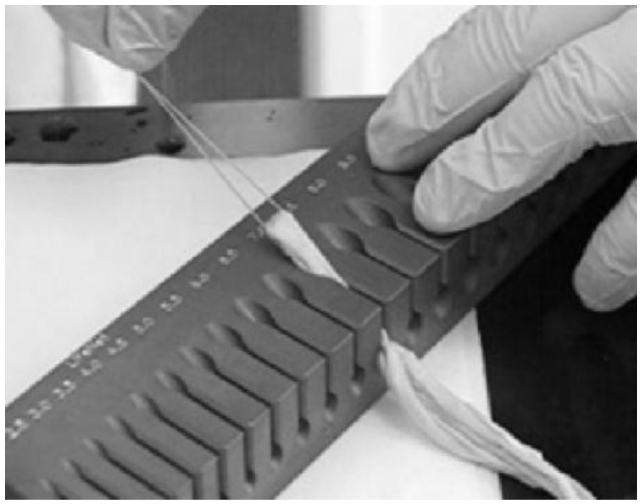

Fig 1. Tendon measuring block used for tendon diameter measurement (in millimeters).

Although a 4-stranded semitendinosus and gracilis graft ("looped graft") has been shown to offer potentially higher load-to-failure values at time 0 than patellar tendon grafts, there is likely much more variability in these values than currently acknowledged. Such variability undoubtedly has significant clinical implications. Indeed, recent evidence has pointed to a higher early failure rate of hamstring autografts in patients with grafts 8 mm or less in diameter when compared with grafts greater than 8 mm in diameter.[10,11]

The purpose of this study was to compare the tensile strength of hamstring grafts of varying combined pull-through diameters within the clinically relevant range of 6 to 9 mm. We hypothesized that there would be a statistical difference between the maximum loads of each graft diameter.

Methods

Gracilis and semitendinosus tendons were harvested from male and female donors, with research consent, ranging in age from 14 to 66 years. Each graft was disinfected using Allowash, a proprietary process developed by LifeNet Health (Virginia Beach, VA), that ensures proper removal of lipid and marrow elements from human tissue (US patents 5,556,379; 5,820,581; 5,977,034; and 6,024,735). Grafts for the purpose of this study were non-irradiated. The tendons were then packaged and stored at −80°C until testing.

One to three tendons were placed together to create one sample construct that represented a combined diameter of either 6, 7, 8, or 9 mm, as shown in Table 1. The construct was sized by placing a suture around the midpoint of the looped graft and then pulling the suture through the pull-through measuring apparatus to determine each construct's final diameter. This process resulted in a construct that comprised 1 to 3 tendons that were looped to create a 2- to 6-stranded graft. The looped end of the construct was clamped into the upper cryofixture. The free ends of the graft were clamped onto the lower cryofixture while equal tension was maintained on each strand. Strands were not sutured together. Pull-through diameters were between 6 mm and 9 mm inclusive, in increments of 1 mm. Each specimen was made up of 1 to 3 tendons with no restriction on the type of tendon to make the appropriately sized graft composite.

An analysis of variance followed by a Tukey post hoc test, with an α level of .05 (95% confidence interval), was used to compare groups. A power analysis was performed before testing using pilot data. The pilot data indicated that expected standard deviations would be approximately 15% of expected means, and a 25% difference in group means was considered a relevant effect size. On the basis of these inputs, a power level of at least 0.80 was ensured using a sample size of 11 specimens per diameter group.

Just before testing, each tendon was thawed in sterile water. Each graft was looped at the midsubstance and measured for diameter using the pull-through technique, as depicted in Figure 1. Size was determined by verifying the smallest sized diameter tunnel that the graft could be realistically pulled through, with the goal of having a very tight fit within the sizing instrument. If a tendon could not be pulled through the instrument with maximal force, it would be assigned to the next size group up.

Tensile testing was performed on a screw-driven Instron materials testing machine (Instron, Norwood, MA). Each sample was gripped using cryogenic clamps to create an unstressed length of approximately 30 to 40 mm. To help achieve equal tension among the tendon strands, the folded portion of the tendons was placed first into the top cryoclamp, allowing equal tensioning of the free ends of the tendon strands. Next, the top clamp was loaded onto the test frame, and the