Quadrupled Hamstring Graft Strength as a Function of Clinical Sizing

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Purpose: This study sought to compare the strength of quadrupled hamstring tendon (QHT) grafts of 6 to 9.5 mm in clinical diameter with that of 10-mm bone–patellar tendon–bone (BPTB) grafts. **Methods:** Twenty cadaveric semitendinosus and gracilis tendons were combined into QHT grafts. These were sized using a standard graft-sizing device and an area micrometer, yielding grafts ranging from 6 to 9.5 mm in diameter. The grafts were tested to failure. Five 10-mm BPTB grafts were also sized and tested. **Results:** Clinical sizing did predict the strength of the graft but not profoundly. As a material alone, without consideration of fixation in bone tunnels, QHT grafts were stronger than BPTB grafts. Graft strength decreased with size, but a linear relation between strength and diameter ($r^2 = 0.715$, $P < .001$) was found to be as good as the expected quadratic fit ($r^2 = 0.709$). Compared with BPTB grafts, even the smallest QHT grafts (diameter <6.5 mm) were still significantly stronger than 10-mm BPTB grafts ($P = .004$). The elastic moduli of the QHT and BPTB grafts were 761 ± 187 MPa and 615 ± 403 MPa, respectively; elongations at failure were 12.0% ± 2.0% and 7.5% ± 1.6%, respectively; and failure stresses were 105 ± 18 MPa and 50 ± 14 MPa, respectively. **Conclusions:** This work shows that a clinical size of QHT grafts of 6 mm in diameter is not a concern regarding the strength itself. For a possible lower-end prediction of acceptable size, assuming that a gracilis-semitendinosus graft would have only the stress of the weakest measured QHT graft of 88 MPa, a graft of 5.5 mm in diameter would suffice, having more strength in newtons than the average patellar tendon. **Clinical Relevance:** Clinically sized QHT grafts have a higher failure strength than 10-mm patellar tendon grafts. Therefore the strength of the graft cannot account for the higher clinical failure rates of smaller hamstring grafts in active patients in clinical studies.

Anterior cruciate ligament (ACL) reconstruction is among the most common surgical procedures performed in young patients, and the two most common autografts used in reconstructions are quadrupled hamstring tendon (QHT) graft and bone–patellar tendon–bone (BPTB) graft. Although BPTB autografts have been considered the gold-standard treatment, hamstring tendon grafts have shown good clinical success and have provided strong reliable tissue for ACL reconstruction.[1] Recent research, however, has reported an increased failure rate in young, active patients when a smaller QHT autograft was harvested.[2] The ability to predict hamstring graft sizes before surgery has been limited at best,[3-5] leading to a clinical situation in which the surgeon may be faced with implantation of a smaller hamstring graft.

Studies have investigated the size of harvested autografts and have examined biomechanical aspects of graft materials.[3-5] Hamner et al.[4] examined the strength and stiffness of single hamstring, double hamstring, and QHT grafts and found that the load was proportional to the cross-sectional area, as predicted by the tests performed by Noyes et al.[6] Noyes et al. compared hamstring tendons with BPTB samples biomechanically and found the hamstring grafts to be significantly stronger per unit area than their BPTB counterparts. Wilson et al.[7] compared the stiffness, strength, and area of hamstring tendons and patellar tendons from the same donor. To our knowledge, however, there have

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The authors report the following potential conflict of interest or source of funding: P.J.S. and M.C.M. receive support from Allegheny Singer Research Institute and Arthrex (not used to test the performance of Arthrex equipment/supplies). D.T.B. receives support from Allegheny Singer Research Institute and Orthopaedic Research and Education Foundation grant 11-254. S.A. receives support from Arthrex. No money was given; however, tendons and suture material were provided by Arthrex. Grafts were provided by RTI Biologics.

Received May 7, 2014; accepted January 16, 2015.

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0749-8063/14392/$36.00
http://dx.doi.org/10.1016/j.arthro.2015.01.013

been no studies evaluating QHT grafts based on clinical size alone and comparing these various sizes directly with concurrently tested standard 10-mm BPTB grafts. The harvest of a small hamstring graft at the time of surgery can leave the surgeon with doubts about the graft's adequacy. A simple biomechanical test could remove doubts.

The purpose of this study was to compare the strength of QHT grafts ranging in size from 6 to 9.5 mm with that of standard 10-mm BPTB grafts. We had 2 hypotheses: (1) there would be a decrease in graft strength with smaller QHT grafts, and (2) the smallest QHT grafts would still be significantly stronger than the standard 10-mm BPTB grafts.

Methods

We paired 20 gracilis tendons and 20 semitendinosus tendons (RTI Biologics, Alachua, FL) (mean age, 61.2 ± 6.6 years; 26 male and 14 female donors) to produce 20 QHT grafts ranging in size from 6 to 9.5 mm. The tendons were received frozen and were thawed twice before load-to-failure testing. The first thawing was for the initial pairing procedure, and the second was followed immediately by load-to-failure testing. The grafts were not trimmed or altered to yield the various QHT sizes. Instead, grafts of various sizes were paired to yield QHT grafts from 6 to 9.5 mm in diameter. Three grafts of diameters 6 mm, 7 mm, 8 mm, and 9 mm and two grafts of diameters 6.5 mm, 7.5 mm, 8.5 mm, and 9.5 mm were assembled. These grafts were measured using a standard graft sizer (DePuy Mitek, Raynham, MA) and an area micrometer.[8]

Five BPTB grafts of 10 mm in width (RTI Biologics) (mean age, 53.6 ± 6.8 years; 5 male donors) were thawed and measured with the area micrometer. The BPTB grafts underwent no preparation other than thawing before testing.

The grafts were mounted into a uniaxial testing machine (MTS Bionix 858; MTS Systems, Eden Prairie, MN) for preconditioning and load-to-failure testing (Fig 1). The QHT grafts were looped around a 5-mm clevis pin, where the clevis width was adjusted to approximately 4 mm wider than the clinical graft diameter to keep the individual tendons next to each other without incurring damage from the clevis itself (Fig 2). To pre-tension the individual tendons of each graft with equal stress, sutures connected to the free ends of the tendons were routed through a pulley system and attached to weights (Fig 1). The smaller of the 2 tendons was loaded with a weight of 410 g. The weight providing the pre-tension in the larger of the 2 tendons was determined by the cross-sectional area ratio of the 2 tendons as determined by the area micrometer.[8] The free ends were then clamped in a custom-built freeze clamp so that the graft length from clevis to clamp was 30 mm. After liquid nitrogen was added to the clamp, the tests

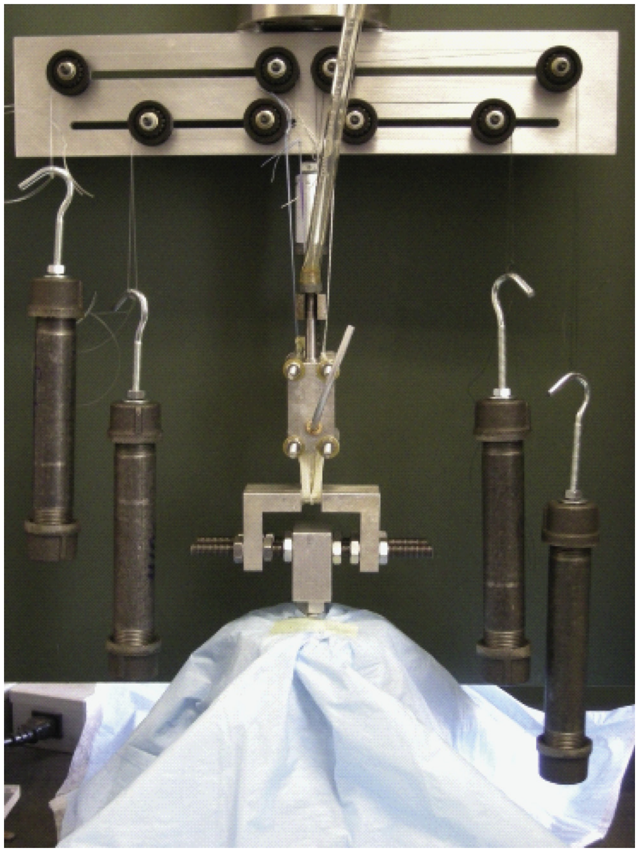

Fig 1. Arrangement of test equipment showing the equal pre-tension applied to quadrupled hamstring tendon grafts.

were initiated when the tendon was visibly frozen 3 mm below the clamp. Temperature measurements with an infrared pyrometer (Fluke 62; Fluke, Everett, WA) reported tendon temperatures of least 15°C at the midpoint between the clamp and the clevis. Care was taken to ensure that the clamp remained frozen through the entirety of the experiment.

BPTB grafts were loaded in a similar manner to the QHT grafts but clamps held both ends. The BPTB grafts were held by means of the bone blocks in the same clamps used for QHT testing. The freeze clamps with liquid nitrogen provided the fixation necessary to load the BPTB specimens to failure. With a freeze clamp at each end, the midsubstance temperature was monitored to ensure that it always exceeded 15°C. BPTB grafts did not receive pre-tension loading because the grafts consisted of only a single length of tissue and were treated differently than the QHT grafts in no other way.

The grafts were preconditioned for 200 cycles with a 1-Hz sinusoidal load that oscillated between 100 N and 200 N. Load-to-failure testing was then performed at a velocity of 4 mm/s or a strain rate of approximately 13%/s. Load and actuator displacement were sampled at 100 Hz, and grip displacement was used in the determination of elongation and modulus.