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A biomechanical comparison of anterior cruciate ligament suspensory fixation devices in a porcine cadaver model

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ABSTRACT

Background: Suspensory fixation use during anterior cruciate ligament reconstruction has increased due to ease of use and high pullout strength. We hypothesize that there are no significant differences in biomechanical performance among four types of suspensory fixation devices: Stryker VersiTomic G-Lok, Smith & Nephew Endobutton, Biomet ToggleLoc, and Arthrex RetroButton.
Methods: Forty fresh frozen porcine femurs and flexor digitorum profundus tendons were obtained. Each tendon graft was sized to 8.5 mm or 9.0 mm. Ten of each device were used to fix the grafts in the femur at the 2 o'clock (left) or 10 o'clock (right) position. The graft–femur complex was secured to a servohydraulic test machine in line with the femoral tunnel. The graft was cyclically loaded from 50 to 250 N for 1000 cycles at 1 Hz then loaded to failure at 20 mm/min. Actuator load and displacement were recorded. Data were analyzed with multiple one-way ANOVA and Tukey HSD post-hoc tests. Bonferroni correction was applied resulting in $P \leq 0.005$ considered statistically significant for ANOVA, $P \leq 0.05$ for Tukey.
Findings: There were no significant differences in cyclic displacement among any of the groups ($P = 0.43$). The only significant difference in failure properties is the Endobutton exhibited at least 50% greater displacement at failure than the other three devices.
Interpretation: Suspensory femoral soft tissue fixation devices are biomechanically similar with respect to failure load but differ in failure displacement. However, there was no significant difference in displacement after cyclic loading. All four fixation devices should withstand the forces associated with daily activities without failure.

1. Introduction

A majority of anterior cruciate ligament (ACL) injuries are treated with ACL reconstruction surgery. Unfortunately not all ACL reconstructions are successful. The failure/reoperation rate has been reported to be as low as 3% and as high as 27% (Allen et al., 2003; Bach, 2003; Fox et al., 2004; Miyasaka et al., 1991; Strand et al., 2005; Weiler et al., 2007). Failure may be attributed to recurrent instability, graft failure, or arthrofibrosis (Miyasaka et al., 1991). There are multiple potential causes of mechanical failure with respect to graft fixation on the femoral side, including graft slippage, loss of fixation, and graft rupture. Failure can occur with repetitive sub-threshold failure loads or as a result of one catastrophic event (Miyasaka et al., 1991). Daily activities such as standing from a seated position place forces on the ACL ranging from 59 to 100 N, and up to 445 N of force is generated when walking down an incline (Kvist and Gillquist, 2001; Noyes et al., 1984). Clinical graft failure has been defined as greater than 5 mm of graft lengthening which can lead to meniscus and cartilage damage (Conner et al., 2010). Ideal fixation techniques would withstand daily activity forces without graft lengthening or failure until the graft is fully incorporated into the femoral tunnel (Beynnon et al., 2005; Conner et al., 2010; Quatman et al., 2011; Rodeo et al., 2006; Wilson et al., 2004).

There are multiple options available for femoral-side graft fixation. Recent femoral tunnel drilling techniques including retrograde and medial portal drilling have made it more challenging to use transfixation pins. Suspension fixation techniques have been shown to have higher pullout strength in soft tissue grafts when compared to interference screws resulting in more frequent use of suspensory fixation devices (Ahmad et al., 2004). With several suspensory fixation devices currently available it is important to have a direct biomechanical comparison among the devices to help the surgeon decide which device to use. This study aims to determine if there is a significant difference in biomechanical performance in an in-vitro porcine model among four types of suspensory fixation devices: Stryker VersiTomic G-Lok (Stryker Joint Preservation, Mahwah, NJ, USA), Smith & Nephew Endobutton (Smith & Nephew, Andover, MA, USA), Biomet ToggleLoc (Biomet Sports Medicine, Warsaw, IN, USA), and Arthrex RetroButton (Arthrex, Naples, FL, USA). The hypothesis is that there are no significant differences in biomechanical performance among the four devices tested.

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2. Methods

Forty fresh frozen 2-year-old Yorkshire-cross porcine hind limbs (10 per group) were obtained from an abattoir (Thomas D. Morris, Inc., Reisterstown, MD, USA). No IRB approval is needed by our institution for testing of dead animal tissue. The femurs were removed of all flesh and their flexor digitorum profundus (FDP) tendons were harvested for grafts. Porcine femora were chosen due to the ability to select specimens with a BMD (bone mineral density) that is similar to that of healthy, active, young adult humans (Conner et al., 2010; Espejo-Baena et al., 2006; Miyata et al., 2000). Young human cadaver specimens are difficult to obtain, whereas there is a high availability of porcine tissue available from abattoirs. Porcine flexor digitorum profundus tendons were also chosen based on their high availability and due to their consistent size and mechanical properties similar to a human hamstring tendon (Conner et al., 2010). The FDPs were folded in half to make double bundled grafts and at least 70 mm in length. The graft size was measured with a standard measuring block ranging from 4.5 mm to 12.5 mm in 0.5 mm increments (Stryker Joint Preservation, Mahwah, NJ, USA). Of the forty FDPs tested, 33 were 9.0 mm and 7 were 8.5 mm. Of the seven 8.5 mm FDPs, 1 was tested with the Endobutton, 1 with the G-Lok, 2 with the ToggleLoc, and 3 with the RetroButton. The device used was randomly assigned to a specimen resulting in unequal numbers of specimens tested with 8.5 mm grafts. The loose ends of the grafts were whip stitched with number 2 Force Fiber (Stryker Endoscopy, San Jose, CA, USA). The femoral tunnel was prepared by first drilling a 2.4 mm guide pin through the lateral cortex. The 9 mm diameter socket tunnel was then reamed to the appropriate depth for a 20 mm suspensory fixation device by over drilling the guide pin. After the socket tunnel was reamed a 4.5 mm reamer was used over the guide pin and drilled through the lateral cortex. The double bundled grafts were then placed in the femur at the 2 o'clock (left) or 10 o'clock (right) position using a Stryker G-Lok, Smith & Nephew Endobutton, Biomet ToggleLoc, or Arthrex RetroButton (Fig. 1). All suspensory devices had 20 mm loops. Suspensory fixation was placed through the femoral tunnel onto the lateral cortex, and the button was toggled flush against the cortex in order to place maximum force perpendicular to the bone surface.

The femur was secured to the base of an Instron Model 1351 (Instron Inc., Canton, MA, USA) servohydraulic test machine with a custom built test fixture (Fig. 2).

The distance from the bottom edge of the fixture to the graft was 3 cm. The femoral tunnel was aligned with the axis of the actuator to maximize the tension on the suspensory fixation device and reduce the load sharing at the graft–tunnel interface. The graft was fixed in a custom built cryo-clamp. The distance from the edge of the cryo-clamp to the cortex of the femur was 4 cm. The graft was cyclically loaded from 50 to 250 N for 1000 cycles at 1 Hz then loaded to failure at 20 mm/min (Ahmad et al., 2004). Actuator load and displacement were recorded at 100 Hz on a PC equipped with a Keithley 1802HC (Keithley Instruments Inc., Cleveland, OH, USA) analog to digital board and TestPoint (Capital Equipment Corp., Billerica, MA, USA) data acquisition software. The mode of failure was noted. The results reported from the cyclic data are displacement after 1, 10, 50, 100, and 1000 cycles. The results reported from the single load to failure are the failure load and displacement at failure (defined as the first peak in load), yield load and displacement at yield defined at 0.2% offset, and stiffness. To determine the yield point the load and deflection data were converted to stress and strain. Stress was calculated by dividing the load by the cross sectional area of the graft that was either 9.0 mm or 8.5 mm in diameter. The strain was calculated as the displacement of the actuator divided by the initial length of the graft

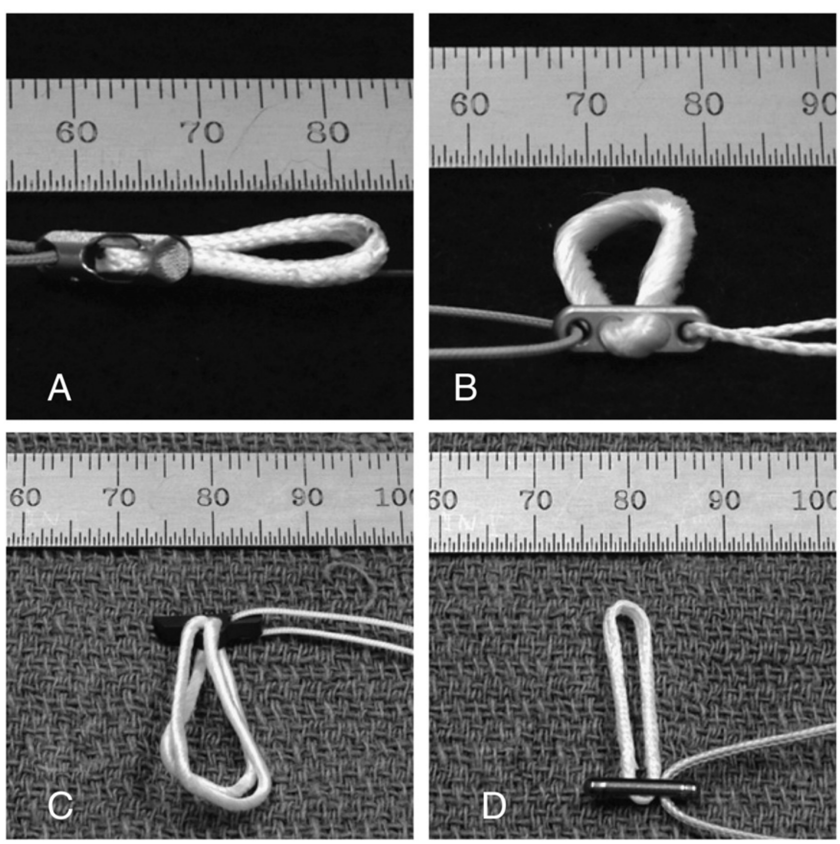

Fig. 1. Suspensory fixation devices: A. Stryker VersiTomic G-Lok, B. Smith & Nephew Endobutton, C. Biomet ToggleLoc, D. Arthrex RetroButton.