A Comparison Between a Retrograde Interference Screw, Suture Button, and Combined Fixation on the Tibial Side in an All-Inside Anterior Cruciate Ligament Reconstruction

A Biomechanical Study in a Porcine Model

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Background: Effective soft tissue graft fixation to the tibial tunnel in all-inside anterior cruciate ligament reconstructions has been reported to be a problem and may lead to retrograde pullout at ultimate load testing.

Hypothesis: A combined retrograde bioabsorbable screw and cortical-cancellous suture button suspension apparatus would gain stiffness from the button and strength from the screw, thus providing for a larger pullout ultimate load, yield load, and stiffness when compared with either fixation alone in an all-inside anterior cruciate ligament reconstruction.

Study Design: Controlled laboratory study.

Methods: Eighteen porcine tibias (average bone mineral density of 1.46, measured by dual-energy x-ray absorptiometry scan) and 18 bovine extensor tendon allografts were divided into 3 groups: retrograde bioabsorbable screw fixation, cortical-cancellous suture button suspension apparatus fixation, and combined fixation in the tibia, with 6 specimens per group. They were biomechanically tested with cyclic (500 cycles, 50-250 N, 1 Hz) and load-to-failure (20 mm/min) parameters.

Results: During cyclic testing, the retrograde screw–only group had a larger cyclic displacement (2.98 ± 2.28 mm) than the suture button with retrograde screw combination group (1.40 ± 0.34 mm). The combination fixation group also produced a higher cyclic stiffness (161.93 ± 61.81 N/mm) than the retrograde screw–only group (91.59 ± 43.26 N/mm). In load-to-failure testing, the retrograde screw with suture button combination group withstood significantly higher initial failure forces (873.87 ± 148.74 N) than the retrograde screw–only (558.44 ± 126.33 N) and suture button–only (121.76 ± 40.57 N) groups. Additionally, ultimate loads were also significantly higher for the combination group (1027 ± 157.11 N) than either the retrograde screw group (679.00 ± 109.44 N) or the suture button group (161.00 ± 29.27 N). The retrograde screw with suture button combination group showed significantly higher pullout stiffness (152.50 ± 46.37 N/mm) than either the retrograde screw–only group (78.31 ± 12.85 N/mm) or the suture button–only group (25.79 ± 9.30 N/mm).

Conclusion: Soft tissue grafts fixed with a combination of a retrograde screw and a suture button were able to withstand higher initial failure and ultimate failure loads and were also stiffer than grafts fixed with either a retrograde screw or a suture button alone.

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Clinical Relevance: These findings may prove useful in providing additional stability when using an all-inside technique in a difficult case, or in a patient with poor bone stock, and may also be useful as an alternative to more commonly used tibial tunnel soft tissue fixation techniques.

Keywords: all-inside anterior cruciate ligament reconstructions; tibial tunnel; soft tissue graft fixation; RetroScrew; suture button

A recently introduced all-inside anterior cruciate ligament (ACL) tibial tunnel fixation system (RetroScrew, Arthrex, Naples, Florida) uses biodegradable interference screws with the ability to tension the graft in a proximal cortical bone location and increases graft tension as the screw is inserted.[14,17,18] However, a recent study has reported lower biomechanical parameters for tibial tunnel retrograde bioabsorbable screw fixation when compared with antegrade tibial tunnel bioabsorbable screw fixation during cyclic and ultimate load testing. Failure modes were reported to be graft displacement and dislodgment of the retrograde screw into the joint.[4] Soft tissue graft fixation with interference screws has been questioned due to low ultimate failure loads and has warranted caution in the early phase of ACL reconstruction when interference screws are used to fix soft tissue grafts, because strengths may be suboptimal for daily activities and progressive rehabilitation programs.[1,12,13,15,20] In addition, it has been reported that soft tissue fixation with interference screws allows for the potential of considerable graft slippage, which could be theoretically prevented by using a backup or hybrid fixation.[26]

Because of these findings, using a cortical-cancellous suspension apparatus at the distal tibial tunnel as a backup has been suggested[14] as this fixation method may allow for increased strength and decreased displacement of the graft, yet still allow for an all-inside ACL reconstruction technique. Therefore, in this study we quantitatively assessed the differences in ACL graft load and stiffness when comparing a retrograde bioabsorbable screw, a cortical-cancellous titanium suture button suspension apparatus, and a combined fixation for an all-inside ACL reconstruction. We hypothesize that a combined retrograde bioabsorbable screw and cortical-cancellous suture button suspension apparatus will gain stiffness from the button and strength from the screw, thus providing for a higher pullout ultimate load, yield load, and stiffness when compared with either fixation alone in an all-inside ACL reconstruction. The purpose of this study is to assess whether there is a synergistic effect and thus supportive fixation when including a suture button with the retrograde screw for tibial tunnel ACL graft fixation.

MATERIALS AND METHODS

Eighteen proximal, skeletally mature, fresh-frozen, intact porcine tibias (obtained from the Veterinary Department, University of Minnesota) and 18 fresh bovine extensor tendons (Frontier BioMedical, Logan, Utah) were used to determine cyclic displacement (mm), cyclic stiffness (N/mm), initial failure load (N), ultimate load (N), pullout displacement (mm), and pullout stiffness (N/mm) for varying fixation techniques in an all-inside ACL tibial tunnel reconstruction. The tibias had no sign of previous injury, abnormality, or disease; in addition, the tendons were free from any damage along their length. The tendons were stored in a 0.9% saline solution at –20°C before graft preparation. The tibias were also stored in a freezer at –20°C before ACL reconstruction.

Bone Mineral Density Analysis

A prospective analysis of the bone mineral density (BMD) of the specimens before biomechanical testing was performed. Each sample was scanned twice by dual energy x-ray absorptiometry (DEXA) using a GE Lunar Prodigy Advance (General Electric Healthcare, Milwaukee, Wisconsin) for determination of BMD (g/cm^2). The region of interest was the proximal tibia to 14 cm distal to the tibial plateau and its surrounding soft tissue. Thirty specimens were scanned, of which 18 had BMD values (mean, 1.476 g/cm^2; standard deviation, 0.134; range, 1.220-1.675 g/cm^2) (Table 1) that met the inclusion criteria of values comparable to a young athletic population (range, 1.24-1.62 g/cm^2)[2,21,22,25] and were included in the study.

Specimen Preparation

Specimens were thawed in a 2°C refrigerator before dissection and subsequent biomechanical testing. The tibial diaphysis was cut with an oscillating bone saw 14 cm distal to the tibial plateau. The distal end of the tibia was placed inside a 6-cm × 5-cm metal cylinder and filled with polymethylmethacrylate (PMMA) (Dentsply, York, Pennsylvania). To ensure a static fixation of the tibia in the PMMA, 2 screws were fixed into opposing sides of the distal tibia, with approximately 1 cm of the screw remaining outside the cortex before potting in the PMMA. All grafts were commercially prepared and were preselected by the supplier (Frontier BioMedical) to be of equal size. After preparation, the total graft length was 170 mm (Figure 1). The fresh-frozen allograft tendons were wrapped in normal saline-soaked gauze and kept at room temperature for 30 minutes before preparation. The ends of the allograft were marked with a surgical marker at 35 mm from each end and then separately whipstitched as previously described[5] with a modified technique using a No. 2 continuous braided polyester/polyethylene suture loop (FiberLoop, Arthrex) from the 35-mm mark to the end of the ACL graft (Figure 1). The diameters of the prepared grafts (doubled over) were measured to be 9 mm by pulling them through a graft-sizing block. Those grafts that were larger than 9 mm were sharply trimmed parallel to the fiber orientation. We made the cross-sectional area of each graft to be of similar size and quality due to the fact that a larger graft size would produce a higher stiffness and higher ultimate loads.[31]

TABLE 1
Specimen and Biomechanical Testing Results for the 3 Fixation Groups[a]

Group	Specimen	Bone Mineral Density (g/cm^2)	Cyclic Displacement (mm)	Cyclic Stiffness (N/mm)	Initial Failure Load (N)	Ultimate Failure Load (N)	Pullout Displacement (mm)	Pullout Stiffness (N/mm)
Retrograde screw	1	1.3667	1.3	153.85	634.00	716.8	7.66	80.31
	2	1.3800	2.16	92.59	616.94	779.11	7.46	95.82
	3	1.3833	3.18	62.89	424.17	613.5	6.67	63.62
	4	1.5200	1.9	105.26	695.39	757.78	7.49	89.54
	5	1.4500	7.46	26.81	379.31	488.70	5.86	65.59
	6	1.6750	1.85	108.11	600.84	720.63	8.32	74.97
Mean ± SD		1.4625 ± .1190	2.98 ± 2.28	91.59 ± 43.26	558.44 ± 126.33	679.00 ± 109.44	7.24 ± 0.86	78.31 ± 12.85
Suture button	1	1.4800	—	—	126.03	140.25	6.44	20.96
	2	1.5050	—	—	94.93	136.8	4.21	29.29
	3	1.4100	—	—	73.2	135.18	10.47	9.35
	4	1.5100	—	—	126.38	177.85	5.47	29.06
	5	1.6400	—	—	193.1	208.54	6.34	30.65
	6	1.2550	—	—	116.91	168.61	4.1	35.39
Mean ± SD		1.4667 ± .1277	—	—	121.76 ± 40.57	161.00 ± 29.27	6.17 ± 2.33	25.79 ± 9.30
Combined	1	1.3950	0.711	281.29	741.79	803.39	3.66	217.20
	2	1.4650	1.57	127.39	696.95	910.86	9.19	81.38
	3	1.6450	1.59	125.79	1094.00	1198.26	6.56	181.8
	4	1.6150	1.5	133.33	958.66	1115.79	7.99	132.60
	5	1.2200	1.41	141.84	820.12	966.44	6.7	139.80
	6	1.6500	1.6	125.00	931.68	1164.99	6.96	162.2
Mean ± SD		1.4680 ± .1717	1.40 ± 0.34	161.93 ± 61.81	873.87 ± 148.74	1027 ± 157.11	6.84 ± 1.85	152.50 ± 46.37

[a]SD, standard deviation.

Figure 1. Extensor tendon graft was prepared to be 170 mm in length, with each end whipstitched 35 mm into the graft (graduated interdigitations = 5 mm).

Surgical Technique

One surgeon (R.F.L.) was assigned to perform the ACL reconstructions as previously described[14,17,18] in order to reduce variance in surgical skill. Tibias were divided into 3 graft fixation groups, 6 specimens per group, with a resultant mean BMD being equal among groups (Table 1). The retrograde bioabsorbable screw was used in group I; in group II, the cortical-cancellous suture button suspension apparatus; and in group III, the combined retrograde bioabsorbable screw and cortical-cancellous suture button suspension apparatus in the tibia.

The tibial ACL adapter drill guide (Arthrex) was placed over the previously established porcine tibial ACL footprint.[7,14] The drill sleeve was positioned on the anteromedial aspect of the tibial cortex. The intraosseous pin length on the drill sleeve was set at 45 mm for each specimen. The guide pin was advanced superiorly and engaged with the 9-mm retrograde drill bit. The drill bit disengaged from its original position on the adapter as it engaged with the guide pin (Figure 2). On the guide pin, a black rubber O-ring was pushed to the end of the drill sleeve superiorly to determine the starting point of the tibial socket. Retrograde force on the drill was applied and the O-ring traveled 35 mm from the original position on the drill guide, thus creating a 35-mm all-inside tibial socket. After removal of the retrograde cutter, this depth was verified with a depth gauge. A No. 2 nonabsorbable polyester/polyethylene suture (FiberStick, Arthrex) was then passed through the cannulation of the retrograde drill guide pin and the end of the suture was then tied into a loop. The whipstitched graft sutures were then placed through the suture loop and pulled distally through the tibial tunnel via the suture loop. Both ends of the graft were then pulled inside the 35-mm tibial tunnel and the 4 strands of whipstitch suture were pulled distally outside the tibial cortex.

For group I, a cannulated hex-tipped retrograde screwdriver was passed proximally through the tibial tunnel, anterior to the graft. The No. 2 FiberStick suture was advanced up through the driver's cannulation and out through the tibial plateau and advanced into the cannulation of a 9-mm × 20-mm poly-L-lactide (PLLA) bioabsorbable retrograde screw (RetroScrew, Arthrex) (Figure 3). The suture end was tied into a 3-mm Mulberry (interference) knot. The retrograde screw length is clinically limited to 20 mm because this technique requires the screw to be flipped in the tightly spaced intercondylar notch. The No. 2

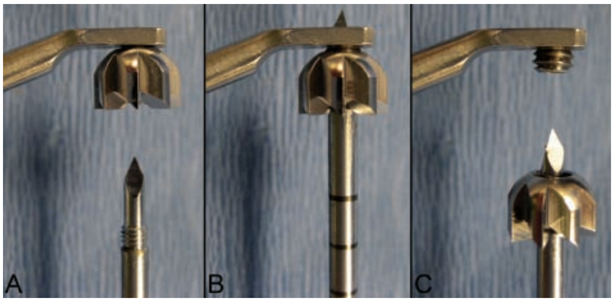

Figure 2. The retrograde drill bit disengages from its original position on the C-ring drill guide (A) as it is engaged with the guide pin (B). The guide pin, with the recently engaged retrograde drill bit, is pulled inferiorly to create a 35-mm tibial tunnel (C).

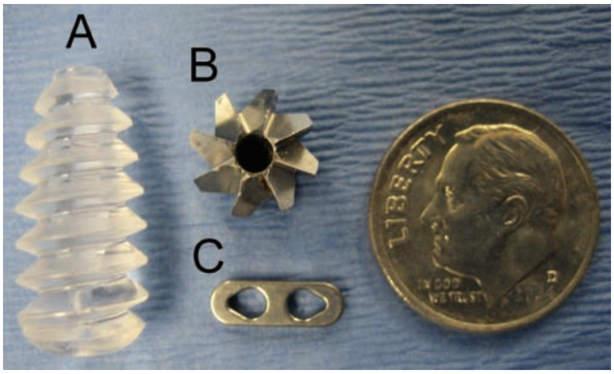

Figure 3. A, 9-mm retrograde bioabsorbable screw; B, 9-mm retrograde drill bit; and C, 9-mm × 3.5-mm suture button.

nonabsorbable polyester/polyethylene suture exiting the handle of the screwdriver was tensioned and securely tightened onto the grommets located on the screwdriver, and the retrograde screw was then screwed counterclockwise to engage it into the tibial tunnel, flush with the tibial plateau. The suture was then removed.

In group II, a 9-mm × 3.5-mm, 2-holed titanium suture button (Arthrex) (Figure 3) was then used to secure the 4 whipstitch suture tails. As we were unable to find a previously described method for this, we chose to combine suture tails from opposing ends of the graft together into each hole and then used the opposing pairs together to tie a single surgical knot followed by 5 square knots. The suture buttons were used as the primary fixation in this group.

Group III used a hybrid fixation, with a combination of the retrograde screw detailed in group I and the suture button described in group II. The procedures outlined for groups I and II were used in succession (ie, the retrograde screw was fixed before securing the suture button).

Biomechanical Testing

Tibial specimens were mounted in a customized apparatus to enable the displacement force vector to be applied in direct alignment with the tibial tunnel. The prepared tibias were locked into an Instron 5865 (Instron Systems, Norwood, Massachusetts). Mounting of the looped free end of the graft to the Instron device was achieved by inserting a 3.5-mm aluminum rod through the loop and fixing this to a customized apparatus to replicate the pull of the femoral ACL attachment site (Figure 4). This method was used because prior reports of suboptimal results with ACL soft tissue graft clamping, due to a rise of stress on the graft and slippage.[31] The distance from the entrance of the bone tunnel to the tendon grip was 50 mm to simulate the intra-articular space (30 mm) and femoral tunnel length (20 mm) of the ACL.[15]

Loading data were recorded by Instron Bluehill software at a rate of at least 100 Hz. The grafts were isolated and preconditioned from 10 N to 50 N at 0.1 Hz for 10 cycles. This allowed for a starting point between all tested specimens and the ability to compare between different fixation techniques.

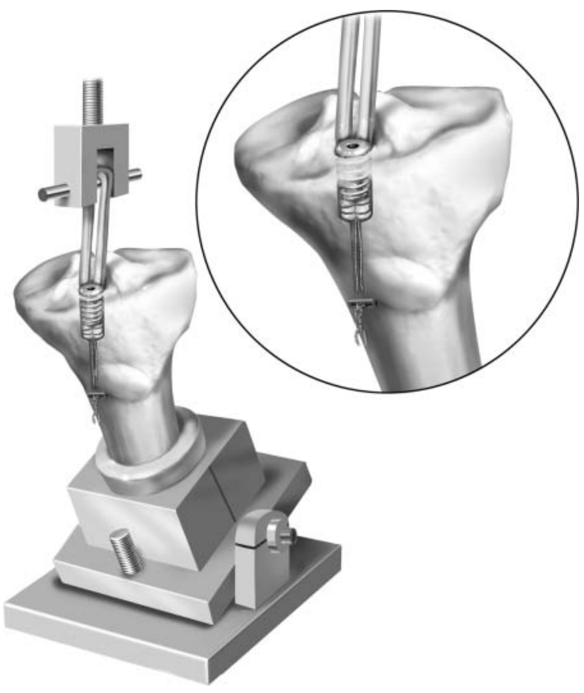

Figure 4. The combined retrograde bioabsorbable screw and suture button group was mounted on a customized apparatus to enable the displacement force vector to be applied in direct alignment with the tibial tunnel. The distal end of the graft was secured with an aluminum dowel through the looped end. Tibias were potted in polymethylmethacrylate to allow for a solid fixation in the apparatus.

The grafts were then immediately subjected to cyclic loading under repeated loads for 500 cycles between 50 N and 250 N at a frequency of 1 Hz; the loads simulate previously measured forces in the ACL during passive extension at the knee,[16] the frequency of 1 Hz simulated the reported frequency of walking,[11] and 500 cycles was chosen to simulate an early rehabilitation protocol of flexion-extension loading on the reconstructed graft (Figure 5).[31] Immediately after

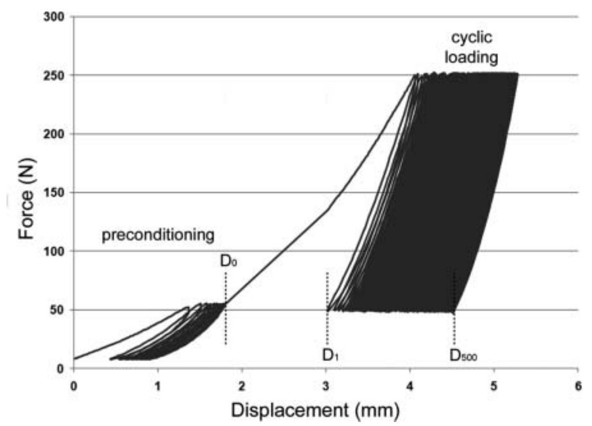

Figure 5. Representative cyclic loading curve used to calculate cyclic displacement (mm), and cyclic stiffness (N/mm). Grafts were preconditioned from 10 N to 50 N at 0.1 Hz for 10 cycles. Cyclic loading consisted of repeated loads for 500 cycles between 50 N and 250 N at a frequency of 1 Hz.

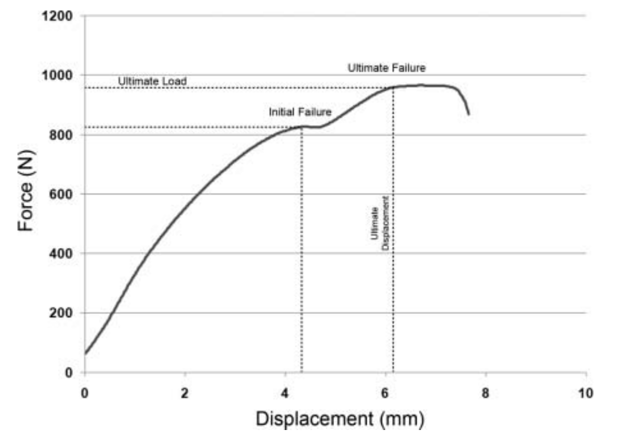

Figure 6. Representative load-displacement curve used to determine initial failure load (N), ultimate load (N), pullout displacement (mm), and pullout stiffness (N/mm). Grafts displaced at 20 mm/min until failure.

cyclic testing was completed, the grafts were further displaced at 20 mm/min until failure and the mechanism of failure was subsequently noted (Figure 6). Cyclic displacement (mm), cyclic stiffness (N/mm), initial failure load (N), ultimate load (N), pullout displacement (mm), and pullout stiffness (N/mm) were determined. We acquired the ultimate load, which was defined as the maximum endured load during testing. Additionally, we noted the ultimate elongation, which was defined as the displaced length of the ligament at the ultimate load. Stiffness was calculated as the slope of the linear region of the load-elongation curve corresponding to the steepest straight-line tangent to the curve. Due to prior reports of a decreased tissue stiffness and strength with desiccation,[10] tissues were frequently hydrated with a saline-filled spray bottle during all stages of specimen preparation and testing of the tissues. Measurements were analyzed and plotted with Microsoft Excel software (Microsoft Inc, Redmond, Washington).

Statistical Analysis

Statistical analysis was performed with the use of SAS software (SAS Institute, Cary, North Carolina). We compared the BMD, initial failure load, ultimate failure load, pullout displacement, and pullout stiffness for each fixation group using a 2-way analysis of variance. Cyclic displacement and cyclic stiffness were not normally distributed and were thus analyzed with a Friedman 2-way analysis of variance of ranks, a nonparametric procedure. Post hoc Tukey tests were conducted to assess if there was a significant difference among fixation techniques for failure testing results. Significant difference was determined to be present for $P < .05$.

RESULTS

Biomechanical test results are presented in Table 1. Thirty specimens were scanned, but after DEXA scanning, 18 specimens (mean, 1.476 g/cm^2; standard deviation, 0.134; range, 1.220-1.675 g/cm^2) met the BMD inclusion criteria. The BMD value differences among the 3 fixation groups were not significant.

All 18 specimens survived preloading; however, none of the 6 specimens in the suture button group survived cyclic testing. Consequently, because these specimens did not complete 500 cycles, there were no data for this group pertaining to cyclic testing; the initial and ultimate failure values in the suture button–only group were thus taken from the cyclic testing data. During cyclic testing, the retrograde screw–only group had a larger cyclic displacement (2.98 ± 2.28 mm) when compared with the suture button with retrograde screw combination group (1.40 ± 0.34 mm) ($P < .05$). Furthermore, the combination fixation group produced a higher cyclic stiffness (161.93 ± 61.81 N/mm) when compared with the retrograde screw–only group (91.59 ± 43.26 N/mm) ($P < .05$).

In load-to-failure testing, initial failure load was largest for the combined suture button and retrograde screw group (873.87 ± 148.74 N) when compared with either the suture button–only group (121.76 ± 40.57 N; $P < .0001$) or the retrograde screw–only group (558.44 ± 126.33 N; $P < .01$). The retrograde screw also produced a significantly higher load when compared with the suture button in initial failure ($P < .001$). The ultimate failure loading demonstrated similar relationships in which the largest load was endured in the combined suture button and retrograde screw group (1027 ± 157.11 N) when compared with either the suture button–only group (161.00 ± 29.27 N; $P < .0001$) or the retrograde screw–only group (679.00 ± 109.44 N; $P < .01$). The retrograde screw also produced a significantly higher load when compared with the suture button in ultimate failure loads ($P < .0001$). Pullout stiffness was significantly higher for the combined suture button and retrograde screw group (152.50 ± 46.37 N/mm) when compared with either the suture button–only group (25.79 ± 9.30 N/mm; $P < .0001$) or the retrograde screw–only group (78.31 ± 12.85 N/mm; $P = .01$). The retrograde screw also produced significantly higher pullout stiffness when compared with the suture button ($P < .05$).

Modes of failure were consistent between groups. It was noted that all 6 specimens in the suture button–only group failed by graft tearing at the suture-tendon interface. In the retrograde screw–only group, 5 specimens failed by complete pullout by the limb of the graft not in contact with the retrograde screw; the other specimen failed by a graft pullout away from the screw-tendon interface. In the retrograde screw with suture button combination group, all specimens failed by graft pullout at the inner suture site followed by complete pullout past the retrograde screw. It was also noted that there were no instances of retrograde screw migration out of the tibial tunnel nor any cases of either the suture button knot or suture button itself failing.

DISCUSSION

In this study, we found that grafts that were fixed with a combination of a retrograde screw and a suture button were able to withstand higher initial failure and ultimate failure loads and were also stiffer than the grafts fixed with either a retrograde screw alone or a suture button alone. We noted the retrograde screw with suture button combination group to have significantly greater initial failure load (873.87 ± 148.74 N) and ultimate failure load (1027 ± 157.11 N) than either the suture button–only group or the retrograde screw–only group. These values were noted to be above the previously hypothesized upper limit of normal activity loads of 454 N.[23] While reviewing the literature, we found only one other biomechanical study using a retrograde interference screw. This previous study used a retrograde screw, however, in a transtibial tunnel technique with an additional antegrade interference screw inserted as a backup.[4] These investigators found an average ultimate failure load of 778.7 ± 177.5 N, which was slightly higher than the values seen in our retrograde screw–only group (679.00 ± 109.44), and lower when compared with the suture button and retrograde screw combination group in our study (1027 ± 157.11 N). One potential reason for the observed difference in the prior study can be attributed to the use of porcine tibias with a lower BMD (1.21 ± 0.12 g/cm^2),[4] while our study used tibias with an average BMD of 1.468 ± .1717 g/cm^2. It is possible that this difference in BMD led to subsequent differences in load values and stiffness between the study groups, as prior reports have demonstrated a high correlation between graft fixation failure and BMD values.[3,24,31]

A review of the literature reveals multiple studies of pullout strength and stiffness in commonly used methods of tibial fixation. One study compared 6 tibial fixation devices in porcine tibias by subjecting them to 1500 cycles between 50 N and 200 N at 1 cycle every 2 seconds, followed by ultimate failure.[13] This study[13] used a transtibial, or "outside-in" method of fixation, as opposed to the all-inside technique used in our study. The authors reported the following ultimate failure loads: 917 ± 234 N for the WasherLoc (Arthrotek, Ontario, California), 675 ± 190 N for the tandem spiked washers (Linvatec, Largo, Florida), 1309 ± 302 N for the Intrafix (DePuy Mitek, Raynham, Massachusetts), 567 ± 156 N for the BioScrew (Linvatec), 423 ± 75 N for the SoftSilk interference screw (Acufex Microsurgical Inc, Mansfield, Massachusetts), and 694 ± 173 N for the SmartScrew ACL (Linvatec). This study also reported the following pullout stiffness values for the 6, respectively: 87 ± 23 N/mm, 69 ± 14 N/mm, 223 ± 62 N/mm, 91 ± 34 N/mm, 61 ± 12 N/mm, and 115 ± 34 N/mm. Another study[15] compared 6 tibial fixation devices in porcine tibias by determining yield load and pullout stiffness; however, the investigators did not subject the reconstructions to cyclic testing. This study[15] also used a transtibial, or outside-in, method of fixation. The authors reported the following ultimate failure values: 776 ± 155 N for an interference screw (Smith & Nephew Donjoy, Carlsbad, California), 821 ± 193 N for the WasherLoc, 830 ± 187 N for sutures tied to a post (No. 5 Ethibond, Ethicon Inc, Johnson & Johnson, Somerville, New Jersey), 705 ± 174 N for 2 staples (Smith & Nephew Richards, Memphis, Tennessee), 724 ± 284 N for a 20-mm spiked metal washer (Linvatec), and 1375 ± 213 N for 2 soft tissue washers (Synthes, Paoli, Pennsylvania). The study also reported the following stiffness values for the 6 devices, respectively: 476 ± 251 N/mm, 429 ± 269 N/mm, 70 ± 19 N/mm, 174 ± 92 N/mm, 192 ± 61 N/mm, and 420 ± 180 N/mm. Although it appears that the retrograde screw–alone fixation may be adequate for most reconstruction cases when compared with other fixation techniques, the use of a suture button can provide for added fixation in patients with suboptimal bone quality. However, despite being proven biomechanically, further clinical studies are recommended to determine the best tibial fixation technique and long-term outcome.

Few studies have attempted to use a cortical-cancellous suspension device alone for tibial fixation. One biomechanical study of tibial fixation showed that graft motion and displacement were significantly higher and stiffness was significantly lower in tibial fixation of hamstring tendons when comparing a 14-mm titanium suture button with interference screws; the study also showed, however, that there was no significant difference between the 2 groups in ultimate load.[20] Other studies have attempted to use suspension devices other than buttons in hybrid fixation with interference screws. One biomechanical study demonstrated that tibial hybrid fixation of bovine extensor grafts with both a double-spiked plate and an interference screw showed significantly less displacement, and higher stiffness and ultimate failure loads, than when using either method alone.[29] Another study reported that when fixing human patellar tendon grafts, stiffness and ultimate load were greater when using both an interference screw and a suture-post screw than when using the interference screw alone.[28] Although these backup devices are similar to suture buttons in that they can all be considered cortical-cancellous suspension devices, they are not indicated for all-inside repairs like the suture button. Because of these findings, it was thought that the addition of a suture button to an interference screw in the tibial tunnel would prove to be stronger than either alone, while still allowing for an all-inside ACL reconstruction.[14]

One advantage of this study is the DEXA scanning of the specimens. Because most acute ACL injuries occur in young adult athletes, we felt that obtaining donor tissue with similar qualities to young athlete bones was essential to biomechanical testing. However, most human donor tissue is obtained from an elderly population; with these elderly donors, the cancellous and cortical bone density would be significantly less than that seen in the population of patients who typically qualify for ACL reconstruction. This was noted in a study comparing bone density measurements of porcine and human cadaveric bone to young human bone by DEXA scan, which reported the average density of porcine bone (1.42 g/cm^2) to be similar to that of young human bone (1.30 g/cm^2) yet significantly higher than that of elderly human cadaveric bone specimens (0.30 g/cm^2).[19] Therefore, with the knowledge of these BMDs, we also believed that the porcine model for biomechanical evaluation of an ACL reconstruction was more characteristic of young human bone than that of elderly cadaveric bone.

Our testing method was designed to isolate differences in the structural properties of the fixation techniques. The loading was directed in line with the tibial tunnel, which reduced the effect of friction at the tunnel edge, thus effectively testing only the fixation properties of the fixation device.[1,15] Cyclic loading was chosen to simulate the postoperative rehabilitation, where graft constructs are subjected to repetitive loading in the critical time period in which biologic incorporation has not yet occurred.[1,8,9] After cyclic loading, initial and ultimate failure load were also determined to evaluate catastrophic failure strength characteristics. Although ultimate failure loads are the "gold standard" of biomechanical testing of ACL fixation, we also thought it was important to include initial failure load, because this is the point at which damage is first initiated and could lead to clinical failure of the reconstruction.[31] In addition, the measurement of fixation properties such as displacement and stiffness were included in our study to theoretically assess the ability of a graft to maintain stability of the reconstructed knee during intensive rehabilitation.[15]

One limitation of our study is that we used porcine tibias and bovine extensor tendons rather than human specimens. It would be ideal to obtain human cadaver specimens for testing if we could obtain a sufficient number of cadaveric samples from young, active humans. However, cost, sufficient numbers, and the fact that most available specimens are from elderly cadavers and do not have the same material qualities as young human specimens made it difficult to use human specimens.[19] Moreover, the porcine tibia model has been previously described as an effective means for biomechanical testing,[4,13,27,32] and we considered bovine extensor tendons as suitable replacements for human soft tissue grafts because it has been shown that bovine extensor tendons have structural properties similar to those of a double-looped semitendinosus and gracilis graft from young humans.[6] Therefore, we believed that it was acceptable to use these animal tissues in place of human tissues.

The second limitation is that pullout testing was performed on the tibia, which is the weaker point of ACL graft fixation,[13,15,29] and the direction of the force was aligned along the long axis of the graft. This allowed for loading along the tunnel axis to be directed solely at the fixation site and represented a "worst-case scenario" that may not be representative of an in vivo situation.[30] Under physiologic conditions, pullout forces on the fixation may be lower due to additional shearing forces and friction at the tunnel edge that increase graft strength; it has been demonstrated that a "physiologic" axis results in a 10% reduction in the tension at the site of fixation compared with the worst-case scenario used in our study.[15]

In summary, soft tissue grafts fixed with hybrid fixation were able to withstand higher initial failure and ultimate failure loads and were also stiffer than the grafts fixed with either a retrograde screw alone or a suture button alone. These findings may prove useful to the surgeon desiring additional stability when using an all-inside technique in a difficult case or in a patient with poorer bone stock, and they may also be useful to the surgeon looking for an alternative to more commonly used soft tissue fixation techniques.

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