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Biomechanical Comparison of Achilles Tendon Pullout Strength Following Midline Tendon-Splitting and Endoscopic Approaches for Calcaneoplasty

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Abstract

Background: Calcaneoplasty is a common procedure performed for the management of Haglund's syndrome when nonoperative management fails. Midline tendon-splitting and endoscopy are 2 common approaches to calcaneoplasty. Studies have suggested that an endoscopic approach may allow earlier return to activity and superior outcomes, but there are no biomechanical or clinical studies to validate these claims. The goal of this study was to quantify and compare Achilles tendon pullout strength following midline tendon-splitting and endoscopic calcaneoplasty in cadaveric specimens.

Methods: Twelve match-paired cadaveric specimens were randomly divided into 2 groups: endoscopic and midline tendon-split. Following calcaneoplasty, fluoroscopy was used to match bone resection and the Achilles was loaded to failure in a mechanical testing system. A paired-samples *t* test was conducted to compare bone resection height, bone resection angle, load to failure, and mode of failure.

Results: The endoscopic approach yielded a 204% greater postsurgical pullout strength for the Achilles tendon than the midline tendon-split (1368 ± 370 N vs 450 ± 192 N, respectively) ($P < .05$). There were no differences in resection angle or resection height. All specimens failed due to bone or tendon avulsion.

Conclusion: Endoscopic calcaneoplasty had more than 3 times greater pullout strength than the midline tendon-splitting approach.

Clinical Relevance: This may allow earlier return to functional rehabilitation following endoscopic calcaneoplasty, but further studies are needed to determine if these differences are clinically significant. Further understanding of the time-zero biomechanics following calcaneoplasty may provide guidance regarding postoperative management with respect to surgical approach.

Keywords: Haglund's syndrome, endoscopic calcaneoplasty, open calcaneoplasty, Achilles tendon

Calcaneoplasty is a common procedure performed for Haglund's syndrome after failure of nonoperative treatment. Multiple open approaches have been reported in the literature for the treatment of Haglund's syndrome, including lateral, medial, midline, transverse, J-shaped, and combined incisions.[5,12,13,18,21] Recent clinical studies have reported improved clinical results following a midline tendon-splitting approach compared with other open techniques.[1,2,4,8,13,14,17,19,22] A 2007 retrospective review compared midline tendon-splitting to an open lateral approach and found no difference in American Orthopaedic Foot & Ankle Society (AOFAS) and Short Form-36 scores, but reported a statistically significant 2-month earlier return to normal activity in the midline tendon-splitting cohort.[1]

Since 2000, endoscopic calcaneoplasty for Haglund's syndrome has gained popularity with reports of improved patient-reported outcomes.[6,7,9,11,15,20] Many of these studies state decreased complication rates, shorter recovery times,

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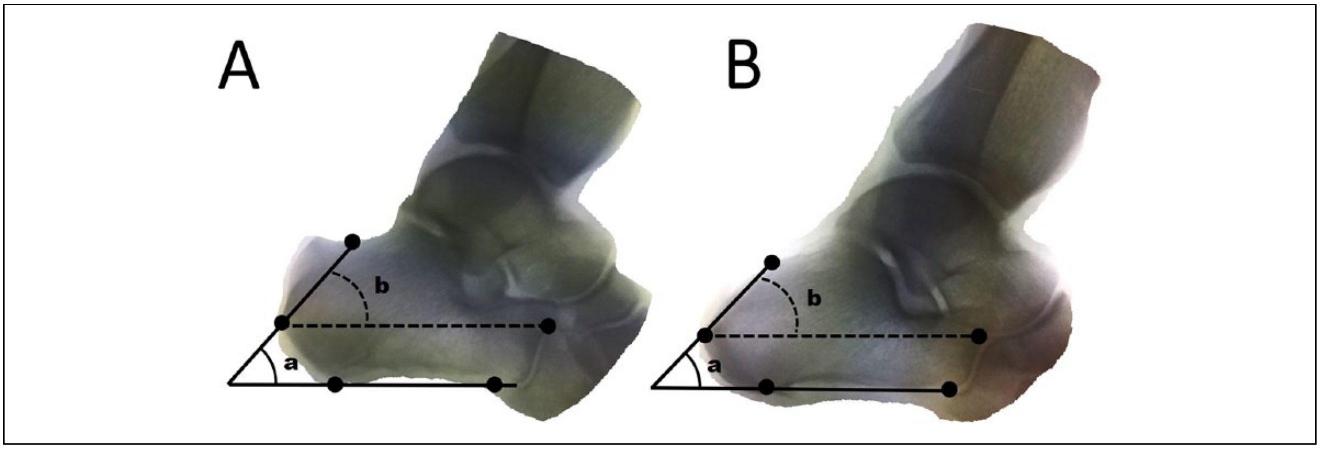

Figure 1. (A) Pre-resection radiograph demonstrating the calcaneal resection angle reported in this study (a, Fowler-Philips angle) and the angle used by Leitze et al (b, Steffensen's angle).[11] (B) Postcalcaneoplasty resection again demonstrating the resection angles.

and an earlier function rehabilitation with endoscopy compared with open techniques despite limited direct comparisons.[9,20] The only direct comparison was a prospective study by Leitze et al[11] comparing endoscopic versus open lateral approach calcaneoplasty, which found no statistical differences in mean AOFAS score or University of Maryland score improvements, and no difference in time to recovery. While a reduction in complications was observed in the endoscopic cohort, it was not a statistically significant difference.

A potential complication of all calcaneoplasty techniques is postoperative Achilles tendon rupture. A cadaveric biomechanical study by Kolodziej et al[10] analyzed Achilles tendon pullout strength following interval resection of the footprint and determined that up to 50% of the superior-to-inferior insertion could be safely resected without risk of rupture. Following this work, Calder and Saxby[3] performed a clinical study that allowed immediate mobilization and partial weightbearing for the first 2 weeks if less than 50% of the Achilles tendon had been resected with a midline tendon-splitting approach. They reported 2 ruptures in 49 heels with this protocol and concluded that with appropriate patient selection this protocol may be instituted.

While the incidence of postoperative Achilles tendon rupture is unknown, it has been reported following both open and endoscopic calcaneoplasty.[3,12,15] Most of the postoperative tendon ruptures were reported as a single traumatic event or fall leading to an avulsion at the bone-tendon interface rather than a gradual fatigue failure.[3,12] The largest study of calcaneoplasty reported a 4% rupture rate following a midline approach, although a full Achilles detachment and reattachment was performed.[12] A recent cadaveric biomechanical study revealed a 45% decrease in postsurgical Achilles pullout strength following midline tendon-splitting calcaneoplasty compared with the native tendon in matched pairs.[16] There are currently no data available to determine whether using an endoscopic approach can improve immediate postsurgical strength.

Midline tendon-splitting and endoscopic calcaneoplasty are 2 of the most popular approaches for the operative treatment of Haglund's syndrome. The goal of both techniques is a return to baseline function while minimizing the risk of postoperative complications, including Achilles rupture. The purpose of this investigation was to quantify and compare Achilles tendon pullout strength between these 2 procedures.

Methods

Specimens

Twelve fresh-frozen match-paired cadaveric legs (average age, 56 years; range, 39-70 years) were procured from an institute-approved tissue bank. All specimens were stored at −30°C and defrosted at room temperature 12 hours prior to testing. Specimens were radiographically and clinically evaluated to ensure no bony deformities or calcifications within the Achilles tendon. Matched pairs were divided into 2 groups: (1) endoscopic and (2) midline tendon-split.

Fluoroscopic Bony Resection

There is much debate regarding the amount of decompression or bony resection required during both open and endoscopic calcaneoplasty techniques. In order to normalize the resection performed, resection of the posterior tuberosity was performed under fluoroscopy, which is similar to the resection (based on the Fowler-Philip's angle) performed clinically by the senior author (G.B.P.) and within the acceptable radiographic parameters previously described (Steffensen's angle, 38-59 degrees) (Figure 1A and B).[11,17]

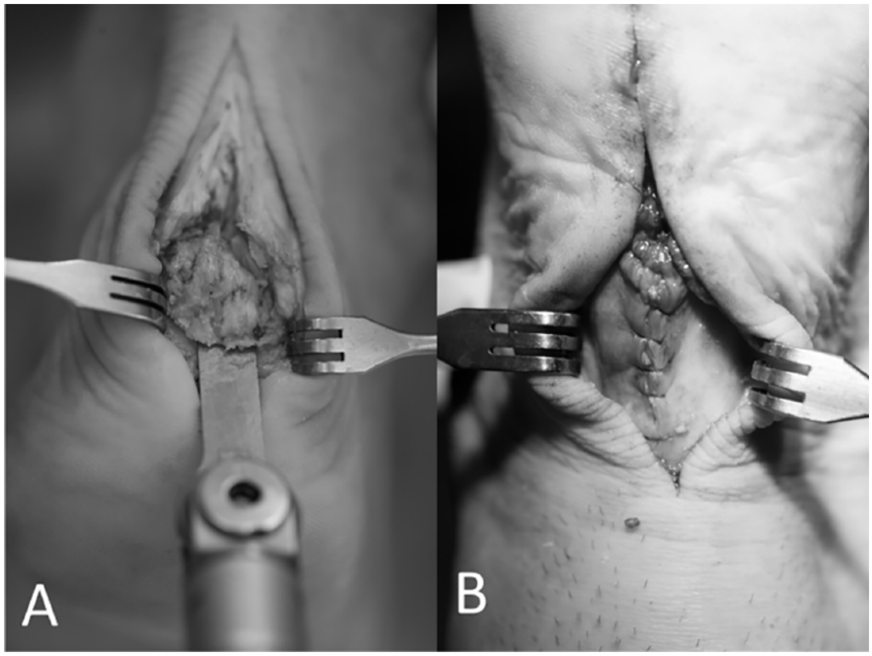

Figure 2. (A) Open midline tendon-splitting calcaneoplasty being performed with a microsagittal saw. (B) Closure of the Achilles tendon following resection.

Midline Tendon-Split

A midline tendon-splitting calcaneoplasty using a posterior approach was performed on 1 specimen from each matched pair, alternating left and right. A direct posterior midline incision was made in the skin and dissected to the Achilles tendon. The tendon was then split in line with its fibers extending distally on the posterior calcaneus. Medial and lateral flaps were elevated to allow calcaneoplasty with a microsagittal saw without damaging the tendon. The medial and lateral flaps were carefully dissected, disrupting the minimal amount of Achilles tendon footprint while performing adequate bony resection under fluoroscopy as described above. Next, 2 suture anchors (Juggerknot, Biomet, Warsaw, IN) were used to reapproximate the tendon to the underlying posterior tuberosity. The anchors were included in the study to replicate the surgical procedure as performed by the senior author and as described in the literature.[4,8,16] Suture anchors placed within the remaining metaphyseal bone are primarily a means of reapproximating the tissues rather than to resist avulsion of the tendon immediately postoperatively. The midline tendon-split was then repaired with 2-0 Vicryl suture (Figure 2).[4]

Endoscopic

An endoscopic approach was used in each of the contralateral matched pairs. Using a simulated prone position jig for the cadaveric specimen, we made a lateral portal incision at the level of the superior aspect of the calcaneus just anterior to the Achilles tendon (Figure 3). The retrocalcaneal space was entered by a blunt trocar. The 2.7-mm 30-degree arthroscope was inserted and a spinal needle was introduced medially at the level of the superior aspect of the calcaneus under direct visualization. A 4-mm burr was used to perform a decompressive calcaneoplasty under fluoroscopy. The amount of bone removed was based on the open procedure radiographs. The Achilles footprint was elevated both medially and laterally as needed to allow adequate bone

Figure 3. Endoscopic calcaneoplasty performed with medial and lateral portals.

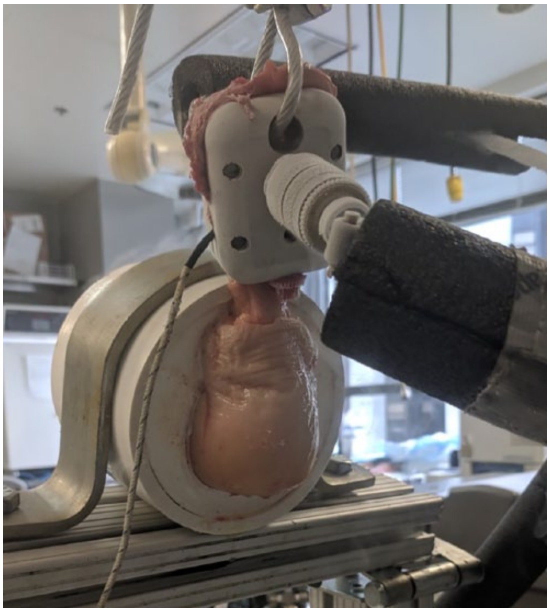

Figure 4. Close-up view of testing setup with custom freeze-clamp apparatus connected to the Achilles tendon.

resection to replicate the open calcaneoplasty performed on the matched pair.

Biomechanical Testing

Biomechanical load-to-failure testing of the Achilles tendon was performed with a 20-degree calcaneal pitch angle as previously described.[16] The Achilles tendon was freeze-clamped with a custom clamp and loaded to failure using a servohydraulic mechanical testing system (370.02 Bionix, MTS Systems Corp., Eden Prairie, MN) at a rate of 0.5 mm/s until failure (Figure 4). A single pull to failure was performed to mimic the reported clinical failures. The mode of failure for each specimen was recorded as bone avulsion, tendon avulsion, or tendon tear.

Radiographic Analysis

Pre- and postresection radiographic images were imported into computational software (MATLAB, MathWorks, Inc., Natick, MA) for digital analysis. These images were used to calculate the calcaneal resection angle (Figure 1) and height of resection for comparison between open and endoscopic matched pairs as previously described in the literature.[16] Briefly, the height of resection is reported as a percent of the distance between the most posterior aspect of bony resection to the line tangent to the posterior facet parallel to the calcaneal inclination and the total distance between the posterior facet and the calcaneal inclination line.

Statistical Analysis

An a priori power analysis (G*Power 3.0.10) with alpha set at 0.05 and an estimated effect size of 0.8 was used to determine that 6 matched pairs (12 specimens) would be required to achieve 80% power. Statistical analyses were performed using R statistical computing software (version 3.2.3, r-project.org). After testing for normality, between-group comparisons of ultimate load to failure, angle, and height of resection were calculated using a paired *t* test. Significance was set at $P < .05$.

Results

All data are presented as the mean ± standard deviation (Table 1). Load to failure of specimens with an endoscopic calcaneoplasty was significantly higher than that for specimens with an open midline tendon-splitting calcaneoplasty (1368 ± 370 N vs 450 ± 192 N, respectively) ($P < .05$) (Figure 5). The calcaneal resection angles (39.4 ± 5.5 degrees vs 36.8 ± 3.4 degrees) were not statistically different between endoscopic and open calcaneoplasty ($P = .30$). Additionally, the height of bony resection (49.2 ± 4.9 mm vs 51.7 ± 2.8 mm) was not statistically different ($P = .40$). The failure mode was tendon avulsion for 10 specimens, bony avulsion for 1 specimen (specimen 6, endoscopic), and 1 specimen was not noted.

Discussion

The main finding of this study was that the time-zero post-surgical pullout strength following endoscopic calcaneoplasty was significantly higher than that for midline tendon-splitting calcaneoplasty. Our results demonstrate an average 204% increase in the pullout strength of the Achilles tendon when an endoscopic approach is used. There was no difference in mode of failure or in the amount of bone resected as measured by the angle and height of the resection.

The average pullout strength of specimens with a midline tendon-splitting calcaneoplasty in the present study is similar to those reported in a biomechanical study comparing the postoperative strength of an open midline tendon-split calcaneoplasty to the strength of the native Achilles insertion.[16] The average pullout strength following endoscopic resection was 1368 ± 370 N, which is similar to the previously reported strength of native Achilles tendons of 1300 ± 370 N. This suggests that the endoscopic technique preserves the native Achilles strength. The aforementioned study also reported a significant positive correlation between Achilles pullout strength and bone density as determined by dual-energy x-ray absorptiometry (DEXA). Since the specimens in the present study were not DEXA scanned, we cannot directly compare these results. It is also notable

Table 1. Specimen Demographics and Biomechanical Testing Results.

Specimen	Age, y	Sex	Side	Treatment	Peak Force, N	Height of Cut, %	Angle of Cut, deg
1	53	Male	Right	Endoscopic	951	47.1	31
			Left	Open	273	51.3	34
2	70	Male	Left	Endoscopic	1317	46.2	45
			Right	Open	435	53.1	41
3	39	Male	Right	Endoscopic	1837	54.2	42
			Left	Open	640	50.6	36
4	63	Female	Left	Endoscopic	1345	45.2	46
			Right	Open	277	53.7	37
5	48	Female	Right	Endoscopic	1008	46.6	38
			Left	Open	210	52.0	42
6	64	Female	Left	Endoscopic	819	56.8	44
			Right	Open	642	46	41

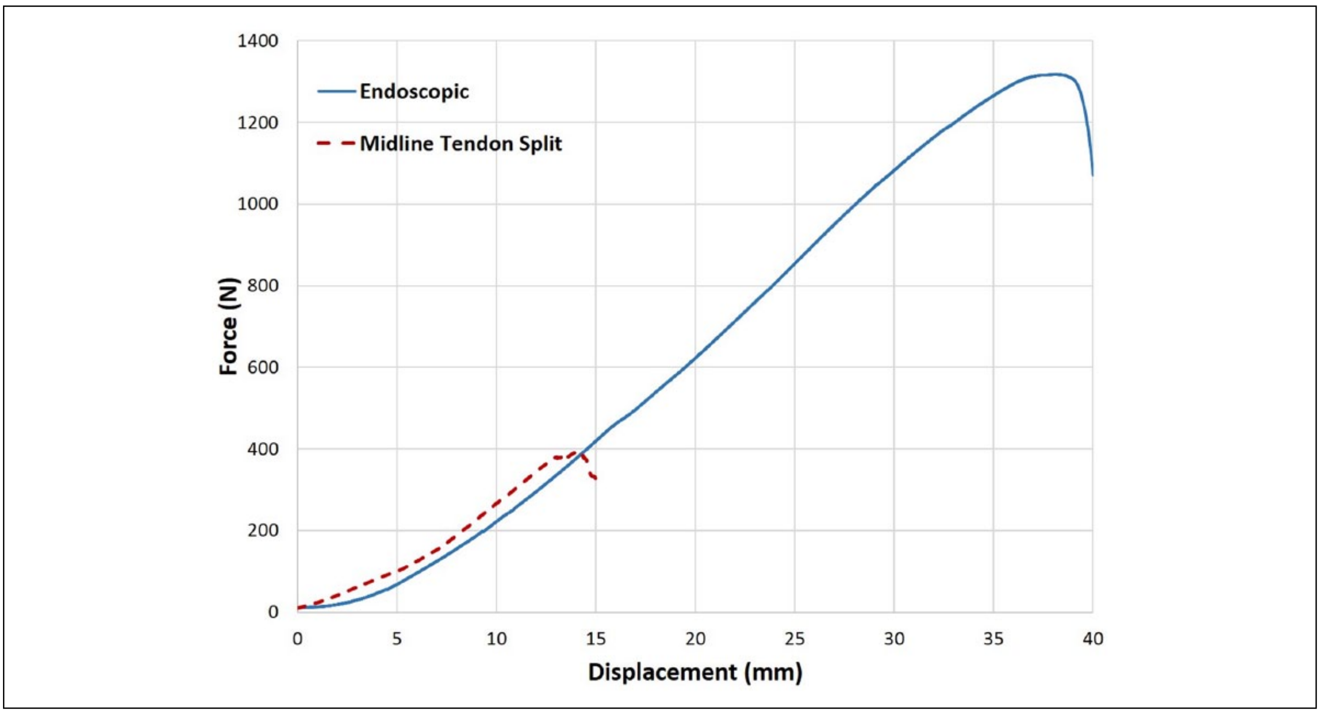

Figure 5. Typical load versus displacement curve for midline tendon-splitting and endoscopic approaches.

that the Achilles footprint was elevated in the endoscopic cohort, but only to the extent necessary to match the bone resection of the midline tendon-split. The difference in pull-out strength between the cohorts in this study may be due to the added dissection required to allow for clearance of the saw blade.

The mode of failure for all specimens recorded was avulsion at either the tendon or bone with no midsubstance tendon tears. This is in contrast to the results of a previous cadaveric study looking at pullout strength following interval resection of the Achilles footprint in which all specimens failed by intratendinous oblique shear tears.[10] This difference in mode of failure is likely due to the use of cyclic loading with a lower applied force. A higher loading rate, as used in the present study, simulates the mode of failure described in the immediate postoperative setting. For instance, in studies that report acute postcalcaneoplasty Achilles tendon ruptures, all were described as a single, catastrophic loading event.[3,12,15] Additionally, the location of failure was described at the bone-tendon interface in these clinical reports, which is similar to the mode of failure demonstrated in this present study.[3,12]

The average resection angle measured using fluoroscopic images was an average of 39.8 degrees. This is lower than the average value of 51 degrees, but within the range of open calcaneoplasties (range, 38-59 degrees) reported by Leitze et al.[11] The method for measuring the amount of resection in our study closely mimics that used by Leitze et al. Our resection angle is on the lower end of their range, which may reflect differences in bony morphology associated with Haglund's syndrome in the clinical trial compared with cadaveric specimens.

This study had several limitations. The data are limited to a small number of cadaveric specimens with an average age of 56.1 years. Advanced age predisposes these specimens to a lower bone mineral density but is likely mitigated using matched pairs. These results are not generalizable to all patients with Haglund syndrome because those with large intratendinous calcifications are not candidates for endoscopic calcaneoplasty. Single load to failure rather than cyclic loading was chosen as this more closely replicates the clinically reported catastrophic traumatic avulsions in the early postoperative treatment. Additionally, single load to failure may better approximate the early postoperative phase while cyclic loading is occurring as the tendon begins to heal to the bone. Bony resection in this study was based on published literature and what is typically performed during open Haglund resection by the senior author. The suture anchors used in the midline tendon-splitting technique were primarily used to reapproximate the healing Achilles tendon to the calcaneus and likely did not affect the pullout strength. Stronger configurations using more anchors, anchors implanted into cortical bone, or anchors designed for cancellous healing would likely provide increased pullout strength and may be a clinical consideration when concerned about the amount of resection intraoperatively. Ideally, the percentage of footprint elevated between the groups would be compared, but this would require extensive dissection prior to the procedures and may affect the pullout strength and alter the surgical technique, which would not mimic the clinical surgical setting.

Conclusion

This is the first biomechanical study to provide evidence that the endoscopic technique results in superior immediate Achilles postoperative strength compared with the midline tendon-splitting approach. This supports clinical studies that suggest that early weightbearing and faster return to sports may be possible after endoscopic calcaneoplasty. This would be particularly important for athletes and other patients requiring faster rehabilitation. Clinical trials are necessary to compare endoscopic and midline tendon-splitting approaches to determine if an initial 204% increase in pullout strength is clinically significant to allow faster recovery and return to sports.

Declaration of Conflicting Interests

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