A Biomechanical Analysis of Peroneus Brevis Split Lesions, Repair, and Partial Resection

Tudor Trache, MD, Roland S. Camenzind, MD, Elias Bachmann, MSc, Arnd Viehöfer, MD, Lukas Jud, MD, Stephan Wirth, MD, and Florian B. Imhoff, MD

Abstract

Background: Peroneus brevis tendon tears are associated with chronic ankle pain and instability following sprain injuries. The aim of this study is to elucidate the biomechanical changes induced by a peroneus brevis split and surgical treatment by tubularizing suture or partial resection.

Methods: Nine human lower leg specimens were biomechanically tested. Preexisting tendon pathology was ruled out by magnetic resonance imaging and histology. Specimens were subjected to sequential testing of 4 conditions of the peroneus brevis tendon: (1) native, (2) longitudinal lesion, (3) tubularizing suture, and (4) 50% resection. The outcome parameters were the tendon stiffness (N/mm) and the length variation of the split portion at 5 N load.

Results: The median specimen age at death was 55.8 years (range 50-64 years). The longitudinal tendon split led to an elongation by 1.21 ± 1.15 mm, which was significantly reduced by tubularizing suture to 0.24 ± 0.97 mm (P = .021). Furthermore, 50% resection of the tendon elongated it by a mean 2.45 ± 1.9 mm (P = .01) and significantly reduced its stiffness compared to the intact condition (4.7 ± 1.17 N/mm, P = .024) and sutured condition (4.76 ± 1.04 N/mm, P = .011).

Conclusion: Longitudinal split and 50% resection of the peroneus brevis tendon led to elongation and loss of tendon stiffness. These properties were improved by tubularizing suture. The significance of these changes in the clinical setting needs further investigation.

Clinical Relevance: Tubularizing suture of a peroneus brevis split can restore biomechanical properties to almost native condition, potentially aiding ankle stability in symptomatic cases. A split lesion and partial resection of the tendon showed reduced stiffness and increased elongation.

Keywords: Peroneal tendon, longitudinal lesions, tubularizing suture, ankle instability, ankle sprain

Introduction

Ankle sprain and joint injuries belong to the most common sports injuries. The lateral ligament complex is most often affected: the anterior talofibular ligament (ATFL) up to 85%, the calcaneofibular ligament in 50% to 75%, and the posterior talofibular ligament in less than 10%. A large retrospective analysis of athletes with ankle sprains describes a moderate overall prevalence of acute tendon injuries. Nevertheless, peroneal tendon lesions with longitudinal tears can result from sprains and are a significant cause of chronic ankle pain in athletes and nonathletes. The peroneus longus and brevis provide both active and passive stabilization of the ankle joint, which makes them vulnerable to longitudinal injury during forceful inversion/supination of the foot. Longitudinal peroneus brevis tendon tears also occur in patients with lateral ankle instability and often cause persistent symptoms that require surgery. Peroneal tendon reconstruction is often performed together with lateral stabilization procedures and

1Balgrist University Hospital, Department of Orthopedics, University of Zurich, Zurich, Switzerland
2Institute for Biomechanics, Balgrist Campus, University of Zurich, Zurich, Switzerland

Corresponding Author:
Florian B. Imhoff, MD, Oberarzt Orthopädie, Balgrist University Hospital, University of Zurich, Forchstrasse 340, CH-8008 Zürich, Switzerland.
Email: florian.imhoff@balgrist.ch
yields relevant improvement of symptoms and ankle stability. The choice of procedure to address these lesions depends on the preserved amount of viable tendon substance. In literature, a direct repair with a suture uniting the 2 halves and restoring the oval form of the tendon section (described as a “tubularizing” suture) is recommended if 50% of the tendon can be preserved after debridement of frayed tissue. Otherwise, a transfer of the peroneus brevis to the peroneus longus tendon or a graft interposition is considered to be a viable option. Wagner et al suggested that resection of two-thirds of the tendon can be preserved. A biomechanical cadaver study by Wagner et al suggested that resection of two-thirds of the tendon does not necessarily increase the risk of spontaneous tendon rupture. However, a comprehensive analysis of the biomechanical changes induced by longitudinal lesions, partial tendon resection, and tendon suture is missing.

The purpose of this study was to investigate the effect of longitudinal split lesions, tubularizing suture, and partial resection on elongation and stiffness of the peroneus brevis tendon. The hypothesis was that a longitudinal tear reduces stiffness and adds elongation to the tendon, and that tendon suture restores these properties. It was also hypothesized that partial resection leads to significant elongation and diminishes tendon stiffness.

Materials and Methods

The biomechanical properties of the peroneus brevis tendon were tested for the following conditions: (1) native tendon, (2) artificially induced, standardized longitudinal split lesion, (3) sutured tendon, and (4) resection of 50% of the tendon substance over the length of the split. The study was approved by the local ethics committee. All testing procedures, storage, handling, and disposal of the specimens were performed according to the guidelines of the Ethics Committee, following international standards.

Specimens

A total of 15 fresh-frozen lower leg and foot specimens (knee exarticulated) from human donors (females: 40%; right: 46.6%; median age at death: 56.5 years, range 50-64 years) were obtained from MedCure Inc and stored deep-frozen in our on-campus research facility.

A priori power analysis was conducted based on the study of Wagner et al. It was assumed that a sample size of at least 8 specimens would allow detection of significant changes in tendon biomechanics.

Before dissection, thawed specimens underwent magnetic resonance imaging with a standardized DIXON protocol (axial T1 slices) on a 3-tesla machine (Siemens MAGNETOM Prisma; Siemens Healthcare GmbH). Imaging was performed with support of the Swiss Center for Musculoskeletal Imaging, SCMI, Balgrist Campus AG, Zurich. One specimen with a prior peroneal tendon lesion was excluded. Two specimens were used for pilot testing of the construct and testing procedure. It was documented that after sequential testing of up to 200 N of cyclic loading, one tendon in the split lesion condition, and 2 tendons in the partially resected condition failed by intratendinous rupture. Therefore, biomechanical testing was done as stated below to ensure complete data output without tendon failures. Nine specimens were included in the final analysis.

Post hoc histologic samples of the peroneus brevis tendon were retrieved from the middle portion after biomechanical testing and embedded in paraffin. They were stained with hematoxylin and eosin and examined using a light microscope 1 to 4 weeks after successful testing. All slides were assessed independently for signs of tendinopathy according to the semiquantitative BONAR scale by 2 of the authors. The intraclass correlation coefficient was used to test the agreement of the 2 readers (intraclass correlation coefficient = 0.93, 95% CI 0.7635-0.982). None of the included specimens had more than 2 points on the BONAR scale.

Biomechanical Setup and Outcome Parameters

The lower leg was fixed in a customized testing frame. The tibia and fibula were sawed off 10 cm above the upper ankle joint line. The specimens were fixed with a 5-mm metal rod transversally through the middle of the tibia above the syndesmosis. This was clamped into the frame at both sides, so that the plantigrade foot stood firmly on the base plate. The foot was fixed to the base plate by 1.6-mm Kirschner wires through the head of the first metatarsal, the calcaneus, and through the base, the shaft, and the head of the fifth metatarsal, respectively (Figure 1). No longitudinal load was applied to the tibia. The construct was mounted in a universal material testing machine (Zwick 1456; Zwick/Roell). The proximal end of the peroneus brevis (musculotendinous junction) was clamped into the load cell unit. The peroneus longus tendon was grasped in whipstitch technique using an Ethibond 6 suture (Ethicon Inc). Throughout testing of the peroneus brevis tendon, a static load of 35 N was applied to the head of the fifth metatarsal, respectively (Figure 1). No longitudinal load was applied to the tibia. The construct was mounted in a universal material testing machine (Zwick 1456; Zwick/Roell). The proximal end of the peroneus brevis (musculotendinous junction) was clamped into the load cell unit. The peroneus longus tendon was grasped in whipstitch technique using an Ethibond 6 suture (Ethicon Inc). Throughout testing of the peroneus brevis tendon, a static load of 35 N was applied to the peroneus longus tendon to simulate the tendon tension during the standing phase. After 20 preconditioning cycles, 4 different conditions—native, split, sutured, and partial resection—of the peroneus brevis were sequentially tested. Force-controlled cyclic loading was performed from 35 to 100 N (100 cycles), on the basis of a previously published protocol. After each test sequence, all load was removed for 60 seconds. Phosphate-buffered saline solution was intermittently applied to prevent the tendons from drying.
Outcome measurements were defined as (1) tendon stiffness (N/mm) during cyclic loading and (2) the variation of length (mm) of the split tendon portion at a defined load tension of 5 N. Stiffness was calculated as mean value from cycles 10 to 90. The stiffness variation between the first and the last 10 cycles was also extracted.

Surgical Intervention

The peroneus brevis and longus muscles were dissected from the bone, and all muscle tissue was resected down to the musculotendinous junction. The retromalleolar peritenonous sheath was not opened. The specimen was mounted on the testing frame and the native condition was tested. The tendon sheath was then opened and a standardized midline longitudinal lesion was created starting at the apex of the retromalleolar groove, extending 20 mm distally and proximally. The lesion length was measured with digital calipers (Figure 2). After testing of the split condition, the lesion was sutured with Monocryl 4.0 (Ethicon Inc). The suture inverts the 2 split halves (Figure 3), modifying the section of the sutured tendon from a flattened and/or split shape to an oval and more compact shape, resembling the section of the native tendon. Although the technique has been described as a “tubularizing” suture, it does not produce a cylindrical tendon.12,25

After testing the sutured condition, the suture was opened and one of the tendon halves was resected. Testing of the partial resection condition was then performed. After each intervention on the tendon, the superior peroneal retinaculum was reattached with 3 single stitches (Monocryl 3-0, Ethicon Inc) and the skin incision was closed after every intervention. All surgical procedures were performed with the specimen mounted in the testing machine.

Statistical Analysis

Normal data distribution was confirmed with the Shapiro-Wilk test ($P > .1$). The repeated measures analysis of variance with Bonferroni correction was used to compare changes throughout the different conditions. The stiffness values at the end of cycling loading (last 10 cycles) were compared to those at the beginning (first 10 cycles) with the paired samples $t$ test. The length variation in different states compared to the native state was calculated as percentage value of the split section. All statistical analysis was performed with the SPSS Statistical Analysis software, version 25 (IBM).

Results

The pilot specimens and specimens with previous longitudinal peroneal tendon lesion were excluded. Sequential testing of up to 200 N of cyclic loading led to premature failure of one tendon in the split lesion condition and 2 tendons in the partially resected condition by intratendinous rupture. These specimens were excluded from the final data set. Thus, a total of 9 specimens (females: 30%; right: 30%; median age at death: 55.8 years, range 50-64; mean body mass index $23.2 \pm 5.05$) were included for analysis. None of
the included specimens showed relevant tendinopathy. Two of the samples had 2 points on the BONAR scale, 1 had 1 point, and 6 had 0 points. None of the tested tendons ruptured upon cyclic loading within the above-mentioned protocol.

**Stiffness**

Compared to the native condition, the split lesion induced a slight, not significant, decrease in tendon stiffness. The stiffness measured in the sutured condition did not differ from the native stiffness. Resection of 50% of the tendon substance induced a significant decrease in stiffness (Table 1).

A statistically significant increase in tendon stiffness was observed in all testing states between the first and the last 10 cycles (Table 2). This difference was highest in the sutured condition.

**Load Behavior (Length Variation at 5 N Load)**

The longitudinal tendon split led to a 3% mean functional elongation (1.21 ± 1.15 mm) of the split portion. This elongation was reversed by suture (0.24 ± 0.97 mm, $P = .021$).
Resection of 50% of the tendon led to a significantly higher elongation (6.1%, 2.45 ± 1.9 mm, P = .01).

**Discussion**

The most important finding of this study is that a longitudinal split of the peroneus brevis tendon leads to a small (3% on average) increase of relative tendon length under the loading conditions we applied in this cadaver-based experiment. Tendon length can be effectively restored by (tubularizing) suture. Resection of 50% of the retromalleolar portion of the tendon leads to a reduction of stiffness and to 6% functional elongation on average. These changes may influence ankle stability and foot function.

Longitudinal peroneal tendon lesions occur because of compression of the tendon against the posterior ridge of the fibula during forceful ankle inversion. Repeated inversions in the context of lateral ankle instability may lead to split progression. Subluxation of the peroneal tendons can follow the initially occurred lesion, owing to increased strain on the superior peroneal retinaculum. Thus, these lesions have been reported to be associated with chronic ankle instability in athletes or active patients. This study shows that the retromalleolar portion of the brevis tendon elongates by 3% on average owing to the longitudinal split. Combined with possible increased retinacular laxity, this loss of tension could facilitate tendon subluxation, aggravate pain, and precipitate tendon degeneration. The correlation between elongation of the peroneus brevis tendon and deficient active and passive ankle stability can be assumed from the results of this study and of other biomechanical experiments but still has to be proven in a clinical setting.

Several options are available for operative treatment of the peroneus brevis tendon. A tendon-preserving reconstruction is desirable. Tendon suture described as tubularizing has been advocated for cases with 50% or more tendon preserved after debridement. This cadaver-based study found that suturing the tendon can restore its functional length and stiffness, but that resection of 50% significantly weakens it, although in our experiments it did not lead to spontaneous rupture. Thus, the tubularizing suture appears to be biomechanically superior to partial resection of the peroneus brevis tendon at time zero. However, 3 specimens had to be excluded owing to spontaneous rupture throughout the sequential testing in the split (1 specimen) and partial resection (2 specimens) conditions. These failures may have been caused by the sequential procedure that came with our biomechanical study setup. A randomized paired analysis using more specimens could provide the answer to this question, which was not part of our purpose. The authors believe that restoring biomechanical properties such as functional length and stiffness of the peroneal tendons may lead to beneficial clinical outcomes, because of the hypomochlion effect of the distal fibula in the active stabilization of the ankle.

If only a small amount of viable tendon tissue can be preserved, a peroneus longus to brevis tendon transfer or a

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**Table 1. Decrease in Stiffness Induced by the Various Conditions.**

| Condition     | Mean difference (%) | SE  | P Value |
|---------------|---------------------|-----|---------|
| 50% vs.       |                     |     |         |
| Intact        | 4.7 (18.8)          | 1.17| .024    |
| Split         | 3.81 (15.6)         | 1.27| .1      |
| Tubularized   | 4.76 (19.9)         | 1.04| .011    |
| Split vs.     |                     |     |         |
| Intact        | −0.8 (−3.2)         | 0.38| .3      |
| Tubularized   | −0.94 (−3.9)        | 0.48| .5      |
| Tubularized vs. intact | 0.06 (0.24) | 0.51| >.99    |

**Table 2. Stiffness Increase at the End of Cyclic Loading.**

| Condition     | Mean Difference, % | SD  | P Value |
|---------------|--------------------|-----|---------|
| Intact        | 2.4 (9.6)          | 0.9 | <.001   |
| Split         | 2.18 (8.9)         | 1.02| <.001   |
| Tubularized   | 3.55 (14.8)        | 0.94| <.001   |
| 50%           | 1.99 (9.6)         | 1.16| .001    |
tendon graft reconstruction are thinkable options. Even though tenodesis of the peroneus brevis to longus could not effectively restore tendon tension in an in vitro cadaver study, clinical studies reported good functional outcomes. A reconstruction technique with hamstring tendon autograft also showed promising results in a recent case series.

Limitations
As with many biomechanical cadaver studies, the main limitation of this study is that it uses a standardized, simplified model of tendon injury to characterize a complex situation in vivo, where gradual wear and incurring tendinopathy play an important role. Furthermore, cadaver studies cannot account for the biology of healing and the time course of recovery. The applied model of a peroneus brevis tendon lesion used a longitudinal split in the middle portion, but the tear irregularity, the scarring, and the tendinopathy were not accounted for. Furthermore, resection of 50% of tendon substance was performed without recording which of the 2 halves (medial or lateral) was resected. It was assumed that any differences between the 2 halves would be negligible, but this aspect is a clear limitation. The consecutive testing of all conditions in the same specimen is also a potential source of bias, because of changes in tendon biomechanics induced by repetitive loading alone. It was attempted to reduce this effect by unloading the tendons after every cycle and by preventing them from drying out during testing.

The applied testing protocol comprised 100 loading cycles between 35 and 100 N with a plantigrade foot, without accounting for inversion stress or loading peaks that occur in the setting of lateral ankle instability. The in vivo loading pattern of the peroneus brevis was not accurately reproduced, and changes induced by different flexion grades of the ankle on the hypomochlion mechanism of the fibular groove were not investigated. Therefore, the in vivo role of the observed biomechanical changes can be approximated but not accurately quantified.

A further limitation is the low sample size. This is the first study to investigate the functional elongation and stiffness behavior of injured peroneal tendons in a cadaver model. The sample size calculation was approximated according to existing literature in the broader field of peroneal biomechanics, which investigated the load-to-failure behavior of partially resected peroneal tendons.

Conclusion
Longitudinal split and 50% resection of the peroneus brevis tendon lead to elongation and loss of tendon stiffness, which may affect the in vivo function. These properties were improved by tendon suture (described as a tubularizing suture). The significance of these changes in the clinical setting needs further investigation.

Declaration of Conflicting Interests
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ORCID iDs
Tudor Trache, MD, https://orcid.org/0000-0001-9013-7649
Lukas Jud, MD, https://orcid.org/0000-0001-8128-3927
Florian B. Imhoff, MD, https://orcid.org/0000-0002-2159-2071

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