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Use of Metatarsophalangeal Joint Dorsal Subluxation in the Diagnosis of Plantar Plate Rupture

Marie-Christine Bergeron, DPM, AACFAS[1,2], Julie Ferland, DPM, FACFAS[2,3], D. Scot Malay, DPM, MSCE, FACFAS[2,4], Sara E. Lewis, DPM, AACFAS[2,4,6], Jennifer A. Burkmar, MD, MBA[7], Nicholas A. Giovinco, DPM, AACFAS[2,5,8]

[1] *Faculty, Department of Surgery, New York College of Podiatric Medicine, New York, NY*
[2] *Faculty, The Podiatry Institute, Decatur, GA*
[3] *Staff Surgeon, Kosciusko Community Hospital, Warsaw, IN*
[4] *Staff Surgeon and Director of Podiatric Research, Penn Presbyterian Medical Center, Philadelphia, PA*
[5] *Resident, Dekalb Medical Center Podiatry Residency, Decatur, GA*
[6] *Fellow, The Southeast Permanente Medical Group, Atlanta, GA*
[7] *Primary Care Physician, Dekalb Medical Physicians Group, Lilburn, GA*
[8] *Staff Surgeon, Piedmont Clinics Physician, Newnan, GA*

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ABSTRACT

A dorsal drawer exam, also known as a *modified Lachman's test*, is a common clinical test for plantar plate insufficiency. This disorder presents as a dislocated metatarsophalangeal joint. The aim of this cadaveric case study was to quantify the degree of the plantar plate pathology necessary to correlate with a positive Lachman's test. The second metatarsophalangeal joint was tested on 18 cadaveric lower extremities. Limbs with previous digital surgery or with an obvious digital deformity were excluded from this study. A plantar linear incision over the plantar aspect of the second metatarsophalangeal joint was performed, and the flexor tendons were retracted to expose the plantar plate. After evaluating the plantar plate's integrity and measuring its width, a Lachman's test was then performed under fluoroscopy. The plantar plate was subsequently severed in a serial manner in 2-mm increments. A modified Lachman's test was performed with the different levels of rupture to assess the degree of dislocation. We found that a tear as small as 2 mm, detected in 12 (66.7%) of 18 specimens, produced gross instability in the second metatarsophalangeal joint. We also showed that a simulated plantar plate tear ≥4 mm but <6 mm resulted in joint subluxation (positive modified Lachman's test) with a sensitivity of 90.3%. This study reinforces the finding that a modified Lachman's test is a clinical exam that demonstrates high sensitivity in diagnosing plantar plate insufficiency.

The plantar plate is a thick fibrocartilaginous structure of the metatarsophalangeal joint (MTPJ). It is composed of multidirectional type I and type II collagen, with bundles separated by loose connective tissue, chondrocyte groups, and fibroblasts in a nonhomogeneous fashion. The orientation of this collagen is longitudinal except for one third, at the level of the deep transverse intermetatarsal ligament, whereby the collagen fibers are in a transverse alignment (1).

This construction and composition is suited to resisting compressive and tensile forces generated by weight-bearing during gait (2). The plantar plate plays an important role as a static restraint for stabilizing the MTPJ and works in conjunction with the capsule and collateral ligaments, in synergy with the dynamic intrinsic and extrinsic muscles (3). Previous work has shown the plantar plate to be the dominant stabilizing structure of the MTPJ, due to its central location and the number of important structures anchored to the plate (1,4–6). Previous studies have measured and calculated the average length of the plantar plate to be 18.8 mm, its width to be 10 mm, and its mean thickness to be 2 mm (3,7). Its strongest attachment is to the base of the proximal phalanx, where its medial and lateral attachments create a socket for the metatarsal head to sit, particularly as the foot goes through late midstance and into propulsion.

Although the plantar plate displays a relatively thin attachment to the proximal metatarsal head, it is reinforced by the collateral ligaments, accessory collateral ligaments, and the plantar fascia as it participates in the windlass mechanism that gains tension as the foot enters and goes through the propulsion phase of gait. Deland et al (1)

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Address correspondence to: Marie-Christine Bergeron, DPM, AACFAS, New York College of Podiatric Medicine, 53 East 124th Street, New York, NY 10035.
E-mail address: mcbergeron89@gmail.com (M.-C. Bergeron).

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compared the plantar plate's function at the lesser MTPJs to that of the sesamoid apparatus at the first MTPJ.

The exact cause of second MTPJ instability is inconsistent in the current literature, even though instability of the lesser MTPJ is a common cause of foot pain in the general population (5). Second MTPJ instability is very prevalent in the female population, thought to be related to shoe wear preferences, although it has also been identified in young male athletes (3,5,6). It was also historically hypothesized that high-fashion footwear maintained the digits in constant hyperextension, leading to strain and eventual dislocation of the second MTPJ (8). Current literature proposes that second-digit deformity is likely due to lateral capsule and collateral ligament disruption, with resultant plantar plate rupture (9,10). Contributing factors are most often a combination of biomechanical and anatomic influences and can also be the result of trauma (11).

Furthermore, biomechanical factors, such as first ray instability, may transfer weight to the second metatarsal that may eventually damage the plantar plate and destabilize the second MTPJ. Imbalance between the intrinsic and extrinsic musculature of the toes, with resultant hyperextension of the proximal phalanx, also creates instability of the MTPJ (8,12–14). Moreover, a long second metatarsal is associated with increased pressure at the second MTPJ as well as deviation of the second digit (4,5,15). It is therefore assumed that this pressure promotes weakening and attenuation of the plantar plate, as well as the supporting periarticular structures that stabilize the MTPJ (4,16). Kaz and Coughlin (5) studied the demographics of the crossover second-toe deformity and found that this condition was associated with female patients older than 50 years and the presence of hallux valgus or hallux limitus. Surprisingly, they did not find a strong correlation of plantar plate disruption with the length of the second metatarsal, as only 44% of their study population had a long second metatarsal (17).

An accessory tendon has also been identified in a cadaver study performed in second-digit crossover deformities and is thought to contribute to deformity of the second MTPJ when present. Lucien (18) reported that this accessory tendon may occur as frequently as 34% of the time. This accessory tendon originates from the extensor digitorum brevis, courses medially along the extensor digitorum longus, and inserts on the dorsal-medial aspect of the second proximal phalanx base. When present, it functions as a deforming force contributing to the crossover second-toe deformity (18,19).

Second MTPJ plantar plate tear (rupture) does not always result in immediate pain, which can contribute to the misdiagnosis of plantar plate insufficiency and an overall delay of care. Its progression can lead to a complete dislocation of the MTPJ. Attention has been paid to the need for objective and accurate diagnostic methods to promptly treat the patient with a plantar plate tear (20–23). Literature shows many methods used to evaluate this pathology. First, clinical assessment of the patient should be performed. The patient typically complains of pain on palpation at the plantar aspect of the MTPJ, plantar hyperkeratotic lesions, edema, and sagittal or transverse plane deformity of the digit (20).

Lachman's test, or the dorsal drawer test, can be used to identify MTPJ instability and is easy to perform (24). As defined by Thompson and Hamilton (24), the proximal phalanx is in approximately 25° of dorsiflexion compared with the metatarsal as dorsal translation stress is applied to the proximal phalanx in attempt to dislocate the MTPJ. A positive test is described as 50% joint subluxation in the sagittal plane (3). A positive Lachman's test is a reliable finding in the diagnosis of plantar plate tear (5) and can also be used to evaluate the surgical repair after surgery (6).

The paper pull-out test is a dynamic way to measure digital purchase (25). As described by Bouché and Heit (25), a piece of paper is placed under the second digit, and the patient is prompted to flex the toe downward against the substrate. If the patient is unable to prevent the paper from being pulled from beneath the digit, the test is considered positive.

Radiography can also be used to evaluate the integrity of the plantar plate by assessing the alignment of the MTPJ. The alignment of the joint should be evaluated on anteroposterior radiography, as well as the position of the toe in the transverse plane. The lateral radiograph is useful to determine the level of subluxation of the toe in the sagittal plane. The most reliable radiographic indicator of second MTPJ instability is the angle of the second MTPJ in relation to hallux and third MTPJ angle. Kaz and Coughlin (5), in their retrospective study, demonstrated that the second MTPJ angle was significantly higher in the bunion group (hallux valgus angle >16°) than in the non-bunion group (−0.6° vs −5.30°). They also found no significant relationship between a crossover second-digit deformity and the length of the second metatarsal, metatarsal cortex thickness, radiographic measurement of pes plano valgus metatarsus adductus, or metatarsus primus elevatus.

Arthrography of the second MTPJ was evaluated and determined to be a valuable diagnostic tool to evaluate joint capsule integrity. It should, however, be correlated with the clinical scenario because there are several potential sources of errors, including needle track extravasation and anatomic variances (26).

Magnetic resonance imaging (MRI) is another diagnostic modality used to assess the plantar plate. In a prospective study by Sung et al (21) that compared MRI findings with intraoperative findings, MRI scans had a sensitivity of 95% and a specificity of 100% in the diagnosis of a plantar plate tear. They tried to correlate the severity of the tear with the plantar plate tear grading system described by Weil (27), and the concordance was moderate (63%). This finding was also observed by Yao et al (28) (62%), with greater concordance occurring at higher grades of plantar plate tear. Sung et al (21) also emphasized that their clinical examination determined plantar plate injury 91% of the time, meaning that MRI improves accuracy in diagnosing plantar plate tears by 5% compared with clinical examination alone. Their clinical diagnosis included the presence of plantar edema and recalcitrant pain at the second MTPJ with equivocal findings on weightbearing radiographs, as well as a positive drawer (Lachman's) test with >2 mm of dorsal displacement. Given the high accuracy of the clinical examination, MRI is most helpful when the decision to operate will be sufficiently influenced by the MRI result (28).

The plantar plate has also been evaluated using diagnostic ultrasound scanning, which has the benefit of assessing the plantar plate dynamically. A prospective analysis of the ultrasound diagnosis of plantar plate pathology by Klein et al (22) with 50 patients had a sensitivity of 91.1% and a specificity of 25%, with a diagnostic accuracy of 90% for longitudinal ultrasound. They concluded that ultrasound scanning was a viable alternative to MRI in well-trained hands but that it should not replace MRI in all cases.

Several classification systems are available to describe the stages of second MTPJ instability. Plantar plate dysfunction has been divided into stages based on clinical staging, including the presence or absence of a positive Lachman's test result and on intraoperative anatomic grading of plantar plate dysfunction (3,6). Sung et al (21) described a classification based on intraoperative and MRI description, wherein grade 0 indicates an intact plate, grade 1 an attenuated plate with discoloration, grade 2 a longitudinal tear at the point of maximal weight bearing, grade 3 a tear <50% of the width of the plate, and grade 4 a tear >50% of the width of the plate.

Conservative treatment of a plantar plate rupture might offer some relief, and modalities such as rest, ice, compression and elevation, the use of nonsteroidal antiinflammatory drugs, as well as oral or injectable corticosteroids have been described, but injectables should be used judiciously (29,30). Digital plantarflexor taping of the proximal phalanx over the metatarsal can be used to diminish strain at the rupture site and may help decrease symptoms and the progression of the deformity. Similarly, accommodative padding, rocker-bottom shoes, physical therapy, and stretching may also be useful for this condition. Surgically, 2

main approaches are used for direct plantar plate repair, often in conjunction with a hammertoe repair and MTPJ release, as well as tendon rebalancing, because these deformities are frequently concomitant (29). Either a dorsal or plantar approach to the plantar plate can be used, at the surgeon's discretion (29). After visualization of the tear, it can be primarily repaired with or without a wedge of the plate taken out to address the transverse plane deformity (4).

To associate the degree of plantar plate tear (rupture) with the degree of MTPJ dislocation, we undertook a cadaveric study primarily to identify the amount of second MTPJ plantar plate rupture required to effect a significant change in a Lachman's test. A secondary aim of the study was to determine whether a positive Lachman's test could be present in the presence of an intact plantar plate. If lesser MTPJ instability was identified before primary transection, or if primary transection failed to produce a positive Lachman's test, then the results of this investigation could possibly lend support to the idea that stability of a second MTPJ is not entirely determined by the status of the plantar plate alone. Our overall goal was to further our understanding of the meaning of Lachman's test as it relates to the structural integrity of the plantar plate and stability of the second MTPJ.

Materials and Methods

Fresh frozen adult lower extremities from Platinum Training (Atlanta, Georgia) were used in this study. Our criteria for selection included no previous surgeries localized to the second toe, no second metatarsal or plantar plate, and no evidence of trauma to these structures. All of the specimens had to have a second toe without frontal, sagittal, or transverse plane deformities. The selection process was carried out by 2 authors (J.F. and M.B.). Of 22 cadaver specimens available for inclusion, 4 (18%) did not meet our inclusion criteria and were excluded. Of the 18 specimens that met our criteria, 6 (33%) were right feet, and 12 (67%) were left feet. It should be noted that the specimens were procured from those that had been used in a prior cadaver surgery workshop (if the forefoot structures were visibly preserved), and precise demographic variables (age, gender, race, and disease status) for the human beings that donated their bodies for scientific research were not available for the cadaver specimens used in this investigation. The experimental manipulations were performed from November 2013 to January 2014, at the Podiatry Institute in Decatur, Georgia. A dorsal drawer test was performed by the authors (J.F. and M.B.) under fluoroscopy to evaluate the stability and integrity of the joint on a standard non-weight-bearing lateral fluoroscopic image prior to any dissection. A linear incision on the plantar aspect of the foot from the sulcus of the second toe to the base of the second metatarsal was then performed and deepened through the subcutaneous tissue. The long and short flexor digitorum tendons were identified and retracted. When the plantar plate of the second MTPJ was directly visualized, a transverse line was drawn at the widest aspect of the plantar plate (Fig. 1). The plantar plate width was then measured (by J.F. and M.B.) with a handheld ruler used on each specimen at this level, and the data were recorded (Table 1).

An initial Lachman's test was captured under fluoroscopy, after which a no. 61 blade (Glassvan; MYCO Medical Incorporated, Cary, NC) was used to make a 2-mm incision along the plantar plate at the level of the joint centrally, which was then reevaluated with Lachman's test under fluoroscopy. We defined a positive Lachman's test result as a minimum of 50% of joint subluxation in the sagittal plane (3). This same process was subsequently repeated in sequential steps incising the plantar plate medially and laterally in 4-mm, 6-mm, and 8-mm increments, simulating progressive rupture, and finally a complete rupture, of the plate (Fig. 2). Using the printed fluoroscopic images, the degree of subluxation of the second MTPJ was measured (J.F. and M.B.), recorded as a percentage of the amount of displacement of the proximal phalanx base on the metatarsal head, and compared at sequential levels of rupture for all of our specimens (Table 2). This information is presented in Table 2, whereby increased displacement is evident with increased tear, and a greater than 50% rupture was deemed a positive Lachman's test. The data were evaluated and reviewed by 2 of the authors (J.B. and D.S.M.), with attention paid to type and distribution, and then described in statistical terms. Null hypothesis tests and Spearman's rank correlation, as well as receiver operator characteristic (ROC) curve analyses and computations of diagnostic operational characteristics, were also undertaken. Statistical significance was defined at the 5% ($p \leq .05$) level. The statistical analyses were performed by a coauthor (D.S.M.), who did not participate in any of the cadaver dissections or measurements, and the analyses were conducted using Stata/SE 9.2 for Macintosh (Stata Corporation, College Station, TX). All of the authors contributed to writing and reviewing the manuscript prior to submission to a peer-reviewed scientific journal.

Results

The overall mean plantar plate width for the 18 specimens was 1.027 ± 0.0752 cm (range 0.8 to 1.1 cm) (Table 1). Figure 3 compares the simulated tear length and the degree of dislocation of the second MTPJ, 50% being the cutoff threshold for a positive Lachman's test. The measured values suggested that a tear length of 2 mm was sufficient to elicit a positive Lachman's test in 12 (66.7%) specimens. Interestingly, the intact plantar plate was in some

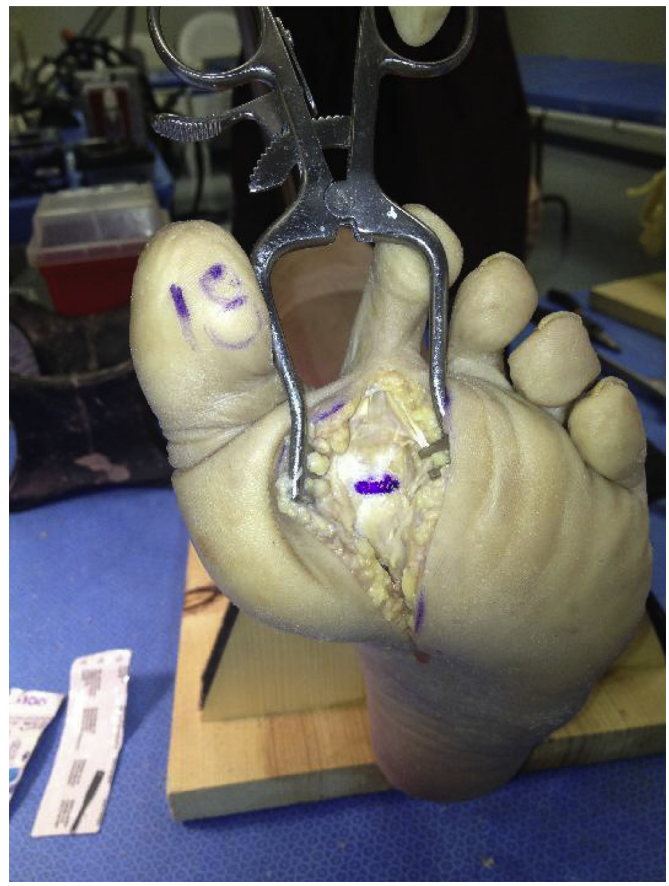

Fig. 1. Dissection showing intact plantar plate with planned transection marked in gentian violet.

Table 1
Mean average width of cadaveric second metatarsophalangeal joint plantar plate (N = 18; 12 [66.7%] left and 6 [33.3%] right feet)

Specimen	Side	Plantar Plate Width (cm)
1	Right	1.1
2	Left	1.1
3	Right	1.1
4	Left	0.8
5	Left	1.1
6	Right	1.1
7	Left	1.1
8	Left	1.0
9	Left	1.0
10	Left	1.0
11	Right	1.0
12	Left	1.0
13	Left	1.0
14	Left	1.1
15	Left	1.0
16	Left	1.0
17	Right	1.0
18	Right	1.0
Mean ± standard deviation (range), left side		1.0167 ± 0.0835 (0.8 to 1.1)
Mean ± standard deviation (range), right side		1.05 ± 0.0548 (1 to 1.1)
Mean ± standard deviation (range), overall		1.0278 ± 0.0752 (0.8 to 1.1)

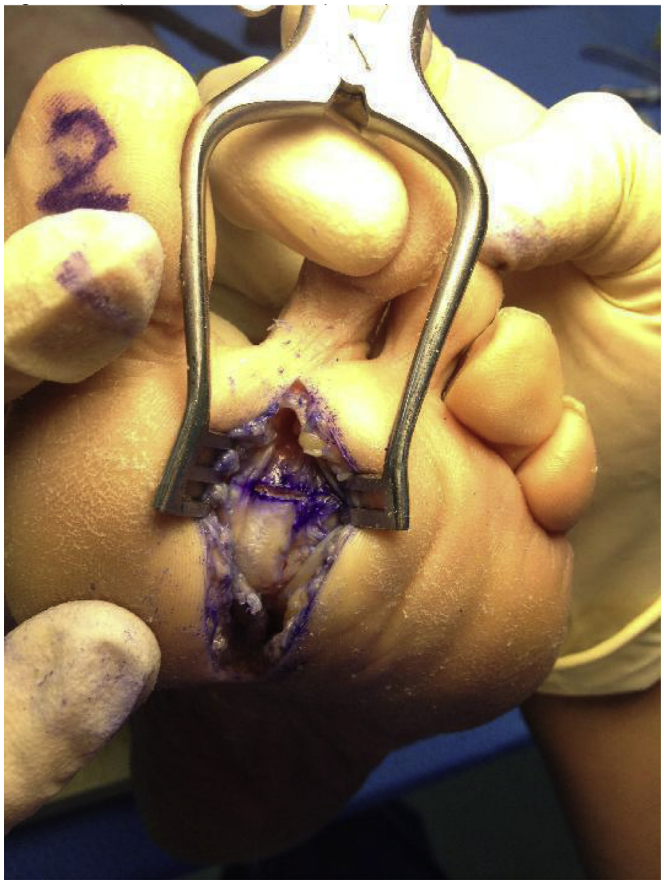

Fig. 2. Plantar plate after simulated complete rupture.

instances associated with a positive Lachman's test, based on a minimum displacement of at least 50% of the joint alignment (Fig. 3). One-way analysis of variance showed a statistically significant difference ($p < .0001$) between the tear length groups and the amount of joint subluxation (Table 2), and larger tears were significantly associated with larger degrees of subluxation at each measured interval.

Tukey's multiple comparisons test suggested that a tear as small as 2 mm was sufficient to elicit a positive Lachman's test, but once the tear was >4 mm, no further significant increase in joint subluxation was observed between the groups of simulated plantar plate ruptures (Table 3). Tear length and joint subluxation were positively correlated such that joint subluxation increased as tear length increased with a statistically significant positive Spearman correlation coefficient (r) of 0.65 (results not shown).

Diagnostic sensitivity, specificity, predictive value positive, predictive value negative, likelihood ratio positive, likelihood ratio negative, and diagnostic accuracy were calculated for 2-mm, 4-mm, 6-mm, and 8-mm simulated tears of the plantar plate (Table 4). For a 4-mm tear, sensitivity was 86.67%; for sectioning a >4-mm tear up to a 6-mm tear, sensitivity was 93.33%; and for transection of a >6-mm tear and up to an 8-mm tear, sensitivity was 100%. When the sensitivities were calculated for the simulated plantar plate tears ranging from one cutoff value to the next, the sensitivities increased in comparison to the simulated value at the precise cutoff value (Table 5), as would be expected. These results demonstrated that a simulated plantar plate tear ≥4 mm but <6 mm resulted in joint subluxation (positive Lachman's test) with a sensitivity of 90.3%. Table 6 shows the area under the ROC curves and the respective 95% confidence interval about the estimate, by the length of the simulated plantar plate tear. The greatest area under the curve was 0.7667, which was computed for the 4-mm simulated plantar plate tear. This curve is depicted in Figure 4.

Table 2
Percentage of cadaveric second MTPJ dislocation associated with different lengths of plantar plate tear (percentage of dislocation measured on printed fluoroscopic images and capped at 100%; N = 18; 12 [66.7%] left and 6 [33.3%] right feet)

	Length of Simulated Plantar Plate Tear (Incision)					
Specimen	Intact	2 mm	4 mm	6 mm	8 mm	Complete Sectioning
	Percentage of MTPJ Dislocation (%)					
1	40.00	53.33	66.67	66.67	66.67	80.00
2	16.67	58.33	66.67	66.67	83.33	83.33
3	36.36	90.91	72.73	100.00	100.00	100.00
4	0.00	66.67	66.67	100.00	100.00	100.00
5	0.00	41.67	41.67	50.00	50.00	58.33
6	35.71	28.57	35.71	35.71	57.14	57.14
7	15.00	50.00	90.00	90.00	70.00	70.00
8	15.38	46.15	69.23	69.23	76.92	92.31
9	25.00	50.00	50.00	83.33	83.33	83.33
10	50.00	50.00	50.00	50.00	70.00	80.00
11	45.45	63.64	63.64	81.82	90.91	90.91
12	63.64	54.55	63.64	81.82	81.82	81.82
13	54.04	66.67	66.67	77.78	100.00	100.00
14	40.00	60.00	70.00	60.00	70.00	90.00
15	14.29	14.29	50.00	64.29	71.43	100.00
16	0.00	0.00	23.08	23.08	30.77	53.85
17	20.00	30.00	40.00	50.00	55.00	50.00
18	26.67	66.67	76.67	80.00	76.67	80.00
One-way Analysis of Variance	Parameter	Df	SS	MS	F	*p* Value
	Between groups	5	33,281	6656	18.62	<.0001
	Within groups	102	36,464	357		
	Total	107	69,746			

Abbreviations: Df, degrees of freedom; F, F ratio; MS, mean square; MTPJ, metatarsophalangeal joint; SS, sum of squares.

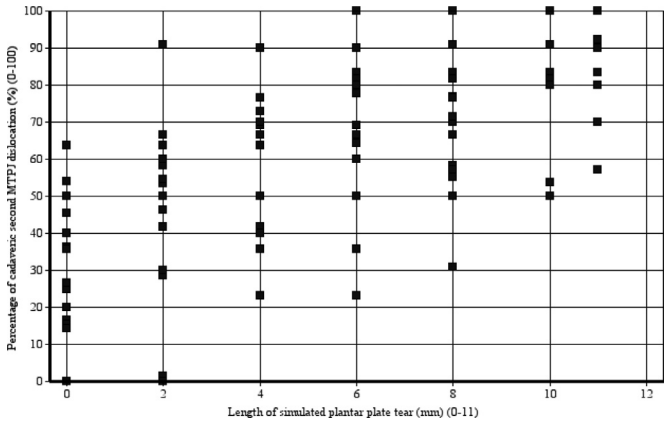

Fig. 3. Percentage of cadaveric second metatarsophalangeal joint dislocation by length of simulated plantar plate tear (N = 18; 12 [66.7%] left and 6 [33.3%] right feet).

Discussion

This study demonstrated that a statistically significant disruption of the cadaveric second MTPJ can be induced with transection of the plantar plate as small as 2 mm. Our study did not account for acquired pathology localized to the plantar plate or other associated capsuloligamentous structures. These results suggest that a tear as small as 2 mm (approximately 19% of the mean total width) is sufficient to produce a positive modified Lachman's test, with a sensitivity of 66.7%. Sensitivity continued to rise with each 2-mm incremental increase in the length of the simulated transection. At 4 mm, the modified Lachman's test had a sensitivity of 77.8%, and we observed that 90.3% of our specimens with a ≥4-mm tear had a positive modified Lachman's test. Based on our observations in a cadaver model, the modified Lachman's test can be used to identify tears of the plantar plate as small as 2 mm in length.

It is interesting to consider the fact that the sensitivity for diagnosing high-grade plantar plate tears with MRI was reported to be 95% (4,21). Our results showed that the dorsal drawer test significantly changed with a tear as small as 2 mm, in a cadaver model. Since the concordance of the tear and its surgical grading on MRI was reported to be 62% (21), it seems that the usefulness of MRI in regard to plantar plate tears, in particular small tears, is debatable (21).

Table 3
Tukey's honest significant difference test for multiple comparisons of cadaveric second MTPJ dislocation by interval transection of the plantar plate (N = 18; 12 [66.7%] left and 6 [33.3%] right feet)

Length (mm) of Simulated Plantar Plate Tear		Probability of Significant Difference Between MTPJ Dislocation by Length of Simulated Plantar Plate Tear*
0	2	≤.05
	4	≤.05
	6	≤.05
	8	≤.05
	Complete	≤.05
2	4	>.05
	6	≤.05
	8	≤.05
	Complete	≤.05
4	6	>.05
	8	>.05
	Complete	≤.05
6	8	>.05
	Complete	>.05
8	Complete	>.05

Abbreviation: MTPJ, metatarsophalangeal joint.
*Statistical significance defined at the 5% ($p \leq .05$) level.

Although our cadaveric study does not compare directly with clinical results of the previously mentioned publications, it does lend further support that a Lachman's test is a viable option for diagnosis in a clinical setting. This may prove a reasonable substitution when use of ultrasound or MRI is unavailable.

When the results are compared to clinical patient demographics, this study had several weaknesses. An obvious flaw is the cadaveric nature of the specimens versus live tissue. The clinical history of the specimens was unavailable; therefore, factors such as sex, age, body mass index, and medical history were not obtained. Also, the physical strength applied, and the rate of application, in performance of the modified Lachman's test were not quantified. Moreover, the inter-rater and intra-rater reliability between clinicians performing the modified Lachman's test were not computed in this study (or in any prior studies in the literature), and the overall sample size was not large. The variability between the percentages of second MTPJ dislocation in Table 2 could be explained by the fact that our measurements were made on a lateral view of a fluoroscopic image, and a slight irregularity in the projection axis could have led to a skewed or incorrect amount of translation.

In our study, 3 (16.7%) specimens had a positive drawer test while the plantar plate was still intact, prior to transection. The exact reason for this observation was unclear; however, this finding could be interpreted as a result of a variety of endemic presentations and anatomic variations in tissue composition (we did have clinical information regarding connective tissue disease, prior injury, and similar information). Other known pathologic etiologies of lesser MTPJ instability, such as plantar plate attenuation without clear rupture, or an early stage of instability from acquired pathology to the supporting capsuloligamentous structures of the lesser MTPJ, may help explain this finding.

Several additional presentations of plantar plate pathology were reported by Coughlin et al (3) in their anatomic grading of the plantar plate tears. This structure may be attenuated, have a longitudinal or transverse tears, or even a button hole. In our study, we only evaluated the correlation of the dorsal drawer test with a transverse type of tear.

As a general rule regarding clinical scenarios, the results of outcome studies can be used to guide the use of advanced imaging modalities (31). A better understanding of lesser MTPJ pathology would add strength to our diagnostic techniques and potentially avoid unnecessary healthcare expenditures. An interesting study was performed by the Norwegian Medical Association (32), which concluded that 57% of doctors underestimated or overestimated the cost of MRI. Being aware of the economic effect of the tests that we frequently order should influence our conscious decisions for which ones are truly needed to inform the treatment plan of foot and ankle surgeons. Perhaps a better understanding of the meaning of the lesser MTPJ Lachman's test could be used to reduce healthcare costs related to the prevalent use of MRI studies.

This investigation, being a cadaver study, is limited in regard to generalization to actual living patients. Although the precise clinical meaning of the joint misalignments that we measured after sectioning the plantar plate in cadaver specimens is difficult to determine, we believe that the findings could be useful to surgeons evaluating the stability of the second, and perhaps other, lesser MTPJs, in that the use of cadaver specimens, in our opinion, is likely to closely simulate the response of the joint to varying degrees of plantar plate rupture. Our methods of plate transection, measurement, and the statistical analyses were straightforward and employed to limit biases.

Table 4
Diagnostic operational characteristics of length of simulated cadaveric second MTPJ plantar plate tear for dislocation (N = 18, 12 [66.7%] left and 6 [33.3%] right feet)

Tear Length (mm)	Sensitivity (%)*	Specificity (%)†	PV(+)‡	PV(−)§	LR(+)‖	LR(−)¶	Diagnostic Accuracy (%)**
2	73.33	66.67	0.6667	0.5333	2.2	0.4	72.22
4	86.67	66.67	0.6667	0.6667	2.6	0.2	83.33
6	93.33	33.33	0.3333	0.9333	1.4	0.2	83.33
8	100	33.33	0.3333	1	1.5	0	88.89

Abbreviations: LR(−), likelihood ratio negative; LR(+), likelihood ratio positive; MTPJ, metatarsophalangeal joint; PV(−), predictive value negative ; PV(+), predictive value positive.
*Probability of a torn plantar plate if Lachman's test is positive.
†Probability of an intact plantar plate if Lachman's test is negative.
‡Probability of a positive Lachman's test if the plantar plate is torn.
§Probability of a negative Lachman's test if the plantar plate is intact.
‖Posterior probability of a positive Lachman's test for those with a torn plantar plate.
¶Posterior probability of a positive Lachman's test for those with an intact plantar plate
**Proportion of positive Lachman's tests in the presence of a torn plantar plate

Table 5
Total tear length dislocation sensitivity (N = 18; 12 [66.7%] left and 6 [33.3%] right feet)

Tear Length (mm)	Sensitivity (%)
≥2 but <4	85.6
≥4 but <6	90.3
≥6 but <8	94.4
≥8 but <complete	97.2

Table 6
Area under the ROC curve (N = 18; 12 [66.7%] left and 6 [33.3%] right feet)

Tear Length (mm)	Area Under the ROC Curve (95% Confidence Interval)
2	0.6444 (0.12224, 1.00000)
4	0.7667 (0.41254, 1.00000)
6	0.6333 (0.03779, 1.00000)
8	0.6889 (0.07840, 1.00000)

Abbreviation: ROC, receiver operating characteristic.

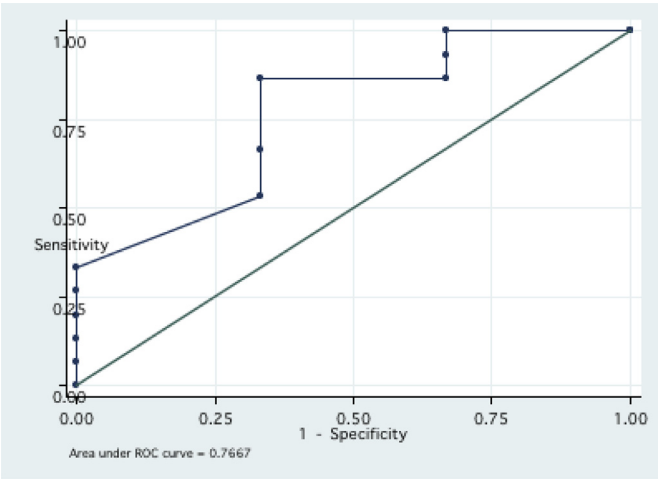

Fig. 4. Receiver operating characteristic curve for 4-mm simulated plantar plate tear associated with a positive cadaveric second metatarsophalangeal joint (MTPJ) Lachman's test indicative of MTPJ dislocation (N = 18; 12 [66.7%] left and 6 [33.3%] right feet).

In conclusion, this cadaveric study showed that disruption of lesser MTPJ stability, as measured with use of the modified Lachman's test, is evident with as little as a 2-mm transection of the plantar plate. The modified Lachman's test was diagnostically most sensitive for transections of the plantar plate ≥4 mm, with the test's sensitivity increasing with increasing disruption of the plate. The results of this cadaveric study could be used in the development of future clinical investigations that focus on the use of the modified Lachman's test for diagnosis of lesser MTPJ plantar plate disruption.

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