Diagnostic accuracy of 3D color volume-rendered CT images for peroneal tendon dislocation in patients with acute calcaneal fractures

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Diagnostic accuracy of 3D color volume rendered CT images for peroneal tendon dislocation in patients with acute calcaneal fractures

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Abstract

Background: Use of 3D color volume rendered images has been reported to be more time-efficient compared to that of cross-sectional CT images for the diagnosis of peroneal tendon dislocation. However, the diagnostic performance of this technique has not been studied.

Purpose: To test diagnostic accuracy of 3D color volume rendered CT images of ankle for peroneal tendon dislocation in patients with acute calcaneal fractures.

Materials and Methods: The study consisted of 121 ankle CT studies from 105 consecutive patients (85 males and 20 females; mean age, 42 year-old; range, 16 – 75 years) with acute calcaneal fractures. Peroneal tendon dislocation was diagnosed on multiplanar CT images by consensus of 2 experienced musculoskeletal radiologists, which served as the reference standard. Three other musculoskeletal radiologists independently reviewed 3D images alone on a workstation. The readers determined whether or not there was peroneal tendon dislocation using three degrees of certainty (definite, probable, and possible). Diagnostic performance of 3D images for peroneal tendon dislocation was evaluated by calculating the sensitivities, specificities and area under the receiver operating characteristic (ROC) curves.

Results: Forty eight (40%) out of 121 studies showed peroneal tendon dislocation based on the expert readings using MPR images. Sensitivities/specificities of 3D images measured 0.92/0.81, 0.88/0.90, and 0.81/0.92 for three readers, respectively. Area under the proper binormal ROC curve based on all three readers (0.93, 0.94, & 0.92) measured 0.93 with a 95% confidence interval of 0.89 – 0.98.

Conclusion: Diagnostic accuracy of 3D images is comparable to, but not as good as that of MPR images for the diagnosis of peroneal tendon dislocation in patients with acute calcaneal fractures.

Keywords

CT-Spiral, tendons, adults and pediatrics, technology assessments

Introduction

Magnetic resonance imaging (MRI), or sonography, is the study of choice in the evaluation of the tendons. Computed tomography (CT), however, is also used for the diagnosis of peroneal tendon subluxation/dislocation (1-3). Peroneal tendon subluxation/dislocation is commonly associated with calcaneal fractures (2, 4), for which CT is increasingly used for pre-operative evaluation (5-7). Detection of the peroneal tendon subluxation/dislocation on the CT study is therefore important, as it may influence the treatment and prognoses of the patients (3, 8, 9). Cross-sectional images of CT (multi-planar reformatted images or MPR images) have been used as the standard technique. 3D color volume-rendered (VR) images of bone and tendon are currently available on some 3D software and provide perspective views of the tendons (10, 11). A previous study compared the VR images and MPR images for the diagnosis of peroneal tendon subluxation/dislocation and found that the use of VR images is more time-efficient for the detection of peroneal tendon subluxation/dislocation (12). However, the study was limited in sample size to test the diagnostic accuracy.

The objective of this study was to test diagnostic accuracy of 3D color volume rendered CT images of ankle for peroneal tendon dislocation in patients with acute calcaneal fractures.

Materials and Methods

Patients

Our institutional review board approved this retrospective study; patient informed consent was not required. The study was performed in accordance with the federal Health Insurance Portability and Accountability Act (HIPAA). One hundred and twenty-one CT studies of the ankle (76 rights and 45 lefts) were collected from 105 consecutive patients with acute calcaneal fractures over nearly a 5-year period (August 2001 to June 2006) (Fig. 1). A portion of our patient population including 37 CT studies from January 2003 to January 2004 has been included in a previous report (12). The calcaneal fractures with no posterior subtalar joint involvement were excluded. The mean age of the patients was 42 years ranging from 16 years to 75 years (85 men and 20 women). Sixteen patients had bilateral ankle and foot CT studies. The mean interval from the injury to the CT study was 2 days (0 – 20 days).

Reference standard and ancillary data

Consensus readings by two musculoskeletal radiologists (K.O. and G.Y.K.; 8- to 9-years of experience in musculoskeletal multi-detector row CT, MD-CT) based on multi-planar reformatted (MPR) images were used as a reference standard. Previously reported CT criteria of normal peroneal tendons were used (3). On the axial images, normal peroneal tendons were defined being posterior to the posterolateral margin of the distal fibular cortex and medial to the superior retinaculum. On the coronal images, normal peroneal tendons were defined being posterior to the fibular groove. Displacement of one of the peroneal tendons from its normal anatomical location was considered a subluxation or dislocation (Fig. 2). We did not distinguish between subluxation and dislocation. The term dislocation is used hereafter to include both conditions. No measurement criteria were used because the study sample was from patients with acute calcaneal fractures, in which normal bony landmarks might be violated.

The same two musculoskeletal radiologists classified calcaneal fractures according to the Sanders classification system (5). The presence or absence of fibular fractures was also recorded. For the cases with peroneal tendon dislocation, one other musculoskeletal radiologist (T.I., 6-years of experience in MD-CT) assessed the degree of peroneal tendon dislocation by measuring the distance from the anterior border of the tendon to the posterior cortex of the fibula at the level of distal end of the fibula using multi-planar reformatted (MPR) images.

MD-CT acquisition and image processing

CT studies were performed either by a four-detector-row helical CT scanner (Aquilion, Toshiba American Medical Systems, Tustin, CA, USA), a six-detector-row helical CT scanner (Emotion 6, Siemens USA, Malvern, PA, USA), or a sixteen-detector-row helical CT

(Sensation 16, Siemens USA, Malvern, PA, USA). With the four-detector-row CT, the imaging parameters included 120 – 135 kVp, 0.5-sec scanning time per gantry rotation, 75 – 225 mAs, a field of view (FOV) of 240 mm, reconstructed FOV of 120 – 180 mm, 512 x 512 matrix, 1 – 2 mm detector collimation, 3.5 – 7.0 mm table travel per rotation, reconstruction thickness of 1 – 2 mm, and 50 – 75 % overlap. With the six-detector-row CT, the following imaging parameters were used: 130 kVp, 0.5-sec scanning time per gantry rotation, 75 – 150 mAs, a FOV of 500 mm, reconstructed FOV of 120 – 180 mm, 512 x 512 matrix, 0.5 mm detector collimation, 3.0 mm table travel per rotation, reconstruction thickness of 0.63 mm, and 50% overlap. With the sixteen-detector-row CT, the following imaging parameters were used: 120 kVp, 0.75-sec scanning time per gantry rotation, 75 – 150 mAs, a FOV of 500 mm, reconstructed FOV of 120 – 180 mm, 512 x 512 matrix, 0.75 mm detector collimation, 6.6 mm table travel per rotation, reconstruction thickness of 0.75 mm, and 50% overlap. The medium smooth (or standard soft tissue) kernel was used for the image reconstructions. The reconstructed images were sent to a computer workstation (Vitrea 2, version 3.8, Vital Images, Plymouth, MN, USA) over an intradepartmental picture archive communication system (Eastman Kodak Company, Rochester, NY, USA), using the DICOM (Digital Imaging and Communications in Medicine) protocol.

Readers and 3D VR image review

Three musculoskeletal radiologists (J.M.A., D.L.B., M.G., 1-4 years of experience in 3D color VR images) independently reviewed 3D VR images alone (Fig. 2) for the diagnosis of peroneal tendon dislocation (normal vs. dislocation) using a computer workstation (Vitrea 2, version 3.8, Vital Images, Plymouth, MN, USA). The readers did not know the name, sex, age, or other clinical information of the patients. Previously reported criteria of peroneal tendon dislocation were used (12). The relationship between the peroneal tendons and posterolateral margin of the distal fibula was evaluated using the 3D images interactively reviewed from posterior to lateral aspects. Obliteration of the posterolateral margin of the fibula by the peroneal tendons (overlap of the peroneal tendons with the fibular margin), or visualization of the posterolateral margin of the fibula behind the peroneal tendons was considered a dislocation. The reader's certainty as to the presence or absence of dislocation was rated as either definite, probable, or possible.

Statistical analysis

A six-point rating scale was created from the reader's judgments as follows: definitely absent = 1, probably absent = 2, possibly absent = 3, possibly present = 4, probably present = 5, definitely present = 6. These rating data were analyzed using multi-reader ROC methodology (13, 14). The multi-reader, multi-case ROC analysis was conducted using software called H/OR/DBM MRMC 2.3 (15). Options selected included the proper binormal model (propROC) as the ROC model (16) with readers treated as a fixed factor and patients treated as a random factor. To test diagnostic performance of the VR images in diagnosing peroneal tendon dislocation, the sensitivities and specificities for the three readers were calculated. Pearson chi-square tests were used to test the significance of association of CT findings related to peroneal tendon dislocation. (BMDP2V Release: 8.0. Copyright 1993 by BMDP Statistical Software, Inc., Statistical Solutions Ltd., 8 South Bank, Crosse's Green, Cork, Ireland, http://www.statsol.ie). Incidence of peroneal tendon dislocations was compared among the Sanders calcaneal fracture types (I, II, III, and IV). Cases of Sanders type II and III fractures were subdivided into lateral group (IIA, IIIAB, and IIIAC) and the others (IIB, IIC, and IIIBC). The incidence of peroneal tendon dislocations was compared between these two groups. The incidence of peroneal tendon dislocations was also compared between the cases with and without fibular fractures.

Results

Peroneal tendon dislocation based on MPR images

Based on consensus readings by 2 musculoskeletal radiologists (reference standard), peroneal tendon dislocation was seen in 40% (48/121) of the CT studies in patients with acute calcaneal fractures. Mean displacement of peroneal tendons measured 8.8 mm ranging from 1.9 mm to 26.3 mm based on MPR images. Incidence of peroneal tendon dislocations in each type of Sanders calcaneal fracture classification is shown in Table 1. The incidence of peroneal tendon dislocations significantly increased as the severity of calcaneal fractures increased ($p < 0.001$). A total of 80 cases of Sanders type II and III fractures was subdivided into 49 cases of lateral group (IIA, IIIAB, and IIIAC) and 31 cases of the others (IIB, IIC, and IIIBC). There was no significant difference in the incidence of peroneal tendon dislocations between these two groups (14/49 in lateral group vs. 8/23 in the others, $p = 0.79$). Twenty-three cases (19% of 121 cases) were associated with fibular fractures, in which 83% (19/23) showed peroneal tendon dislocations. This was significantly higher than the incidence of peroneal tendon dislocations seen in cases without fibular fractures (30%, 29/98, $p < 0.001$).

Performance of 3D VR images

Sensitivities/specificities among three readers using 3D VR images were 0.92/0.81, 0.88/0.90, and 0.81/0.92, respectively. All 3D VR images were diagnostic for peroneal tendon dislocation. Area under the proper binormal ROC curve based on the three readers measured 0.93 with a 95% confidence interval of 0.89 – 0.98 (Fig. 3). Examination of the estimated area under ROC curves revealed only a small amount of variability, with the largest and smallest reader values differing only by .02 (.94 – .92). Moreover, the reader variance component estimate was zero, implying that the observed reader variability can be completely attributed to measurement error due to the moderate case-sample size, rather than difference between the latent reader area under ROC curve (17). In other words, the observed variability between the readers was similar to what we expect to see from one reader reading three different case samples.

Discussion

In order to assess the diagnostic performance of 3D color VR images for detecting peroneal tendon dislocation, we used a group of consecutive patients with acute calcaneal fractures. In our institution, patients with calcaneal fractures are commonly evaluated with CT for preoperative planning and to detect postoperative complications. The reported incidence of peroneal tendon dislocations in patients with calcaneal fractures is between 25% and 47.5% (2, 4), which is similar to the incidence in our study population (40%, 48/121). In the acute trauma setting, the clinical diagnosis of tendon dislocation is difficult because of soft tissue edema and distortion of bony anatomy. Localization of the tendons with CT images is also difficult due to surrounding soft tissue edema. We believe our results in a trauma setting would likely apply to non-trauma patients where visualization of the tendons on CT is not interfered with by the surrounding soft tissue edema.

The incidence of peroneal tendon dislocations increases with the grade of Sanders classification, which coincides with the severity of the calcaneal fractures. Type II and III calcaneal fractures are further divided depending on the location of the major fracture line(s) at the posterior subtalar facet (5). Calcaneal fractures involving the lateral aspect (IIA, IIIAB, and IIIAC) are not significantly associated with an increased incidence of peroneal tendon dislocation as compared with the rest of the type II and III fractures. The presence of fibular fractures is significantly associated with peroneal tendon dislocation. Fibular avulsion fractures associated with the superior retinaculum are well known to be associated with peroneal tendon dislocation (1).

Cross-sectional images have been used to assess tendon dislocation on CT (1-3). Multiplanar reformatted (MPR) images provide cross sectional images orthogonal to the bony landmark regardless of the patient's positioning. To utilize high-quality MPR images of the ankle, usually more than 500 axial thin slices are reconstructed from a volumetric data set of MD-CT. Radiologists page through all these cross-sectional images for interpretation on a computer monitor. Three-dimensional color volume-rendered images of tendon and bone have been introduced and used clinically (10, 11). The 3D images are displayed in a matter of a few seconds once the radiologist starts loading the data. The course of the tendons is easily appreciated in relation to the bony landmarks as the radiologist interactively rotates the 3D VR images on a workstation. One of the advantages of 3D images is the reduction in time needed to identify abnormalities by providing an effective search pattern (12, 18). This is important for radiologists who deal with an ever increasing number of images. There may be an argument against the benefit of 3D images when you review the 2x2 display format which accommodates both MPR and 3D images. Practically speaking, the majority of the radiologist's time is spent with MPR images to evaluate the bony structures (calcaneal fractures in our study population) with a wide window setting. Evaluation of tendons is another separate task, whether you use MPR images with a soft tissue window or 3D images. The image data processed with a soft tissue kernel should be used for evaluation of the tendons as its visualization is limited with a bone kernel, which may be preferred for delineation of calcaneal fractures.

It would be ideal to have both high accuracy and time efficiency in one method, which is not always possible. Some may prefer to use a more time efficient method over another method that has a higher accuracy provided the difference in accuracy is reasonably small. Further investigation is necessary to assess if this degree of accuracy trade-off of 3D VR images compared with MPR images significantly affects the management and outcome of patients with a peroneal tendon dislocation. It is important, however, for radiologists to know the trade-off related between these two imaging methods.

Limitations of our study include the use of MPR images of CT as the reference standard for the diagnosis of peroneal tendon dislocation. Diagnosing peroneal tendon dislocation with MPR images is unlikely to be perfect and any differences in performance between the MPR images and 3D VR images would be counted against the 3D VR images. The clinical significance of the CT findings of peroneal tendons in our study population is unknown, since we made no clinical correlation. In patients with severe calcaneal fractures, peroneal tendon dislocation may not manifest clinically. Likewise, transient peroneal tendon dislocation with spontaneous reduction can be missed using CT (19, 20). This study, however, was designed to compare two viewing methods from the same CT data sets. In order to collect a reasonably large sample, some studies were performed with old CT scanners. However, the image quality of the older studies is comparable to those obtained with newer CT scanners with similar scanning parameters and reconstruction techniques.

In conclusion, our results provide evidence that the diagnostic performance of 3D color VR images for the diagnosis of peroneal tendon dislocation is comparable to that of MPR images. However, it is not quite as accurate as that of MPR images. Most likely there is a trade-off between accuracy and time efficiency between these two methods. Radiologists need to be aware of this trade-off when evaluating peroneal tendon dislocation using 3D color VR images. Whether this degree of loss in diagnostic accuracy using the VR images affects patient management or outcome requires further investigation.

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Fig. 1 Flow diagram of the patient recruitment. Flow diagram shows the patient recruitment from 204 consecutive patients for whom CT was performed under the diagnosis of calcaneal fracture. A total of 121 CT studies from 105 patients were included (16 patients had bilateral CT study).

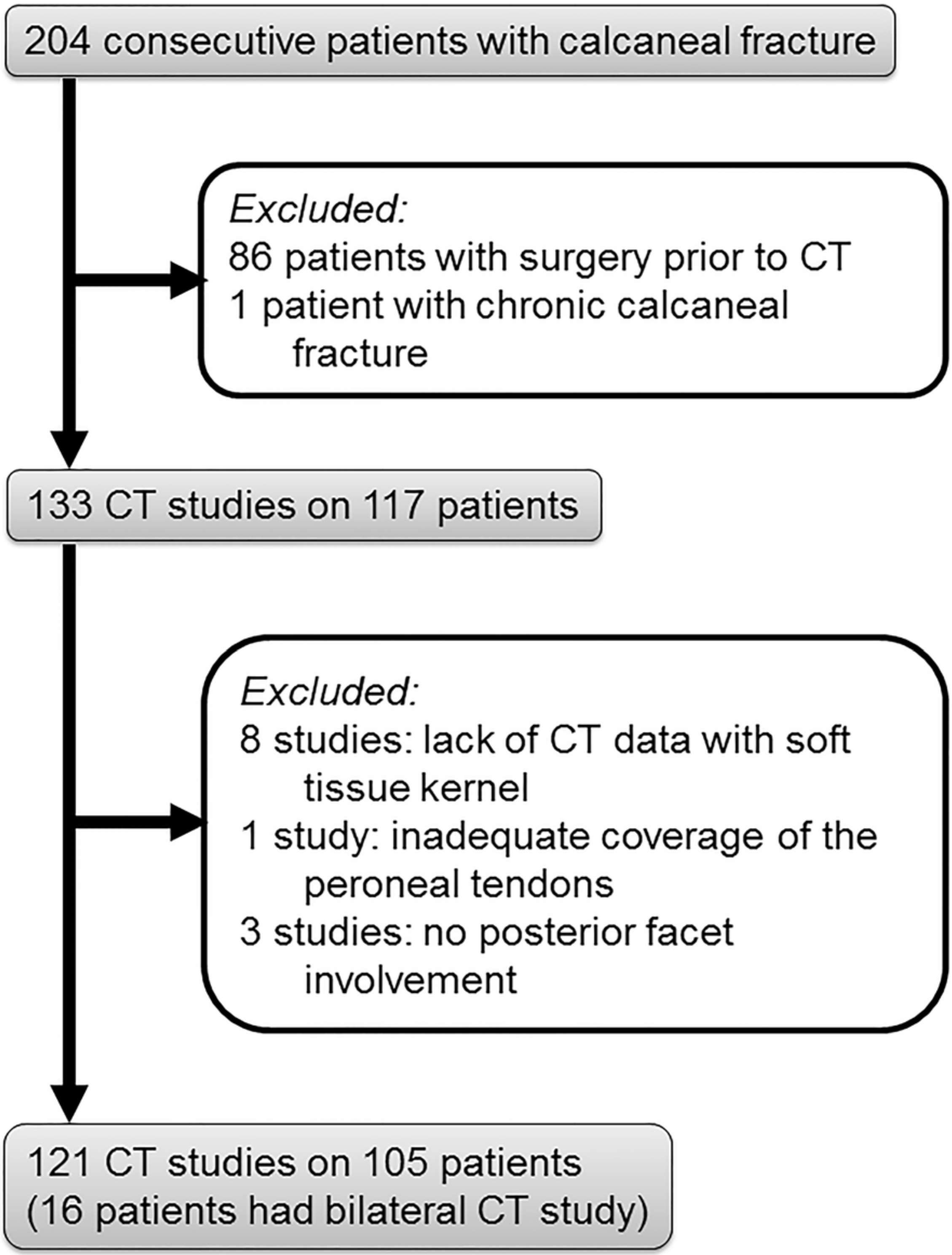
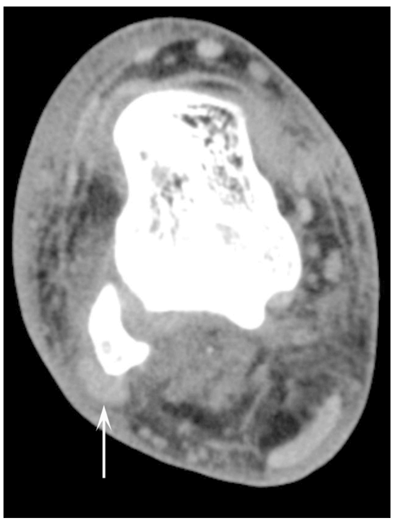

204 consecutive patients with calcaneal fracture
Excluded:
86 patients with surgery prior to CT
1 patient with chronic calcaneal fracture
133 CT studies on 117 patients
Excluded:
8 studies: lack of CT data with soft tissue kernel
1 study: inadequate coverage of the peroneal tendons
3 studies: no posterior facet involvement
121 CT studies on 105 patients
(16 patients had bilateral CT study)

Fig. 2 A 33-year-old man with acute calcaneal fracture. (a), MPR image (axial) at the level of distal fibula shows peroneal tendon dislocation (arrow). The tendon is indistinct due to increased density in subcutaneous fat tissue. (b), Three-dimensional color volume rendered image for tendon and bone reveals peroneal tendon dislocation (arrow). The ankle is viewed from lateral.

(a)



(b)

Fig 3 Receiver operating characteristic (ROC) curves of the three readers

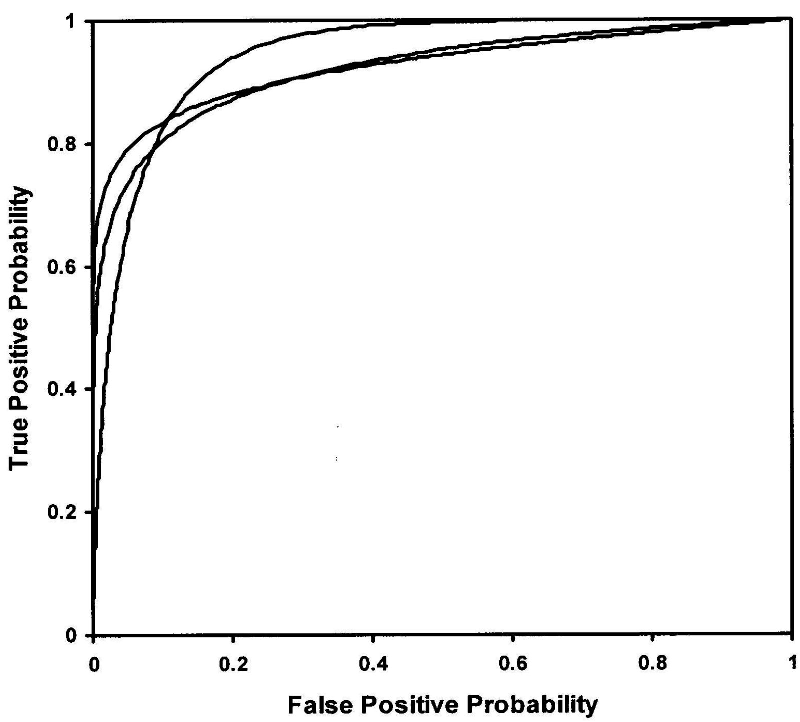


Table 1. Incidence of peroneal tendon dislocations according to Sanders calcaneal fracture types

Sanders classification	Subtypes: Number of cases	Number of cases	Peroneal tendon dislocation
Type I		4	0% (0/4)
Type II	A: 29, B: 21, C: 10	60	25% (15/60)
Type III	AB: 9, AC: 11, BC: 0	20	35% (7/20)
Type IV		37	70% (26/37)

The numbers of the cases of peroneal tendon dislocation are shown in corresponding Sanders types of calcaneal fractures. Sanders type II fractures are two-part fractures of the posterior facet, which are further divided into IIA, IIB, and IIC depending on the location of the primary fracture line (The lines A, B, and C are located from lateral to medial). Type III fractures are three-part fractures and further divided into IIIAB, IIIAC, and IIIBC depending on the locations of the primary fracture lines (5).