27. Milz P, Milz S, Steinborn M, et al: Lateral ankle ligaments and tibifibular syndesmosis. Acta Orthop Scand 69:51–55, 1998
28. Nazarian L, Rawool N, Martin C, et al: Synovial fluid in the hindfoot and ankle: Detection of amount and distribution with US. Radiology 197:275–278, 1995
29. Oliver T, Beggs I: Ultrasound in the assessment of metatarsalgia: A surgical and histological correlation. Clin Radiol 53:287–289, 1998
30. Provost N, Bonaldi V, Sarazin L, et al: Amputation stump neuroma: Ultrasound features. J Clin Ultrasound 25:85–89, 1997
31. Redd R, Peters V, Emery S, et al: Morton neuroma: Sonographic evaluation. Radiology 171:415–417, 1989
32. Riebel T, Nasir R, Nazarenko: The value of sonography in the detection of osteomyelitis. Pediatr Radiol 26:291–297, 1996
33. Rockett M, Gentile S, Gudas C, et al: The use of ultrasonography for the detection of retained wooden foreign bodies in the foot. J Foot Ankle Surg 34:478–484, 1995
34. Rockett M, Waitches G, Sudakoff G, et al: Use of ultrasonography versus magnetic resonance imaging for tendon abnormalities around the ankle. Foot Ankle Int 19:604–612, 1998
35. Rosenberg ZS, Cheung Y, Jahss M, et al: Rupture of posterior tibial tendon: CT and MR imaging with surgical correlation. Radiology 169:229–235, 1988
36. Rubin J, Bude R, Carson P, et al: Power Doppler US: A potentially useful alternative to mean frequency-based color Doppler US. Radiology 190:853–856, 1994
37. Shapiro P, Shapiro S: Sonographic evaluation of interdigital neuromas. Foot Ankle Int 16:604–606, 1995
38. Silvestri E, Martinoli C, Derchi L, et al: Echotexture of peripheral nerves: Correlation between US and histologic findings and criteria to differentiate tendons. Radiology 199:767–772, 1996
39. Sobel M, Geppert M, Olson E, et al: The dynamics of peroneus brevis tendon splits: A proposed mechanism, technique of diagnosis, and classification of injury. Foot Ankle Int 13:413–422, 1992
40. Sobiesk G, Wertheimer S, Schulz R, et al: Sonographic evaluation of interdigital neuromas. J Foot Ankle Surg 36:364–366, 1997
41. van Holsbeeck M, Introcaso J: Musculoskeletal Ultrasound. St. Louis, Mosby-Year Book, 1991
42. van Holsbeeck M, Kolowich P, Eyler W, et al: US depiction of partial-thickness tear of the rotator cuff. Radiology 197:443–446, 1995
43. van Hosbeeck M, Powell A: Ankle and foot. Clinics in Diagnostic Ultrasound 30:221–237, 1995
44. Waitches G, Rockett M, Brage M, et al: Ultrasonographic-surgical correlation of ankle tendon tears. J Ultrasound Med 17:249–256, 1998
45. Wall J, Harkness M, Crawford A: Ultrasound diagnosis of plantar fasciitis. Foot Ankle Int 14:465–470, 1993
46. Yang P, Wang C, Wu C, et al: sonography of pigmented villonodular synovitis in the ankle joint. J Clin Ultrasound 26:166–170, 1998
47. Yao L, Do H, Cracchiolo A, et al: Plantar plate of the foot: Findings on conventional arthrography and MR imaging. AJR 163:641–644, 1994
48. Zanetti M, Strehle J, Zollinger H, et al: Morton neuroma and fluid in the intermetatarsal bursae on MR images of 70 asymptomatic volunteers. Radiology 203:516–520, 1997

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ARTHROGRAPHY OF THE FOOT AND ANKLE

Ankle and Subtalar Joint

Hans-Jörg Trnka, MD, Gerd Ivanic, MD, and Siefried Trattnig, MD

Arthrography involves the intra-articular injection of contrast media in combination with various radiographic projections.[23] It has been an established diagnostic technique for over 60 years, and provides the radiographic means of evaluating the status of the articular surface, the synovial lining, and the status of the supporting ligaments.

Arthrography of the ankle joint has been performed since 1925.[2] Wolff[32] in 1940 and Hanson in 1941[14] reported on arthrography of the subtalar joint in supination trauma of the ankle joint. Initially arthrography of the ankle joint was primarily used as a diagnostic tool after injuries to the ankle joint. Little on this subject had been published in the American literature until 1969.[21] Berridge and Bonnin[1] discussed ankle arthrography for the rupture of the tibiofibular syndesmosis, but they did not feel that arthrography of the ankle provided any additional benefit compared to ankle stress views. To the contrary, in the European literature, for example Broström et al[4] and Olson,[22] indicated the ankle arthrography for ankle sprains.

Arthrography of the subtalar joint is performed less commonly than arthrography in the ankle joint; there are only a few reports in the literature. The main indication is the evaluation of developmental disorders such as talocalcaneal coalition and club feet,[16, 17] although tears of the deep talocalcaneal, cervical and bifurete ligaments may also be diagnosed.

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There are no absolute contraindications to an arthrographic examination. A side effect of arthrography is minimal temporary discomfort several hours following the arthrography owing to joint distension. Allergic reactions, such as sneezing or hives, occasionally occur in patients who are sensitive to iodine. Infection is a possible complication, but the risk is minimal if sterile technique is maintained.[6, 23]

INDICATIONS

An arthrogram is useful in patients who have both acute and chronic injuries. Inversion injuries of the ankle are among the most common injuries (30% of all sports-related injuries) and can lead to considerable disability. If ligament sprain is the only injury, nonsurgical treatment with either immediate mobilization or functional bracing are the treatment modalities of choice. Exact diagnosis by clinical examination and stress radiographs of the ligamentous structures of the ankle are often very difficult in the acute situation.[4, 6, 32, 33] Ankle arthrography provides a relatively simple method for investigating acute ruptures around the ankle.[4, 6, 22, 32] Since the collateral ligaments of the ankle are intimately associated with the joint capsule, most ligament tears also produce rents in the joint capsule, which can be demonstrated arthrographically. Other abnormalities of the ankle joint, such as degenerative joint disease, osteochondral fractures, loose bodies, and posttraumatic adhesive capsulitis[10] can also be diagnosed arthrographically.

In the past, the diagnosis of supination trauma of the ankle was the main indication for ankle arthrography. Determining if, or what, structures are torn is always a concern when an ankle is sprained. Identification of the extent of injury to the ligaments of the ankle is important for the prognosis of stability. Physical examination is the key to the diagnosis of ankle sprains. If no swelling, hematoma, or edema is present, rest and functional treatment is indicated. Increased swelling, hematoma, and edema are suspicious for a more severe injury. To further examine the ankle for potential ligament ruptures, several techniques have evolved. These include stress views under local or general anesthesia, and arthrography of the ankle.[6, 32] Further indications for ankle arthrography are syndesmosis ruptures, transchondral fractures, intra-articular debris and, adhesive capsulitis.[9, 10, 12]

The recommended acceptable time period between injury and arthrography varies in the literature. Olson[22] states that the examination should be ideally carried out as soon as possible but he does not name a specific time frame. Broström et al[4] and Fussell[9] report reliable arthrography results up to 7 days after the supination trauma. Van Dijk[32] recommends less than 48 hours as acceptable Flötteröd and Reichelt[8] find up to 3 days acceptable for reliable arthrography results, but state that in all patients who have insufficient filling of the ankle joint with contrast medium the injury was more than 48 hours old. All authors agree that the capsular tears are rapidly sealed by clots and fibrin, and extensive leakage of contrast medium is not observed if the examination is delayed. Opacification of the peroneal tendon sheath and small, well-defined recesses spreading beyond the normal margins of the lateral capsule are abnormal and are considered to be the result of a previous tear of the calcaneofibular ligament and lateral capsule tears. In 1986 Dory[7] performed a study on 61 patients complaining of chronic ankle instability at least 2 weeks after acute injury. Of the 25 patients who underwent operative evaluation, 20 had arthrography results that correlated with surgical findings. He concluded that arthrography is useful in the preoperative assessment of chronic ankle instability.

An important argument for ankle arthrography is its sensitivity. Van Dijk[32] performed a prospective study on 160 consecutive patients who presented to the emergency department within 48 hours after acute injury of the ankle. Arthrographic examination was performed on all patients. Of 135 patients who underwent surgery, 13 (10%) had only a capsular lesion, a partial anterior tibiofibular ligament, or a partial syndesmosis rupture. Overall, sensitivity was 96% and specificity was 71%. This was confirmed by Raatikainen and Puranen[24] who performed a prospective study in 589 patients who sustained ruptures of the lateral ankle ligaments. All patients received arthrography of the ankle joint prior to surgery. They concluded that arthrography was almost 100% reliable for diagnosing a fresh anterior talofibular ligament rupture. Van Moppes[33] compared ankle arthrography to stress views under local anesthesia and stress views under general anesthesia prior to surgery. The results of this study revealed that stress examination under general anesthesia and arthrography is a sensitive indicator of lateral ankle ligament pathology (91%, 96% resp). Arthrography was significantly superior to inversion stress examination under local anesthesia.

A rupture of the tibiofibular syndesmosis on stress views is not always visible.[17] Wrazidlo[35] presented a series of 114 patients who had diagnosed syndesmosis rupture among 2020 patients who underwent ankle arthrography. He concluded that the diagnosis of isolated tear of the tibiofibular syndesmosis revealed a sensitivity of 90% and a specificity of 67%.

ANKLE ARTHROGRAPHY: ANATOMY

Interpretation of arthrography for ankle instability is easier if the clinician understands the anatomy of the important structures.[19] The clinician has to distinguish between the lateral collateral ligamentous complex, medial collateral ligaments, and syndesmotic ligamentous complex.

Lateral Collateral Ligamentous Complex

Anterior Talofibular Ligament

The anterior talofibular ligament (ATFL) originates from the anterior surface of the distal portion of the fibula. The fibers course anteromedially and insert on the talar body just anterior to the lateral malleolar articular surface. Fibers of the ATFL are within the substance of the lateral ankle capsule.

Calcaneofibular Ligament

The calcaneofibular ligament (CFL) originates from the posterior aspect of the distal portion of the fibula and inserts on the superior posterolateral aspect of the calcaneus. The CFL is extracapsular.

Posterior Talofibular Ligament

The posterior talofibular ligament (PTFL) arises from the medial aspect of the distal portion of the fibular close to the origin of the CFL. It courses horizontally and medially and inserts in the posterolateral talar tubercle.

Anterior Inferior Tibiofibular Ligament

The anterior inferior tibiofibular ligament (AITFL) extends from the anterior and lateral aspect of the distal portion of the tibia to the adjacent anterior portion of the distal fibula (distal syndesmosis).

Medial Collateral Ligaments (Deltoid Ligament)

Deltoid Ligament

The deltoid ligament, which originates from the medial malleolus and inserts into the talus and the calcaneus, can be divided into superficial and deep components. The superficial portion consists of tibionavicular and tibiocalcaneal parts and the deep portion consists of anterior and posterior tibiotalar parts.

- Tibionavicular part. The tibionavicular part of the deltoid ligament courses superficially and inserts into the navicular.
- Tibiocalcaneal part. The tibiocalcaneal part of the deltoid ligament also courses superficially and inserts into the sustentaculum tali of the calcaneus.
- Anterior tibiotalar part. The anterior tibiotalar part of the deltoid ligament courses deep and inserts into the medial aspect of the talar neck.
- Posterior tibiotalar part. The posterior tibiotalar part of the deltoid ligament inserts into the posteromedial talar tubercle.

Syndesmotic Ligamentous Structures

Anterior Tibiofibular Ligament

The anterior tibiofibular ligament originates from the longitudinal tubercle located on the anterior border of the lateral malleolus. The fibers of the ligament are directed upward and medially and insert on the anterolateral tubercle of the tibia.

Posterior Tibiotalar Ligament

The posterior tibiotalar ligament originates from the posterolateral tibial tubercle and courses obliquely downward to insert in the posterior and distal aspect of the lateral malleolus. The posterior tibiotalar ligament has both superficial and deep components. The superficial portion originates from the posterior border of the tubercle located above the malleolar fossa of the lateral malleolus, and the fibers insert into the posterolateral tibial tubercle. The deep component is located inferiorly and has been designated as the inferior transverse ligament, deep transverse ligament, or transverse ligament.

TECHNIQUE[25]

After clinical evaluation and satisfactory plain radiographs have been obtained, the patient is placed on the fluoroscopic table. Following sterile preparation, a point for insertion of the needle is selected just between the anterior tibial tendon and the medial malleolus. A 20-gauge disposable needle is introduced into the ankle joint under fluoroscopic guidance and local anesthesia. The needle enters the ankle joint distal to and medial to the upper medial corner of the articular surface of the talus. A hematoma should be aspirated. Six mL to 10 mL of 60% Renografin (methylglucamine diatrizoate), which may be mixed with approximately 1.0 mL of lidocaine, is instilled under fluoroscopic control into the ankle joint. The contrast material runs along the top of the talus, in the tibiotalar joint, indicating an intra-articular placement. Following verification of intra-articular placement, the remaining contrast material is injected. If there is resistance, slight distraction is applied to the ankle joint. Excessive distention should be avoided; this may cause pain and tends to create leaking around the needle entry point.

The patient is urged to dorsiflex, plantarflex, supinate, and pronate the foot several times to disperse the medium throughout the ankle. Radiographs are obtained in anteroposterior, lateral, and both internal and external oblique views (Fig. 1*A* and *B*). Discomfort is often felt during this period, but as the patient rests on the table, by the time the films are developed, the discomfort is usually gone. Rest and elevation are recommended for several hours to avoid the occurrence of reactive synovitis, which can follow arthrography.

FINDINGS OF ARTHROGRAPHY IN THE NORMAL ANKLE JOINT[24, 25]

In a normal arthrogram the contrast medium results in opacification of the articular cavity without evidence of extra-articular leakage. The

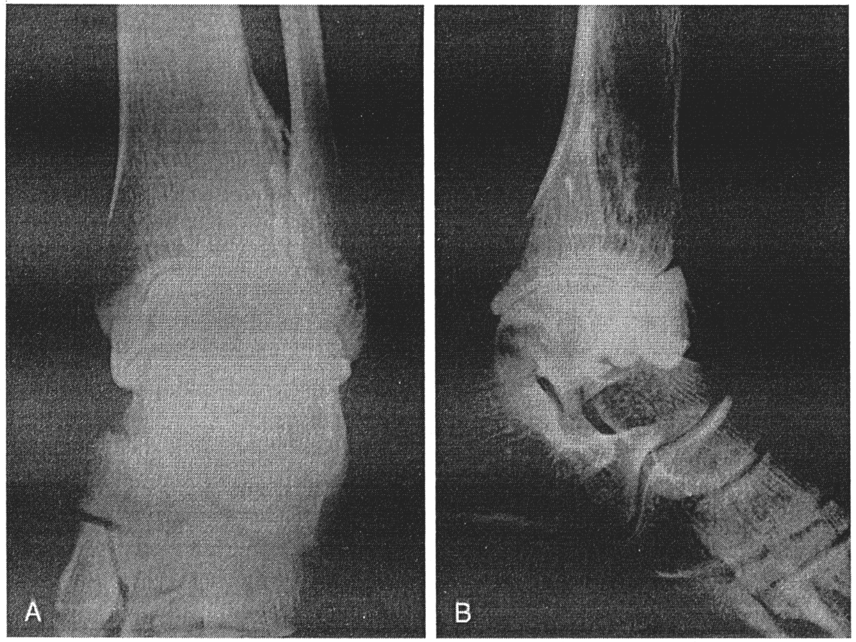

Figure 1. Normal arthrography of ankle joint. *A*, anteroposterior view. *B*, lateral view.

articular surfaces are smooth and uniform in thickness, and are best seen on the ankle mortise view. Three normal recesses are noted. The anterior and posterior recesses are of variable size and shape in the lateral view. A smooth, syndesmotic recess is noted on both the anteroposterior (AP) and mortise views. It extends between the distal tibia and the fibula and averages 1.0 cm to 2.5 cm in length. Filling of the tendon sheaths of the flexor digitorum longus, the flexor hallucis longus, or both are seen in approximately 20% of the patients. A communication between the ankle and the posterior subtalar joint is present in about 10% of patients (see Fig. 1*A* and *B*). Extravasation of contrast material outside the ankle joint is abnormal and confirms a ligamentous tear.

PATHOLOGIC FINDINGS[22, 24]

Acute Injuries

Anterior Talofibular Ligament Injury

The anterior talofibular ligament (ATFL) is the most commonly injured ligament. It is in continuity with the capsule. With tears, contrast material is seen both inferior and lateral to the distal end of the fibula on AP radiographs, and anterior to the distal part of the fibula on lateral radiographs (Fig. 2*A*).

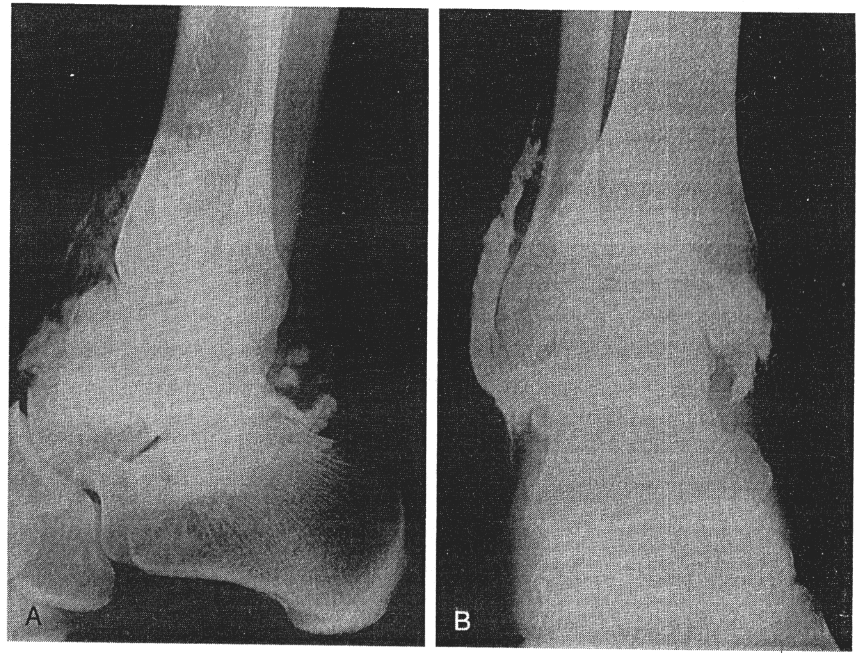

Figure 2. Rupture of anterior talofibular ligament (ATFL), the calcaneofibular ligament (CFL), and posterior talofibular ligament (PTFL) in 23-year-old man following supination injury to left ankle. *A*, Lateral view with extravasation of the contrast material anterior to ATFL and posterior to PTFL. *B*, Extravasation of contrast material into peroneal tendon sheath.

Calcaneofibular Ligament Injury

Rupture of the CFL is invariably associated with tearing of the anterior talofibular ligament. Because the CFL lies immediately deep to the peroneal tendon sheath, when the ligament ruptures, tearing of the deep aspect of the tendon sheath of the peroneal muscle allows the contrast material to extravasate into that sheath. This injury is identified on all routine views (see Fig. 2*B*).

Posterior Talofibular Ligament Injury

The posterior talofibular ligament is in close apposition to the joint capsule. This ligament always ruptures in conjunction with a tear of the anterior talofibular ligament and the calcaneofibular ligament. With tears, contrast material is seen both inferior and lateral to the distal end of the fibula on frontal radiographs and posterior to the distal part of the fibula on lateral radiographs (see Fig. 2*A*).

Deltoid Ligament Injury

A rupture of the deltoid ligament is uncommon and rarely occurs in all of its 4 parts. It usually involves only the anterior tibiotalar part and the tibionavicular part. If it is ruptured, contrast medium leaks out of the joint into the medial soft tissues. It can be best seen on anteroposterior or mortise views.

Syndesmosis Injury

A rupture of the syndesmosis is diagnosed by the proximal extension of contrast medium between the tibia and fibula beyond the normal 1.0 cm to 2.5 cm recess. This injury is best identified on mortise views. A rupture of the syndesmosis is usually associated with a rupture of the deltoid ligament.

Transchondral Fracture

Osteochondral fractures or osteochondritis dissecans of the talar dome are not infrequent. Arthrography outlines the integrity of the overlying cartilage and the presence of intra-articular cartilaginous bodies. The arthrographic examination to evaluate the articular cartilage covering an osteochondral defect should include anteroposterior and lateral views.[22]

Adhesive Capsulitis

Posttraumatic adhesive capsulitis is a well-known condition. It is diagnosed by a decrease of articular capacity, obliteration of the normal anterior and posterior recesses, and extravasation of the contrast medium along the needle track.[28]

MR IMAGING ARTHROGRAPHY OF THE ANKLE

Recently arthrography of the ankle joint has been succeeded by MR imaging arthrography. MR imaging arthrography combines the benefits of arthrography and MR image, and is accurate in acute and chronic injuries. With the intra-articular injection of contrast material, the beneficial effect of joint fluid is recreated. MR imaging arthrography has a high sensitivity for staging and detecting osteochondritis dissecans of the talus, and for diagnosing anterolateral soft-tissue impingement as a cause of chronic ankle pain.

Normal arthrography has limitations depicting chronic lateral ankle instability[50]; MR imaging arthrography has been used (Fig. 3). MR imaging has the advantage of direct simultaneous visualization of both osseous and soft tissues. Normal and abnormal ankle ligaments are accurately depicted,[18] and the location and extent of ligamentous tears are well demonstrated.[5] The visualization of intra-articular structures is increased in the presence of joint fluid. Because joint effusions are often absent in subacute or chronic conditions, the addition of contract material aids in the sensitivity and specificity of diagnosis.

Figure 3. T1-weighted fat-suppressed SE sequence images with gadolinium contrast medium arthrography. *A*, Coronal view of normal ankle joint. *B*, Axial view. Extravasation of contrast material anterior to anterior talofibular ligament and posterior to calcaneofibular ligament. *C*, Coronal view. Osteochondritis dissecans of medical talar dome. Stage 3 of Berndt and Harty classification, stage 3B of University of Pittsburgh classification.

MR Imaging Arthrography Technique

The technique of injecting the contrast medium is the same as in normal arthrography. Special care should be taken to avoid introduction of air bubbles to prevent magnetic susceptibility artifact.

Imaging should be performed within 30 to 45 minutes of contrast material administration. A longer delay results in contrast material absorption and, consequently, decreased joint distention. Images are obtained in axial, sagittal, coronal, and coronal oblique planes of section. T1-weighted sequences (600/200) [TR/TE] with fat-suppression technique are used. Fat suppression increases the contrast between enhanced joint fluid and periarticular structures.[15]

Complications

Complications of MR imaging arthrography of the ankle are rare events. Patients sometimes describe transient pain and swelling. Hemorrhage and infection are potential risks.

Pathological Findings

For patients who have acute ligament rupture, the findings are similar to normal arthrography. Extravasation of contrast material is seen anterior to the ATFL in patients who have ATFL rupture, lateral to the CFL or into the peroneal sheath in patients who have CFL rupture, and posterior to the ligament in patients who have PTFL rupture in the soft tissue. For chronic lateral ligament ruptures, MR imaging arthrography yielded sensitivities of 100% for ATFL tears and 90% for CFL tears.[5]

Anterolateral soft-tissue impingement is sometimes a cause of chronic ankle pain. Hypertrophic synovium, fibrotic scars, or parts of the ATFL or AITFL become trapped in the anterolateral gutter of the ankle. These findings can be excellently detected by MR imaging arthrography.[15]

Accurate assessment of the integrity of the articular cartilage before MR imaging arthrography was possible only with arthroscopy of the ankle joint. For osteochondral lesions as well as intra-articular osteochondral loose bodies, MR imaging arthrography has been found to be most sensitive for detecting and staging these lesions. The classic staging system was presented in 1959 by Berndt and Harty.[3] In this classification, Stage 1 is a small area of subchondral compression, Stage 2 is a partially detached fragment, Stage 3 is a detached fragment in situ, and Stage 4 is a displaced fragment.

Most recently, Taranow et al presented the University of Pittsburgh classification.[30] Using preoperative MR imaging evaluation and articular surface determination with arthroscopy, they primarily distinguish between grade A (viable and intact cartilage) and grade B (breached or nonviable cartilage). Stage 1 is a subchondral compression or bone bruise, appearing as high signal on T2-weighted images, Stage 2 lesions are subchondral cysts and are not seen acutely, Stage 3 lesions are partially separated or detached fragments in situ, and Stage 4 represents displaced fragments.

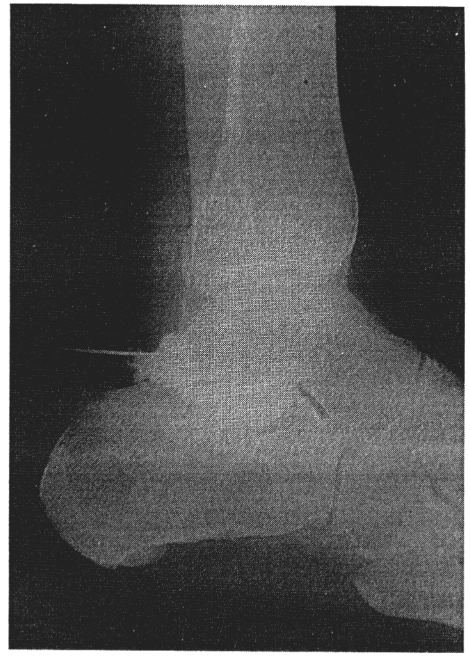

Figure 4. Normal arthrography of subtalar joint.

SUBTALAR ARTHROGRAPHY

Arthrography of the subtalar joint is far more uncommon than the arthrography of the ankle joint (Fig. 4). There are few reports of subtalar arthrography in the literature.[13, 18, 23, 29] Subtalar arthrography is used to evaluate posttraumatic changes, such as fibrous ankylosis or sinus tarsi syndrome, and it has been employed in the evaluation of developmental disorders such as talocalcaneal coalition.[13] Simultaneous arthrography of the ankle and subtalar joint has been reported to be helpful in the analysis of children with club feet.[16, 27]

The subtalar joint may be divided into the anterior (sinus tarsi) and posterior subtalar joint. A posterior subtalar arthrogram can help determine a posterior (middle facet) subtalar coalition or help evaluate the articular cartilage of the joint. In 10% of the population, the posterior subtalar joint communicates with the ankle joint. The anterior subtalar arthrogram is indicated in patients who have sinus tarsi syndrome. In ankle sprains, the isolated tear of the calcaneofibular ligament is rare. The calcaneofibular ligament stabilizes both the ankle and the subtalar joints. Demonstration of instability of the subtalar joint by stress radiography is not easy. Subtalar arthrography can help identify injuries of the interosseous ligament and CFL, both of which can contribute to subtalar instability.

Technique

The posterior subtalar joint is injected from the lateral aspect.[11, 23] or the posterolateral aspect.[29] The posterior subtalar joint is located fluoroscopically with a metal circle. After sterile preparation and draping of the area, a 20-gauge needle is inserted under fluoroscopic control. When the needle is properly positioned the injected contrast flows away from the needle.

Normal Posterior Subtalar Arthrographic Findings

The posterior subtalar joint demonstrates a linear dense area between the posterior portions of the talus and calcaneus along the lateral aspect of the foot. The articular cartilage is normally uniform in thickness on both sides of the joint. Leakage of the contrast medium to the peroneal tendon from the subtalar joint indicates a tear of the CFL,[11] but has also been regarded as normal.[20] A communication between the ankle and the subtalar joint is common, with a frequency of 20% reported by Resnick,[25] 15.6% by Broström, Liljedahl, and Lindvall,[4] and 11% by Gordon[12] (Fig. 4).

Abnormal Posterior Subtalar Arthrographic Findings

If contrast medium cannot be injected, there is a fibrous or cartilaginous coalition. Thinning of articular cartilage indicates degenerative changes. Synovial hypertrophy, thickening, or lymphatic uptake indicates an inflammatory arthritic process. Synovial contraction indicates an adhesive capsulitis. Leakage of the contrast medium into the sinus tarsi indicates rupture of the interosseous ligament or of the anterolateral capsule of the posterior facet.[18, 23]

CONCLUSION

Although arthrography of the ankle and the subtalar joint is not advised for every ligamentous ankle injury or routine examination, it is

often a valuable aid, especially in patients who have questionable instability, developmental disorders, or chronic subtalar pain. MR imaging arthrography combines the advantages of both modalities, making it a powerful diagnostic tool.

References

1. Berridge FR, Bonnin JG: Radiographic examination of ankle joint including arthrography. Surgery Gynecology and Obstetrics 79:383–389, 1944
2. Borak J, Goldhamer K: Experimentelle Beiträge zur Röntgenanatomie und-pathologie der Gelenke. Röfo Fortschr Geb Rontgenstr Neuen Bildgeb Verfahr 33:341–358, 1925
3. Berndt AL, Harty M: Transchondral fractures (osteochondritis dissecans) of the talus. J Bone Joint Surg 41A:988–1020, 1959
4. Broström L, Liljedahl SO, Lindvall N: Arthrographic diagnosis of recent ligament ruptures. Acta Chir Scand 129:485, 1965
5. Chandnani VP: Chronic ankle instability: Evaluation with MR arthrography, MR imaging, and stress radiography. Radiology 192:189–194, 1994
6. Crespi Porro R: Die Arthrographie des oberen Sprunggelenkes. Rofo Fortschr Geb Rontgenstr Nuklearmed 140:191–195, 1984
7. Dory MA: Arthrography of the ankle joint in chronic instability. Skeletal Radiol 15:291–294, 1986
8. Flötteröd K, Reichelt HG: [Arthrography—expanded diagnosis in capsule-ligament injuries of the upper ankle joint]. Unfallchirurg 13:207–217, 1987
9. Fussell ME: Ankle arthrography in acute sprains. Clin Orthop 93:278–290, 1973
10. Goldman AB: Posttraumatic adhesive capsulitis of the ankle: Arthrographic diagnosis. AJR American Journal of Roentgenology 127:585–588, 1976
11. Goossens M: Posterior subtalar joint arthrography. A useful tool in the diagnosis of hindfoot disorders. Clin Orthop :248–255, 1989
12. Gordon RB: Arthrography of the ankle joint. Experience in one hundred seven studies. J Bone Joint Surg [Am] 52:1623–1631, 1970
13. Haller J: Arthrography, tenography, and bursography of the ankle and foot. Clin Podiatr Med Surg 5:893–908, 1988
14. Hanson EC: Adhesive capsulitis of the wrist. Diagnosis and treatment. Clin Orthop 234:51–55, 1988
15. Helgason JW: Magnetic resonance imaging arthrography of the ankle. Top Magn Reson Imaging 9:286–294, 1998
16. Hjelmstedt A: Simultaneous arthrography of the talocrural and talonavicular joints in children. III. Measurements on normal feet. Acta Radiologica [Diagn] (Stockh) 18:513–522, 1977
17. Hollmann J, Langenbruch K: Die Arthrographie als diagnostische Maßnahme bei Band-Kapselverletzungen des oberen Sprunggelenkes. Röntgenblätter 35:222–228, 1982
18. Kaye JJ, Ghelman B, Schneider R: Talonavicular joint arthrography for sustentacular-talar tarsal coalitions. Radiology 115:730, 1975
19. Lee SH, Jacobson J, Trudell D and Resnick D: Ligaments of the ankle: normal anatomy with MR arthrography. J Comput Assist Tomogr 22:807–813, 1998
20. Meyer JM: [Arthrography of the infra-astragalian joint in the post injury pain syndrome of the posterior tarsal bone]. Rev Chir Orthop Reparatrice Appar Mot 60:321–330, 1974
21. Olson RW: Arthrography of the ankle: Its use in the evaluation of ankle sprains. Radiology 92:1439–1446, 1969
22. Olson RW: Ankle arthrography. Radiol Clin North Am 19:255–268, 1981
23. Pavlov H: Ankle and subtalar arthrography. Clin Sports Med 1:47–69, 1982
24. Raatikainen T, Puranen J: Arthrography for the diagnosis of acute lateral ligament injuries of the ankle. Am J Sports Med 21:343–347, 1993
25. Resnick D: Arthrography, tenography, and bursography. *In* Resnick D, Niwwayama

G (eds): Diagnosis of Bone and Joint Disorders. Philadelphia, WB Saunders, 1988, pp 412–440
26. Rosenberg ZS, Cheung Y: Diagnostic imaging of the ankle and foot. *In* Jahss MH (ed): Disorders of the Foot & Ankle. Philadelphia, WB Saunders, 1991, pp 109–154
27. Sahlstedt B: Simultaneous arthrography of the talocrural and talonavicular joints in children. Acta Radiologica [Diagn] 17:545–556, 1976
28. Spiegel PK, Staples S: Arthrography of the ankle joint: Problems in diagnosis of acute lateral ligament injuries. Radiology 114:587–590, 1975
29. Sugimoto K: Subtalar arthrography in acute injuries of the calcaneofibular ligament. J Bone Joint Surg Br 80:785–790, 1998
30. Taranow WS, Bisignani GA, Towers JD, et al: Retrograde drilling of osteochondral lesions of the medial talar dome. Foot Ankle Int (20)8:474–480, 1999
31. Trattnig S: MR-Arthrography des Sprunggelenks. Radiologe 39:47–51, 1999
32. van Dijk CN: Value of arthrography after supination trauma of the ankle. Skeletal Radiol 27:256–261, 1998
33. van Moppes FI: Arthrography, talar tilt and surgical findings after inversion trauma of the ankle. Rofo Fortschr Geb Rontgenstr Nuklearmed 134:413–416, 1981
34. Wolff A: Arthrographi av ankelled. Nord Med 8:2449–2456, 1940
35. Wrazidlo W: [Arthrographic diagnosis of rupture of the anterior syndesmosis of the upper ankle joint]. Rofo Fortschr Geb Rontgenstr Nuklearmed 148:492–497, 1988

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MR IMAGING OF ANKLE MARROW

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The diagnosis of marrow disorders of foot and ankle is among the more challenging aspects of MR interpretation. It is also one of the more rewarding because, although the disorders on the surface have quite similar appearances, patterns, location, and differences in signal intensity on different sequences often allow for specific diagnosis.

TRAUMA

Fracture

The best way to diagnose a fracture with MR imaging is to see a fracture line. Visibility of fracture lines is variable; however, they are most often seen on STIR or T2-weighted images. Occasionally fracture lines will be visible on T1-weighted images.[6, 20, 24, 38, 54]

The most typical locations to see a fracture line include the talar neck, the cuboid, and the cuneiforms; however, injuries which behave clinically as fractures may be seen without visible fracture lines. In fact, several authors believe that all traumatic disorders of the bone marrow found on foot and ankle MR images represent occult fractures. The edema of most true fractures is as easy to see on T1-weighted images as on STIR or T2-weighted images. Bone bruises are usually much more obvious on T2-weighted images than they are on T1-weighted images.

With early healing (resorption) the fracture line becomes more visible, and at 2 to 3 weeks can be best seen. Even though the fracture

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