Tarsal Coalitions: Radiographic, CT, and MR Imaging Findings

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Abstract *Background:* Tarsal coalitions affect up to 13% of the population and can be a cause of chronic ankle and hindfoot pain. They can be subdivided as osseous, cartilaginous, or fibrous types, each with unique radiographic, CT, and MR imaging findings. In particular, MR imaging offers the unique ability to determine the exact type of tarsal coalition that is present as well as whether any associated soft tissue abnormalities are present. *Questions/Purposes:* The purposes of this paper were to (1) review the anatomy of the hindfoot; (2) review the radiographic, CT, and MR imaging findings of tarsal coalitions; and (3) review the imaging appearance of the specific types of tarsal coalitions. *Methods:* Online searches were performed using Google Scholar with the search criteria of “tarsal coalition,” “hindfoot anatomy,” and “subtalar coalition,” and limiting the searches to papers published in the last 10 years in major radiology journals. *Results:* The anatomy of the hindfoot is complex but essential to understand. There are various radiographic, CT, and MR imaging findings that can be consistently noted in cases of tarsal coalition. The specific types of tarsal coalition demonstrate characteristic imaging findings. *Conclusions:* Knowledge of the normal

anatomy of the foot, in particular the hindfoot, combined with the knowledge of the imaging characteristics of different histologic subtypes of coalitions (osseous, cartilaginous, and fibrous) is essential for interpreting radiographic, CT, and MR images of the ankle and foot.

Keywords tarsal coalition · subtalar coalition · calcaneonavicular coalition

Introduction

Tarsal coalition is a congenital bridging of two or more tarsal bones. The bridging may be fibrous (syndesmosis), cartilaginous (synchondrosis), or osseous (synostosis). Osseous coalition is generally readily apparent on cross-sectional imaging. Cartilaginous and fibrous coalitions may be more subtle on cross-sectional imaging but generally are associated with some osseous deformity along the margin of the coalition [25]. Tarsal coalitions are thought to be due to a failure of mesenchymal differentiation and segmentation, resulting in failure of normal tarsal joint formation [8, 9, 11]. A possible autosomal dominant form of inheritance with variable penetrance has been proposed [10, 12]. The incidence of tarsal coalition is classically thought to be approximately 1%; however, many feel that this is an underestimate as only the symptomatic cases come to attention [13]. For example, cadaveric series has described an incidence of up to 13% [16, 17, 27].

Most commonly, tarsal coalitions present in late childhood or adolescence. This is likely related to the fact that osseous coalitions usually ossify when patients are 8–16 years old, leading to restricted motion and subsequent symptomatology [13]. In particular, calcaneonavicular coalitions present in younger patients than talocalcaneal coalitions (8–12 years old versus 12–16 years old) due to the different normal ossification patterns of the tarsal bones [17]. The condition is bilateral in 25–50% of cases, although the two sides do not necessarily need to be symptomatic [21]. Tarsal coalitions may clinically manifest as tarsal or hindfoot pain and stiffness, decreased subtalar motion, valgus deformity, and non-healing

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ankle sprains [11, 26]. Symptoms of coalitions include peroneal spastic flatfoot, rigid flatfoot attributed to peroneal spasm, or adaptive peroneal shortening in response to heel valgus [17]. Treatment options range from conservative to surgical. More conservative options include arch supports for minor symptoms, a short-leg walking cast for immobilization in neutral or a slight varus position with decreased activity, and/or anti-inflammatory medications. Surgical treatments are typically reserved for recalcitrant cases, and surgical options include resection of an abnormal osseous bar with arthrodesis or primary arthrodesis [17].

The first purpose of this article is to review the anatomy of the hindfoot. Second, this article will review the radiographic, CT, and MR imaging features of tarsal coalitions. The third purpose of this article is to review the types of tarsal coalitions, giving specific explanations and detailed imaging findings for each type.

Search Strategy and Criteria

Online searches were performed using Google Scholar with the search criteria of “tarsal coalition,” “hindfoot anatomy,” and “subtalar coalition.” The search criteria of “tarsal coalition” identified 3,870 results, “hindfoot anatomy” identified 18,400 results, and “subtalar coalition” identified 2,020 results. Priority was initially given to articles written in the past 10 years, which decreased the search results to 2,100, 10,700, and 1,160, respectively. Priority was then given to

Fig. 2. Normal anatomy of the foot. Schematic of the hindfoot and midfoot from a superior view demonstrating the normal bones and ligaments.

articles written in Radiology-based journals, using search inclusion criteria of “Radiology,” “Radiographics,” and “American Journal of Roentgenology,” which yielded 84,

Fig. 1. Search strategy and criteria.

Fig. 3. Normal anatomy of the foot. Schematic of the calcaneus from a superior view demonstrating the relationship of the three subtalar joints.

179, and 43 results (Fig. 1). Articles were then reviewed to determine if the content was applicable. Additional articles were incorporated into the manuscript as specific topics needed to be addressed.

Anatomy

The hindfoot is composed of several joints with complex motions. The talonavicular joint occurs between the convex talar head and the concave proximal aspect of the navicular (Fig. 2). The talocalcaneonavicular joint is a single joint cavity that permits communication of the talonavicular facet as well as the middle and anterior subtalar facets. The calcaneocuboid joint occurs between the anterior process of the calcaneus and the cuboid, which are joined by the bifurcate ligament (Fig. 2). This joint acts in concert with the talonavicular joint, the Chopart joint, as the articulation between the hindfoot and the midfoot. Finally, the talocalcaneal joint (subtalar joint) is comprised of three facets and two joint capsules (Fig. 3). The talocalcaneal joint's complexity warrants further discussion.

Table 1 Ligamentous support of the posterior subtalar joint

Intracapsular ligaments	Extracapsular ligaments
Posterior talocalcaneal ligament	Calcaneofibular ligament
Lateral talocalcaneal ligament	Superficial deltoid ligament
Anterior capsular ligament	Interosseous talocalcaneal and cervical ligaments
	Variably present: medial talocalcaneal ligament

The posterior subtalar joint is stabilized by a variety of intracapsular and extracapsular ligaments

Table 2 MR signal characteristics of the various subtypes of tarsal coalitions. While these findings are characteristic for the subtypes of tarsal coalitions, in some instances the imaging appearance can be difficult to categorize

Type of coalition	T1-weighted characteristics	T2-weighted fat-suppressed characteristics	Other findings
Osseous	Hyperintense	Hypointense	Signal intensity follows marrow signal on all pulse sequences
Cartilagenous	Intermediate	Intermediate to Hyperintense	Commonly see irregular joint space narrowing and/or bone marrow edema in the region of the coalition
Fibrous	Hypointense	Hypointense	Commonly see irregular joint space narrowing and/or bone marrow edema in the region of the coalition

Posterior Talocalcaneal Joint

The posterior talocalcaneal joint is the articulation between the posteroinferior aspect of the talar body and the posterosuperior aspect of the calcaneus. It is located immediately posterior to the sinus tarsi. The joint has both intracapsular and extracapsular ligamentous structures that provide support to the joint (Table 1). Relative to the sole of the foot, the facets are angled down anteriorly 25–40° in the sagittal plane in 90% of patients [21]. It is important to note that the joint has a very complex geometry, and the angle of the joint surface can change dramatically depending on which sagittal or coronal imaging plane is being considered.

There are many known anatomic variants of the posterior talocalcaneal joint. One example is medial extension of the articular surfaces to involve the sustentaculum and the anteroinferior margin of the posteromedial process of the talus [13] (Figs. 15 and 16). Another example is extension of the articular facets to involve the base of the anterior process of the calcaneus as well as the anterior margin of the lateral process of the talus and talar body [13]. The medial talocalcaneal ligament is a normal structure that connects the medial tubercle of the posterior aspect of the talus with the posterior aspect of

Table 3 Utility of various signs for diagnosing subtalar coalition

Sign	Sensitivity (%)	Specificity (%)
Talar beak	48	91
C sign	88	87
Drunken waiter sign/dysmorphic sustentaculum tali sign	82	70
Absent middle facet sign	100	42

Fig. 4. Forty-two-year-old man with chronic ankle pain. Lateral radiograph of the foot demonstrates the “C sign” (arrows), talar beak (asterisk), and failure to visualize a normal subtalar joint. The findings are consistent with middle subtalar joint osseous coalition.

the sustentaculum tali; it is important to realize that this is a normal structure and not confuse it for an extra-articular non-osseous coalition [20]. It is important to be aware of these variants so as not to confuse them with pathology.

Middle Talocalcaneal Joint

The middle talocalcaneal joint is formed by the articulation of the sustentacular articular facet of the calcaneus and the middle talar articular facet of the talus. This joint communicates with the talonavicular joint. Occasionally, the middle and anterior calcaneal and talar articular facets may be contiguous [13]. Similar to the posterior talocalcaneal joint, the facets of the middle talocalcaneal joint are normally angled down anteriorly 25–40° in 90% of cases [21]. Similar to the posterior talocalcaneal joint, the middle talocalcaneal joint has a very complex geometry, and the angle of the joint surface can change dramatically depending on which sagittal or coronal imaging plane is being considered.

The posterior capsule of the middle talocalcaneal joint has a variable thickness. Importantly, there is an anatomic variant of relative thickening of the posterior capsule of the

Fig. 6. Fifty-two-year-old man with chronic ankle pain and decreased range of ankle motion. Coronal reconstructed image through the level of the middle subtalar joint demonstrates joint space narrowing, sclerosis, bone proliferation, and irregularity of subchondral bone plate (arrow). The findings are consistent with a non-osseous middle subtalar joint coalition.

middle talocalcaneal joint, which may be confused with a fibrous coalition; however, the astute imager will avoid misinterpretation by knowing this normal variant [6, 15].

Anterior Talocalcaneal Joint

The anterior talocalcaneal joint is variably present. When present, it is the smallest of the three talocalcaneal joints. It is located anterior and lateral to the middle talocalcaneal joint (Fig. 3). The lateral aspect of the talar head articulates with the facet along the superomedial aspect of the anterior process of the calcaneus.

Fig. 5. Thirty-seven-year-old man with chronic ankle pain. **a** Lateral radiograph of the ankle demonstrates the “C sign” (arrows) and failure to visualize middle facet, known as the absent middle facet sign. The findings are consistent with middle subtalar joint osseous coalition. **b** Normal lateral radiograph of the contralateral ankle demonstrates absence of the “C sign” and a normal appearing middle subtalar joint (arrowheads). It is important to remember that visualization of the middle subtalar joint depends on true lateral technique. If the lateral view is technically limited, the middle subtalar joint may not be visualized due to technical error. In particular, positioning of the foot in abduction or inversion may obscure the middle facet joint space due to the overlap of the lateral process of the talus and/or the sustentaculum tali.

Fig. 7. Sixty-four-year-old woman with chronic hindfoot pain. Sagittal (a) and coronal (b) CT reconstructed images through the middle subtalar joint demonstrate bony coalition (*asterisk*). The findings are in keeping with an osseous middle subtalar joint coalition.

Imaging Findings of Tarsal Coalition

Radiographic imaging of tarsal coalition is generally the first imaging test performed, as it is readily available and relatively inexpensive. There are several direct and indirect findings that may be seen in the setting of tarsal coalition. The CT and MR imaging features of tarsal coalition are remarkably similar. Knowledge of the normal hindfoot and midfoot anatomy will allow the radiologist to identify where the abnormality is located, and remembering a few simple facts about the imaging appearances will allow the radiologist to reliably recognize the different types of tarsal coalitions, wherever they may occur.

Radiographs

Radiographic findings in the setting of tarsal coalition may be broken into direct and indirect findings. Direct findings demonstrate an osseous continuity between two tarsal bones

in the setting of osseous coalition. Indirect findings are more subtle. In the case of non-osseous coalitions, the two involved bones can demonstrate abnormal narrowing and irregularity of the involved joint space, which may radiographically appear to be degenerative changes. The patient's age may also clue in the interpreter, as oftentimes these degenerative changes will be present in a relatively young patient where you would not expect to see any degenerative disease.

Additionally, numerous signs have been described that are indicative of tarsal coalitions, including the talar beak sign, C sign, drunken waiter sign, absent middle facet sign, and anteater sign, among others. These will be discussed in further detail later.

CT Imaging

Depending on the type of coalition that is present, different CT findings will be present. Osseous coalitions are mostly straightforward and will demonstrate abnormal osseous continuity of

Fig. 8. Thirty-two-year-old female with vague ankle discomfort. Sagittal (a) and coronal (b) T1-weighted images through the level of the middle subtalar joint demonstrate an osseous coalition as evidenced by continuity of bone marrow signal across the expected region of the middle subtalar joint space (*arrows*).

the two bones. Non-osseous coalitions are generally more subtle and manifest as abnormal narrowing of the joint space with minimal marginal reactive osseous changes. Oftentimes, non-osseous coalitions have an imaging appearance similar to osteoarthritis, with joint space narrowing, eburnation, and subchondral cystic changes in one of the tarsal joints in an otherwise normal, non-arthritic appearing foot. As previously mentioned, the patient's age may also clue in the interpreter.

MR Imaging

MR imaging demonstrates various abnormalities that vary depending on whether the coalition is osseous, cartilaginous,

or fibrous. In osseous coalitions, bone marrow signal will continue across the fused articulation, seen as high signal intensity on T1-weighted images and low-signal intensity on T2-weighted fat-suppressed images, similar to normal bone marrow (Table 2). Non-osseous coalitions demonstrate narrowing of the affected joint space, and irregularity of the bone interface is a common feature of cartilaginous and fibrous coalitions. Commonly, there may be bone marrow edema in the region of the coalition [23]. In addition, cartilaginous coalitions will generally demonstrate signal intensity similar to fluid or cartilage, which will manifest as intermediate T1 signal and intermediate-to-hyperintense T2 signal (Table 2). In contradistinction,

Fig. 9. Fifty-nine-year-old man with ankle swelling and pain. **a** Sagittal T1-weighted image through the middle subtalar joint demonstrates narrowing of the joint with an irregular cortical edge/subchondral bone plate (*arrow*). Also note the talar beak (*asterisk*). Coronal T1-weighted (**b**) and T2-weighted fat-suppressed (**c**) images through the middle subtalar joint show the bony proliferation of the sustentaculum tali (*arrowhead*), the abnormal narrowing and oblique orientation of the joint (*curved arrow*), and associated bone marrow edema. There is intermediate signal at the level of non-osseous coalition, denoting a cartilaginous coalition of the middle subtalar joint.

fibrous coalitions will demonstrate low-signal intensity on all pulse sequences across the affected joint (Table 2). While the findings of cartilaginous versus fibrous coalitions can at times be straight forward, many times the imaging characteristics are difficult to definitively categorize; in these instances, we prefer to state that there is a non-osseous tarsal coalition with findings that preclude definitive characterization.

Types of Tarsal Coalition

Approximately 90% of all tarsal coalitions involve the calcaneus and navicular bones or the talocalcaneal joint, with roughly half of those cases occurring in each location [27]. The location and morphology of talocalcaneal coalitions are variable and may be classified as intra- or extra-articular [7].

Intra-articular Talocalcaneal (Subtalar) Coalitions

Intra-articular talocalcaneal coalitions most commonly involve the middle talocalcaneal joint and usually involve the entire joint [13]. Unusual locations for intra-articular coalitions include posterior talocalcaneal joint coalitions, which classically involve only the posteromedial aspect of the joint, and anterior talocalcaneal coalitions, which are extremely uncommon as an isolated anomaly, rather they typically coexist with a middle talocalcaneal coalition [1, 16].

There are multiple radiographic signs associated with talocalcaneal coalition, many of them representing changes secondary to the underlying coalition (Table 3). The talar beak sign may be seen in either calcaneonavicular or talocalcaneal coalition; however, it is more commonly seen with talocalcaneal coalitions (Fig. 4). The sign is present

Fig. 10. Twenty-one-year-old man with chronic heel pain. Sagittal T2-weighted fat-suppressed image through an abnormal middle subtalar joint (arrow) demonstrates narrowing of the joint space, irregularity of the bone edges, and thin bands of decreased signal intensity. The findings are in keeping with a fibrous middle subtalar joint coalition.

when there is an osseous excrescence that extends from the distal dorsal aspect of the talus superiorly and away from the talonavicular joint. The tarsal coalition decreases the normal motion of the hindfoot, and the talonavicular joint develops compensatory increased motion; consequently, the superior aspect of the articular facet of the talar head shows a focal bony prominence related to the formation of a traction osteophyte at the talar insertion of the dorsal talonavicular ligament. The sensitivity and specificity of the talar beak sign in detecting talocalcaneal coalition are 48% and 91%, respectively, thus making it a helpful sign if present, but the absence of the talar beak cannot be used as a helpful distinguisher [5]. It is important to note that there are several other osseous outgrowths that occur along the dorsal aspect of the talus that are not associated with tarsal coalition. From proximal to distal, dorsal osteophytes may form along the articular margin of the trochlea of the talus in the setting of tibiotalar osteoarthritis, the talar ridge located approximately 1 cm distal to the trochlea may become prominent with

Fig. 11. Thirty-six-year-old man with chronic posterior ankle pain. **a** Sagittal reformatted CT image demonstrates an area of osseous proliferation, approximation, and irregular borders at the subtalar coalition between the posteromedial process of the talus and the posterior surface of sustentaculum (arrow). The findings are consistent with a non-osseous extra-articular talocalcaneal coalition. Note the normal middle subtalar joint (arrowhead). **b** Axial CT image through the area of coalition on the medial aspect (arrow) shows the bony abnormality and proliferation that bulges into the tarsal tunnel region. Given its location, it may be a cause of tarsal tunnel syndrome. **c** Surface rendered three-dimensional image, viewing from medial to lateral, demonstrating the area of abnormal coalition (arrow) and the normal middle subtalar joint (arrowhead). **d** Surface rendered three-dimensional image, viewing from posterior to anterior, demonstrating the area of abnormal coalition (arrow).

Fig. 12. Thirty-nine-year-old man with chronic posterior ankle pain. **a** Coronal T1-weighted image through the ankle demonstrates intermediate signal intensity between the talus and sustentaculum tali (arrowhead) with associated irregularity of the bony margins. **b** Sagittal T2-weighted image with fat saturation demonstrates an extra-articular cartilaginous coalition between hypertrophied posteromedial process of talus and posterior surface of sustentaculum tali. Note the bony irregularity and the intermediate-to-slightly increased signal between bony surfaces denoting cartilaginous coalition (arrowhead). Small cystic changes are also present in the posteromedial process of talus.

enthesophytes in a variety of settings (such as in athletes or in patients with diffuse idiopathic skeletal hyperostosis), and dorsal osteophytosis may form along the articular margin of the talonavicular joint in the setting of osteoarthritis [22]. Of these three additional causes of dorsal osseous excrescences, the one that most closely resembles the talar beak is the osteophytes along the articular margin of the talonavicular joint; however, these can be distinguished from the talar beak of tarsal coalition by recognizing that the talar beak arises in the region of the talar ridge and extends distally towards the talonavicular joint, as opposed to arising at the articular margin of the talonavicular joint and are generally accompanied by osteophytes along the dorsal aspect of the navicular.

Fig. 13. Twenty-eight-year-old woman with palpable abnormality along the medial aspect of the ankle. Sagittal T1-weighted image through the medial aspect of subtalar joint (**a**) and coronal T1-weighted image posterior to subtalar joint (**b**) demonstrate low to isointense T1 signal along the posterior aspect of the middle subtalar joint between the posterior medial process of the talus and posterior aspect of sustentaculum tali (arrow). The findings are consistent with a fibrous extra-articular talocalcaneal coalition. Also note the normal middle subtalar joint more anteriorly (arrowhead).

Another radiographic sign of talocalcaneal coalition is the C sign. The C sign is best seen on lateral radiographs and is created by the bony continuity of the inferomedial border of the talus with the sustentaculum tali (Figs. 4 and 5) [5]. The sensitivity and specificity of the C sign are 88% and 87%, respectively; thus, the specificity and sensitivity are not high enough to definitively diagnose or exclude talocalcaneal coalition based on its presence or

Fig. 14. Forty-three-year-old woman with pain in the region of the distal Achilles tendon. Sagittal proton density-weighted image at the level of the middle subtalar facet demonstrates an accessory articular facet between the posterior margin of the sustentaculum and the posteromedial process of the talus (arrow). This facet is a normal variant and is usually continuous with the medial aspect of the posterior subtalar joint. In contradistinction to tarsal coalitions, note that there is no irregularity associated with the margin of the bones. The middle subtalar joint (asterisk) appears normal. The Achilles tendon demonstrated findings of paratendinitis (not shown).

Table 4 Utility of various signs for diagnosing calcaneonavicular coalition

Sign	Sensitivity (%)	Specificity (%)
Talar break	49	91
Bony bar sign	73	100
Anteater sign	72	91
Reverse anteater sign	18–50	100

absence [5]. Interestingly, the C sign is more indicative of a pes planus deformity than of tarsal coalition [2].

Another radiographic sign of talocalcaneal coalition is the dysmorphic sustentaculum tali, also known as the drunken waiter sign, as some have likened it to a waiter having trouble carrying his tray (Fig. 6) [17]. Normally, the sustentaculum tali appears rectangular on a lateral radiograph; however, when a subtalar coalition is present, the inferior border of the sustentaculum tali becomes enlarged and rounded, which causes the sustentaculum tali to have a convex undersurface as opposed to its normal flat contour [4]. The sensitivity and specificity of the dysmorphic sustentaculum tali are 82% and 70%, respectively. Thus, similar to the C sign, due to the relatively low sensitivity and specificity, it is not a useful sign to diagnose or exclude talocalcaneal coalition [5].

The absent middle facet sign is another radiographic sign associated with talocalcaneal coalition. The finding occurs on well-positioned lateral radiographs of the foot where either a complete osseous bar or the obliquity of the narrowed cleft between the bones in non-osseous coalition obscures the middle subtalar facet (Fig. 5) [14]. It must be stressed that the radiograph needs to be obtained with the patient positioned properly, as improper positioning can

either create a false sense of the sign being present or a false negative absence of the sign. The sensitivity has been reported as high as 100%, which makes absence of the sign a reliable way to exclude talocalcaneal coalition [5]. However, the specificity of the sign is only 42% making its presence rather nonspecific [5].

CT imaging is useful and generally straightforward in evaluating osseous talocalcaneal coalitions (Fig. 7). However, the CT imaging findings are generally subtle in cases of non-osseous coalition, as was discussed earlier (Fig. 6) [18].

As previously mentioned, MR imaging can do an excellent job demonstrating which particular type of coalition is present. Osseous subtalar coalitions demonstrate bone marrow signal continuing across the fused articulation (Fig. 8), cartilaginous subtalar coalitions generally demonstrate signal intensity similar to fluid or cartilage extending across the abnormal joint (Fig. 9), and fibrous subtalar coalitions demonstrate low-signal intensity on all pulse sequences across the affected joint space (Fig. 10). As previously described, non-osseous subtalar coalitions create abnormal mechanical stress across the affected joint with resultant bone marrow edema adjacent to the articulation (Fig. 9) [18]. Also, it is important to evaluate the sinus tarsi on the MR images because edematous changes may be present in the sinus tarsi when there is a talocalcaneal non-osseous coalition. Sinus tarsi syndrome, which may be caused by hemorrhage or inflammation of the synovial recess of the sinus tarsi, classically presents with pain along the lateral aspect of the hindfoot and hindfoot instability [19].

Extra-articular Talocalcaneal (Subtalar) Coalition

Extra-articular talocalcaneal coalitions most commonly involve the interval between the posterior margin of the

Fig. 15. Twenty-six-year-old man with chronic ankle pain. **a** Oblique radiograph of the right hindfoot demonstrates narrowing of the calcaneonavicular space (*circle*). The findings are consistent with a non-osseous calcaneonavicular coalition. **b** Comparison view of the contralateral foot demonstrates the normal wide space between calcaneus and navicular bones (*dashed circle*).

Fig. 16. Thirty-seven-year-old woman with chronic ankle pain. Lateral radiograph of the ankle demonstrates elongation of the anterior process of the calcaneus (*dashed line*) with associated blunting of the tip of the anterior process of the calcaneus (*asterisk*), known as the anteater sign. The finding is consistent with an osseous calcaneonavicular coalition.

sustentaculum and the posteromedial process of the talus, just posterior to the middle talocalcaneal joint [13]. The facets of the middle talocalcaneal joint remain intact with no evidence of coalition or bony irregularity.

Fig. 17. Fifty-one-year-old man with chronic midfoot pain. Internal oblique radiograph of the foot demonstrates prominence of the posterolateral aspect of the navicular bone (*asterisk*). Prominence of the posterolateral aspect of the navicular is known as the reverse anteater sign. Also note that on this oblique view the calcaneus and navicular surfaces are approximated with space narrowing and irregularity of the bone margins. The findings are consistent with a non-osseous calcaneonavicular coalition.

Abnormalities may be detected on radiographs, often with bone proliferation and irregularity of the bony margins at the level of coalition. CT and MR imaging findings have been discussed earlier and will be specifically located in the extra-articular region (Figs. 11, 12, and 13). Additionally, it is important to evaluate the tarsal tunnel in cases of cartilaginous extra-articular talocalcaneal coalition, as there is often associated osseous protrusion into the tarsal tunnel or coalition-associated ganglions that may decompress into the tarsal tunnel, possibly causing tarsal tunnel syndrome [16]. Tarsal tunnel syndrome classically presents with an insidious onset of paresthesia and pain along the plantar aspect of the foot with presence of the Tinel sign due to entrapment of the posterior tibial nerve [19].

Anatomic Variants of the Hindfoot: a Potential Pitfall

It is important to remember that there are several anatomic variants that may be confused with extra-articular subtalar coalitions. Congenital thickening of a normal ligament involving the medial talocalcaneal ligament, the posterior capsule of the middle subtalar joint, and the anterior capsule of the posterior subtalar joint have been well described as normal variants that may resemble fibrous coalition; however, the lack of osseous deformities and irregularity as well as the lack of bone marrow edema should make it clear that the abnormality is an anatomic variant rather than a form of coalition [15]. Additionally, a normal accessory articular facet may occur between the posterior surface of the sustentaculum tali and the posteromedial process of the talus (Fig. 14) [15].

Calcaneonavicular Coalition

The calcaneus and the navicular do not normally articulate. Calcaneonavicular coalitions are difficult to visualize on radiographs due to the complex orientation of the joint; however, the best view to see the coalition is an internal oblique view as this lays the calcaneonavicular interface out for inspection and therefore best displays various signs of a calcaneonavicular coalition (Table 4).

With osseous coalitions, a bony bar will be present. The specificity of the bony bar on radiographs is 100%, thus making it a very useful sign if present [5]. However, the sensitivity of the bony bar is only 73%, making the absence of the sign unhelpful in deciding whether a calcaneonavicular coalition is present on radiographs [5].

In cartilaginous and fibrous calcaneonavicular coalitions, the bones will be in abnormally close proximity with enlargement/hypertrophy and irregularity of the bony surfaces of the coalition (Fig. 15). There are many signs associated with calcaneonavicular coalition, many of them representing changes secondary to the underlying coalition. As was mentioned earlier, the talar beak sign may be seen in calcaneonavicular coalition; however, the talar beak is more commonly seen with talocalcaneal coalitions. The sensitivity and specificity of the talar beak sign in diagnosing calcaneonavicular coalitions are 49%

Fig. 18. Forty-five-year-old woman with chronic ankle pain. **a** Axial T2-weighted image with fat suppression demonstrates bone marrow edema in the proximal aspect of the navicular (*arrowhead*). Increased signal between navicular and calcaneus surfaces denotes a cartilaginous calcaneonavicular coalition. In contradistinction, note that decreased signal intensity on fluid sensitive sequences would be consistent with a fibrous coalition. **b** Axial T1-weighted image demonstrates approximation of the joint surfaces and irregularity of the bone margins. There is hypertrophy of the proximal portion of the lateral aspect of the navicular bone (*arrow*), which correlates with the radiographic reverse anteater sign. **c** Sagittal T1-weighted image demonstrates a prominent anterior process of calcaneus (*circle*), the MR equivalent to the radiographic anteater sign.

and 91%, respectively, thus making its presence useful, although not diagnostic [5]. Absence of the sign does not exclude calcaneonavicular coalition.

The anteater sign is highly suggestive of calcaneonavicular coalition, with a specificity of 94% [5]. It is best seen on oblique images of the foot [24]. The normal triangular morphology of the anterior process of the calcaneus becomes elongated and squared distally, resembling the snout of an anteater (Fig. 16). The anteater sign may be seen on lateral radiographs of the foot as well, but it can be more difficult to appreciate due to superimposition of multiple osseous structures. The sensitivity of the sign is only 72%, thus making the absence of the sign unhelpful in excluding calcaneonavicular coalition [5].

A related radiographic sign is known as the reverse anteater sign, which is best seen on AP or oblique views of the foot. The sign is due to the navicular bone extending further laterally and posteriorly than normal, causing it to abnormally approximate the anterior process of the calcaneus

(Fig. 17). Sensitivity of this sign ranges from 18% to 50%, and specificity has been reported to be 100%, thus making it a very helpful sign if present [4, 5].

CT and MR imaging findings of tarsal coalitions have been discussed previously and will appear in the region of the calcaneonavicular joint (Figs. 18 and 19).

Other Tarsal Coalitions

Rarely, a tarsal coalition may involve the talonavicular, calcaneocuboid, or naviculocuneiform joints [3]. Extensive fusions of the hindfoot are very rare. They are commonly associated with congenital syndromes, such as fibular hemimelia or Alpert syndrome [4].

There are case reports of naviculocuboid coalition, which demonstrate similar radiographic and cross-sectional imaging features to the other types of tarsal coalitions [28]. The radiograph will demonstrate a bony bar in the case of osseous coalitions or joint space narrowing and

Fig. 19. Seventeen-year-old boy with chronic ankle pain and decreased range of motion of the ankle. Sagittal T1-weighted (**a**) and T2-weighted with fat suppression (**b**) images demonstrate a low-signal intensity band between calcaneus and navicular (*arrows*) with irregular bone edges and slight adjacent edema, consistent with a fibrous calcaneonavicular coalition.

Fig. 20. Forty-year-old man with chronic midfoot pain. Oblique radiograph of the foot demonstrates joint space narrowing and irregularity of the bony margins between the navicular and cuboid (*circle*), consistent with a non-osseous naviculocuboid coalition.

irregularity of the bony margins in non-osseous coalitions (Fig. 20). CT imaging will demonstrate continuity of the two bones in osseous coalition. Non-osseous coalitions will manifest as narrowing of the joint space with minimal marginal reactive osseous changes. MR imaging of naviculocuboid coalitions demonstrates similar features of other tarsal coalitions, with osseous coalitions demonstrating bone marrow signal contiguity across the fused articulation, cartilaginous coalitions demonstrating intermediate T1 signal and intermediate-to-hyperintense T2 signal across the joint space, and fibrous coalitions demonstrating

low-signal intensity across the joint space on all pulse sequences (Figs. 21 and 22).

Attention to the margins of the involved bones is important as normal variant may mimic coalition, such as physiologic thickening of the naviculocuboid ligament (Fig. 23). Lack of osseous deformities and lack of bone marrow edema should make it clear that the abnormality is an anatomic variant.

Discussion

Tarsal coalitions are a not uncommon condition that may cause significant morbidity. While the diagnosis may sometimes be readily evident on clinical examination and/or imaging studies, unfortunately, the clinical examination and imaging findings can be difficult in many cases. The purposes of this paper were to (1) review the anatomy of the hindfoot; (2) review the radiographic, CT, and MR imaging findings of tarsal coalitions; and (3) review the imaging appearance of the specific subtypes of tarsal coalitions.

As reviewed, the anatomy of the hindfoot is complex but important to understand. Given its complexity, the joints of the foot, particularly the hindfoot, warrant careful attention.

The general CT and MR imaging appearances of tarsal coalitions were reviewed. As was reviewed, regardless of location, the fibrous, cartilaginous, and osseous subtypes of coalitions have general imaging features that can readily be applied to different joints of the foot. CT or MR imaging can be useful to both delineate the extent of the coalition as well as depicting associated abnormalities.

Fig. 21. Forty-four-year-old man with vague ankle pain. Axial (a) and sagittal (b) T1-weighted images demonstrate a low-signal intensity band between the navicular and cuboid bones (*asterisks*), consistent with a fibrous naviculocuboid coalition. Also note the irregularity of the bone margins in the region of the coalition (*arrows*). c Axial T1-weighted image of a normal naviculocuboid joint in another patient. Note the normal articular cartilage and subchondral plate (*circle*).

Fig. 22. Fifty-year-old woman with chronic medial ankle pain. **a** Coronal proton density-weighted image demonstrates a low-signal band between the navicular and cuboid bones (*arrow*) with associated irregularity of the bone margins. Sagittal (**b**) and axial (**c**) T2-weighted images at the level of the naviculocuboid joint demonstrates joint space narrowing, irregular bony margins, and a low-signal band spanning the joint space (*arrowheads*). The findings are consistent with a fibrous naviculocuboid coalition. Also note the adjacent bone marrow edema (*asterisks*).

Finally, the particular types of coalitions were reviewed. The awareness of multiple possible sites of tarsal coalition, including the common calcaneonavicular and middle subtalar joint coalitions as well as the less common extra-articular subtalar coalitions, is important to keep in mind.

In summary, knowledge of the normal anatomy of the foot, in particular the hindfoot, combined with the knowledge of the imaging characteristics of different histologic subtypes of coalitions (osseous, cartilaginous, and fibrous) is essential for interpreting radiographic, CT, and MR images of the ankle and foot.

Fig. 23. Thirty-one-year-old man with posterior heel pain. Sagittal (**a**) and axial (**b**) proton density-weighted images demonstrate thickening of the naviculocuboid ligament (*asterisks*), a normal variant. Note that there are no osseous changes or irregularity at joint interface. The patient had retrocalcaneal bursitis (not shown).

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