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A Three-Dimensional Study of Calcaneonavicular Tarsal Coalitions

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Summary: The authors studied 37 presumed calcaneonavicular tarsal coalitions from the Hamann-Todd Osteological Collection at the Cleveland Museum of Natural History. The anatomy of the coalitions and the associated subtalar and transverse tarsal joints was quite variable. The coalitions in 8 specimens completely spared the anterior facet of the calcaneus and in 7 specimens it was partially replaced by the navicular portion of the coalition, whereas in 22 specimens the anterior calcaneal facet was completely replaced by the navicular portion of the coalition. The authors suggest that the pathoanatomy of calcaneonavicular coalitions is not uniform and may involve the subtalar and transverse tarsal joints. This may have clinical relevance and contribute to the unsatisfactory results in feet undergoing coalition resection and soft tissue interposition.
Key Words: Calcaneonavicular coalition—Hamann-Todd Osteologic Collection—Tarsal coalitions.

Painful rigid pes planus and peroneal spastic flat feet are relatively uncommon in children. They are usually due to disorders that compromise one or more of the hindfoot or midfoot joints (talocalcaneal, talonavicular, and calcaneocuboid). The differential diagnosis includes idiopathic, trauma, infection, neoplasm, inflammatory disorders, and congenital malformations. Tarsal coalition is a congenital malformation and is probably the most common condition producing a painful flat foot. Kermisson (9) first showed tarsal coalitions radiographically in 1898, and Slomann (18) described the characteristics of the calcaneonavicular coalition in the oblique radiograph in 1921. With the advent of computed tomography, the morphology of the various coalitions, including the calcaneonavicular coalition, have been better defined (19). Crimm et al. (5) described the use of magnetic resonance imaging to identify fibrous and cartilaginous coalitions. Tarsal coalitions are thought to be the result of failure of segmentation of embryonic mesenchymal tissue (7). The true incidence is difficult to determine because of the presence of asymptomatic coalitions but has been reported to be approximately 1% to 2% (8). Calcaneonavicular and middle facet talocalcaneal coalitions are the most common tarsal coalitions (14).

Classification systems have been proposed for coalitions based on anatomic location (23) as well as the type of tissue making up the coalitions (fibrous, cartilaginous, and osseous) (17). Coalitions can be further classified as to whether they compromise joint cartilage or not. The calcaneonavicular coalition is thought to be a joint-sparing coalition.

The purpose of our study was to analyze the three-dimensional pathoanatomy of untreated calcaneonavicular coalitions and its relationship to the hindfoot and forefoot.

METHODS

The Hamann-Todd Osteological Collection is housed at the Cleveland Museum of Natural History. This vast collection comprises >3,000 human skeletons gathered between 1910 and 1940 from the greater Cleveland area by anatomists Carl A. Hamann and T. Wingate Todd (15). We analyzed 2,982 intact skeletons (5,964 feet) from the collection for possible calcaneonavicular tarsal coalition. We believed that a calcaneonavicular coalition had been present if there was a single bone composed of the calcaneus and navicular or the presence of roughened cancellous bone on the inferior surface of the navicular and the anterior process of the calcaneus *and* if these

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surfaces interdigitated when reapproximated. One hundred twenty-two feet were incomplete or had damaged bones and were excluded, leaving a total of 5,842 feet for analysis.

RESULTS

We found 26 skeletons with 37 presumed calcaneonavicular tarsal coalitions. Thus, the incidence of a calcaneonavicular coalition per individual was 1.2%. Fifteen skeletons had unilateral coalitions and 11 had bilateral involvement (42%). Twenty-two skeletons were males (84%) and four (16%) were female. Eighty-three percent of the skeletons in the collection are male. Fifteen skeletons with calcaneonavicular coalitions were black (58%) and 11 (42%) were white. In the collection, 61% of the skeletons are white. The involved individuals had a mean age at the time of death of 43.5 years (range 7–85). The status of the individuals' feet, such as pain and function, was unknown.

One coalition was fully coalesced; the remaining 37 feet had a presumed fibrous or cartilaginous coalition. The interdigitated junction between the calcaneus and navicular had a mean length of 22.5 mm (range 11.5–32). We have no data concerning the composition of the presumed coalitions.

On reapproximation of the calcaneus, talus, and navicular, we noted that the anterior facet of the calcaneus supported the head of the talus in a normal fashion in only eight feet. In seven feet, the anterior facet of the calcaneus was partially replaced by the navicular portion of the coalition. In these feet, the head of the talus articulated with the interdigitated junction of the calcaneus and navicular. In 22 feet, the anterior facet of the calcaneus was absent and the head at the talus was completely supported by the navicular in these specimens (Fig. 1).

When the plantar surface of the foot was inspected, there was an abnormal navicular facet articulating with the proximal portion of the cuboid. We found this in all 37 feet. In the 22 feet where the anterior facet of the calcaneus was absent, the navicular facet was quite large, providing considerable dorsal and medial support for the cuboid. Because of the absence of soft tissue and articular cartilage, it was not possible to assess accurately the

FIG. 1. A: Dorsal or superior view of the reassembled talus, calcaneus, and navicular of specimen 2,948 (left, calcaneonavicular coalition) and specimen 2,469 (right, normal foot). Observe the changes in the distal calcaneus on the left as well as the coalition. There is rounding at the calcaneus and contact between the calcaneus and navicular. **B:** The tali have been removed from these reassembled specimens. Observe the interdigitation at the site of the calcaneonavicular coalition on the left. On the right, there are normal posterior, middle, and anterior calcaneal facets. On the left, the anterior facet is absent, and there is an enlarged inferior process of the navicular. **C**: Lateral view of the specimens. Observe the calcaneonavicular coalition (top) and the normal foot (below). This is the "surgeon's eye view" of the coalition. **D:** Medial view of the specimens. Specimen 2,948 (top) shows the inferior process of the navicular extending beneath the head of the talus, as it substitutes for the absent anterior facet of the calcaneus. Specimen 2,469 (below) shows the normal relationship between the navicular and the heads of the talus and calcaneus. **E**: Plantar view of the specimen. On the coalition specimen 2,948 (left), the cuboid articulates with the enlarged inferior process of the navicular and its long cuboid facet and the hypoplastic calcaneal head. On specimen 2,469 (right, normal), there is no articulation between the cuboid and the inferior process of the navicular. **F**: The navicular bones have been removed. In specimen 2,948 (left), the anterior facet is absent, as is the dorsal and medial extension of the calcaneus, which forms the medial and dorsal portion of the calcaneocuboid joint. On specimen 2,469 (right), the normal anterior and dorsal extension of the calcaneus provides medial and dorsal support for the cuboid. Normally the anterior facet of the calcaneus rests on the dorsal portion of this extension.

alignment of the hindfoot or the presence of degenerative osteoarthritis.

DISCUSSION

The incidence of tarsal coalition has been estimated to be between 1% and 2% (8). We identified a 1.2% incidence of calcaneonavicular coalitions in our study. Our incidence of 42% having bilateral coalitions was also similar to previous studies, which reported an incidence of bilaterality of 40% to 68% (2,6,10,16,20,22). There was no gender predominance. Previous studies also support no gender predominance (1,11) or a slight male predominance (6,21). In our study, calcaneonavicular coalitions were more common in blacks. However, Rankin and Baker (16) showed no racial predilection for symptomatic tarsal coalitions in a group of 60,000 Army recruits.

We agree with others (6) who suggest that calcaneonavicular coalitions are due to failure of segmentation of embryonic mesenchymal tissue. This is clearly the case in our one complete osseous coalition, where the navicular and calcaneus were coalesced. The remaining specimens represent failure of complete segmentation.

In the 37 presumed calcaneonavicular coalitions, there were three different articulations with the anterior facet of the talus (Fig. 2). In eight mild coalitions (type 1), the anterior facet of the talus articulated with the anterior facet of the calcaneus in a normal fashion. These coalitions probably resulted from incomplete separation of normally formed bones. The etiology of this coalition appears to be similar to that of a complete osseous coalition, with the only difference being fibrous or cartilaginous separation. In seven moderate coalitions (type 2), the anterior facet of the talus articulated with the junction of the navicular and the calcaneus as the anterior facet of the calcaneus was partially replaced by the navicular portion of the coalition. In the 22 severe coalitions (type 3), the anterior facet of the talus articulated with the navicular rather than the anterior facet of the calcaneus. Thus, there was a more extensive malformation in the hindfoot and the midfoot. This seems more than a simple error in segmentation and may represent a more generalized tarsal malformation.

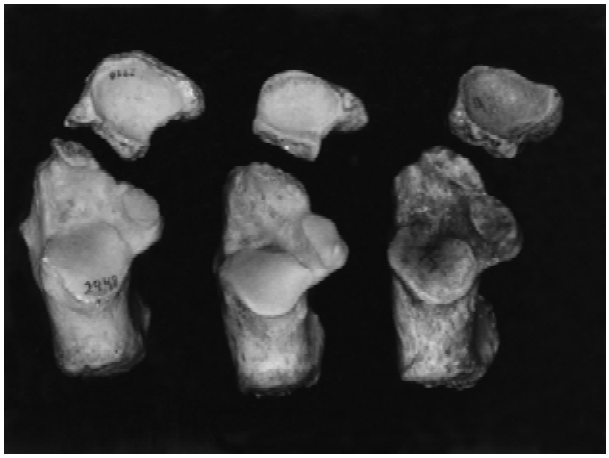

FIG. 2. Three calcaneonavicular coalitions with varying degrees of anterior and medial calcaneal deficiency. On the left (specimen 2,948), the anterior facet of the calcaneus as well as a significant portion of the dorsal and medial aspect of the cuboid facet is absent. In the middle specimen, a portion of the anterior facet is present. On the right, the entire anterior facet of the calcaneus is present and the cuboid facet is nearly normal.

These differences in the pathoanatomy were unexpected and may be clinically relevant if a surgeon decides to resect the coalition and perform some type of soft tissue interposition. In the one complete and eight mild coalitions, the removal of the coalition would not be expected to affect subtalar joint stability adversely because of the presence of a normal anterior talocalcaneal facet. In the moderate and severe coalitions, the excision could affect talocalcaneal and calcaneocuboid joint stability; this could have clinical consequences.

The current procedure of choice for symptomatic calcaneonavicular coalitions resistant to conservative management is excision and extensor digitorum brevis interposition (2,6,13,22). Follow-up studies ranging from 2 to 23 years after this procedure report excellent and good results in 77% to 90% of patients; 10% to 23% have fair and poor results (2,6,13,22). Preexisting talonavicular or subtalar joint arthritis, incomplete excision, and recurrence of the coalition are often cited as causes of unsatisfactory results (6,12,22).

Our specimens suggest that the navicular portion of the coalition provides considerable talar support in many involved feet. It is possible that resection in patients with anteromedial calcaneal insufficiency may create enough instability at the talonavicular joint to exacerbate mild preexisting degenerative changes or cause degeneration of a previously normal joint. The navicular portion of the coalition may also participate in cuboid support. Resection, therefore, could also lead to calcaneocuboid instability. Kitaoka et al. (at the annual Pediatric Orthopedic Society of North America [POSNA] meeting, Vancouver, British Columbia, May 2000) recently reported calcaneocuboid arthritis in 1 of 14 patients followed up 6 to 12 years after calcaneonavicular coalition resection and soft tissue interposition. Longer follow-up should determine whether calcaneocuboid arthritis is common after this procedure.

Our specimens showed variable coalition anatomy. If a surgeon assumes that the coalition is distal to the anterior talocalcaneal facet, resection may be incomplete, especially if it extends proximal to the point. This could lead to incomplete resection and recurrence. We suggest that all patients with calcaneonavicular coalition have radiographs of both feet, because 40% to 68% of patients have bilateral coalitions (2,6,10,16,20,22). All patients with calcaneonavicular coalitions identified radiographically should have computed tomography performed before surgery because talocalcaneal coalitions occasionally occur concomitantly and may adversely affect surgical outcomes (2–4,12,24,25). Tomography should be helpful in delineating the true extent of the coalition and whether the anterior talocalcaneal facet is involved with the coalition. Also, sagittal reconstruction can be

used to delineate the calcaneonavicular coalition in three dimensions, making surgical decisions easier.

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