TARSAL COALITION: CURRENT CLINICAL ASPECTS WITH INTRODUCTION OF A SURGICAL CLASSIFICATION

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INTRODUCTION

Tarsal coalition is a condition that exists when there is absent or restricted motion between two or more tarsal bones. Coalitions can produce a dramatic symptom complex which may ultimately be identified as rigid peroneal spastic flatfoot. Tarsal coalition and its associated symptom complex should be well understood both clinically and radiographically. Such understanding will enable the clinician to properly identify tarsal coalitions and to initiate appropriate treatment.

HISTORICAL REVIEW

Tarsal coalitions have been identified and recorded for several hundred years. Heiple and Lovejoy (1) reported a tarsal coalition in the foot of a pre-Columbian indian skeleton circa A.D. 1000. Coe and Broman (2) found an even older specimen located in the ruins of a Mayan temple. Historically, the first written description of tarsal coalition is attributed to Buffon (3) in 1769. Sir Robert Jones (4) gave the first detailed clinical description of peroneal spastic flatfoot in 1897, but did not associate it with tarsal coalition. The first radiographic demonstration of a tarsal coalition was by Kirmissin (5) in 1898, only three years after Roentgen's discovery of x-rays.

Many years intervened between the earliest anatomic descriptions and the discovery of x-rays, and many more before the identification of the relationship between tarsal coalition and peroneal spastic flatfoot. In this sense, the two most common tarsal coalitions: calcaneonavicular and talocalcaneal, were identified in similar fashion. First, they were identified anatomically, then radiographically, and more recently related to peroneal spastic flatfoot.

Calcaneonavicular coalition was first described anatomically by Cruveilhier (6) in 1829. Slomann (7), in 1921, reported five cases of calcaneonavicular bar and demonstrated the coalition on an oblique radiographic view of the foot. However, not until 1927 when Badgely (8) resected a calcaneonavicular coalition, was the deformity associated with peroneal spastic flatfoot.

Similarly, Zuckerkandl (9) first anatomically identified a talocalcaneal coalition in 1877. Korvin (10), in 1934, utilized an axial radiographic view of the calcaneus to demonstrate a talocalcaneal coalition. In 1948, Harris and Beath (11) popularized the *ski-jump* or axial view of the calcaneus and recognized talocalcaneal coalition as a cause of peroneal spastic flatfoot.

Other tarsal coalitions are less frequent, but have been reported. Talonavicular coalition was first reported by Anderson (12) in 1879. Calcaneocuboid coalition was first described by Holland (13) in 1918. Cubonavicular coalition was first reported by Waugh (14) in 1955. Lusby (15) first identified a naviculocuneiform coalition in 1959. Multiple and massive coalitions involving several tarsal bones have also been reported (16).

ETIOLOGY

Tarsal coalition is clearly the most common cause of peroneal spastic flatfoot. However, the cause of tarsal coalitions is not so clear. Many authors have attempted to attribute all tarsal coalitions to one etiology. It is now certain that there are many etiologies, and that tarsal coalitions can be either congenital or acquired.

Congenital tarsal coalition is more frequently identified and reported, although the mechanism of congenital coalition is not conclusively known. Pfitzner (17) suggested that congenital tarsal coalition is formed from the incorporation of accessory ossicles into the normal tarsal bones on either side. Although this has been shown to be one possible cause of coalition (18), Harris (19) has disproven it as the sole cause by demonstrating a tarsal coalition in a fetus.

Harris' finding supports Leboucq (20) who suggested that congenital coalition results from the failure of differentiation and segmentation of primitive mesenchyme. This theory would attribute congenital coalitions to a heritable defect or to an insult in the first trimester of pregnancy. Subsequently, numerous authors have reported hereditary patterns of coalitions (16, 21-27).

A large field study by Leonard (28) provided the most supportive evidence to Leboucq's theory. Leonard concluded that tarsal coalition was a unifactorial disorder with autosomal dominant inheritance. Thus, today, the most commonly accepted theory for the etiology of congenital coalition is a genetic mutation to an autosomal gene which results in the failure of differentiation and segmentation of primitive mesenchyme.

Acquired tarsal coalition can result from arthritis, infection, trauma, neoplasms, or other causes (29). Acquired coalition will be less common in pediatric and adolescent patients (30). The causes of acquired tarsal coalition can also lead to varying degrees of joint limitation without complete coalition (31). When all age groups are considered, this is a frequent cause of peroneal spastic flatfoot.

INCIDENCE

The incidence of tarsal coalition in the general population is unknown. Vaughan and Segal (32), studying army personnel, found the incidence to be approximately 1% (i.e., 21 cases of tarsal coalition in 2,000 patients). This is the highest reported incidence to date. The actual incidence may be higher or lower.

It should be remembered that the incidence of tarsal coalition is not the same as the incidence of peroneal spastic flatfoot. Peroneal spastic flatfoot is usually a sequela of the tarsal coalition. A tarsal coalition may be present without symptomatology and/or without peroneal spastic flatfoot. Rarely, peroneal spastic flatfoot may be present without tarsal coalition.

Tarsal coalition has been reported to have no race preference. Further, roughly 50% of the cases have been reported as being bilateral (33), although Leonard (28) reported as high as 80% bilateral involvement.

Several authors have suggested a greater incidence of tarsal coalition in males. Beckly et al (34) noted a male:female ratio of 12:5, and Conway and Cowell (35) noted a ratio of 4:1. It has been theorized that this unequal sex predilection may be due to the studies having been performed on army personnel (36). Indeed, if these studies are correct in their suggested predilection, the theory of mutation of an autosomal dominant gene must be reconsidered. Leonard reported a more equal sex incidence in his large study (28). Thus, the actual sex predilection remains unclear.

Talocalcaneal coalition and calcaneonavicular coalition are by far the most common anatomic types. These two tarsal coalitions account for approximately 90% of all tarsal coalitions (37). Controversy does exist as to which of these two coalitions is most prevalent. Leonard (28) reported an extremely skewed study with 27 out of 31 patients having calcaneonavicular coalitions. Other studies have demonstrated a more even division or findings favoring a higher incidence of talocalcaneal coalition. In 68 patients, Jack (38) reported 27 talocalcaneal coalitions and 23 calcaneonavicular coalitions. In Rankin and Baker's (33) series there were 9 talocalcaneal coalitions and 5 calcaneonavicular coalitions. Thus, it is the current consensus of opinion that talocalcaneal coalition is the most common.

Talonavicular coalition appears to be the third most common type of tarsal coalition. This type is rare with less than forty cases reported in the literature. Calcaneocuboid, cubonavicular, naviculocuneiform, combination tarsal coalitions and massive coalitions occur with even less frequency (36,39).

CLASSIFICATION

Tarsal coalitions may be classified in several ways: (1) etiologic type; (2) anatomic type; (3) tissue type; and (4) according to articular involvement. The author proposes the latter classification (i.e., according to articular involvement) as a surgically-based classification which is the only system above that might relate any tarsal coalition to the likelihood of surgical success.

Tarsal coalitions can be classified according to their etiology—either congenital or acquired (37). This classification is not generally helpful in ascertaining the best possible treatment plan.

Further, tarsal coalitions may be classified according to their anatomic constituents. Tachdjian (40) has provided a classification subdividing coalitions into the bones that are abnormally united, or infrequently, as part of a complex malformation (Fig. 1). Although only descriptive in nature, Tachdjian's classification suggests the importance of assessing other areas of the foot and the remainder of the body when an apparently local or isolated coalition is identified.

Another common manner of grouping tarsal coalitions is to classify them according to the tissue type of their union. In this way, a coalition may be a synostosis (osseous union), synchondrosis (cartilaginous union), syndesmosis (fibrous union), or a combination of the above. A synostosis may evolve from a synchondrosis or syndesmosis. This has been theorized to occur with age or possibly after trauma to the coalition (30). A synostosis is also referred to as a complete coalition since all motion is necessarily absent. An incomplete coalition has varying amounts of interposed cartilaginous or fibrous tissue and may allow motion between the bones involved. The tissue type of the coalition is important and should be noted when attempting to diagnose a coalition.

Isolated Anomaly
- Dual between two tarsal bones
  - Talocalcaneal
    - Middle
      - Complete
      - Incomplete
      - Rudimentary
    - Posterior
    - Anterior
  - Calcaneonavicular
  - Talonavicular
  - Calcaneocuboid
  - Naviculocuneiform
- Multiple - combinations of the above
- Massive - all tarsal bones fused together

Part of Complex Malformation
- In association with other synostoses
  - Carpal coalition
  - Symphalangism
- As one of manifestations of a syndrome
  - Nievergelt-Pearlman
  - Apert's
- In association with major limb anomalies
  - Absence of toes or rays
  - "Ball-and-socket" ankle joint
  - Fibular hemimelia
  - Phocomelia
  - Proximal focal femoral deficiency

Fig. 1. Tachdjian's classification of tarsal coalitions. (Revised from Tachdjian MO: *The Child's Foot*, pp 262, WB Saunders, Philadelphia, 1985).

It is the author's impression that the aforementioned classification systems are primarily descriptive in nature. By combining these classifications, a useful description of a tarsal coalition can be made. For example, a tarsal coalition may be described as a congenital synchondrosis of the middle facet of the talocalcaneal joint. Given this information, one can more accurately understand the tarsal coalition present. However, these classification systems, even when combined, provide only a small amount of information related to the development of a surgical treatment plan.

For this reason, a new classification system based upon the articular relationship of the bones involved in the coalition and the indirect effect of the coalition on surrounding joints is proposed (Fig. 2). This articular classification system, when combined with the descriptive parameters already discussed may serve as a basis for communication about possible surgical treatment. The classification assumes that the most important criteria for determining treatment are the age of the patient, the type of coalition, and the degree of secondary arthritic changes.

The classification begins with a division into juvenile (osseous immaturity) and adult (osseous maturity). It is then further subdivided into the types of coalition - whether extra-articular or intra-articular. Extra-articular coalitions are those that occur outside a normal joint. These coalitions have been frequently called bars, and the calcaneonavicular coalition is the most common example. Intra-articular coalitions occur at normal joint sites and have been referred to as bridges. A talocalcaneal coalition of the middle facet of the subtalar joint is the most common example of an intra-articular coalition (Fig. 3). Finally, the classification is further subdivided into the presence or absence of significant secondary arthritis or changes within surrounding joints.

As an example, a middle facet talocalcaneal coalition occurring in an adult with secondary arthritic changes at the talonavicular and/or calcaneocuboid joints would be an *Adult-IIB* coalition (Fig. 4). A calcaneonavicular coalition occurring in a child with no secondary arthritic changes would be a *Juvenile-IA* coalition (Fig. 5). In this manner, treatment plans may be related to the classification system as will be discussed later.

Juvenile (Osseous Immaturity)
- Type I - Extra-articular coalition
  - A - No secondary arthritis
  - B - Secondary arthritis
- Type II - Intra-articular coalition
  - A - No secondary arthritis
  - B - Secondary arthritis

Adult (Osseous Maturity)
- Type I - Extra-articular coalition
  - A - No secondary arthritis
  - B - Secondary arthritis
- Type II - Intra-articular coalition
  - A - No secondary arthritis
  - B - Secondary arthritis

Fig. 2. Articular Classification System. Classification of tarsal coalitions based upon articular involvement. Note that classification can be used as basis for discussion of surgical treatment.

Extra-articular Coalitions
  Calcaneonavicular
  Cubonavicular

Intra-articular Coalitions
  Talocalcaneal
    Middle
    Posterior
    Anterior
    Combination
  Talonavicular
  Calcaneocuboid
  Naviculocuneiform

Fig. 3. Division of tarsal coalitions into extra-articular and intra-articular coalitions. Multiple and massive coalitions are usually intra-articular coalitions and most frequently are associated with degenerative changes.

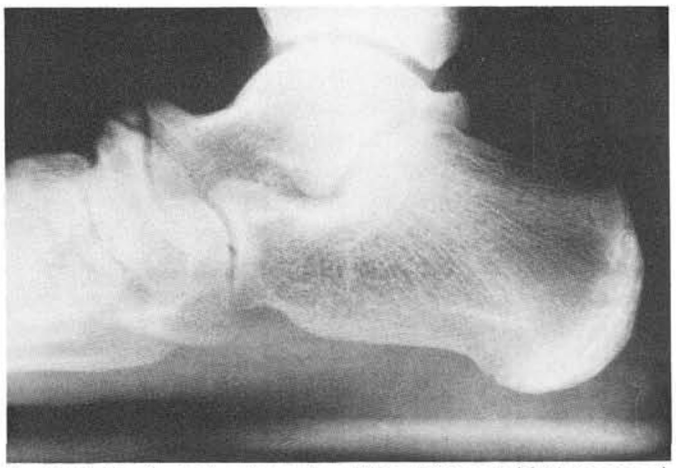


Fig. 4. Middle facet talocalcaneal coalition in 34 year old. Note secondary degenerative changes at talonavicular joint. This would be "Adult-IIB" coalition in articular classification system.

Fig. 5. Calcaneonavicular bar in 11 year old. No secondary arthritic changes are noted. This would be a "Juvenile-IA" coalition in articular classification system.

CLINICAL FINDINGS

Tarsal coalition may be completely asymptomatic and an incidental finding on routine radiographs. In studying 23 patients with tarsal coalition, Jack (38) found that 5 (22%) were asymptomatic. However, three clinical findings: pain, limitation of joint motion, and muscle spasm should make the clinician suspicious of a tarsal coalition.

Pain is a common finding in patients with tarsal coalitions. The pain is usually deep and aching in nature, and is frequently in the area of the tarsal coalition. The patient often can localize the pain to the sinus tarsi, anterolateral ankle, or dorsum of the midfoot. With a middle facet talocalcaneal coalition, the patient may indicate that the pain encompasses the entire rearfoot—localizing the pain to the sustentaculum tali medially and the sinus tarsi laterally (Fig. 6). If significant secondary arthritic changes are present, the pain may be greatest in these latter areas (e.g., pain at the talonavicular joint secondary to arthritic changes from a talocalcaneal coalition). If the patient is unable to localize the pain, the clinician can, in most instances, localize it accurately with firm palpation.

The onset of the pain is usually insidious, developing after some unusual activity (e.g., excessive walking, hiking, or running) or innocuous trauma (e.g., minor ankle sprain). Further, it has been stated that all coalitions are initially cartilaginous in nature, and eventually ossify. Cowell (41) suggested that different coalitions ossify at different ages and that pain begins as this ossification process occurs. He stated that talonavicular coalition ossifies from ages 3 to 5, calcaneonavicular coalition ossifies from ages 8 to 12, and talocalcaneal coalition ossifies from ages 12 to 16 (41) (Fig. 7).

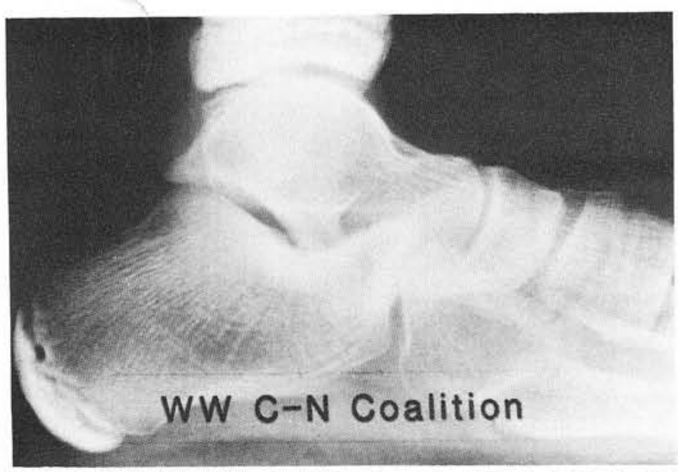


Fig. 6. Patient with middle facet talocalcaneal coalition, localizes pain to sinus tarsi area.

Talonavicular Coalition: 3-5 years

Calcaneonavicular Coalitions: 8-12 years

Talocalcaneal Coalition: 12-16 years

Fig. 7. Age when ossification begins in most common tarsal coalitions. Beginning of ossification may correlate with onset of symptomatology.

The pain associated with a tarsal coalition is usually aggravated by activity and relieved with rest. Upon questioning, the patient will frequently relate pain when walking over rough, uneven terrain, with prolonged standing, or with athletic activity.

Limitation of subtalar and midtarsal joint motion is common with tarsal coalition. Usually the subtalar joint is limited in the direction of inversion. This limitation becomes even more apparent if peroneal muscle spasm is present.

With tarsal coalition, tonic muscle spasm may occur. It should be clearly understood that this is a tonic muscle spasm and NOT clonic muscle spasticity. The peroneus brevis is usually the muscle most significantly involved. However, spasm of the tibialis posterior, tibialis anterior, and peroneus longus can occur (42,43).

It is theorized that as subtalar joint motion becomes painful the peroneus brevis attempts to guard or restrict this motion. This tonic spasm occurs much like abdominal muscle guarding in a patient with appendecitis. It is a subconscious attempt by the peroneus brevis to limit painful motion. This spasm is not neurologic in nature as in clonic spasticity, but simply an increase in tension of the peroneus brevis muscle-tendon unit (i.e., tonic spasm). The muscle spasm, like pain, is precipitated by activity and relieved by rest.

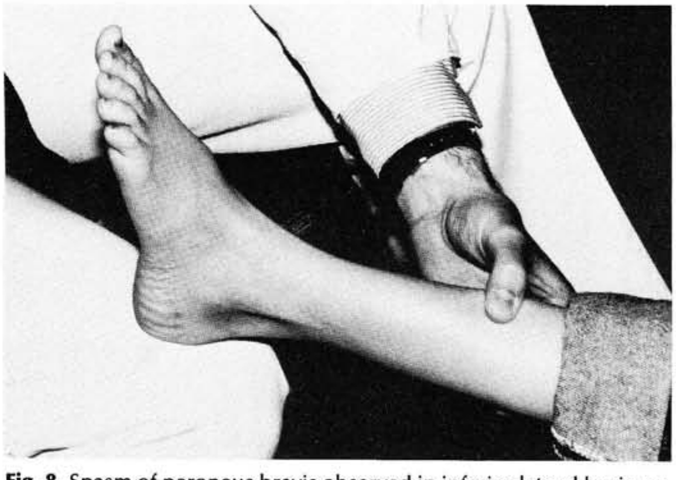


Fig. 8. Spasm of peroneus brevis observed in inferior-lateral leg in patient with peroneal spastic flatfoot secondary to tarsal coalition.

The peroneus brevis muscle spasm may be intermittent or continuous. As the symptoms progress, the muscle guarding or tonic spasm generally becomes more intense. As the peroneus brevis contracts, subtalar joint motion is further restricted and the taut tendon can be palpated and/or observed laterally (Fig. 8). The rearfoot will be maintained in a valgus position with depression of the medial longitudinal arch and abduction of the forefoot. The rearfoot valgus occurs as this is the "position of comfort" of the foot. With time and if left untreated, the deformity will become more rigid in nature. In this manner, tarsal coalition may become associated with rigid peroneal spastic flatfoot. Further, significant forefoot supinatus, forefoot varus, and/or changes secondary to associated ankle equinus may become apparent. Clinical identification of these secondary adaptive changes is imperative to the development of an appropriate treatment plan (Figs. 9 A-B).

It should be remembered that peroneal spastic flatfoot does not always occur with tarsal coalition and that peroneal spastic flatfoot can result from other conditions. Occasionally other muscles may be spastic with a tarsal coalition. If other muscles are involved, the foot may not develop a pes valgo planus attitude. Simmons (43) reported a varus position of the heel in a patient with a calcaneonavicular coalition (Figs. 10 A,B). Further, peroneal spastic flatfoot can occur secondary to other causes including arthropathies, inflammation, infection, and osteochondral fractures (44). These causes may also be considered acquired etiologies of tarsal coalition in certain instances.

When evaluating a patient with a tarsal coalition associated with restricted motion and/or muscle spasm, a local anesthetic injection in the area of the coalition or to a proximal nerve segment (e.g., common peroneal block) may provide valuable diagnostic information. The anesthetic block may relieve the pain and muscle spasm sufficiently to allow a more accurate assessment of joint motion. This will not only allow direct confirmation of the extent of the coalition (i.e., complete versus incomplete), but also can afford information as to the joint motion quality and quantity. This information may be helpful if surgery is considered and resection of the coalition is contemplated.

ROENTGENOGRAPHIC FINDINGS

Roentgenographic evaluation of a suspected tarsal coalition should be performed in a systematic, cost-effective manner. In most instances, routine radiographs will allow an accurate diagnosis of tarsal coalition. More sophisticated studies such as tomography, computed tomography, or magnetic resonance imaging should be

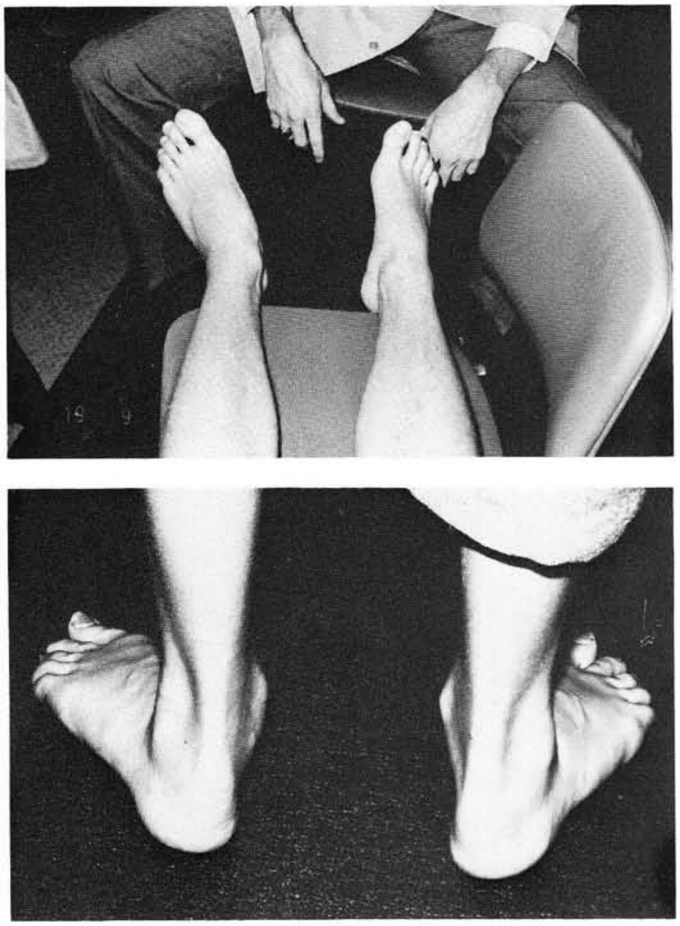


Fig. 9. Peroneal spastic flatfoot of left foot. Note increased rearfoot valgus and forefoot abductus associated with deformity.

A

B

Fig. 10. Cavovarus foot deformity in patient with calcaneonavicular coalition. A. Cavus deformity on lateral view. B. Calcaneonavicular synostosis (i.e., complete coalition) noted more readily on medial oblique view (lateral oblique projection).

reserved for cases where standard radiographs are inconclusive, or where one wishes to assess the identified coalition in more detail.

Radiographic Evaluation

When the clinical findings suggest a possible tarsal coalition, initial routine radiographs (including anteroposterior, lateral, and medial oblique views) should be obtained. In the majority of cases, these routine films will clearly portray a tarsal coalition and confirm its diagnosis. However, one must have a thorough appreciation of the normal radiographic anatomy and the radiographic pathology expected with tarsal coalition if one is to use routine radiographs to maximum benefit. In this sense, different views will be more helpful in different coalitions.

As stated earlier, the calcaneonavicular coalition was first radiographically demonstrated by Slomann (7) on an oblique view. This coalition is still most readily appreciated on the medial oblique view (i.e., lateral oblique projection), although it may be suggested on an anteroposterior or lateral view. The connecting bar between the calcaneus and navicular may be osseous, cartilaginous, fibrous or mixed in nature. Complete osseous union is fairly simple to diagnose (Fig. 10B). However, an incomplete union can be more difficult. In these cases, the calcaneus and navicular are frequently in close proximity to one another and their contiguous cortical surfaces appear flattened and irregular like a pseudarthrosis (Fig. 11).

A talocalcaneal coalition can usually be identified and diagnosed from a lateral radiograph if the normal radiographic anatomy of the subtalar joint is well understood (Fig. 12A). The middle and posterior facets of the subtalar joint can be visualized on a properly taken lateral view. The anterior facet cannot be visualized because its obliquity causes it to be obliterated by other osseous structures (39,45). A talocalcaneal coalition involving the middle or posterior facets may be directly visualized on a lateral radiograph as absent or diminished joint space. It may only be suggested if it involves the anterior facet.

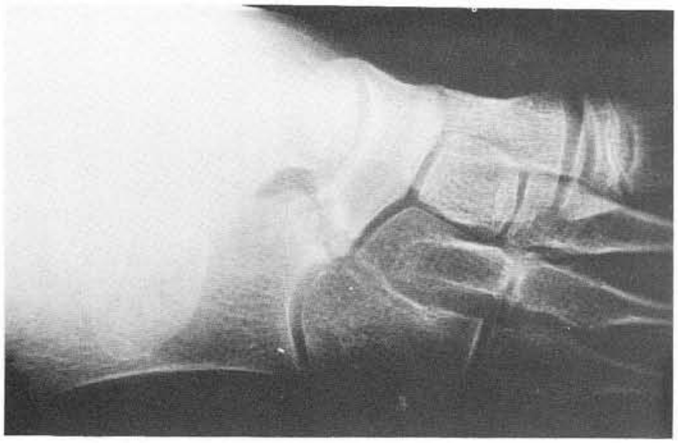


Fig. 11. Incomplete calcaneonavicular coalition noted on medial oblique view (lateral oblique projection). Note that adjacent surfaces of navicular and calcaneus resemble pseudoarthrosis.

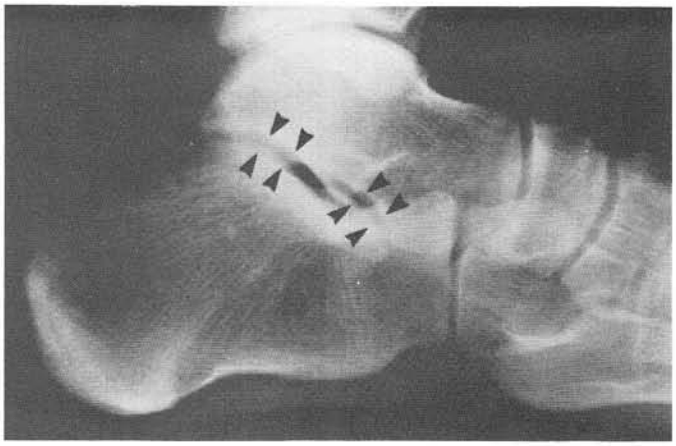
When coalition of the subtalar joint occurs, it is predominantly of the middle facet. The common radiographic hallmarks of a middle facet talocalcaneal coalition seen on a lateral radiograph are: 1) a halo sign representing absence or diminished visualization of the middle facet with enhancement of the sustentaculum tali; 2) narrowing of the posterior facet of the subtalar joint with loss of subtalar joint clarity; 3) talonavicular joint beaking; and 4) flattening of the lateral talar process (Fig. 12B) (30,34). These findings may also be seen with varying degrees in coalitions involving the anterior and posterior facets.

Harris and Beath views (i.e., axial or "ski jump" views) may be performed to obtain additional information as to the status of the middle and posterior facets of the subtalar joint. If a complete osseous coalition is present, the involved facet(s) will not be visualized. If an incomplete coalition is present, the facet(s) involved will usually demonstrate osseous irregularity, joint space narrowing, and facet obliquity. In the normal foot, the posterior and middle facets are parallel to the ground and to one another (Fig. 13A). If a facet is angulated more than 25 degrees from the ground or its neighboring facet, a talocalcaneal coalition can be strongly suspected (41)(Fig. 13B).

Isherwood views can also provide information on a talocalcaneal coalition. Unfortunately, the views require exact positioning of the patient and are very difficult to perform properly (46-48).

Further, neutral position radiographs, radiographs taken while performing the Hubscher maneuver, and lateral stress dorsiflexion ankle radiographs may provide evidence as to the flexibility of the deformity. In complete talocalcaneal coalitions, the deformity will frequently result in a rigid pes valgo planus deformity whether or not it is associated with peroneal muscle spasm. The subtalar joint may be placed in its neutral position and a lateral radiograph taken. No change in the talocalcaneal relationship will be noted if the deformity is rigid.

A



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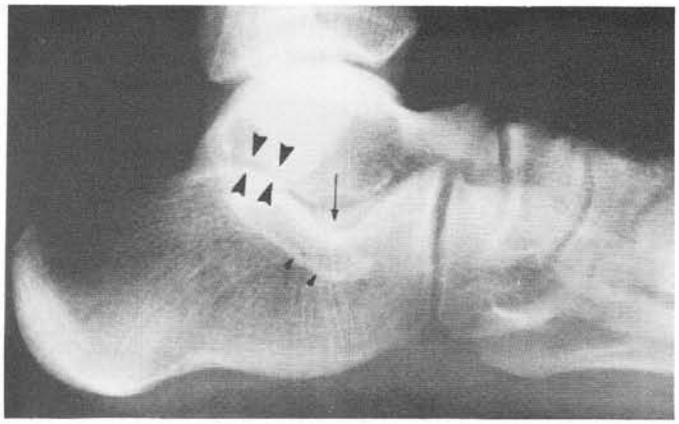
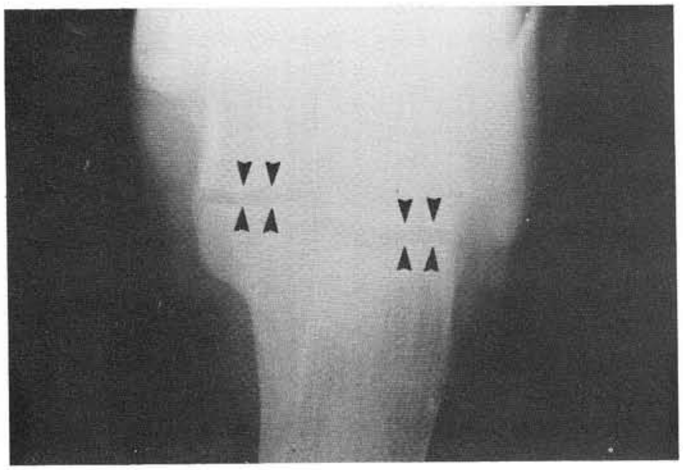


Fig. 12. Lateral radiographic views of: A. Normal right foot. Pointers delineate middle and posterior facets of subtalar joint. B. Right foot with middle facet talocalcaneal coalition. Note four classic features of such coalition: 1) halo sign (small pointers—most inferior), 2) Loss of subtalar joint clarity (large pointers), 3) Talonavicular joint beaking (small pointers - most superior), and 4) Flattening of lateral talar process (arrow).

Another test for flexibility is the Hubscher maneuver. This maneuver involves passive dorsiflexion of the hallux while the patient stands in a normal relaxed position. When the hallux is dorsiflexed, the medial strand of the plantar fascia and flexor hallucis longus are tightened. In the flexible pes valgo planus foot deformity, the medial longitudinal arch will increase in height and the rearfoot will supinate. While holding the hallux in a dorsiflexed position, a lateral radiograph can be taken attempting to demonstrate an increase in the medial longitudinal arch and a change in the lateral talocalcaneal relationship representing rearfoot supination (i.e., a decrease in the lateral talocalcaneal angle) (Fig. 14 A-C).



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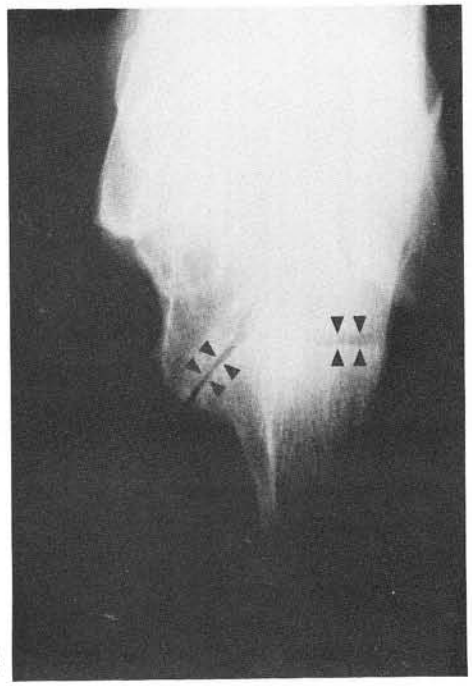
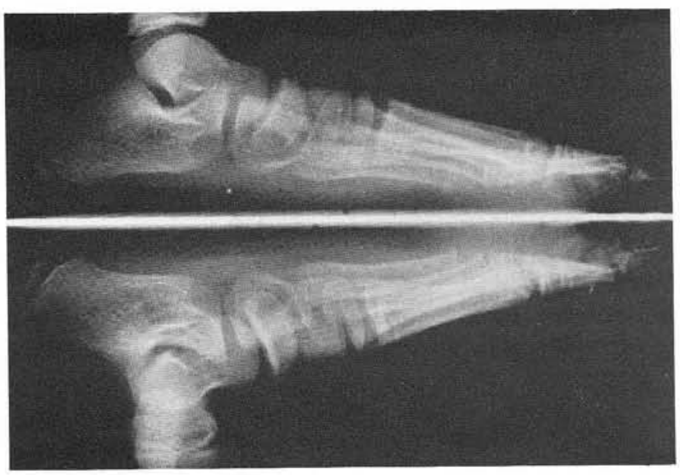


B

Fig. 13. A. Normal Harris and Beath view of right foot. Note that middle and posterior facets (pointers) are parallel with ground and one another. Middle facet is slightly superior to posterior facet in normal foot. B. Abnormal Harris and Beath view in patient with middle facet talocalcaneal coalition of right foot. Note angulation of middle facet with weight-bearing surface and posterior facet.

If this does not occur, the deformity is rigid in nature (49).

Finally, a lateral stress dorsiflexion view of the ankle can be taken. This should place a dorsiflexory force upon the subtalar and midtarsal joints. In a flexible deformity, this will cause pronation of the subtalar joint and the lateral radiograph should demonstrate a decrease in the medial longitudinal arch and a change in the talocalcaneal relationship representing rearfoot pronation (i.e., an increase in the lateral talocalcaneal angle) (Fig. 15A-B). Further, any osseous impingement of the talus and tibia may be documented with this view. This should be differentiated from the talonavicular beaking associated with a tarsal coalition (50).



A

B

C

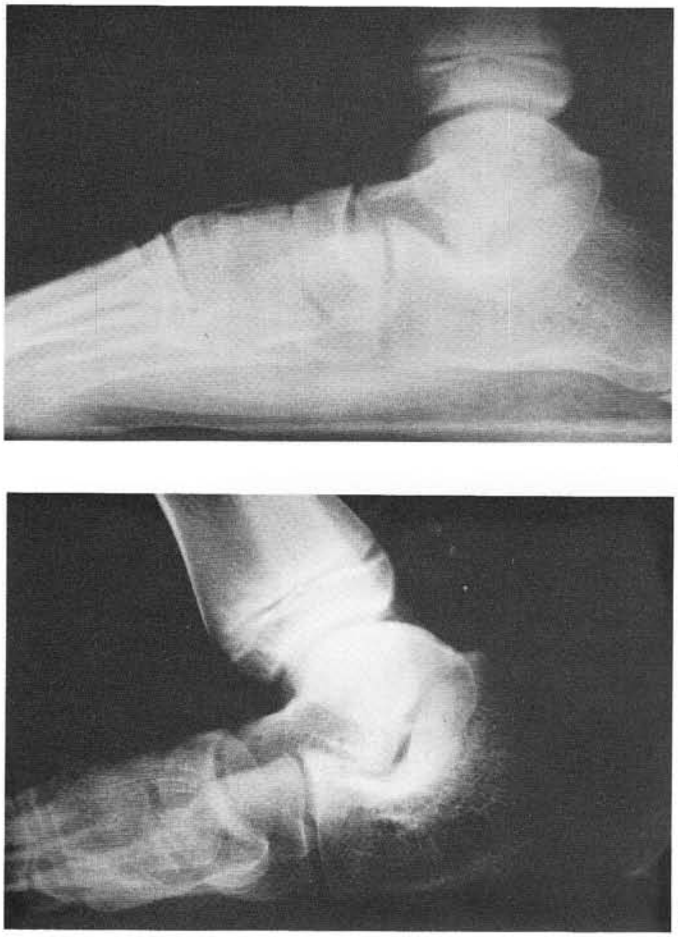
Fig. 14. A. Lateral weight-bearing view of left foot in patient with pes valgo planus deformity. B. Lateral view of same foot with Hubscher maneuver being performed. C. While Hubscher maneuver is performed, note change in talocalcaneal relationship. Lateral talocalcaneal angle has decreased. This is flexible collapsing pes valgo planus deformity.

Talonavicular and other rarer coalitions can usually be easily seen on standard radiographs. The anteroposterior and lateral views will, in most cases, clearly demonstrate these coalitions (Fig. 16). It should be remembered that both feet need to be evaluated for other coalitions when any tarsal coalition is found. This information may suggest a complex malformation (Fig. 1) and will be helpful in the construction of a treatment plan.

Routine radiographs may also be used to evaluate the foot for arthritic changes secondary to the tarsal coalition. These secondary changes include joint beaking (e.g., talonavicular or calcaneocuboid joint beaking), osteoarthritis with diminished joint space, and secondary adaptive changes (e.g., ball-and-socket ankle joint in a talocalcaneal coalition or increased joint motion at the naviculocuneiform joint in a talonavicular coalition). The extent of these secondary arthritic or degenerative changes frequently determines the prognosis and treatment plan.

Tomographic/Cross-Sectional Evaluation

Standard tomography, computed tomography, and magnetic resonance imaging offer the ability to obtain multi-planar cross-sectional images of the foot with minimal bony overlap (39, 51-54) (Fig. 17). These modalities should be reserved for cases in which radiographs are inconclusive, for evaluation of a coalition of the anterior facet of the subtalar joint, and/or for cases in which the treating physician desires more detailed information involving a specific coalition (e.g., a need to determine more specifically the size and tissue

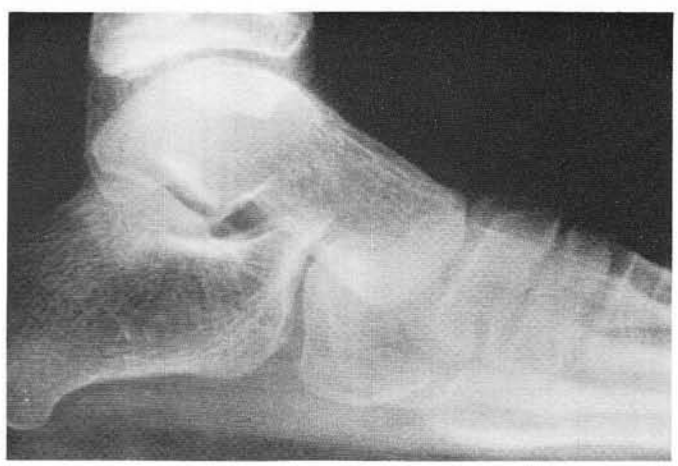


A

B

Fig. 15. A. Lateral weight-bearing view of right ankle and rearfoot. B. Lateral stress dorsiflexion view of same ankle and rearfoot. No change in talocalcaneal relationship is noted. If deformity were flexible, an increase in lateral talocalcaneal angle would be noted. Thus, this is a rigid deformity, which was subsequently found to be due to talocalcaneal coalition on computed tomography images.

A



B

Fig. 16. Anteroposterior (A) and lateral (B) views of talonavicular coalition. Note rounding and increased joint space of naviculocuneiform joints.

type of a coalition). However, one should avoid the expensive pitfall of believing that one of these modalities is always necessary. Most tarsal coalitions can be diagnosed by clinical examination combined with traditional radiographs.

Specialized Studies/Evaluation

Radionuclide scanning and arthrography have also been used in the diagnosis of tarsal coalitions. A bone scan obtained with Technitium-99 methylene methylene diphosphate (Tc-99) may be sensitive to the presence of a tarsal colition (Fig. 18). This sensitivity is secondary to the bone activity generated by the abnormal biomechanical stress and arthritic changes occurring in the area of the coalition. Since many conditions can cause similar activity, a Tc-99 bone scan is nonspecific for tarsal coalition and should only be used as a screening study (55,56). Arthrography of the talocalcaneonavicular joint can be used to detect a talocalcaneal coalition when routine radiographs are inconclusive (57). However, the use of tomographic techniques is more accurate and noninvasive.

TREATMENT

Not all tarsal coalitions are symptomatic. Also when symptomatic, not all coalitions necessarily remain so. Therefore, in most cases, conservative treatment should initially be attempted. If this proves unsuccessful, then surgical intervention may be considered.

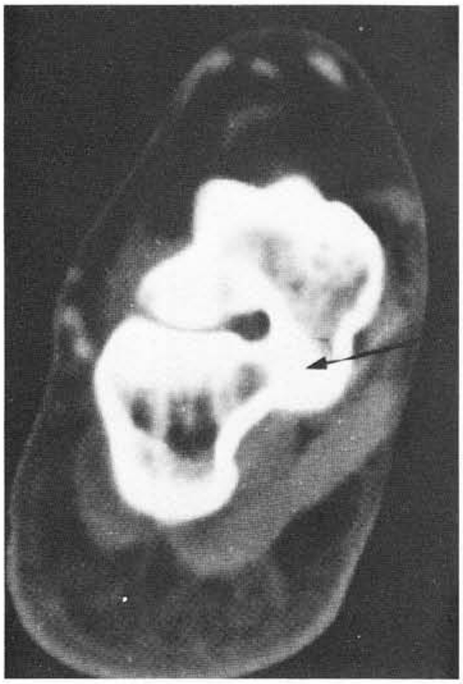


Fig. 17. Computed tomography coronal plane image of middle facet synostosis of talocalcaneal joint (arrow). Note sinus tarsi and posterior facet are clearly visible.

Conservative Treatment

Conservative therapy is directed towards restricting subtalar and midtarsal joint motion, thereby reducing pain and muscle spasm. This may be combined with physical therapy and anti-inflammatory medication as needed.

Subtalar and midtarsal joint motion may be effectively limited with shoe modifications, padding, orthotic devices, or casting. Shoe modifications may include a Thomas heel, medial heel wedge, or longer medial heel counter. Padding in the shoe gear may include a heel wedge or medial longitudinal support. Orthoses should be specifically constructed to limit subtalar joint motion. A neutral position device with a long rearfoot post or an orthotic posted in valgus may prove to be beneficial. If these modalities fail or if the patient has significant symptomatology, a soft cast, strapping, or below-knee walking cast may be considered. If desired, these may be applied after a local steroid injection to the area of the coalition. The below-knee cast is applied with the ankle and subtalar joints in their neutral positions and kept intact for a period of 3 to 6 weeks. In more severe cases, or if initial casting fails, a non weight-bearing cast may be attempted. Jayakumar and Cowell (58) reported that approximately 25 to 30% of their patients improved with casting.

Symptomatic relief of coalitions may be afforded by physical therapy or anti-inflammatory medication. Therapeutic modalities such as heat, warm soaks, paraffin baths, or whirlpool baths may be beneficial. Kendrick (59) suggested manipulation under anesthesia as a possible treatment, but this has not been supported. Local injections of steroid and/or local anesthetic may provide

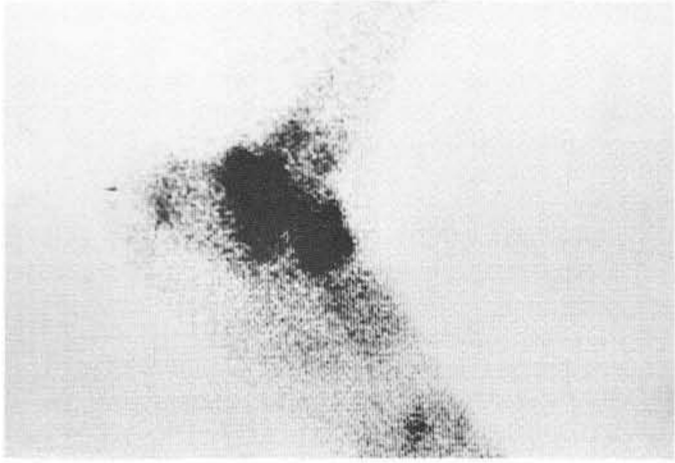


Fig. 18. Technitium-99 bone scan (third phase) of middle facet talocalcaneal coalition. Note activity in area of talonavicular joint as well secondary to biomechanical stress.

relief. Further, injection of a local anesthetic agent into the area of an incomplete coalition may allow increased motion. This can be extremely helpful when evaluating a patient for a coalition and determining a possible surgical treatment plan. Oral anti-inflammatory medication may also provide symptomatic relief.

Surgical Treatment

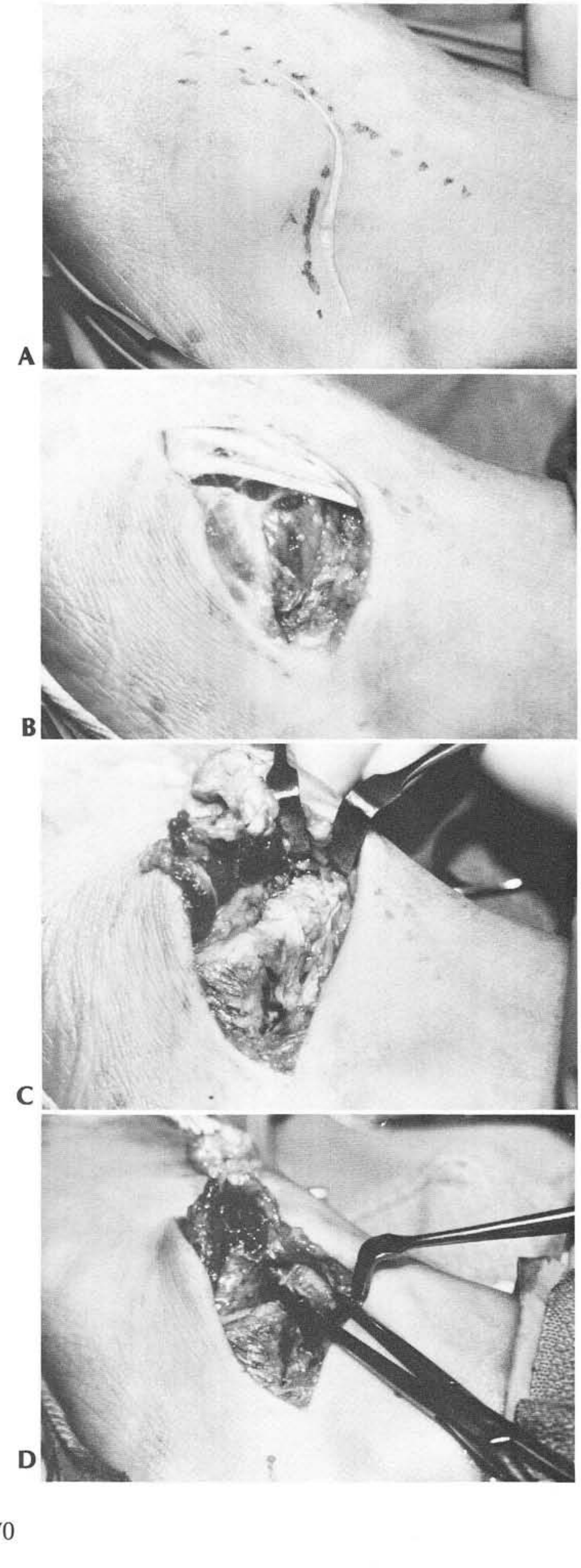
Surgical treatment is essentially confined to either resection of the coalition or fusion of the involved joint complex. However, significant controversy exists as to the indications and results to be expected with these two diverse surgical approaches. For this reason, the author proposes a new classification system (Fig. 2) which may be used as a framework for the construction of an appropriate treatment plan. The classification system is not meant to be all inclusive, but considers several important parameters used in the development of any treatment regime - patient age, articular involvement, and extent of secondary arthritic changes. Certainly, other factors not included in the classification system will need to be considered.

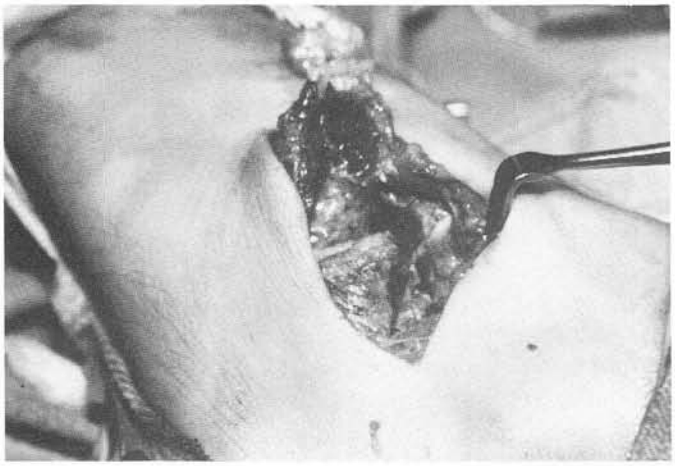
Juvenile - IA

Traditionally, extra-articular coalitions, such as a calcaneonavicular coalition, have been considered more amenable to surgical resection. This is particularly true when no secondary degenerative changes have occurred. Thus, in the younger patient with an extra-articular coalition and minimal secondary arthritic changes, resection arthroplasty is generally the procedure of choice.

If the coalition is a calcaneonavicular bar, the classic procedure, as first described by Badgely (8), is excision of the coalition with interposition of the extensor digitorum brevis muscle belly. The approach for this procedure is through a lateral curvilinear or Ollier-type incision beginning over the lateral calcaneus/sinus tarsi area and extending medially to the lateral aspect of the talonavicular joint (Fig. 19A).

Blunt dissection is then carried through the subcutaneous layer with hemostasis obtained as necessary. The origin of the extensor digitorum brevis is then reflected off the calcaneus and retracted distally (Figs. 19B-C). The calcaneonavicular bar is generously resected with as much bone as possible being removed (Figs. 19D-E). The extensor digitorum brevis muscle belly is then sutured into the defect (Figs. 19F-G). The suture may be placed in the muscle and then directed plantar-medially and sutured over a button on the plantar-medial aspect of the foot (Figs. 19H-I). Alternatively, an internal





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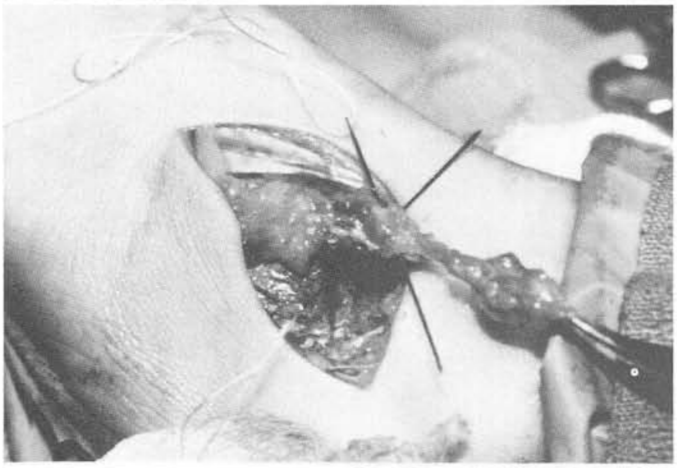

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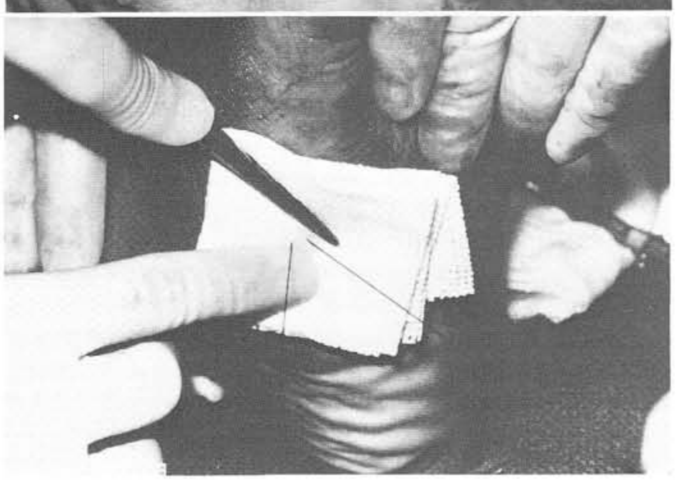

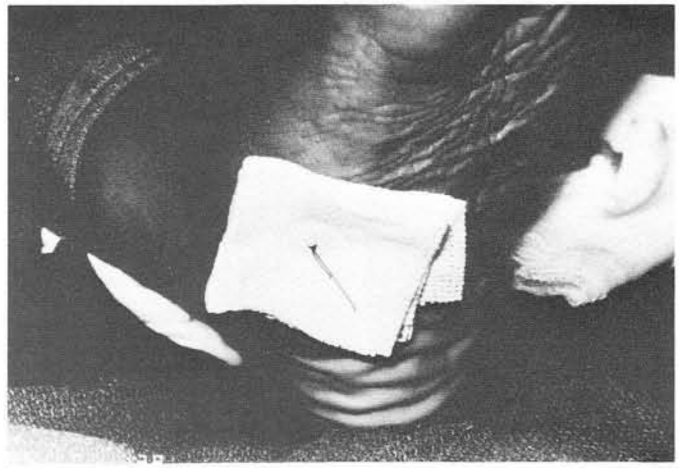

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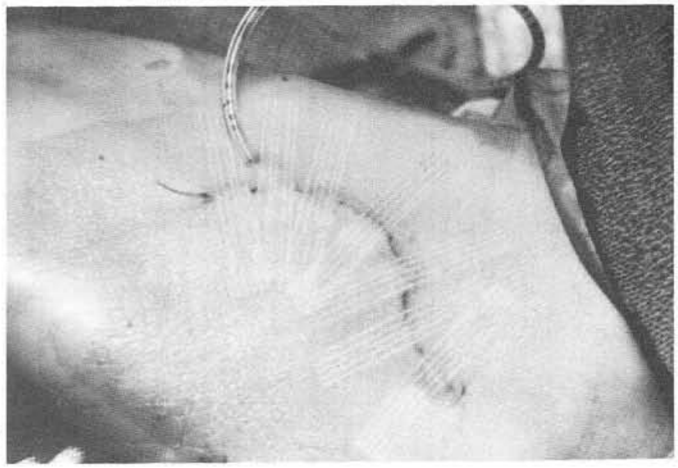

J

Fig. 19. Extensor digitorum brevis arthroplasty. A. Skin incision. B. Extensor digitorum brevis muscle prior to reflection. C. Extensor digitorum brevis retracted distally after reflection from calcaneus. Note calcaneonavicular bar is now visible. D. Resection of coalition. E. Defect between calcaneus and navicular. F. Suture placed in extensor digitorum brevis for insertion into defect. G. Muscle inserted into defect. H. Suture passed through plantar-medial aspect of foot. I. Suture tied over button. J. Anatomic closure with insertion of TLS drain and application of steristrips.

suture technique, where the muscle is anchored to soft tissue or bone, may be employed.

A large closed suction drain is inserted, and anatomic closure performed (Fig. 19J). Postoperatively, a below-knee non weight-bearing cast is applied for 4 to 6 weeks. The cast may be split or bivalved after 2 to 3 weeks and subtalar and midtarsal joint range of motion exercises begun. Weightbearing is initiated after approximately 6 weeks.

Many authors have reported good success with this procedure (58, 60-65). The most frequent postoperative problem reported has been varying amounts of recurrent bone growth of the bar. This has generally not been found to be a problem if a generous resection of the bar was initially performed. Despite this, several suggested modifications have been proposed, including the coagulation of the bone ends (40), the use of bone wax on the bone ends (39), the insertion of adipose tissue between the bone ends instead of the muscle belly (40,44), or the insertion of a silicone implant between the bone ends instead of the muscle belly (66).

In similar fashion, other more rare extra-articular coalitions without secondary degenerative changes, such as a cubonavicular coalition, should offer similar hope of favorable results following resection (39,67).

Several authors (68,69) have discussed the possibility of performing a varus-producing osteotomy of the calcaneus. Dwyer (69) felt that the valgus position of the rearfoot, commonly seen with a tarsal coalition, produced an "oblique strain of the ligaments" in the rearfoot and ankle with resultant pain. He suggested an opening wedge calcaneal osteotomy with a bone graft inserted through a lateral approach. Cain and Hyman (68) reported success in treating coalitions with a similar procedure. Instead of an opening osteotomy, Cain and Hyman performed a closing osteotomy through a medial approach. None of these authors suggested resection of the coalition along with the calcaneal osteotomy. Certainly, the osteotomy alone would seem of limited benefit as demonstrated by orthotic devices which maintain the heel in a varus position, and yet, afford only minimal relief of symptoms. However, if significant heel valgus is present, a varus-producing calcaneal osteotomy combined with resection of the coalition may be of some benefit.

Juvenile IB

An extra-articular coalition with secondary arthritic changes is less amenable to simple surgical resection. However, in the younger patient it should still be strongly considered with arthrodesis presented as a possible future operation.

With a calcaneonavicular coalition, significant degenerative changes may occur over time. Usually, the talonavicular joint will demonstrate the most apparent changes. In the younger patient with mild degenerative changes, extensor digitorum brevis arthroplasty may again be attempted. However, the patient and parents should be told that arthrodesis may need to be performed in the future. With more significant degenerative changes, triple arthrodesis is the procedure of choice (8,11,70). In cases where triple arthrodesis is to be performed, the coalition may be left intact if complete. However, if the coalition is incomplete or if significant positional abnormalities exist, the coalition should be resected to obtain optimal postoperative position and fusion. Triple arthrodesis is usually performed after osseous maturity.

Juvenile IIA

Although extra-articular coalitions are generally reasoned to be more amenable to resection, intra-articular coalitions are traditionally considered an indication for arthrodesis. The exception to this premise might be the "Juvenile IIA" coalition—an intra-articular coalition which occurs in a younger patient with minimal or no secondary degenerative changes. If small enough and/or if incomplete in nature, this coalition may be amenable to resection arthroplasty. It should be remembered that future arthrodesis will many times be necessary.

A common example would be a middle facet coalition of the subtalar joint (Figs. 20A-B). Typically, resection of this coalition leaves a defect and an irregular area in an articular facet of a major weight-bearing joint. However, several authors have described resection of the coalition with or without the interposition of fat grafts, and have reported satisfactory results (40,58,65,71). We have attempted resection of a middle facet talocalcaneal coalition with the insertion of a subtalar joint arthroereisis to maintain the joint space (Figs. 21 A-D). More recently, this was similarly reported by Lepow and Richman (72) with success.

Another example where resection might be preferable, is the posterior facet talocalcaneal coalition secondary to a fractured Stieda's process or os trigonum. Surgical resection of the coalition and/or os trigonum may lead to a satisfactory functional result (18).

Again, several reports (68,69) have indicated that varus-producing osteotomies of the calcaneus may afford relief of symptoms in tarsal coalitions without significant secondary arthrosis. These procedures may be a useful adjunct if concomitant resection of the coalition is attempted, but should not be performed alone.

In those cases with significant coalition involvement or in cases of failed resection, arthrodesis is the procedure of choice. In most instances, triple arthrodesis is preferred. With talocalcaneal coalitions involving the middle facet and without secondary arthritic changes, debate continues as to the preferred arthrodesis - isolated subtalar joint arthrodesis or triple arthrodesis. The author supports, and recent evidence (73) suggests, that isolated subtalar joint arthrodesis generally provides a superior functional result (Figs. 22 A-B). Triple arthrodesis should be reserved for cases where the coalition, although not associated with secondary degenerative changes, is demonstrating significant structural abnormalities (e.g., profound forefoot varus, rearfoot valgus, or equinus). In such cases, triple arthrodesis

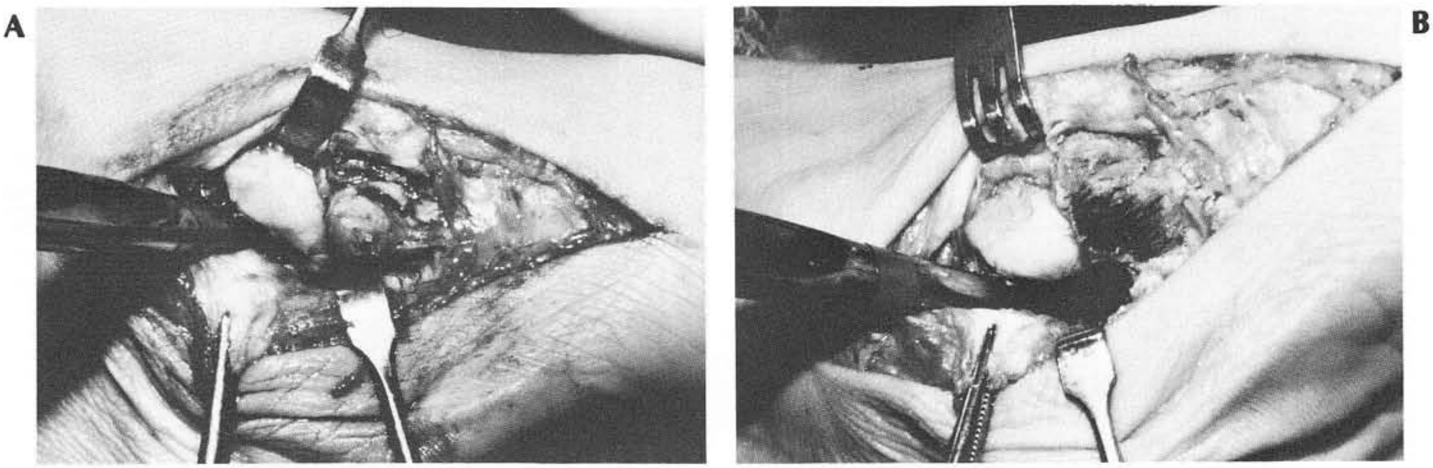

Fig. 20. A. Talocalcaneal coalition of anterior and middle facets of left foot approached through medial incision. B. Same foot after resection of coalition.

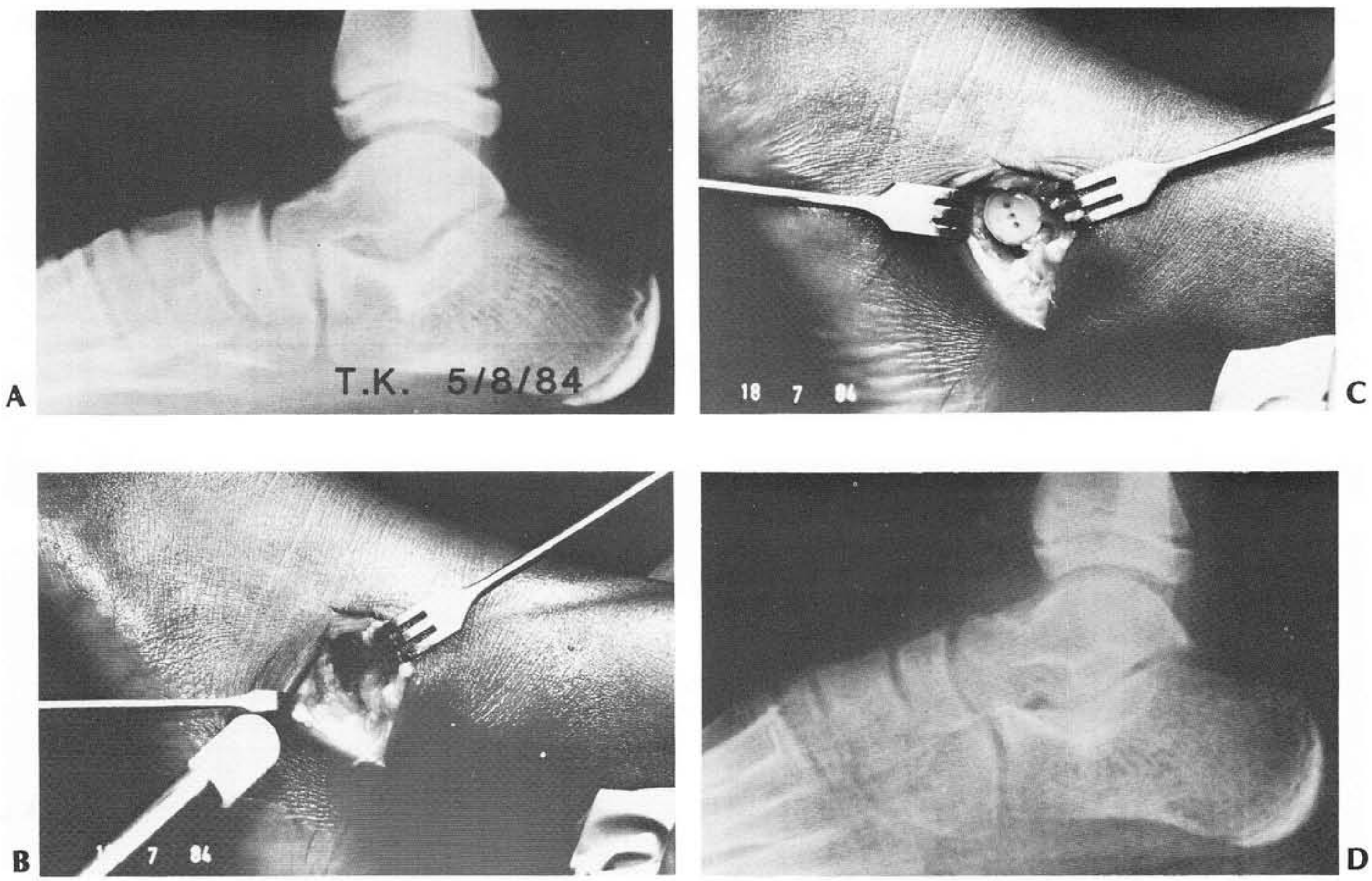

Fig. 21. A. Preoperative lateral view of left foot in 8 year old patient with middle facet talocalcaneal coalition. B, C. Insertion of subtalar arthroereisis after resection of coalition. D. Postoperative lateral view of foot. Note improved talocalcaneal relationship.

will be necessary to obtain a structurally acceptable forefoot to rearfoot relationship.

Juvenile IIB

An intra-articular coalition with moderate to severe secondary arthritic changes is optimally treated with a triple arthrodesis after osseous maturity (Figs. 23 A-B).

Adult IA

In the adult, one generally considers arthrodesis more strongly than in the child. When the coalition is extra-articular and no secondary arthritic involvement is noted, resection arthroplasty may be considered.

Adult IB

When the extra-articular coalition in the adult is associated with secondary degenerative changes, arthrodesis is preferable. In most cases, triple arthrodesis will be indicated.

Adult IIA

Unlike the juvenile patient, resection of an intra-articular coalition should generally not be considered in the adult. Isolated arthrodesis of the involved joint may be performed if no secondary arthritic changes are noted (Figs. 22A-B). Triple arthrodesis may also be considered, and is certainly preferable if one wishes to derotate the forefoot to correct a significant forefoot varus or supinatus deformity.

Adult IIB

When an intra-articular coalition is associated with significant secondary arthritic changes, triple arthrodesis is the procedure of choice (Figs. 23A-B).

Thus, the articular classification system can be considered a surgical classification. In this sense, it provides a superior method of grouping tarsal coalitions. Based upon this, recommended procedures and the report of long-term results can be more accurately related (Fig. 24).

A

B

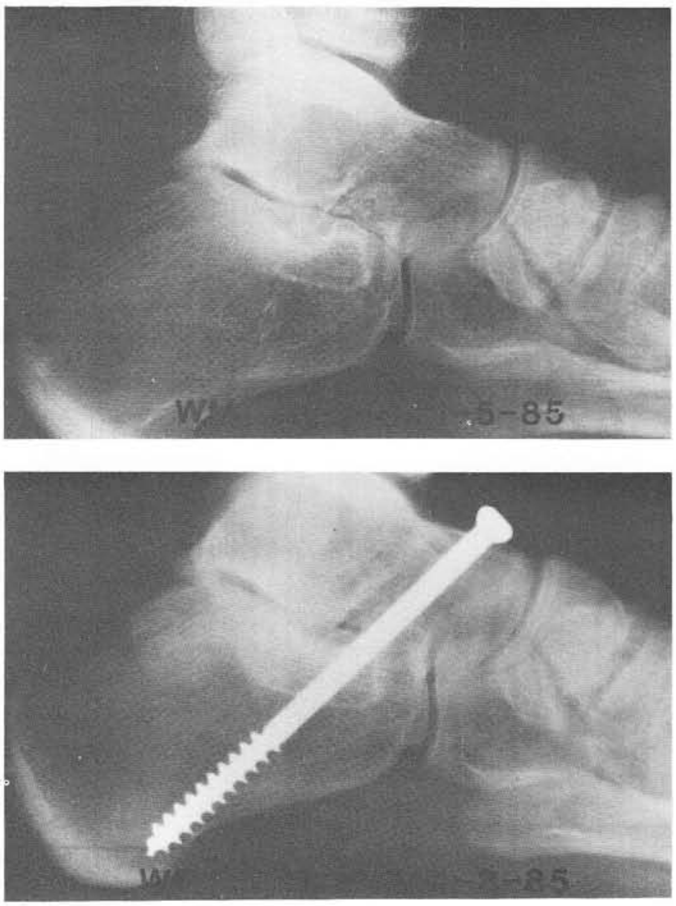

Fig. 22. A. Preoperative lateral radiographic view of 19 year old patient with middle facet talocalcaneal coalition. Note minimal secondary arthritic changes. B. Postoperative lateral view after isolated subtalar joint arthrodesis.

A

B

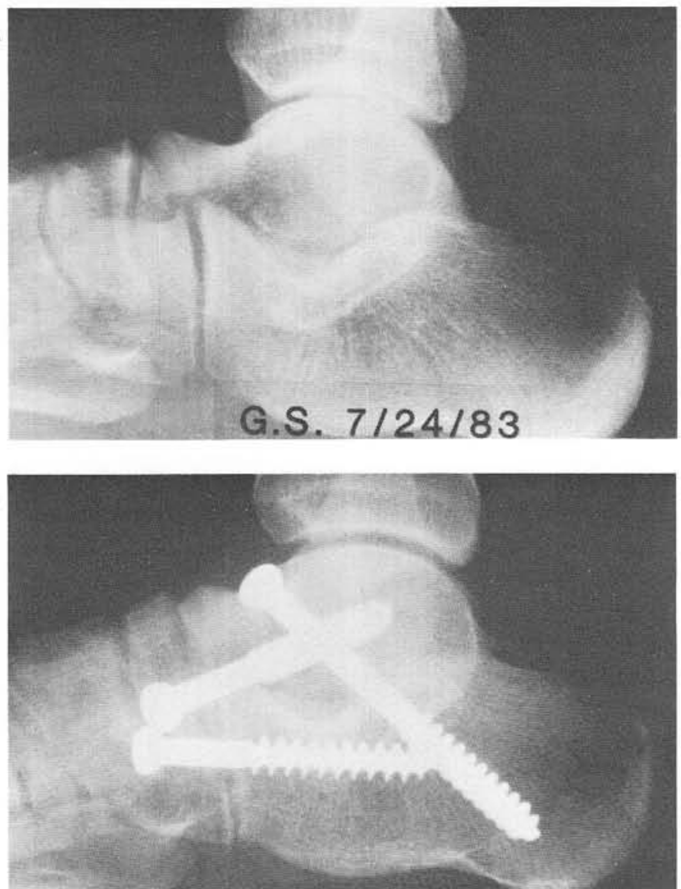

Fig. 23. A. Preoperative lateral radiographic view of 16 year old patient with middle facet talocalcaneal coalition. Note arthritic changes including talonavicular and calcaneocuboid joint beaking. B. Postoperative lateral view after triple arthrodesis.

Juvenile - IA

Resection with interposition of EDB muscle
Resection with interposition of adipose tissue
Resection with varus-producing calcaneal osteotomy
Resection with insertion of implant
Varus-producing calcaneal osteotomy alone

Juvenile - IB

Resection with interposition of EDB muscle
Resection with interposition of adipose tissue
Resection with varus-producing calcaneal osteotomy
Resection with insertion of implant
Varus-producing calcaneal osteotomy alone
Triple arthrodesis

Juvenile - IIA

Resection alone
Resection with interposition of adipose tissue
Resection with interposition of arthroereisis
Resection with varus-producing calcaneal osteotomy
Varus-producing osteotomy alone
Isolated/single arthrodesis
Triple arthrodesis

Juvenile - IIB

Triple arthrodesis

Adult - IA

Resection with interposition of EDB muscle
Resection with interposition of adipose tissue
Resection with varus-producing calcaneal osteotomy
Resection with insertion of implant
Varus-producing calcaneal osteotomy alone
Triple arthrodesis

Adult - IB

Triple arthrodesis

Adult - IIA

Isolated/single arthrodesis
Triple arthrodesis

Adult - IIIB

Triple arthrodesis

Fig. 24. Possible surgical procedures based on articular classification system. Note that procedures listed in bold type are currently recommended.

SUMMARY

An in-depth discussion of tarsal coalitions has been presented, including the introduction of a surgical articular classification system with specific references to treatment. A working knowledge of the clinical and roentgenographic findings is imperative to the construction of a logical treatment plan.

References

1. Heiple KG, Lovejoy CO: The antiquity of tarsal coalition: bilateral deformity in pre-columbian indian skeleton. *J Bone Joint Surg* 51A:979-983, 1969.
2. Coe WR, Broman VL: Excavations in Stella 23 area. *University of Pennsylvania Museum Monographs*, Tikal Report No.25, 1958.
3. Buffon GLL, Comte de: Histoire Naturelle Generale et *Particuliere*. Tome 3, Paris, Panckoucke, 1769, p. 47.
4. Jones R: Peroneal spasm and its treatment. Report of a meeting of the Liverpool Medical Institution. *Liverpool Medico-Chirurgical Journal* 17:442, 1897.
5. Kirmissin E: Double pied bot varus par malformation osseuse primitive associe a des ankyloses congenitales des doigts et des arteils chez quatre membres di'une meme famille. *Rev Orthop* 9:392-398, 1898.

6. Cruveilhier J: *Anatomie Pathologique du Corps Humain*. Tome 1, Paris, J.B. Balliere, 1829.
7. Slomann HC: On coalitio calcaneo-navicularis. *J Orthop Surg* (N.S.) 3:586-602, 1921.
8. Badgely CE: Coalition of the calcaneus and navicular. *Arch Surg* 15:75-88, 1927.
9. Zuckerkandl E: Ueber einen fall von synostose zwischen talus und calcaneus. *Allgemeine Weine Medizinische Zeitung* 22:293-294, 1877.
10. Korvin H: Coalitio talocalcanea. *Z Orthop Chir* 60:105, 1934.
11. Harris RI, Beath T: Etiology of peroneal spastic flatfoot. *J Bone Joint Surg* 30B:624-634, 1948.
12. Anderson RJ: The presence of an astragalo-scaphoid bone in man. *J Anat Physiol* 14:452-455, 1879-1880.
13. Holland CT: Deformity of feet and hands. *Arch Radiol Electrother* 22:234, 1918.
14. Waugh W: Partial cubo-navicular coalition as a cause of peroneal spastic flatfoot. *J Bone Joint Surg* 39B:520-523, 1957.
15. Lusby HLJ: Navicular-cuneiform synostosis. *J Bone Joint Surg* 41B:150, 1959.
16. Bersani FA, Samilson RL: Massive familial tarsal synostosis. *J Bone Joint Surg* 39A:1187-1190, 1957.
17. Pfitzner W: Die variationem im aufbau des fusskelets. *Morphologisches Arbeiten* 6:245-527, 1896.
18. Galinski AW, Crovo RT, Ditmars JJ Jr.: Os trigonum as a cause of tarsal coalition. *J Am Podiatry Assoc* 69:191-196, 1979.
19. Harris B: Anomalous structures in the developing human foot (Abstract). *Anat Rec* 121:399, 1955.
20. Leboucq H: De la soudure congenitale de certains os du tarse. *Bulletin de l'Academie Royale de Medicine de Belgique* 4:103-112, 1890.
21. Boyd HB: Congenital talo-navicular synostosis. *J Bone Joint Surg* 26:682-686, 1944.
22. Glessner JR Jr, Davis GL: Bilateral calcaneonavicular coalition occurring in twin boys. *Clin Orthop* 47:173-176, 1966.
23. Hodgson FG: Talonavicular synostosis. *South Med J* 39:940-941, 1946.
24. Pensieri SL, Jay RM, Schoenhaus HD, Perlman M: Bilateral congenital calcaneocuboid synostosis and subtalar joint coalition. *J Am Podiatr Med Assoc* 75:406-410, 1985.
25. Rothberg AS, Feldman JW, Schuster OF: Congenital fusion of the astragalus and scaphoid: bilateral, inherited. *NY State J Med* 35:29-31, 1935.
26. Webster FS, Roberts WM: Tarsal anomalies and peroneal spastic flatfoot. *JAMA* 146:1099-1104, 1951.
27. Wray JB, Herndon CN: Hereditary transmission of congenital coalition of the calcaneus to the navicular. *J Bone Joint Surg* 45A:365-372, 1963.
28. Leonard MA: The inheritance of tarsal coalition and its relationship to spastic flat foot. *J Bone Joint Surg* 56B:520-526, 1974.
29. Page JC: Peroneal spastic flatfoot and tarsal coalitions. *J Am Podiatr Med Assoc* 77:29-34, 1987.
30. Downey MS, Ruch JA: Juvenile peroneal spastic flatfoot—tarsal coalition. In McGlamry ED (ed): *Doctors Hospital Podiatry Education and Research Institute Fourteenth Annual Surgical Seminar Syllabus*. Atlanta, Doctors Hospital Podiatry Institute, 1985, pp 56-60.
31. Gold GS: Tarsal coalitions: clinical significance, diagnosis and treatment. *J Am Podiatry Assoc* 61:409-422, 1971.
32. Vaughan WH, Segal G: Tarsal coalition, with special reference to roentgenographic interpretation. *Radiology* 60:855-863, 1953.
33. Rankin EA, Baker GI: Rigid flatfoot in the young adult. *Clin Orthop* 104:244-248, 1974.
34. Beckly DE, Anderson PW, Pedegana LR: The radiology of the subtalar joint with special reference to talocalcaneal coalition. *Clin Radiol* 26:333-341, 1975.
35. Conway JJ, Cowell HR: Tarsal coalition: clinical significance and roentgenographic demonstration. *Radiology* 92:799-811, 1969.
36. Ehrlich MG: Tarsal coalition. In Jahss MH (ed): *Disorders of the Foot*, vol 1. Philadelphia, WB Saunders, 1982, pp 521-538.
37. Perlman MD, Wertheimer SJ: Tarsal coalitions. *J Foot Surg* 25:58-67, 1986.
38. Jack EA: Bone anomalies of the tarsus in relation to peroneal spastic flatfoot. *J Bone Joint Surg* 36B:530-542, 1954.
39. Schlefman BS: Tarsal coalition. In McGlamry ED (ed): *Comprehensive Textbook of Foot Surgery*, vol 1. Baltimore, Williams & Wilkins, 1987, pp 483-507.
40. Tachdjian MO: *The Child's Foot*. Philadelphia, WB Saunders, 1985, pp 261-294.
41. Cowell HR: Talocalcaneal coalition and new causes of peroneal spastic flatfoot. *Clin Orthop* 85:16-22, 1972.
42. Maudsley RS: Spastic pes varus. *Proc Royal Soc Med* 49:181, 1956.
43. Simmons EH: Tibialis spastic varus foot with tarsal coalition. *J Bone Joint Surg* 47B:533-536, 1965.
44. Mosier KM, Asher MA: Tarsal coalitions and peroneal spastic flatfoot. *J Bone Joint Surg* 66A:977-984, 1984.
45. Schlefman BS, Ruch JA: Diagnosis of subtalar joint coalition. *J Am Podiatry Assoc* 72:166-170, 1982.
46. Isherwood I: A radiological approach to the subtalar joint. *J Bone Joint Surg* 43B:566-574, 1961.
47. Pinsky MJ: The Isherwood views: a roentgenologic approach to the subtalar joint. *J Am Podiatry Assoc* 69:200-206, 1979.
48. Schlefman BS: Radiology. In McGlamry ED (ed): *Fundamentals of Foot Surgery*, Baltimore, Williams & Wilkins, 1987, pp 136-173.

49. McGlamry ED, Mahan KT, Green DR: Pes valgo planus deformity. In McGlamry ED (ed): *Comprehensive Textbook of Foot Surgery*, vol 1. Baltimore, Williams & Wilkins, 1987, pp 403-465.
50. Downey MS: Ankle equinus. In McGlamry ED (ed): *Comprehensive Textbook of Foot Surgery*, vol 1. Baltimore, Williams & Wilkins, 1987, pp 368-402.
51. Downey MS: Magnetic resonance imaging (MRI) versus computed tomograph (CT): clinical applications. In McGlamry ED (ed): *Reconstructive Surgery of the Foot and Leg - Update '89*. Tucker GA, Podiatry Institute, 1989.
52. Floyd EJ, Ransom RA, Dailey JM: Computed tomography scanning of the subtalar joint. *J Am Podiatry Assoc* 74:533-537, 1984.
53. Herzenberg JE, Goldner JL, Martinez S, Silverman PM: Computerized tomography of talocalcaneal tarsal coalition: a clinical and anatomic study. *Foot Ankle* 6:273-288, 1986.
54. Migliori V, Pupp J, Kanat IO: Computerized tomography as a diagnostic aid in middle facet talocalcaneal coalition. *J Am Podiatr Med Assoc* 75:490-492, 1985.
55. Deutsch AL, Resnick D, Campbell G: Computed tomography and bone scintigraphy in the evaluation of tarsal coalition. *Radiology* 144:137-140, 1982.
56. Goldman AB, Pavlov H, Schneider R: Radionuclide bone scanning in subtalar coalitions: differential considerations. *AJR* 138:427-432, 1982.
57. Kaye JJ, Ghelman B, Schneider R: Talocalcaneonavicular joint arthrography for sustentacular-talar tarsal coalitions. *Radiology* 115:730-731, 1975.
58. Jayakumar S, Cowell HR: Rigid flatfoot. *Clin Orthop* 122:77-84, 1977.
59. Kendrick JI: Tarsal coalitions. *Clin Orthop* 85:62-63, 1972.
60. Andreasen E: Calcaneonavicular coalition. Late results of resection *Acta Orthop Scand* 39:424-432, 1968.
61. Cowell HR: Extensor brevis arthroplasty. *J Bone Joint Surg* 52A:820, 1970.
62. Kendrick JI: Treatment of calcaneonavicular bar. *JAMA* 172:1242-1244, 1960.
63. Mitchell GP, Gibson JMC: Excision of calcaneonavicular bar for painful spasmodic flatfoot. *J Bone Joint Surg* 49B:281-287, 1967.
64. Stoller MI: Tarsal coalitions - a study of tarsal coalition in adolescent athletes. *J Am Podiatry Assoc* 64:1004-1015, 1974.
65. Morgan RC Jr, Crawford AH: Surgical management of tarsal coalition in adolescent athletes. *Foot Ankle* 7:183-193, 1986.
66. Schechter RS, Sollitto RJ, Kittay JM: The use of a silicone implant following resection of a calcaneonavicular coalition: a case report. *J Foot Surg* 18:124-127, 1979.
67. Cavallaro DC, Hadden HR: An unusual case of tarsal coalition: a cuboid navicular synostosis. *J Am Podiatry Assoc* 68:71-75, 1978.
68. Cain TJ, Hyman S: Peroneal spastic flatfoot: its treatment by osteotomy of the os calcis. *J Bone Joint Surg* 60B:527-529, 1978.
69. Dwyer FC: Causes, significance and treatment of stiffness of the subtaloid joint. *Proc Roy Soc Med* 69:97-102, 1976.
70. McGlamry ED, Ruch JA, Mahan K, DiNapoli DR: Triple arthrodesis. In McGlamry ED (ed): *Reconstructive Surgery of the Foot and Leg - Update '87*. Tucker GA, Podiatry Institute, 1987, pp 126-152.
71. Asher M, Mosier K: Coalition of the talocalcaneal middle facet: treatment by surgical excision and fat graft interposition. *Orthop Trans* 7:149, 1983.
72. Lepow GM, Richman HM: Talocalcaneal coalitions - a unique treatment approach in case report. *Podiatry Tracts* 1:38-43, 1988.
73. Mann RA, Baumgarten M: Subtalar fusion for isolated subtalar disorders. *Clin Orthop* 226:260-265, 1988.