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Master's Surgical Technique

Triple Fusion in Children and Adolescents

James Recordon, FRACS and Dawson Muir, FRACS

Department of Orthopaedic Surgery, Tauranga Hospital, Tauranga, NZ

Correspondence: James Recordon, FRACS, Bay of Plenty District Health Board, 829 Cameron Road, Tauranga, New Zealand 3112. E-mail: james.recordon@gmail.com

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Abstract

Most foot deformities affecting children and adolescents can be managed nonoperatively or with joint-preserving procedures. Severe fixed deformities often require more comprehensive treatment, and triple fusion (arthrodesis) remains an option in these situations. Surgical decision-making in electing for a triple fusion in this age group and in these rare conditions can be difficult. The primary goals of treatment are elimination of pain, correction of the deformity, and maintenance of a plantigrade foot. This review aims to outline those situations where triple fusion is warranted and describe our technique.

Key Concepts

- Although uncommon and reserved for severe deformity, triple fusion remains a powerful procedure with satisfactory long-term outcomes.
- Fusion position is the key technical determinant of a successful outcome.
- Robust Internal fixation reduces the rate of nonunion.
- Foot growth is maintained in most children who have triple fusion as young as 8 years of age.

Introduction

While triple fusion (fusion of the subtalar, talonavicular, and calcaneocuboid joints) is a common treatment option for degenerative and inflammatory arthritis in the adult population, it has a role in certain conditions affecting children and adolescents. While joint-sparing procedures are much preferred in this age group, in certain conditions where there is severe fixed deformity, profound neuromuscular imbalance, or underlying dysplastic articulations, triple fusion can be the most reliable treatment.

Treatment Indications

Originally described for use in Polio, triple fusion remains useful in neurologic conditions resulting in

severe muscle imbalance. The most common indication for triple arthrodesis is cerebral palsy (CP) with fixed painful equinovalgus deformity.[1] It is occasionally required in spina bifida, arthrogryposis, and severe Charcot-Marie Tooth (CMT) disease.[2-4] It has been reported in equinovarus caused by spinal cord tumor.[3] On occasion, it is required in over-corrected or multiply operated stiff and painful recurrent clubfeet.[5] In the stiff recurrent clubfoot, decision-making can be more difficult if there is also reduced motion in the ankle joint due to the typical flat top talus. Occasionally patients with tarsal coalitions may require triple fusion.[6] While resection or isolated joint fusion are the mainstay, triple fusion becomes an option when there are large coalitions with significant fixed deformity, failed coalition resection, and when there are multiple coalitions.

Contraindications

There is no consensus on a minimum age to perform triple arthrodesis, with some reports on patients as young as 3 years of age.[3] The underlying concern is stunting foot growth; however, several reports have shown most patients over 8 years of age achieve a foot size comparable to and consistent with the severe nature of the foot condition being treated. In the young individual, triple fusion should only be considered after failure of soft tissue releases and other joint-sparing techniques.[7] A relative contraindication of fusion surgery is the insensate foot, and this is a particular feature in spina bifida, where authors have cautioned against fusion where it may result in pressure-related problems, including ulceration.[8]

Preoperative Evaluation

A thorough history, including details of previous surgery, followed by an examination focusing on the flexibility, or lack thereof, and extent of primary and secondary deformity in multiple planes provides the majority of information required. It is critical to appreciate the preoperative position of the hindfoot as being in either valgus or varus position. For instance, a hindfoot that is in valgus may require structural bone graft to correct the deformity, and a lateral incision may also result in difficulty in closing the wound if the lateral soft tissues are scarred and contracted. In contrast, the varus hindfoot is easier to correct from the standard lateral incision whereby wedges of bone can be taken and the soft tissues are easier to close. Examination of the skin and the presence of any open sores will necessitate treatment prior to reconstruction. Weakness of extrinsic muscles and tendons to the foot will dictate the need for orthosis use after correction of deformity. Concomitant contracture of the triceps surae will require tendoachilles lengthening or gastrocnemius recession. In the multiply operated foot, it will be important to note the status of the arterial blood supply to the foot, and one should remember that many patients with idiopathic clubfoot have baseline deficient dorsalis pedis blood flow.

Weight-bearing imaging is paramount to determine the pathological joint positions and determine the apex of the deformity. Weight-bearing anteroposterior (AP) ankle, AP and lateral foot, and non-weight-bearing oblique foot views are a minimum. These studies can help quantitate deformity in the foot. For example, the talocalcaneal angle helps to document the presence of hindfoot varus or valgus. Meary's angle is helpful for quantitating midfoot cavus or midfoot collapse (Figure 1).

The addition of CT and occasionally SPECT-CT are particularly useful in the evaluation of the neurologically normal painful rigid flatfoot. Unlike in adults, MRI is seldom useful in the work-up of pediatric and adolescent patients who are being considered for triple fusion. Weight-bearing CT is being used with increasing frequency but is not universally available and like MRI, is unlikely to influence management in this patient population.

History of Triple Fusion

Ryerson described the triple fusion in 1923 for Polio using a single lateral incision and no fixation.[9] The talar head was osteotomized and resected to allow cartilage to be denuded on the back table before reimplanting it. This step has since been modified to in situ debridement and maintenance of bony vascularity, but the concept of removing variable amounts of bone to obtain correction persists.

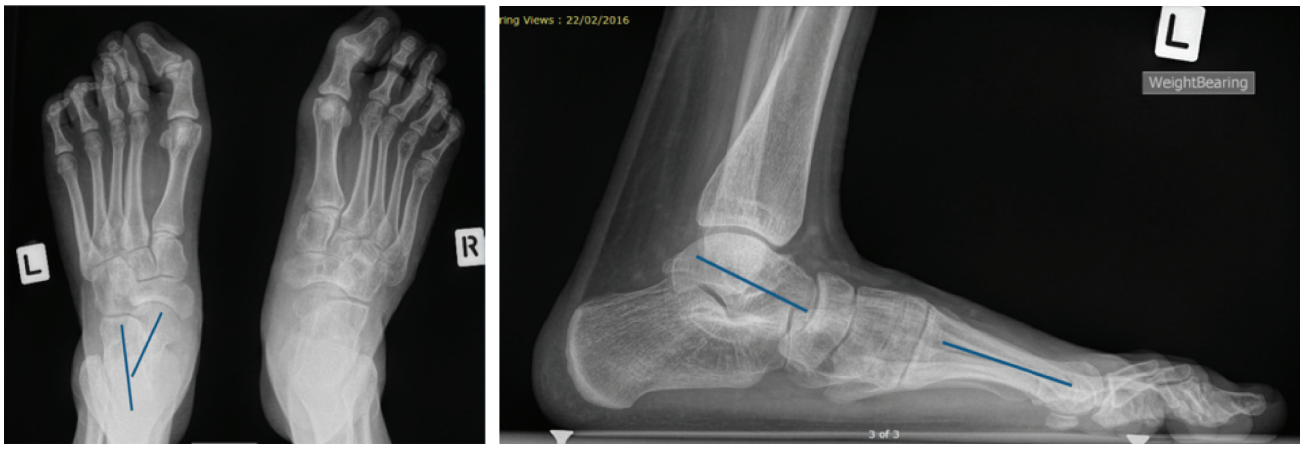

Figure 1. *The talocalcaneal and talus-first metatarsal (Meary's) angles are shown.*

A dual approach is typically preferred to the single lateral approach, with some authors using a direct medial approach to the talonavicular joint (TN).[10] Alternatively, a dorsal approach can be chosen which theoretically preserves the medial vascular supply to the talar neck and allows ease of fixation options across the width of the TN articulation.

The major change over time has been the use of improved fixation techniques: from casting alone to temporary Steinmann pins to internal fixation with screws, plates, and staples. Inlay grafting in a similar manner to a Grice procedure has also been described, where the inlay graft interposes and widens the collapsed sinus tarsi in planovalgus deformities.[11]

Double Arthrodesis

Double arthrodesis involves fusion of the subtalar and talonavicular joints whilst sparing the calcaneocuboid joint. Good results have been reported, particularly in the adult flatfoot population, and techniques evolved, such as a single medial approach.[12-14] This is particularly useful in reducing wound complications where there is poor quality or deficient skin laterally when correcting valgus deformity. The biomechanics of the triple joint complex are such that fusion of the TN and ST joints obliterates any significant motion at the CC joint.[15] The ability to correct severe fixed deformity reduces, however, and so it is often not an option in the pediatric conditions being considered for triple fusion. With respect to the medial double arthrodesis, the medial access to the joint has had the theoretical concern of compromising deltoid function leading to increased ankle valgus, but this has not been shown to occur in retrospective comparison studies.[16]

Author's Preferred Operative Technique (See Video)

The patient is positioned supine, high thigh tourniquet, bumped up under the ipsilateral hip to a neutral rotation. The ipsilateral iliac crest is prepared if structural grafting is a possibility.

The subtalar and calcaneocuboid joints are exposed through a sinus tarsi incision, beginning at the tip of the fibula and extended in line of the 4th ray (Figure 2). The sural nerve is at risk at the proximal aspect and the lateral branch of superficial peroneal nerve can be seen distally. Once deep to them, the peroneal tendons are identified, and above their sheath, Extensor Digitorum Brevis (EDB) is found and reflected as a distally based pedicle keeping its thin epimysium intact to preserve its integrity for later repair.

The sinus tarsi is debrided of its fatty contents, and the bifurcate and interosseous ligaments need to be released to get sufficient access. The peroneal tendons course posteriorly and are protected with a retractor while the lateral wall of the calcaneus is stripped of the calcaneofibular ligament (CFL) insertion, this will help

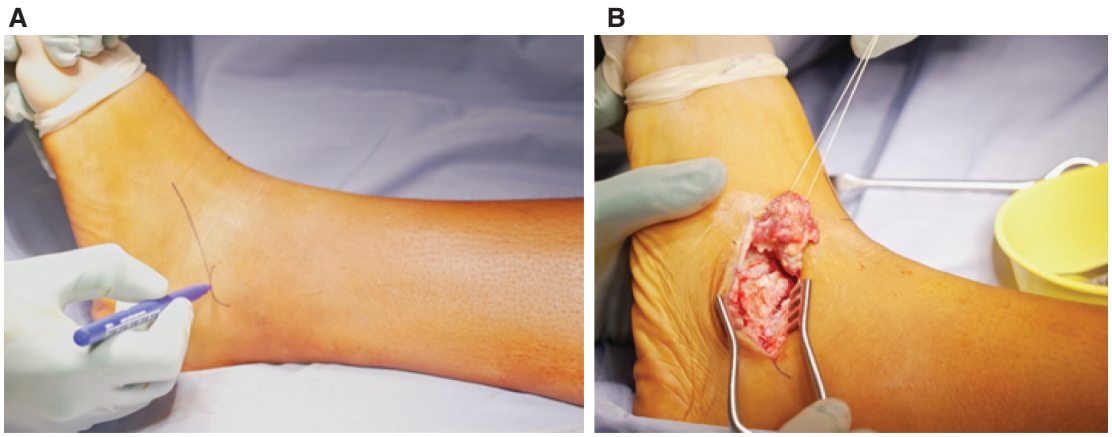

Figure 2. *A. The incision is marked. B. The EDB muscle is reflected distally, exposing the calcaneocuboid joint.*

with opening the subtalar joint with inversion. A small bump is useful to elevate the limb and allow the hindfoot to invert with gravity and further open the sinus tarsi.

Begin debridement with a sharp osteotome at the anterior aspect of the posterior facet. Once space is created, a toothless laminar spreader can be placed on strong bone and provide a sufficient distraction force to allow complete takedown of the posterior facet. This is confirmed with a view of the flexor hallucis longus tendon at the posteromedial corner. The laminar spreader is then moved posterior to allow access to the middle facet which is similarly denuded (Figure 3). The calcaneocuboid joint is more easily accessed and debrided in a similar manner.

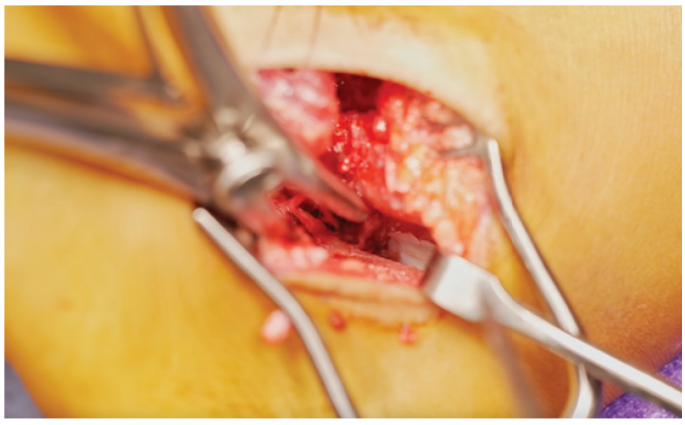

Figure 3. *The view into the subtalar joint, aided by good light and a laminar spreader. There is cartilage still visible on the undersurface of the talus.*

The talonavicular joint is exposed anteriorly, dividing the extensor retinaculum over the EHL tendon and mobilizing the neurovascular bundle from its medial branches so that it retracts laterally without tension. The capsule of the joint is divided midline and then reflected with enough length and width to allow the joint to be distracted and instrumented (Figure 4). Debridement of the joint is achieved with a sharp chisel or osteotome, cleaving residual cartilage from subchondral bone, maintaining the bony morphology, and maximizing contact surface area for fusion.

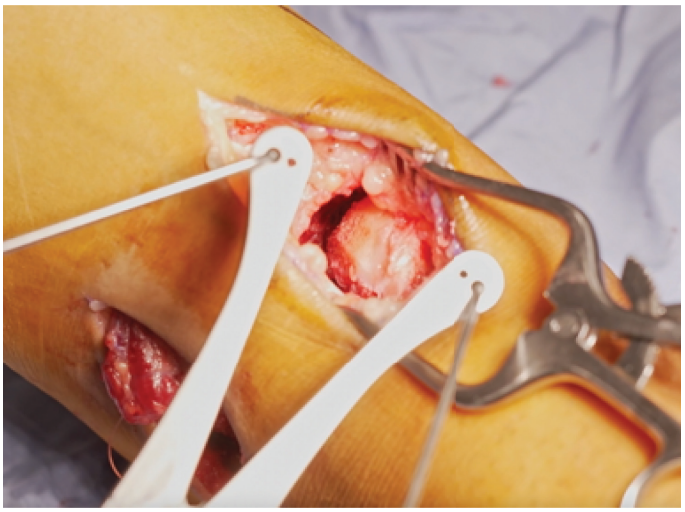

Figure 4. *The talar head has been prepared to a rough surface. In this case, a Hintermann retractor is useful to distract the joint without blocking access to the joint as can be experienced with a lamina spreader placed into a small joint.*

Although not mandatory, the lateral margin of the talonavicular joint can be accessed through the lateral incision, and plantar-lateral cartilage not seen earlier is now debrided. Once the joints are adequately prepared with a burr (Figure 5), they are positioned and temporarily stabilized, clinically and radiologically assessed, then definitively fixed. Working from proximal to distal, the subtalar joint is corrected and held first before correcting the Chopart joints.

Fixation Techniques

The dorsal approach to the talonavicular joint has the distinct advantage of allowing fixation of the subtalar joint from dorsal to plantar, from the neck of the talus just distal to the ankle articular cartilage. Further, the surgeon is afforded improved control and visualization of the hindfoot position without having to elevate the leg and instrument from under the heel. This avoids heel incisions and screw heads which can be problematic and require removal. We have found it beneficial to use headless screws, allowing the starting point to be immediately adjacent to the ankle joint (Figure 6).

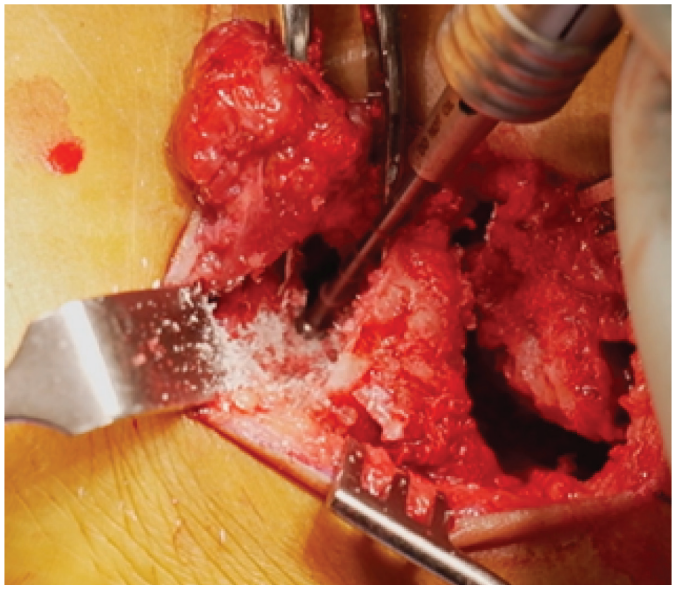

Figure 5. *The denuded joint surfaces are then perforated with a 4 mm burr to expose the subchondral bone. This can also be achieved with a small drill although the 'bone dust' from the burr provides excellent graft material and usually eliminates the need for additional graft.*

The talonavicular and calcaneocuboid joints require compression and rotational stability which can be achieved with trans-articular screws or compression staples or plates. The amount of fixation is titrated according to the quality of bone and the degree of bone contact (Figure 7). Where interposition graft is used, fixation should be more robust. Focal osteopenia is frequently encountered where bone has been unloaded due to the pre-existing deformity and fixation adapted accordingly.

Considerations for Triple Fusion in the Planovalgus Foot

Caskey et al. advocate for the use of lateral column lengthening (LCL) through the CC fusion, using tricortical graft.[17] These authors cite multiple reports of poor outcomes with persistent or recurrent deformity, particularly with planovalgus foot deformity, and report on the use of a wedge graft in the manner of an Evan's LCL interposed in the calcaneocuboid joint. Fusion rates were in keeping with standard triple arthrodesis. In correcting a planovalgus deformity, the hind foot correction can reveal a supination deformity of the forefoot. Pronation correction can be applied across the TN and CC fusion positions, but on occasion, the medial column needs to be plantarflexed via a Cotton osteotomy or 1st tarsometatarsal joint plantar-flexion fusion to restore the neutral tripod position.

Considerations for Triple Fusion in the Equinocavovarus Foot

Here, it is important to consider the condition and context of the deformity. In paralytic foot conditions, following joint debridement, a plantigrade position can often be achieved without difficulty. In recurrent clubfoot, however, larger bone wedges need to be resected due to the medial side soft tissue contracture. Myerson et al. advocate for a single lateral approach with large bone wedges to correct the adductovarus at the Chopart joint.[5] The authors note the importance of tibialis posterior as a deforming force and release it proximal to the ankle joint. For the multiply operated small stiff clubfoot with multiplanar deformity and poor skin quality, frame

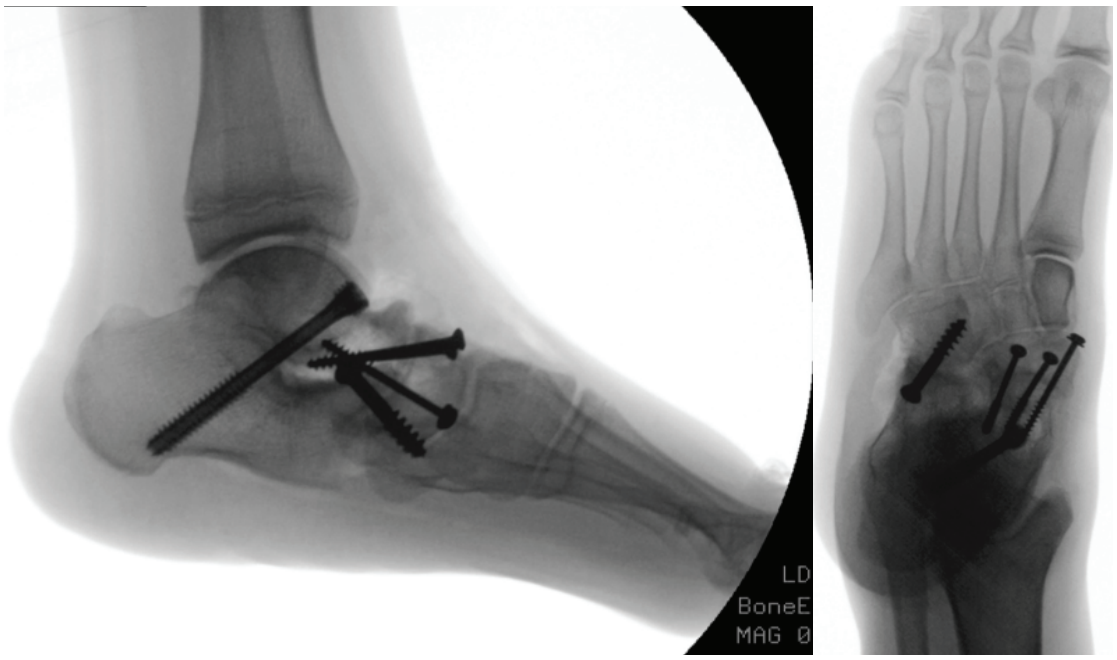

Figure 6. *Triple fusion using screw fixation. Subtalar; A single 7.3 mm headless compression screw, talonavicular; 3 × 4 mm partially threaded screws, calcaneocuboid joint; 6.5 mm partially threaded.*

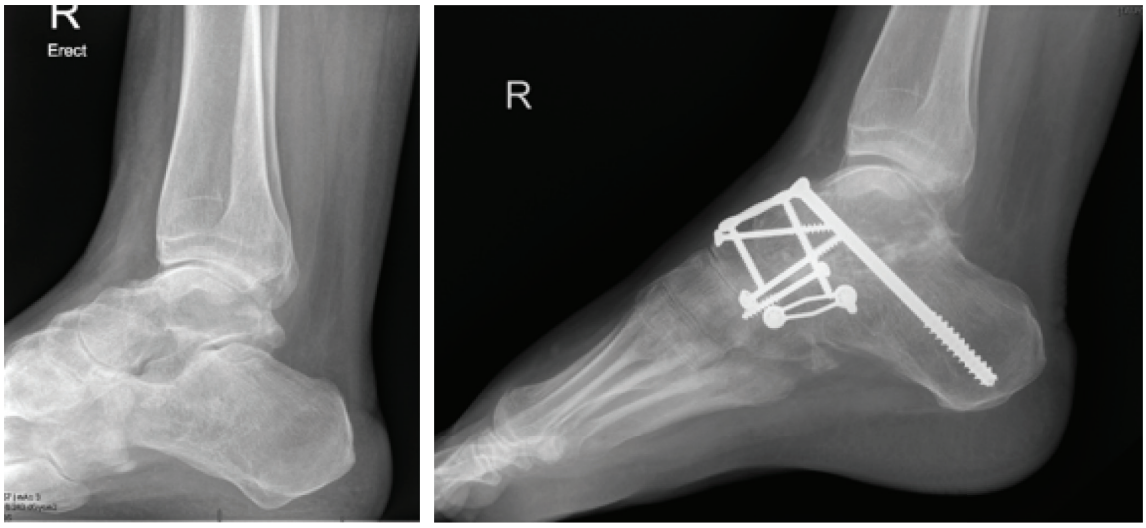

Figure 7. *Lateral x-rays pre- and postoperative in a teenage boy with intellectual impairment and autism with unilateral cavovarus deformity having failed previous soft tissue releases and tibialis posterior tendon transfer, demonstrating hybrid fixation options, with compression screws and compression plating across the talonavicular and calcaneal cuboid joints.*

distraction and gradual correction, with or without U or V hindfoot osteotomies, may be the most reliable option to obtain a better positioned triple fusion. With the widespread use of Ponseti correction, this particular indication is now hopefully disappearing.

In severe equinovarus, triple fusion is an alternative to talectomy, with some authors reporting improved long-term outcomes in the former.[3] In the extreme case with fixed ankle equinus (Figure 8), such as encountered in polio, consideration of a Lambrinudi-type arthrodesis,

Figure 8. *Clinical and radiographic images are presented of recalcitrant deformity that underwent triple arthrodesis, and postoperative radiographs 1 year later reveal stable correction.*

where flat cut bone resections are made to significantly dorsiflex the foot onto a plantarflexed talus.[18]

Case Example 1: A 19-year-old with ataxia telangectasia had residual equinocavovarus despite three previous operations, including multiple tendon transfers and osteotomies. This case highlights the difficulty in predicting the outcome of tendon transfers in patients with ataxia. He underwent triple arthrodesis stabilized with staple fixation; equinus was corrected with removal of large bone wedges and tendoachilles lengthening (Figure 8).

Postoperative Care

- Nonocclusive dressings to allow for early wound ooze due to the superficial nature and tendency for the raw surfaces of the prepared joints to bleed.
- Well-padded postoperative plaster splint allows for swelling.
- Non-weight-bearing for the first 6-8 weeks and then progressive weight-bearing in a supportive splint or boot.

Tips and Pearls

- A dual-incision approach allows thorough joint exposure and preparation, as well as ability to manipulate each joint to an optimal fusion position.
- All joints are prepared first to allow the axis of deformity correction to occur in a multi-planar fashion.
- Subtalar joint access can be difficult in valgus deformities; use hind-foot inversion with gravity, sequential release, and partial joint distraction to begin and increase the working space.
- If using structural graft in the CC joint to lengthen the lateral column, stabilize the subtalar joint to prevent it mal-rotating before correcting the abduction.

Triple Fusion in Charcot Marie Tooth Disease (CMT)

Triple arthrodesis is effective in CMT for severe pes cavovarus and symptomatic instability (Figure 9).
It does not address the foot drop component, and tibialis posterior tendon transfer is required in conjunction.
Rates of persistent pain, anteromedial ankle arthritis and impingement, midfoot arthritis, and plantar callosities are notable in this group, which may reflect the effect of the progressive and sensory component of this neurological disorder.[2,19]

Triple Fusion in Cerebral Palsy (CP)

The neuromuscular imbalance that occurs in cerebral palsy typically deforms the foot into one of two broad categories—equinovarus or planovalgus. In equinovarus

Figure 9. *Severe equinocavovarus in CMT variant occurring from age 14, multiple previous surgeries and nonambulant for 4 years. Limited improvement with 8 weeks of preop casting. Fixation compromised due to small size and osteopenia. Talo-navicular joint was held with a percutaneous temporary k-wire with intra-operative casting helping maintain position. This patient recovered independent mobility post triple fusion.*

deformity, equinus contracture is relatively obvious and needs to be addressed with caution, as it is interlinked with knee kinematics and overlengthening can cause decompensation at the knee including crouch gait. In fixed painful planovalgus, there is dorsolateral subluxation of the navicular, the talar head becomes uncovered and prominent, causing pain and rubbing over the medial foot (Figure 10). There can be symptomatic subfibular impingement due to fixed heel valgus. Often there is early degeneration of the affected joints which makes the decision to fuse somewhat easier. While these patients will often have some degree of gastrocnemius contracture, it may be masked by the aforementioned midfoot break at the talonavicular joint.

Nonoperative measures in cerebral palsy include orthoses, tone management, and muscle and tendon rebalancing surgery. In patients with fixed joint deformity and pain who have failed conservative measures and the foot has become "unbraceable," triple fusion can be considered as a reliable option to restore neutral alignment across the Chopart and subtalar joint and prevent future recurrence despite persisting muscular imbalance. Trehan et al. reported successful maintenance of correction and a high rate of patient satisfaction in 21 patients with CP undergoing triple fusion at long-term follow-up.[20] Tenuta et al. reported on 60 patients at a mean of 17 years with satisfactory results. Their findings were of improved results in the equinovarus feet, postulating that the bone resections in the procedure are more suited to correction of this deformity compared to planovalgus where recurrence and suboptimal outcome were more common in their cohort.[1]

Complications

Short-term complications include infection and nonunion. Nonunion rates reported in the literature are higher (15%) where minimal or no fixation was utilized and typically affect the talonavicular joint. Union rates with rigid compression fixation are much lower.[21] Other complications reported include neuroma and chronic regional pain syndrome. As mentioned earlier, the main long-term complication of concern is adjacent joint arthrosis. This occurs at variable rates in the long-term outcome papers and is not well correlated with pain or function. Wukich et al. report adjacent joint arthrosis at the ankle in 24% and 62% in the midfoot of patients at 10+ years with only 3% graded as severe.[2]

Long-Term Outcomes

One of the most comprehensive reports on triple fusion is a long-term outcome paper of 67 cases, of which over half were polio cases. This review documented high rates of persisting deformity but showed these were subsequently nonprogressive. Rates of nonunion and adjacent joint arthrosis were high, with radiographic degeneration in all ankles (Figure 11). At an average of 44-year follow-up, 69% of patients were graded as "fair" results, although patient satisfaction was high (95%).[22]

Figure 10. *Clinical photographs demonstrating bilateral planovalgus deformity in an 11-year-old boy with cerebral palsy, GMFCS 4.*

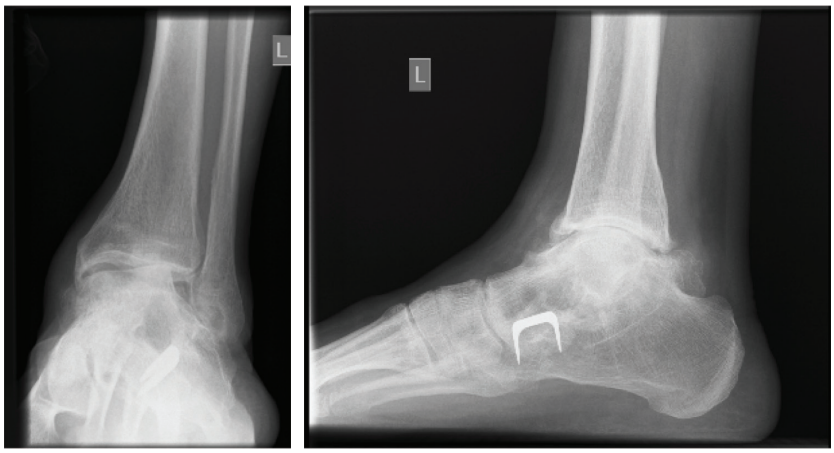

Figure 11. *Weight-bearing AP/lateral x-rays showing marked ankle valgus and arthrosis in a 65-year-old male with a remote history of triple arthrodesis at age 12.*

Other outcome studies show good function at midterm follow-up and high satisfaction, which probably reflects the ability of triple fusion to restore and maintain a plantigrade and stable foot.[4,21]

Of particular importance in the long-term results of triple arthrodesis, progressive valgus at the ankle can be seen in some cases despite satisfactory hindfoot alignment initially. Biomechanical evidence shows an increase in strain on the deltoid in the heel rise position in a cadaveric triple arthrodesis model.[23]

Summary

The senior author's approach to the use of triple fusion in the Pediatric population is outlined. The indications are narrow, reserved for severe fixed deformities, where often joint preserving procedures have failed. Resolving deformity to a plantigrade foot is essential, but nonetheless adjacent joint degeneration is a potential issue at long-term follow-up.

Additional Links

- POSNAcademy: Triple Arthrodesis in the Neuromuscular Foot
- POSNAcademy: Talocalcaneal Tarsal Coalition: Why, When, and How I Treat It

Disclaimer

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References

1. Tenuta J, Shelton YA, Miller F. Long-term follow-up of triple arthrodesis in patients with cerebral palsy. *J Pediatr Orthop*. 1993;13(6):713-716.
2. Wukich DK, Bowen JR. A long-term study of triple arthrodesis for correction of pes cavovarus in Charcot-Marie-Tooth disease. *J Pediatr Orthop*. 1989;9(4):433-437.
3. Galindo MJJ, Siff SJ, Butler JE, et al. Triple arthrodesis in young children: a salvage procedure after failed releases in severely affected feet. *Foot Ankle*. 1987;7(6):319-325.
4. Mann DC, Hsu JD. Triple arthrodesis in the treatment of fixed cavovarus deformity in adolescent patients with Charcot-Marie-Tooth disease. *Foot Ankle*. 1992;13(1):1-6.
5. Li S, Myerson MS. Surgical management of the undercorrected and overcorrected severe club foot deformity. *Foot Ankle Clin*. 2022;27(2):491-512.
6. Lemley F, Berlet G, Hill K, et al. Current concepts review: tarsal coalition. *Foot Ankle Int*. 2006;27(12):1163-1169.
7. Kelly DM. A foot to last a lifetime-is hindfoot fusion ever appropriate for pediatric orthopaedic conditions? *J Pediatr Orthop*. 2021;41(Suppl 1): S39-S46.
8. Swaroop VT, Dias L. Orthopaedic management of spina bifida-part II: foot and ankle deformities. *J Child Orthop*. 2011;5(6):403-414.
9. Ryerson EW. Arthrodesing operations on the feet: Edwin W. Ryerson MD (1872-1961). The 1st president of the AAOS 1932. *Clin Orthop Relat Res*. 2008;466(1):5-14.
10. Seybold JD, Coetzee JC. Primary triple arthrodesis for management of rigid flatfoot deformity. *JBJS Essent Surg Tech*. 2016;6(3):e29.
11. Romness MJ, Menelaus MB. Inlay triple arthrodesis: a technique for the undeformed or valgus foot. *Orthop Traumatol*. 1995;4(2):114-120.
12. Jeng CL, Vora AM, Myerson MS. The medial approach to triple arthrodesis. Indications and technique for management of rigid valgus deformities in high-risk patients. *Foot Ankle Clin*. 2005;10(3):515-521, vi-vii.

13. Jeng CL, Tankson CJ, Myerson MS. The single medial approach to triple arthrodesis: a cadaver study. *Foot Ankle Int*. 2006;27(12):1122-1125.
14. Brilhault J. Single medial approach to modified double arthrodesis in rigid flatfoot with lateral deficient skin. *Foot Ankle Int*. 2009;30(1):21-26.
15. Wülker N, Stukenborg C, Savory KM, et al. Hindfoot motion after isolated and combined arthrodeses: measurements in anatomic specimens. *Foot Ankle Int*. 2000;21(11):921-927.
16. Hyer CF, Galli MM, Scott RT, et al. Ankle valgus after hindfoot arthrodesis: a radiographic and chart comparison of the medial double and triple arthrodeses. *J Foot Ankle Surg*. 2014;53(1):55-58.
17. Frost NL, Grassbaugh JA, Baird G, et al. Triple arthrodesis with lateral column lengthening for the treatment of planovalgus deformity. *J Pediatr Orthop*. 2011;31(7):773-782.
18. Hall JE, Calvert PT. Lambrinudi triple arthrodesis: a review with particular reference to the technique of operation. *J Pediatr Orthop*. 1987;7(1):19-24.
19. Wetmore RS, Drennan JC. Long-term results of triple arthrodesis in Charcot-Marie-Tooth disease. *J Bone Joint Surg Am*. 1989;71(3):417-422.
20. Trehan SK, Ihekweazu UN, Root L. Long-term outcomes of triple arthrodesis in cerebral palsy patients. *J Pediatr Orthop*. 2015;35(7):751-755.
21. Wicks ED, Morscher MA, Newton M, et al. Partial or non-union after triple arthrodesis in children: does it really matter? *J Child Orthop*. 2016;10(2):119-125.
22. Saltzman CL, Fehrle MJ, Cooper RR, et al. Triple arthrodesis: twenty-five and forty-four-year average follow-up of the same patients. *J Bone Joint Surg Am*. 1999;81(10):1391-1402.
23. Song SJ, Lee S, O'Malley MJ, et al. Deltoid ligament strain after correction of acquired flatfoot deformity by triple arthrodesis. *Foot Ankle Int*. 2000;21(7):573-577.