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Tips, Quips and Pearls

Vertical Wire Forefoot Fixation: An Advanced Technique for the Dynamic External Fixation Apparatus

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ABSTRACT

External fixation is used for the correction of select foot and ankle deformities. We have found the traditional forefoot crossing wire technique to be insufficient in terms of both individual metatarsal control and forefoot manipulation when using a dynamic ring fixator to correct forefoot deformities. We developed a forefoot fixation technique at the University of Cincinnati Medical Center, using 5 vertical wires to gain greater forefoot control while performing more precise skeletal manipulation for multiplanar deformity correction. The associated risks of infection, neurovascular injury, and other soft-tissue injury should be further investigated. This proposed vertical wire construct is an advanced method with which the foot and ankle surgeon can correct complex lower limb deformities.

Severe lower extremity deformities can have life-altering effects. The incidence of Charcot-Marie-Tooth disease, which can lead to a cavus foot deformity, is 1 in 2500 people (1). The incidence of metatarsus adductus ranges from 1 to 3 in 1000 births, and the incidence of clubfoot is approximately 1 in 1000 births (2,3). Surgery is indicated to address residual congenital deformities as well as acquired foot deformities (4–6). Serial casting, external fixation, and internal fixation have all been used for the correction of lower extremity deformities (7). The external ring fixator was largely developed by Russian surgeon Gavril Ilizarov and gained popularity in the West in the 1980s (8,9). The next major advancement was the hexapod frame, which uses 6 obliquely oriented struts, and can gradually correct deformities under the guidance of computer software. Hexapod and ring fixation are very versatile and are commonly used to correct multiplanar deformities (10,11).

We have found the traditional forefoot wire technique to be insufficient in terms of both individual metatarsal control and forefoot manipulation when using a dynamic ring fixator to correct forefoot deformities. We have thus developed a vertical, 5-wire technique for forefoot fixation and correction.

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The traditional forefoot wire fixation technique generally consists of 2 transosseous wires directed obliquely across the forefoot with each wire securing 2 to 3 metatarsals. The traditional technique maintains the transverse arch and forefoot position, while a more proximal deformity is being corrected. Axial wires may be necessary to prevent contractures in the toes (8,11). Although this construct does stabilize the forefoot, it limits the ability to manipulate the forefoot because it does not offer independent control of each metatarsal. Such control is often required for correction of forefoot or midfoot deformities in the transverse, sagittal, and coronal planes. It is more difficult to perform gradual correction of a deformity with this traditional construct because forefoot manipulation would create a large opening at cuneiform or metatarsal osteotomy sites (Fig. 1).

Our vertical wire technique provides finer forefoot control during gradual deformity correction with the dynamic Ilizarov apparatus. This technique consists of attaching 5 parallel vertical wires, 1 through each distal metatarsal metaphysis, to a forefoot ring that is usually oriented orthogonal to the second ray. Olive wires may be used if a rotational component in the coronal plane is desired to address forefoot varus or valgus. To the best of our knowledge, there are no existing peer-reviewed publications exclusively outlining this vertical wire technique. It has been pictured and mentioned in the Burn Deformities chapter of Kirienko, Villa, and Calhoun's textbook *Ilizarov Technique for Complex Foot and Ankle Deformities* (11). This technique is a valuable tool for the foot and ankle surgeon who undertakes challenging reconstructive cases of lower limb deformities.

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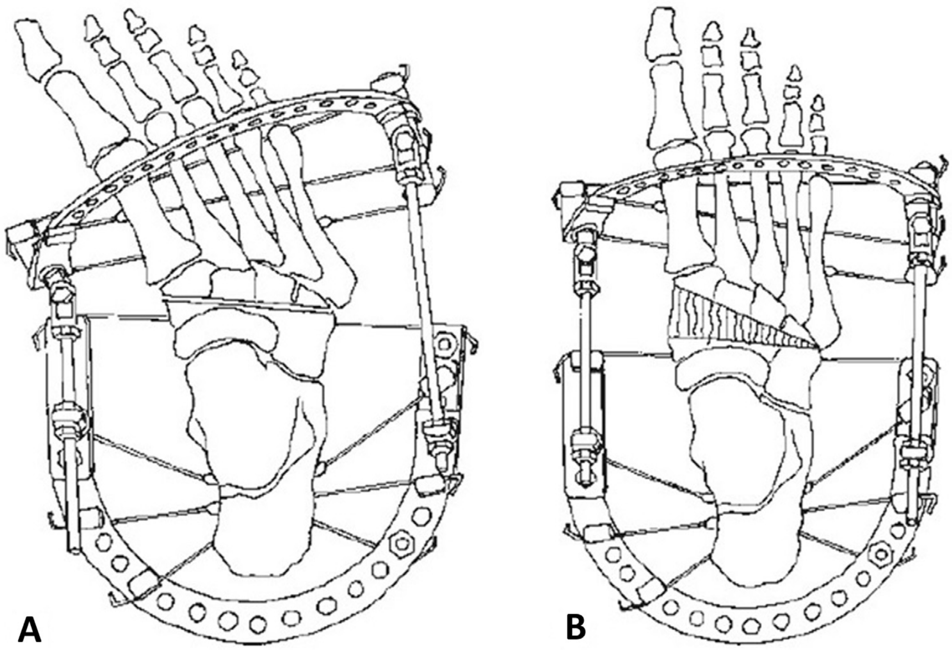

Fig. 1. Traditional forefoot wire fixation technique (*A*). A large amount of osseous regeneration is needed when the forefoot deformity is corrected with the traditional technique (*B*). Images used with permission (11).

Patients and Methods

A thorough preoperative clinical examination with radiographic analysis precedes any lower limb reconstruction operation. Foot and ankle radiographs and long leg films must be evaluated. Computed tomography images can yield additional information, especially when joints are involved in the deformity. The patient is positioned supine on the operating table. Intraoperative fluoroscopy helps direct and ensure proper wire and osteotomy placement when using external fixation. Any acute rearfoot and ankle procedures must be performed before forefoot procedures. The surgeon should use either a buttress or miter frame to allow for all necessary deformity correction. The tibial block and U-ring should be fixated to leg and rearfoot. A forefoot ring is positioned in the coronal plane and fixated to the U-ring with 6 adjustable struts to allow the desired correction. A vertical wire is then driven orthogonally through the distal metaphysis of the second metatarsal. The forefoot ring is secured to this vertical wire. The remaining 4 forefoot wires are passed vertically through and orthogonal to the corresponding metatarsals (Fig. 2). Puncturing or spearing tendons or sesamoid bones should be avoided. Up to 5 wires can be placed if needed, 1 securing each metatarsal. It is important that stable transverse wire fixation proximal to the center of rotation angulation, will act as a buttress during any forefoot deformity correction. The surgeon must perform osteotomies at

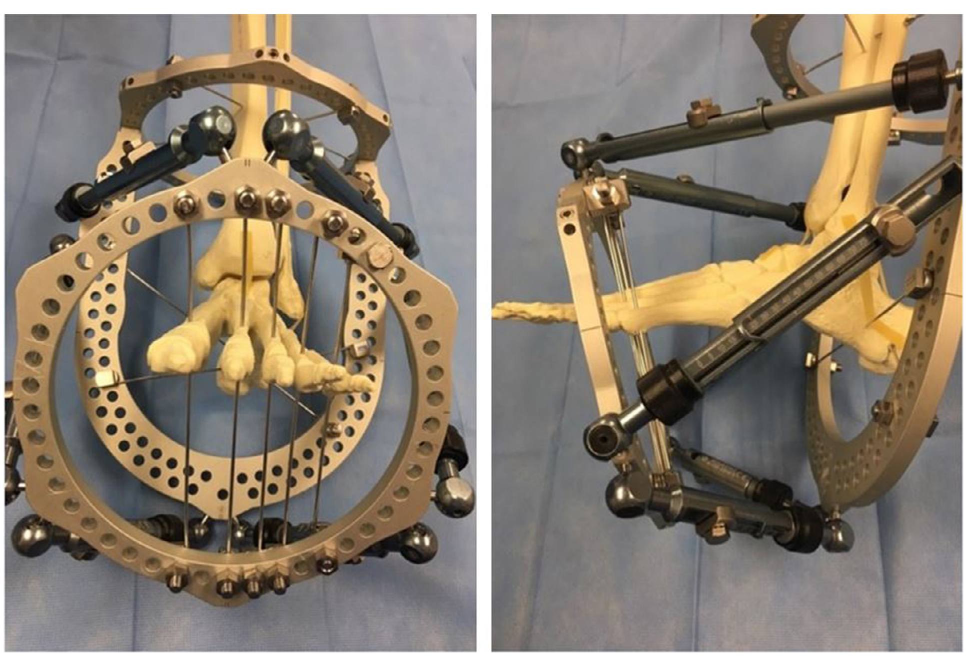

Fig. 2. Five vertical wires are placed orthogonally to the metatarsals. The wires are positioned at the distal metatarsal metaphysis, tensioned, and securely fastened to the forefoot ring. The forefoot ring can move in any plane to correct a deformity using the adjustable struts.

or near the center of rotation angulation, ideally leaving a cortical hinge intact to act as a pivot point. The forefoot is then gradually translated or rotated against the midfoot or rearfoot. Distraction osteogenesis will occur as the forefoot apparatus is adjusted according to surgeon protocol (Fig. 3).

Correcting metatarsus adductus requires a partial osteotomy near the base of each metatarsal while the dynamic forefoot ring—which is attached to 5 vertical wires—gradually rotates, distracts, and translates laterally. A transverse olive wire buttressed against the lateral cuboid provides counterpressure during manipulation (Fig. 3). The osteotomy sites ideally maintain 1 cortex on which to pivot as the forefoot ring rotates laterally. Similarly, correcting a nonprogressive anterior pes cavus deformity requires dorsiflexion of the forefoot with respect to the midfoot (12). After making a plantar midfoot osteotomy, 5 olive wires are placed vertically in the forefoot with the olives abutting the plantar aspect of metatarsals. A transverse olive wire through the midfoot provides stability and counterpressure as the deformity is gradually reduced. Third, correcting a metatarsus primus equinus deformity would entail a corticotomy at the plantar metatarsal metaphysis, a vertical olive wire with the olive abutting the plantar distal metatarsal cortex for distribution of the correcting force, and an olive wire proximally with the olive against the dorsal metatarsal base to resist movement.

Fig. 4 exemplifies our case of a staged reconstruction with initial vertical forefoot wire correction followed by medial column beaming. The patient was partial weightbearing throughout the entire recovery. Fig. 5 demonstrates the vertical wire technique used for staged correction of a complex foot deformity.

It is important to build the frame to the wires, rather than bending the wires to fit the frame, because bent wires place unwanted forces on the soft-tissue and osseous structures. Ensuring good Ilizarov technique can avoid excessive motion at the pin−skin interface and subsequently reduce the risk of pin site irritation and infection (8,13). Olive wires, compared to smooth wires, provide enhanced multiplanar control of individual metatarsals. The buttress of the olive against the metatarsal cortex counteracts the intrinsic deforming forces and transmits the distraction force of the frame to the bone as the apparatus is gradually adjusted. Following wire fixation to the rings, the 6 struts are adjusted to the desired length and then mounted. Before wound closure, a vascular examination should be performed at the toes and incision edges. Wounds are then irrigated and incisions are closed in layered fashion. The incisions, pin sites, and frame are dressed per surgeon preference. The patient is awakened from anesthesia and transferred to the postanesthesia care unit, in which a postoperative neurovascular examination is performed. The patient must remain non-weightbearing on the operative limb because of the orientation of the forefoot wires.

Discussion

Creating osteotomies or corticotomies and using callus distraction allow the surgeon to correct deformities with gradual manipulation of the forefoot construct. The surgeon can rotate, translate, or angle the independent forefoot ring with respect to the proximal frame. Osteotomies are strategically oriented to guide callus distraction and allow translation in the desired plane. An independent forefoot ring in the hexapod construct can accommodate any combination of rotation, translation, angulation, and even axial lengthening or shortening to correct complex forefoot deformities. There has been little variation discussed in foot and ankle literature regarding forefoot wire placement techniques. Nayagam (14) explains the traditional construct of capturing the first and adjacent metatarsals with 1 oblique wire, and the fifth and adjacent metatarsals with a second oblique wire. Some variation of this traditional technique has also been described (11). The goals of our fixation method include achieving optimal control of the metatarsals during deformity correction and minimizing the amount of osseous regeneration needed (thus shortening the time spent on callus distraction and regenerate maturation), all while preserving the contour of the transverse arch and maintaining the relative metatarsal parabola.

There are identifiable weaknesses with this technique. Vertical forefoot wires may pass through muscle, tendon, or neurovascular structures. The risk of soft-tissue entanglement can be reduced by oscillating

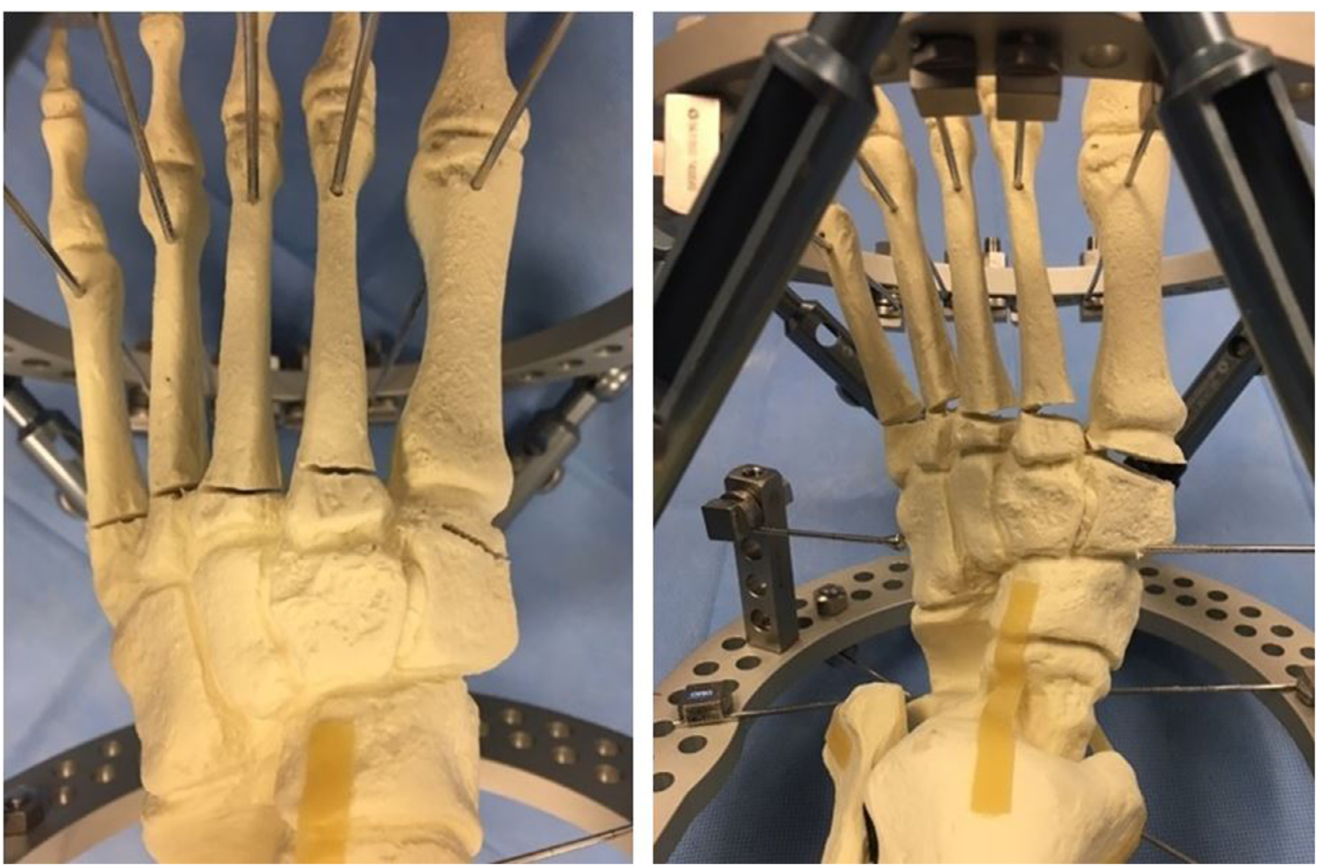

Fig. 3. Cortical hinges are left intact when partial osteotomies are made (left). The lateral translation of the forefoot ring creates 5 small openings, which require osseous regeneration (right). The volume of regenerate needed is significantly lower than the volume needed with the traditional forefoot wire technique, as seen in Fig. 1. Note the transverse midfoot olive wire provides counterpressure on the lateral midfoot.

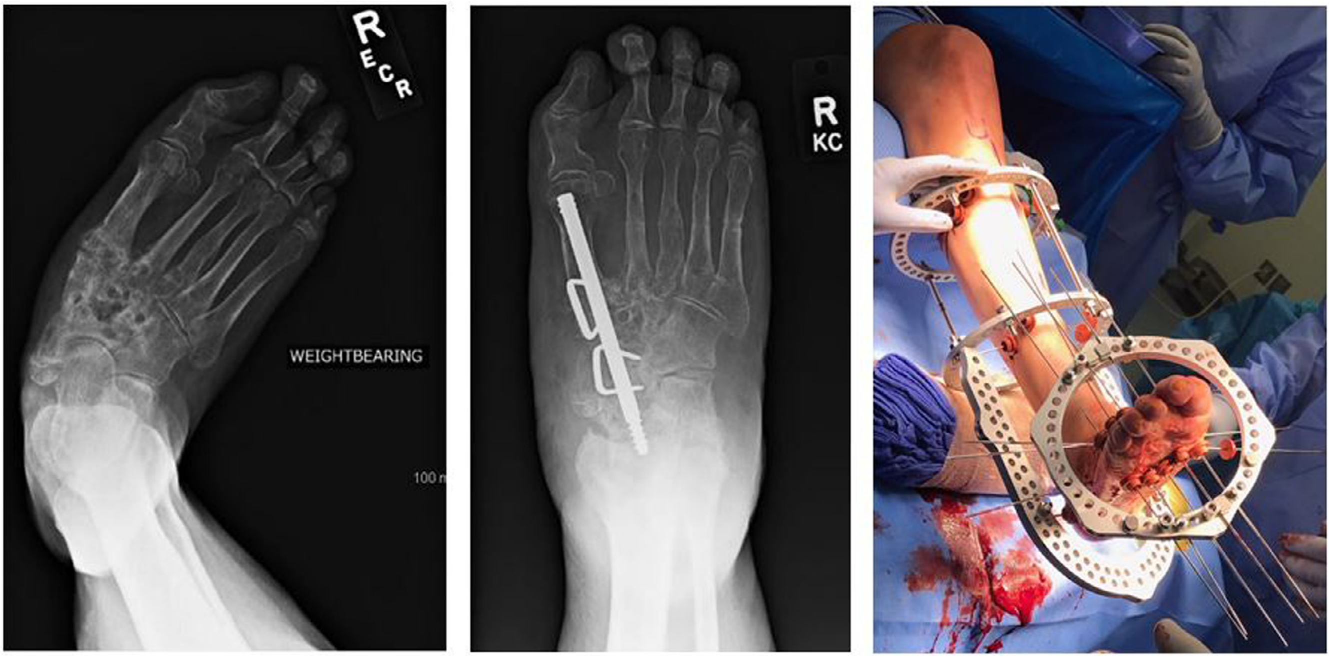

Fig. 4. A preoperative (left) and postoperative (center) radiograph show correction of the deformity. The vertical wire method with small osteotomies in the metatarsals was used to correct the deformity (right). Once corrected, medial column beaming was performed to maintain the medial longitudinal arch. The patient was 50% weightbearing throughout this entire reconstruction.

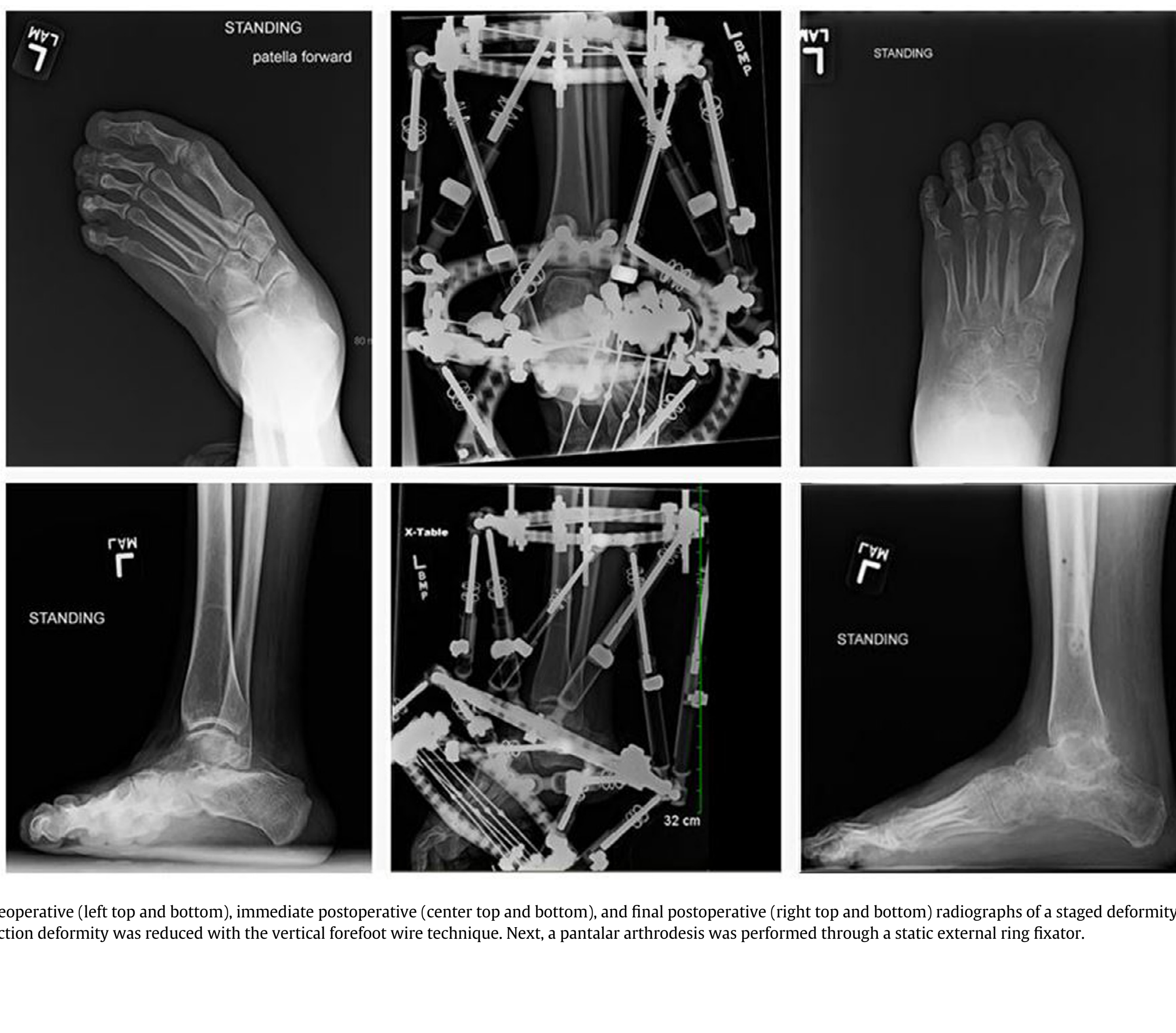

Fig. 5. Preoperative (left top and bottom), immediate postoperative (center top and bottom), and final postoperative (right top and bottom) radiographs of a staged deformity correction. The abduction deformity was reduced with the vertical forefoot wire technique. Next, a pantalar arthrodesis was performed through a static external ring fixator.

the wires as they are driven vertically. Tendon spearing can often be avoided by watching for sudden movements or twitches in the toes as the wires are passed through the foot. These signs offer the surgeon a chance to redirect wires. Metatarsal fracture at the site of wire insertion is a potential risk, although we have not encountered it. It is well documented that using smaller rings, adding more wires, adequately tensioning wires, and ensuring proper wire fixation bolt tightening will increase bone stabilization and frame stability (15−19). Overtightening 1 vertical wire will reduce the tension of adjacent, parallel wires (19). Ideally, all wires on a ring are simultaneously tensioned (20); however, doing so with 5 parallel vertical wires would be nearly impossible. The surgeon must use his or her judgment to obtain similar tension on the wires. Our experience has supported that applying minimal tension to the vertical wires is sufficient to control the forefoot during correction. The ideal amount of tension on vertical forefoot wires is an area for future investigation. We believe the additive stability from the 5 wires contributes to frame stability in the forefoot, but further studies are needed to confirm this.

Neurovascular injury is a potential complication of this technique. The medial terminal branch of the deep peroneal nerve, the branches of the superficial peroneal and sural nerves, the branches of the medial and lateral planter nerves, and the networks of superficial and deep veins and arteries are all at risk of puncture by wire (21−26). The dorsal venous arch runs transversely across the distal metatarsals (24). The dorsal metatarsal arteries travel between the metatarsals rather than directly dorsal to them (22). The deep plantar arterial arch distributes 4 plantar metatarsal arteries, which also travel within the intermetatarsal spaces (23). Solomon et al (25) dissected 68 cadaver lower legs and described 11 patterns of dorsal foot neuroanatomy. The plantar nerves contain communicating branches that course diagonally in the plantar forefoot (26). The significant number of neurovascular structures and their anatomic variation certainly place them at risk for puncture by vertical wires. It is the authors' recommendation to oscillate the wires when driving them through soft tissue to minimize entanglement. The neurovascular structures are small in diameter at the level of the distal metaphysis of the metatarsals, yet an intraoperative vascular examination and postoperative neurovascular examination should be performed to assess neurovascular compromise. We are not aware of any forefoot dissection publications assessing neurovascular injury secondary to vertical wire placement. This is certainly an area for future cadaveric dissection studies.

Finally, all external fixation devices are associated with pin site infections (8,13,27). Accurately placing wires, applying the recommended tension to wires, performing aseptic dressing changes, and addressing patient comorbidities can reduce the risk of postoperative infection. Cellulitis at the pin−skin interface is initially treated with oral antibiotics. According to Gessmann et al (27), a lower number of pin −skin interfaces lowers the risk of local cellulitis. The vertical wire technique creates at least 10 forefoot pin sites so these patients by default remain at higher risk for cellulitis.

Weightbearing is contraindicated while using our method for deformity correction because the forefoot forces associated with ambulation are collinear with the axis of the vertical wires. The metatarsal may only have an olive against the bone cortex to prevent sliding along the wire. One of the principles of Ilizarov technique is applying weight on the operative extremity while in an external fixation frame (11). Our technique does not follow this aspect of Ilizarov technique.

In conclusion, general external fixation principles apply when using this vertical wire fixation technique. We developed this technique to gain greater control of the forefoot while performing more precise skeletal manipulation for deformity correction in any plane. This technique is not without risks, and the potential risks warrant further investigation. The vertical wire construct is an advanced method with which the foot and ankle surgeon can correct complex lower limb deformities.

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References

1. Burns J, Remond A, Ouvrier R, Crosbie J. Quantification of muscle strength and imbalance in neurogenic pes cavus, compared to health controls, using hand-held dynamometry. Foot Ankle Int 2005;26:540–544..
2. Tax HR, Albright T. Metatarsus adducto valgus: a simplified approach to treatment. J Am Podiatry Assoc 1978;68:331–338.
3. Balasankar G, Luximon A, Al-Jumaily A. Current conservative management and classification of club foot: a review. J Pediatr Rehab Med 2016;9:257–264.
4. Hosseinzadeh P, Peterson ED, Walker J, Muchow RD, Iwinski HJ, Talwalkar VR, Milbrandt TA. Residual forefoot deformity predicts the need for future surgery in clubfeet treated by Ponseti casting. J Pediatr Orthop B 2016;25:96–98.
5. Eidelman M, Keren Y, Katzman A. Correction of residual clubfoot deformities in older children using the Taylor spatial butt frame and midfoot Gigli saw osteotomy. J Pediatr Orthop 2012;32:527–533.
6. Pinzur MS. Neutral ring fixation for high-risk nonplantigrade Charcot midfoot deformity. Foot Ankle Int 2007;28:961–966.
7. Lee DJ, Schaffer J, Chen T, Oh I. Internal versus external fixation of Charcot midfoot deformity realignment. Orthopedics 2016;39:595–601.
8. Abicht BP, Roukis TS. History and Evolution of External Fixation. In: Cooper PS, Polyzois VD, Zgonis T, eds. External Fixators of the Foot and Ankle, Philadelphia: Lippincott Williams & Wilkins, 2013.
9. Burns PR, McMillen RL. Safe Lower Extremity Anatomic Zones for External Fixation. In: Cooper PS, Polyzois VD, Zgonis T, eds. External Fixators of the Foot and Ankle, Philadelphia: Lippincott Williams & Wilkins, 2013.
10. Iobst CA. New trends in ring fixators. J Pediatr Orthop 2017;37(suppl 2):18–21.
11. Kirienko A, Villa A, Calhoun JH. Burn deformities. In: Overgaard K, ed. *Ilizarov Technique for Complex Foot and Ankle Deformities*, New York: Taylor & Francis, 2004:1–32.
12. Wicart P. Cavus foot, from neonates to adolescents. Orthop Traumatol Surg Res 2012;98:813–828.
13. Bairaktari C, Athanassiou G, Panagiotopoulos E, Deligianni D. Towards a solution of the wires' slippage problem of the Ilizarov external fixator. Eur J Orthop Surg Traumatol 2015;25:435–442.
14. Nayagam S. Safe corridors in external fixation: the lower leg (tibia, fibula, hindfoot, and forefoot). Strat Traum Limb Recon 2007;2:105–110.
15. Gessmann J, Jettkant B, Schildhauer TA, Seybold D. Mechanical stress on tensioned wires at direct and indirect loading: a biomechanical study on the Ilizarov external fixator. Injury 2011;42:1107–1111.
16. Donaldson FE, Pankaj P, Simpson AH. Bone properties affect loosening of half-pin external fixators at the pin-bone interface. Injury 2012;43:1764–1770.
17. Renard AJ, Schutte BG, Verdonschot N, van Kampen A. The Ilizarov external fixator: what remains of the wire pretension after dynamic loading? Clin Biomech 2005;20:1126–1130.
18. Wu JJ, Shyr HS, Chao EY, Kelly PJ. Comparison of osteotomy healing under external fixation devices with different stiffness characteristics. J Bone Joint Surg 1984;66:1258–1264.
19. Bronson DG, Samchukov ML, Birch JG, Browne RH, Ashman RB. Stability of external circular fixation: a multi-variable biomechanical analysis. Clin Biomech 1998;13:441–448.
20. Sarpel Y, Gulsen M, Togrul E, Capa M, Herdem M. Comparison of mechanical performance among different frame configurations of the Ilizarov external fixator: experimental study. J Trauma 2005;58:546–552.
21. Logan BM, Hutchings RT. Foot. In: Hyde M, Cicalese B, eds. McMinn's Color Atlas of Foot and Ankle Anatomy, Philadelphia: Elsevier Saunders, 2012:68–105.
22. Alagox MS, Orbay H, Uysal AC, Comert A, Tuccar E. Vascular anatomy of the metatarsal bones and the interosseous muscles of the foot. J Plast Reconstr Anesthet Surg 2009;62:1227–1232.
23. Orbay H, Kerem M, Unlu RE. Vascular anatomy of plantar muscles. Ann Plast Surg 2007;58:420–426.
24. Ricci S, Moro L, Antonelli Incalzi R. The foot venous system: anatomy, physiology and relevance to clinical practice. Dermatol Surg 2014;40:225–233.
25. Solomon LB, Ferris L, Tedman R, Henneberg M. Surgical anatomy of the sural and superficial fibular nerves with an emphasis on the approach to the lateral malleolus. J Anat 2001;199:717–723.
26. Jones JR, Klenerman L. A study of the communicating branch between the medial and the lateral plantar nerves. Foot Ankle 1984;4:313–315.
27. Gessmann J, Citak M, Jettkant B, Schildhauer TA, Seybold D. The influence of a weight-bearing platform on the mechanical behavior of two Ilizarov ring fixators: tensioned wires vs. half-pins. J Orthop Surg Res 2011;6:1–11.