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ORIGINAL PAPER

Double calcaneal osteotomy with minimally invasive surgery for the treatment of severe flexible flatfeet

Hany Mourkus [1] · Hari Prem [2]

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Abstract

Background Severe flexible flatfoot deformity in children and adolescents is a complex problem. Calcaneal lengthening remains the gold standard for surgical correction at this institution. However, in a minority of patients, inadequate correction of valgus is noted at surgery and a further calcaneal shift osteotomy is done.

Methods We have conducted a retrospective review of ten patients who received 15 combined minimally invasive calcaneal shift and calcaneal lengthening osteotomies, which were all performed by the senior author. All patients had failed conservative treatment. We describe our technique for double calcaneal osteotomy combining minimally invasive surgery (MIS) for the medial calcaneal shift with traditional open calcaneal lengthening osteotomy for treating children and adolescents with severe flexible flatfoot deformity.

Results The average shift achieved was 8.07 mm. The average improvement in Meary's angle was 14.99°. All of them had radiological and clinical union at 12 weeks. None of the patients developed sural nerve injury, wound breakdown, or infection of the MIS incision.

Conclusion In double calcaneal osteotomies, the MIS calcaneal medial shift technique can be used safely with potentially lower risks of wound complications and sufficient medial shift, compared to conventional open extensive surgery.

Implications MIS calcaneal shift osteotomy has an advantage over open conventional open technique in cases where the skin is under tension like in combined calcaneal lengthening osteotomy. With experience, the procedure can be faster than an open procedure.

Keywords Calcaneal lengthening · Calcaneal osteotomy · Calcaneal osteotomies · Minimal invasive surgery · Flatfoot deformity · Flexible flatfoot

Introduction

Most children with flexible flat feet have mild to moderate deformities and remain asymptomatic or minimally symptomatic. However, severe flexible flatfoot deformity in children and adolescents is a complex problem. These patients are recalcitrant to treatment with insoles and physiotherapy and remain symptomatic with pain and functional limitations in activities of daily living. In our experience, these patients have a severe heel valgus with a lax subtalar joint and subluxation of the midfoot into abduction at the talonavicular joint, creating a severe shortening of the lateral column.

Surgical intervention can be considered in such cases [1]. Surgical options include arthroereisis (sinus tarsi implant) [2], foot reconstruction (calcaneal lengthening or medial shift osteotomies, first ray stabilization procedures, gastrocnemius recession, tibialis posterior tendon augmentation) [3–6], or triple arthrodesis. Arthrodesis is generally avoided, as the severe stiffness alters the mechanics of the foot and is only used in very severe cases, especially those associated with neuromuscular conditions [7–9].

Calcaneal lengthening remains the gold standard for surgical correction at this institution. However, in a minority of patients, inadequate correction of valgus is noted at surgery and a further calcaneal shift osteotomy is done.

We describe our technique for double calcaneal osteotomy combining minimally invasive surgery (MIS) for the medial calcaneal shift with traditional open calcaneal lengthening

✉ Hany Mourkus
hany.mourkus@nhs.net

1 University Hospitals of North Midlands NHS Trust, Stoke-on-Trent, UK

2 The Royal Orthopaedic Hospital NHS Foundation Trust, Birmingham, UK

osteotomy for treating children and adolescents with severe flexible flatfoot deformity.

Materials and methods

We have conducted a retrospective review of ten patients who received 15 combined minimally invasive calcaneal shift and calcaneal lengthening osteotomies, which were all performed by the senior author. All patients had failed conservative treatment. Five were bilateral procedures done simultaneously and the other five were unilateral procedures. All underwent autologous iliac tricortical bone graft and gastrosoleus “tongue in groove” fractional lengthening. In addition, medial cuneiform dorsal open wedge osteotomy was performed in all of them, except one patient.

Surgical technique

All the procedures were done under general anesthesia supplemented with a regional anesthetic block. Intravenous antibiotics were given on induction of anesthesia. Thigh tourniquet was used in all patients to control bleeding. Patients were positioned supine with a sandbag under the ipsilateral hip to allow internal rotation of the hip and improve the exposure to lateral aspect of the foot. A sterile bowl was used to elevate the leg and have the heel hang free over the edge. The sandbag was removed after the calcaneal osteotomies were performed, to allow better access to the medial cuneiform.

An image intensifier (II) was used for obtaining axial, AP, and lateral views. It was also used to mark the site of the MIS osteotomy. It is useful to draw an outline of the calcaneum and lines representing the osteotomies. These lines act as a visual aid when positioning and moving the MIS burr.

Under anaesthesia, dorsiflexion of the foot was attempted with the heel in neutral, in the coronal plane. If dorsiflexion was not possible due to tight calf muscles, fractional lengthening of the gastrosoleus was done through a posterior incision. In all these patients, knee flexion did not produce adequate dorsiflexion, and therefore none had isolated gastrocnemius release. Once dorsiflexion was achieved, we proceeded to do the bony reconstruction.

Through a horizontal incision centered on the anterior third calcaneum, a vertical calcaneal osteotomy was performed 1.5 cm proximal to the calcaneocuboid joint and in front of the middle facet. A 2-mm K-wire was advanced from the interspace between the fourth and fifth metatarsals across the cuboid and the anterior calcaneal segment, to stabilize the calcaneocuboid joint and avoid subluxation of the anterior calcaneum. In some cases an additional K-wire was added if there was subluxation at the calcaneocuboid joint during distraction inspite of one transfixing wire.

A tricortical trapezoid autologous iliac bone graft was obtained and inserted into the osteotomy to allow lengthening of the lateral column. The K-wire was then advanced across the osteotomy site to engage the posterior calcaneal fragment.

If after this correction, the first metatarsal head was elevated compared to the fifth metatarsal head with the hindfoot in neutral position, medial cuneiform dorsal open wedge osteotomy was performed to correct the forefoot supination deformity. The cuneiform osteotomy was performed through a direct dorsal longitudinal incision, just medial to the extensor hallucis longus. No fixation was used for the cuneiform osteotomy.

The “Plantar Malleoli View Sign” (suggested by Pellegrin [10]) was used to assess the correction. The correction is ideal if both malleoli are seen. If just the lateral malleolus is seen, there is overcorrection. If only the medial malleolus is seen, there is undercorrection, and MIS medial calcaneal shift osteotomy was performed.

Under II, the calcaneal shift osteotomy line was marked with a pen in a superior-inferior direction, using a hypodermic needle as a radiological marker. This line should be at least 5–6 mm anterior to plantar fascia attachment on the heel. The midpoint of the line was then identified and a 3–4-mm vertical incision is made down to bone in line with the osteotomy. A small periosteal elevator, which is part of the MIS kit, is used to elevate the periosteum in line with the osteotomy and to get a tactile feedback about the superior and inferior borders of the calcaneum. A 3 × 20 mm Shanon burr (Wright Medical UK Ltd., Hertfordshire, UK) was used with a low-speed high-torque power unit. The entry point for the burr in the lateral wall of the calcaneus was the midpoint of the osteotomy line. Once the burr penetrated the lateral cortex, it was moved in the manner of a windshield wiper blade, keeping the burr perpendicular to the lateral cortex and gently advancing it to reach the medial cortex. The lateral cortex is initially cut only to the extent that a free movement of the burr is facilitated, in line with the osteotomy (usually for about 1 cm). The medial cortex is then penetrated and completely cut. The burr is then rotated until the superior, inferior, and lateral cortices are also cut, with tactile feedback playing an important role. Confirmation of the cut can be made with a 3–4-mm Lambotte osteotome.

Once the osteotomy was completed, a small bone lever/ Lambotte osteotome was introduced through the osteotomy into the distal fragment and then the mobile proximal tuberosity fragment was shifted medially by leaning the instrument against it. This osteotomy resulted in excision of a 3-mm segment of the calcaneum (the width of the burr), reducing soft tissue tension and allowing easy mobilization of the tuberosity. Once the medial shift was satisfactory, it was maintained during fixation by keeping the leverage instrument in situ. If the calcaneal apophysis was closed, a 3.2-mm cannulated screw guide wire was advanced under II control, across the osteotomy, through a stab incision on the heel. A 5.5-mm cannulated drill was passed over the guide and fixation was done using a 8-mm cannulated screw. If the apophysis was open, two 2-mm K-wires were used to achieve fixation. The wires were subsequently removed after 6 weeks in the out-patient department (OPD).

All wounds were closed with absorbable sutures. The MIS wound required only a single stitch. The foot was immobilized in a well-padded below-knee cast in neutral position. Patients were mobilized non-weight bearing for six weeks.

Postoperatively, patients were reviewed in OPD for wound check and change of plaster at three weeks. At six weeks, they were reviewed for removal of the calcaneocuboid wire and cast change. Full-weight bearing was commenced in the new cast and maintained for six weeks. The prolonged immobilization was directed towards the calcaneal lengthening site and was not for the calcaneal MIS osteotomy. At the three month follow-up, radiographs were obtained and the patients were allowed unaided full-weight bearing and were referred for physiotherapy and advised gradual return, as tolerated to all normal activities.

Results

Patients were aged between nine and 19 years old (average 13.53). All patients in this series had medial midfoot pain and aches around the hindfoot with prolonged walking, physical education activities, and sports, after at least six months of conservative management.

Eleven calcaneal shift osteotomies were fixed with a single 8-mm cannulated screw, while four calcaneal shift osteotomies were fixed with percutaneous 2-mm K-wires that were removed after six weeks in the out-patient department.

We measured the amount of shift using digital imaging software Fiji [11]. The average shift achieved was 8.07 mm (Table 1; Figs. 1, 4, 5, and 6). The average improvement in Meary's angle was 14.99° (Table 1, Figs. 2, 3, 4, 5, and 6).

Table 1 Achieved patient correction

Patient	Translation	Initial angle	Final angle	Angle correction
A01	8.88	− 24.20	− 13.40	10.80
A02	6.78	− 18.60	− 2.30	16.30
A03	6.76	− 24.30	− 18.70	5.60
A04	6.80	− 13.10	− 2.40	10.70
A05	7.53	− 22.90	− 7.60	15.30
A06	3.63	− 29.60	− 0.30	29.30
A07	9.91	− 21.50	− 2.40	19.10
A08	6.13	− 14.60	− 10.30	4.30
A09	10.96	− 13.10	− 9.10	4.00
A10	8.32	− 16.10	− 2.80	13.30
A11	11.86	− 11.30	2.10	13.40
A12	9.47	− 5.20	14.10	19.30
A13	5.47	− 2.80	10.80	13.60
A14	6.74	− 19.60	1.10	20.70
A15	11.82	− 19.10	10.00	29.10
Average	8.07	− 17.07	− 2.08	14.99

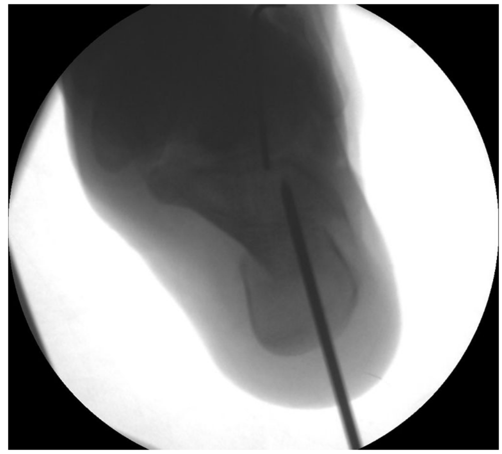

Fig. 1 Patient A10 intra-operative axial image intensifier X-ray showing lateral calcaneal translation of 8.32 mm (3.2 mm guide wire is used as a marker for measuring)

All of the patients received the same post-operative protocol. All of them had radiological and clinical union at 12 weeks. None of the patients developed wound breakdown or infection of the MIS incision. However, one patient had migration of the lengthening osteotomy K-wire under the skin and needed removal of the K-wire under anesthesia. Another patient developed superficial infection of the lengthening incision that responded to oral antibiotics. There was no sural nerve injury in any of the patients.

Patients were followed up for an average of 29.88 weeks. At the final review, none of the patients had medial foot pain. Except for one patient who was not happy with the final shape of the foot and the lateral prominence at the calcaneocuboid joint, all the rest of the patients were satisfied with the outcome (14 out of the 15 osteotomies performed). All but one patient stated that they would undergo the procedure again.

Fig. 2 Patient A10 pre-operative weight-bearing lateral foot X-ray showing Meary's angle of − 16.10°

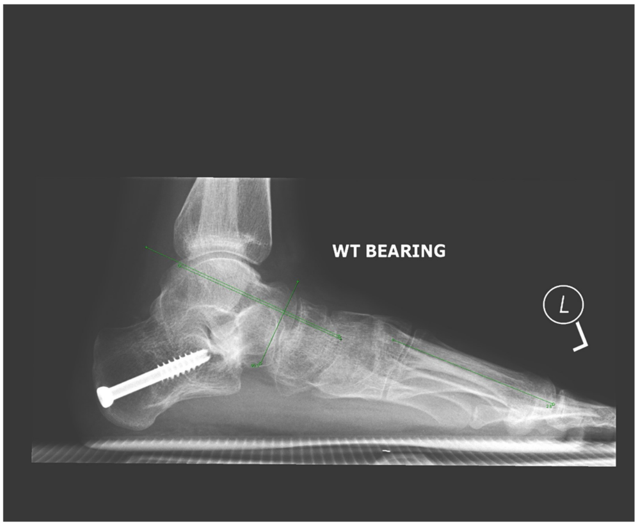

Fig. 3 Patient A10 post correction weight-bearing lateral foot X-ray showing Meary's angle of − 2.8°

Discussion

There is no universally agreed protocol for treating children and adolescents with symptomatic flexible flatfeet [1, 3]. The non-operative management includes corrective orthotics and physiotherapy for Achilles stretches and tibialis posterior strengthening. Surgical intervention aims to restore the normal alignment of the tarsal bones, especially the talus and calcaneum.

While calcaneal lengthening is popular among paediatric surgeons, calcaneal medial shift osteotomy is the preferred solution in adults with flatfeet [12]. The senior author uses calcaneal lengthening with iliac crest graft and open wedge osteotomy of the medial cuneiform along with gastrosoleus/gastrocnemius fractional lengthening for majority of the paediatric patients with significantly symptomatic flatfeet. However, in a small minority of patients, who have an extremely severe lateral column shortening, where the heel valgus improves but not sufficiently, even after calcaneal lengthening, a second calcaneal medial shift osteotomy becomes necessary.

While the final decision about a double osteotomy is taken at surgery, in the senior author's experience, a predictive clinical sign of patients at risk of requiring a double osteotomy is the lack of heel tilt into varus, when attempting a high single leg tip toe stance, even though passive subtalar movement is not restricted. It is possibly a result of the tibialis posterior being mechanically disadvantaged having to pull around the corner of a laterally subluxed navicular in an abducted forefoot, compared to its normal straight line pull on a normally aligned navicular.

Traditionally, double osteotomies are done through two incisions or an extended lateral approach to the calcaneus [13, 14]. However, the skin remains at risk of having wound healing problems, as the lateral skin is forcibly stretched when the heel is shifted from severe valgus to normal alignment. The skin is stretched in three directions—(i) longitudinally by about 1 cm at the site of the anterior osteotomy, (ii) dorsal to plantar direction with change from valgus to varus, and (iii) at the tuberosity due to the tenting of the skin by the bone margins following the shift.

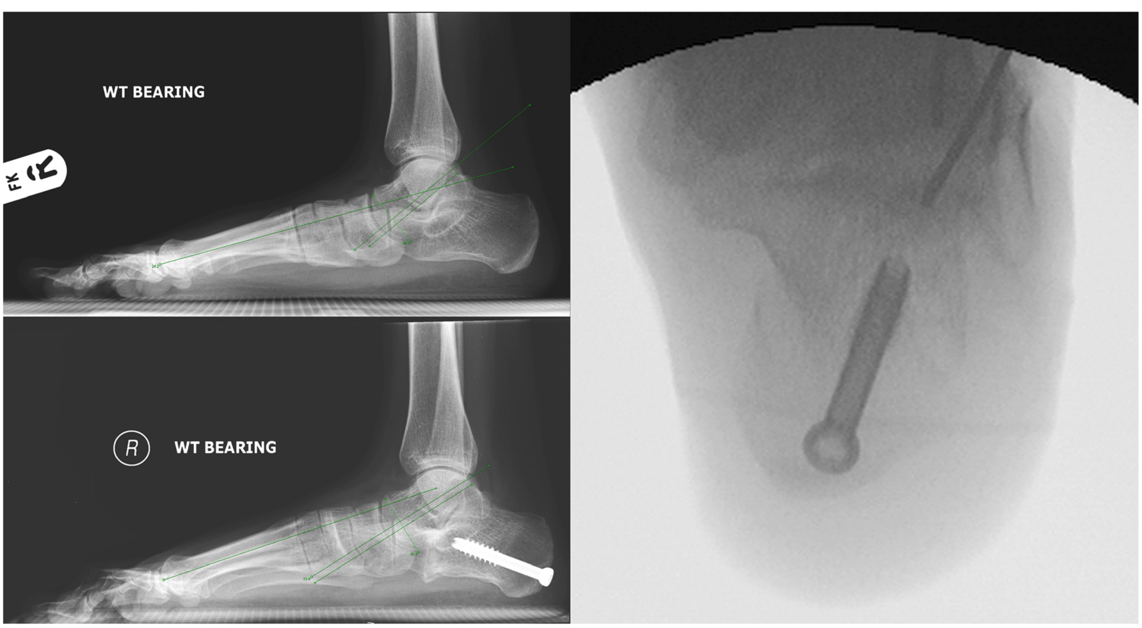

Fig. 4 Patient A1. Top left, pre-operative weight-bearing lateral foot X-ray showing Meary's angle of − 24.20°. Bottom left, post correction weight-bearing lateral foot X-ray showing Meary's angle of − 13.40° (10.80° correction). Right, intra-operative axial image intensifier X-ray showing lateral calcaneal translation of 8.88 mm (8.0 mm cannulated screw is used as a marker for measuring)

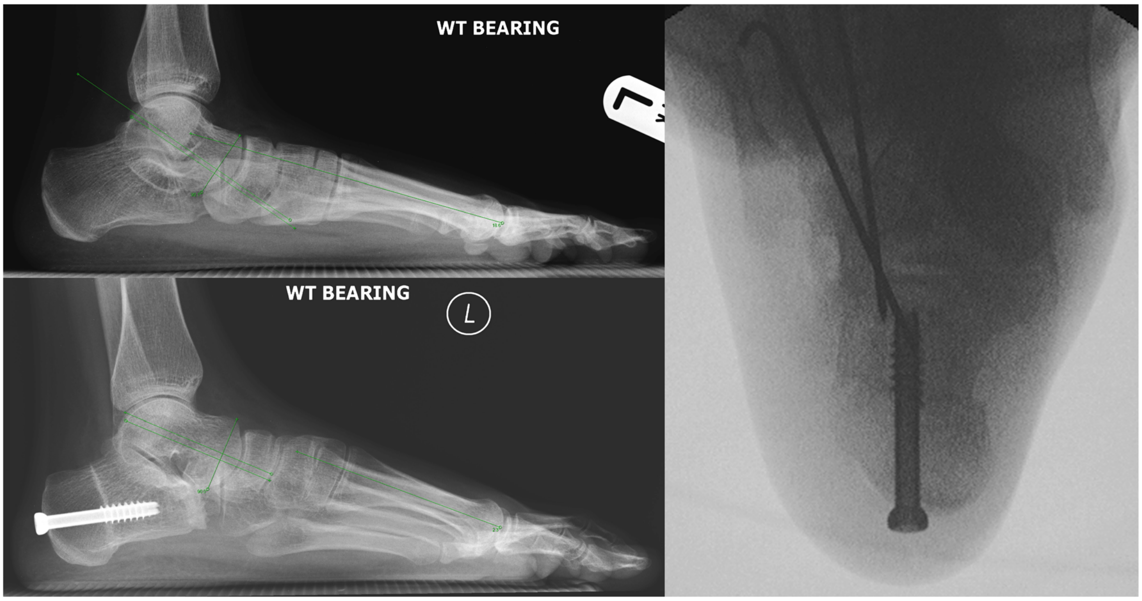

Fig. 5 Patient A2. Top left, pre-operative weight-bearing lateral foot X-ray showing Meary's angle of − 18.60°. Bottom left, post correction weight-bearing lateral foot X-ray showing Meary's angle of − 2.30° (16.30° correction). Right, intra-operative axial image intensifier X-Ray showing lateral calcaneal translation of 6.78 mm (8.0 mm cannulated screw is used as a marker for measuring)

Prior to the use of the MIS technique, the senior author avoided an extended lateral approach and used a horizontal incision over the anterior calcaneum and a separate incision over the posterior calcaneum in line with the tuberosity osteotomy. The relatively vertical second incision was done to reduce risk of gapping from lateral skin tension, while correcting the valgus deformity. In spite of these modifications, some patients had delayed wound healing due to minor gapping. This was possibly due to residual skin tension and relative vascular compromise at the incision sites, due to their close proximity to each other. As there is minimal subcutaneous tissue in this area covering the bone, there is always concern about secondary infection affecting the osteotomy site, with delayed wound healing.

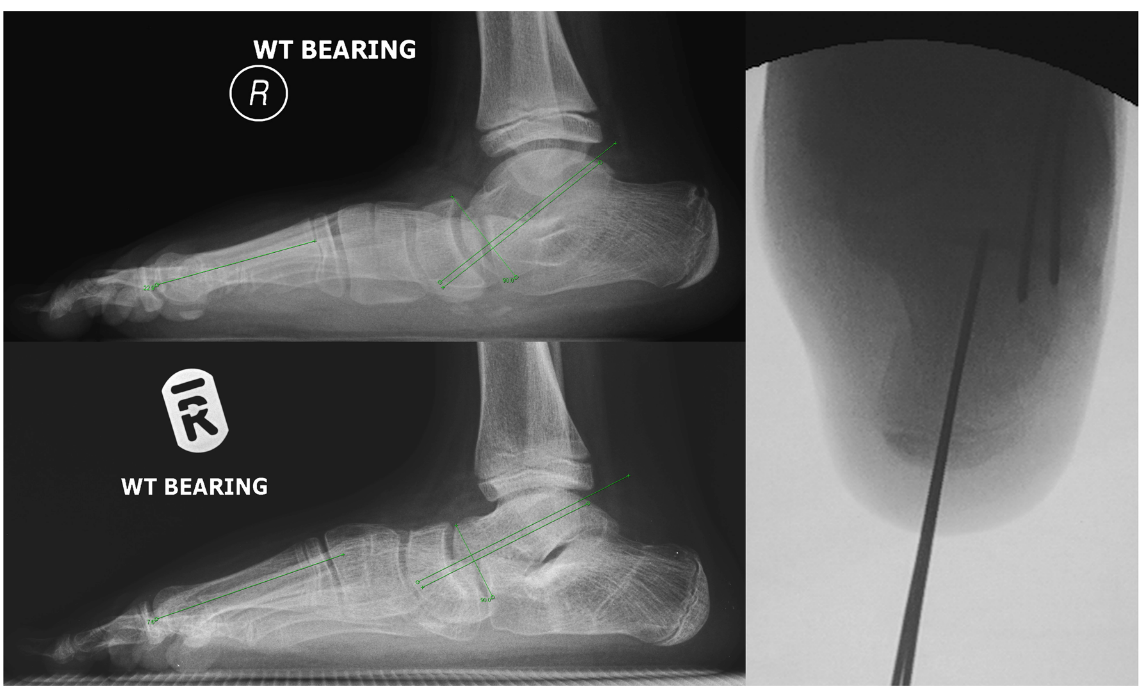

Fig. 6 Patient A5. Top left, pre-operative weight-bearing lateral foot X-ray showing Meary's angle of − 22.90°. Bottom left, post correction weight-bearing lateral foot X-ray showing Meary's angle of − 7.60° (15.30° correction). Right, intra-operative axial image intensifier X-ray showing lateral calcaneal translation of 7.53 mm (2.0 mm K-wire is used as a marker for measuring)

With the advent of minimally invasive surgery, the incision for the calcaneal shift osteotomy can be minimized to just 3–4 mm. Importantly, no skin retraction is needed with bone levers or self-retaining forceps, actions which risk damaging skin margins and delaying wound healing. MIS techniques have been used only recently for medial displacement calcaneal shift osteotomy, with good results [15]. Compared to conventional surgical approach, MIS calcaneal osteotomy has significantly lower incidence of infection, wound breakdown, wound healing problems, or sural nerve injury [16].

An anatomical study concluded that the sural nerve lies safely well away from the MIS incision for calcaneal shift [17]. In addition, the 3-mm burr used to perform the MIS calcaneal shift is thicker than a conventional saw blade (0.5 mm), and the consequent decompression allows more easy displacement and results in less tension on the skin. We accept that this reduction will cause a minimal reduction in the lever arm of the Achilles tendon when compared with the usage of a saw blade. This loss in calcaneal length is compensated in part by the lengthening of the lateral column, which usually measures about 1 cm, as measured by the iliac graft. Since using the small stab incision for the MIS technique, there have been no wound healing problems in our experience.

The senior author had to go through a learning curve to achieve consistently significant amounts of calcaneal medial shift. Our smaller shifts are a result of this learning process. The training courses he attended recommended using manual pressure for shifting with no means of visualizing and controlling the extent of the shift. He developed his own technique of using a very small periosteal elevator to "walk" across the osteotomy surface of the anterior fragment while pushing the posterior fragment with the shoulder of the instrument. Pushing it into the soft cancellous bone helps stabilize the shift. If when checking under II the shift is inadequate, the process can be repeated by levering more and shifting the elevator and pegging it at a new site more laterally. It is important to maintain this pressure while fixation is done and equally important to minimize the duration of the fixation process by keeping all the tools ready, to reduce any ill effects of the pressure of the elevator on the skin. Clinically, the extent of medial shift achieved with MIS was comparable to that with conventional open surgery.

Conclusion

In double calcaneal osteotomies, the MIS calcaneal medial shift technique can be used safely with potentially lower risks of wound complications and sufficient medial shift, compared to conventional open extensive surgery [16].

Study limitations

More cases and longer follow-up are needed to verify the study's conclusions.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Informed consent Informed consent was obtained from all individual participants included in the study.

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