



# Minimally invasive fixation for displaced intra-articular fractures of calcaneum: a short-term prospective study on functional and radiological outcome

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## Abstract

**Introduction** Studies have demonstrated a decrease in the incidence of late consequences and the socio-economic burden of intra-articular fractures of calcaneum when treated by surgical fixation. Operative management of displaced intra-articular calcaneal fractures (DIACF) pose significant challenges such as technical difficulty, wound healing and long-term pain and disability.

**Materials and methods** All patients presenting to the ER with DIACF over a period of 2 years and matching the inclusion criteria were enrolled in the study. Percutaneous fixation with 4 mm CC screw was undertaken with a minimally invasive sinus tarsi approach. All patients were available for a minimum follow-up of 24 months. Six radiological parameters were assessed, and functional outcome was evaluated using AOFAS score.

**Results** Thirty-four patients with 42 calcaneal fractures were included in the study, and all patients were available for minimum follow-up period. All radiological parameters were attained within anatomic normal range and maintained at 24 months of follow-up. AOFAS score showed a mean value of 90.10 which is considered an excellent outcome. Superficial wound infection was seen in two patients, but no patients required a revision surgery.

**Conclusion** Displaced intra-articular fractures pose a treatment dilemma, more so in cases of soft tissue complications like open injury or blisters. Percutaneous screw fixation with limited sinus tarsi incision has shown good functional and radiological outcome with minimal complications and can be undertaken without delay.

**Keywords** Displaced intra-articular calcaneal fracture · Sander's type 2 · Sander's type 3 · Sinus tarsi approach · Minimally invasive fixation

## Background

Displaced intra-articular fractures of the calcaneum (DIACF) account for 75% of calcaneal fractures [1, 2]. These fractures are a result of high-velocity injury including road traffic accident or fall from height [3]. There are

significant challenges in the management of these fractures due to early and late complications such as wound healing problems, chronic pain, and eventually subtalar arthritis [4–9]. Various modes of treatment have been described including conservative management, open reduction and minimally invasive fixation (MIF).

The available literature fails to give clear recommendations for treatment but makes unanimous observation that the best and worst outcomes are seen in operative management of DIACF the latter due to need for repeat surgeries and wound complications [7, 10–12]. The patient comorbidities, age, occupation and fracture pattern have also been found to have a significant association with the outcome, and careful patient selection is mandated for optimal outcome [12–14]. Considering the above factors, surgical management was associated with early return to work, less economic burden,

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better patient satisfaction and eventually fewer incidence of subtalar arthritis [15].

Restoring the normal anatomy of calcaneum including the calcaneal height, articular congruity, calcaneal length and correcting the altered radiographic parameters like Bohler's and Gissane angle are paramount to obtaining the best functional and radiological outcome [16]. The present gold standard of treatment is open reduction and internal fixation (ORIF) with an extensile lateral approach [17]. Although this approach gives good visibility of the fracture pattern and manoeuvrability for attaining reduction, it is associated with significant risks of wound complications with studies stating as high as 28% incidence of such complications. The complications varying from superficial wound dehiscence to deep wound infection and necrosis have been a major cause of apprehension in operative management and resorting to conservative treatment with compromised outcome [12, 17, 18]. MIF has emerged as a promising treatment modality and is being resorted in many fractures [19–29].

MIF has theoretical advantages over the present gold standard starting with time to surgery. ORIF unlike MIF can be undertaken only after the swelling subsides, and this may take weeks. The functional outcome has been shown to decline if the surgery is differed for more than 2 weeks [12]. The wound healing complication could be less as there is little or no soft tissue handling. We aimed at studying the functional and radiological outcomes in DIACF managed with MIF with cannulated cancellous (CC) screws.

## Patients and methods

We performed a single-centre prospective study of patients who sustained DIACF and treated with surgical fixation with CC screws using minimally invasive sinus tarsi approach. All patients who presented with DIACF from May 2013 to May 2015 and deemed fit for surgery after routine pre-operative work up, consented to take part in the study and be available for routine follow-up were included in the study. All surgeries were performed by two surgeons who are specialised in foot and ankle surgeries and have an overall experience of 10 years in handling orthopaedic trauma. A third surgeon who was not involved in the surgery evaluated the patient in follow-up and recorded radiological parameters and functional outcome. Institutional ethical committee clearance was obtained prior to initiation of the study, and written informed consent was obtained from all patients who took part in the study. Apart from routine radiographs, computed tomography was obtained for all patients prior to surgery and fractures were categorised using Sander's classification [30].

The inclusion criteria were set to be

1. All patients between 18 and 65 years who sustained DIACF categorised as Sanders' type 2 or type 3.
2. No prior injuries or surgeries to the foot and ankle or any pre-existing arthritis.
3. Available for a minimum follow-up of 24 months
4. No major medical comorbidities

A total number of 34 patients with 42 calcaneal fractures were included in the study. All patients were available for minimum of 24-month follow-up. Among the study participants, 20 were male and 14 were females, and 26 patients had unilateral fractures and 8 were bilateral. The mean age of patients was 31.2 years ranging from 18 to 65 years. Thirty patients had sustained injury due to fall from height and four were due to road traffic accidents. Twenty-two patients had isolated calcaneal fractures with no other associated injuries, while 12 patients' sustained associated injuries: among the patients who sustained associated injuries were 8 patients with unilateral calcaneal fracture and 4 with bilateral calcaneal fractures. Thirty-four fractures were categorised as Sander's type 2 injuries and eight were Sander's type 3. The average duration from time of injury to surgery was 3.14 days ranging from 1 to 14 days. The patient who was operated 14 days after injury had sustained multiple associated injuries, and three other patients had presented 4 days after injury. The mean duration of hospital stay was 5.9 days ranging from 3 to 17 days (Table 1).

## Surgical technique

The sinus tarsi approach was used for all cases which allow direct visualisation of the articular surface. All surgeries were performed under epidural anaesthesia, and an electric pneumatic tourniquet was used at level of thigh. The patient

**Table 1** Demographic data

Parameters	N (%)	Mean	Range
Age		31.2 years	18–65
Gender			
Female	20 (58.82)		
Male	14 (41.17)		
Sander's type			
Type 2	34 (80.95)		
Type 3	8 (19.05)		
Fracture site			
Unilateral	22 (64.71)		
Associated injuries	12 (54.54)		
Bilateral	12 (35.29)		
Associated injuries	8 (66.66)		
Time till surgery		3.14 days	1–14
Duration of hospital stay		5.9 days	3–17

was placed in floppy lateral position, and a folded towel was placed under the foot. An incision of 3–4 cm is made from the tip of the fibula towards the base of the fourth metatarsal. The sural nerve or superficial peroneal nerve branches may rarely have anatomic variations and needs careful dissection to avoid injury. The peroneal tendons are identified and carefully retracted. Next, the capsular structures are identified, they may be disrupted as a result of the fracture and the calcaneofibular ligament is often intact and is incised.

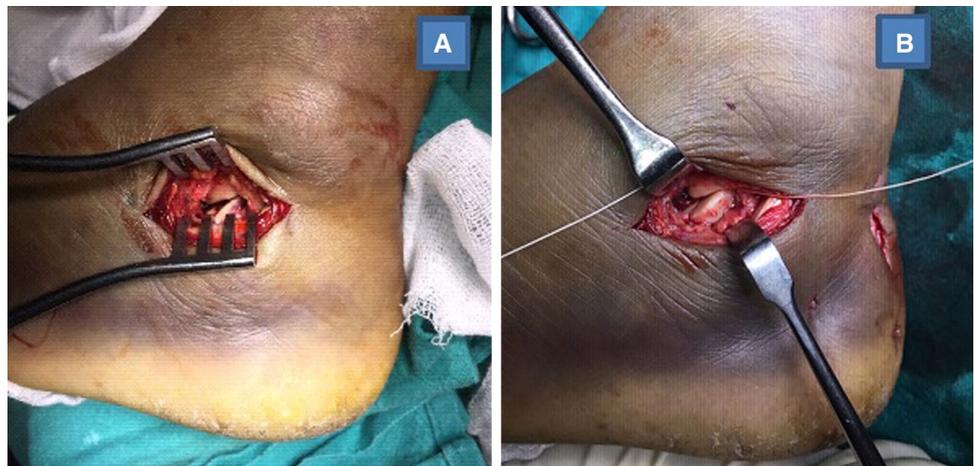
The position of the folded towel can be changed to allow the foot to fall into inversion, which further opens the joint space. After clearing the fracture haematoma, the depressed posterior facet was visualised. A freer elevator is used to elevate the facet. Along with elevation of depressed fragment, heel length and varus malalignment are corrected by using a Steinmann pin inserted into the calcaneal tuberosity and applying traction along the long axis of the foot, alternatively a hintermann distractor can be used medially to correct varus (Fig. 1). Once anatomic reduction is obtained, provisional K wires are placed to maintain reduction, which is verified using intra-operative fluoroscopy (Fig. 2). Heel width is generally improved with elevation of the posterior

facet. Once satisfactory reduction is obtained, the K wires are exchanged for 4 mm CC screws over guide wire (Fig. 3). Screws maintain subtalar joint reduction, calcaneal length and prevention of varus. The screws directed towards the sustentaculum tali parallel to the facet act as raft screws preventing the depression of the elevated articular fragment.

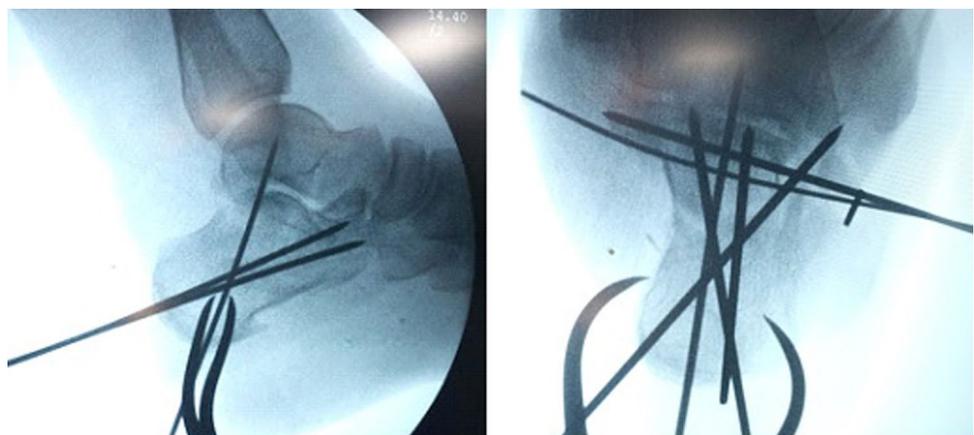
### Functional and radiological assessment

Six radiological parameters were assessed in standardised lateral and calcaneal axial radiographs; this included Bohler's angle, Gissane angle, posterior facet inclination angle, calcaneal width, height and length. Radiographs were obtained pre-operatively, immediate post-operatively, at 6 weeks, 12 weeks, 6 months, 1 year and 2 years of follow-up (Figs. 4, 5). All radiological parameters were calculated by the third orthopaedic surgeon who was not involved in surgery using our institute's PACS (medSynapse 5.0.1.3 version) under uniform magnification. These values were compared with those of an independent observer using the same software. In case of a discrepancy, a mutually agreed value was chosen. Functional outcome was analysed using

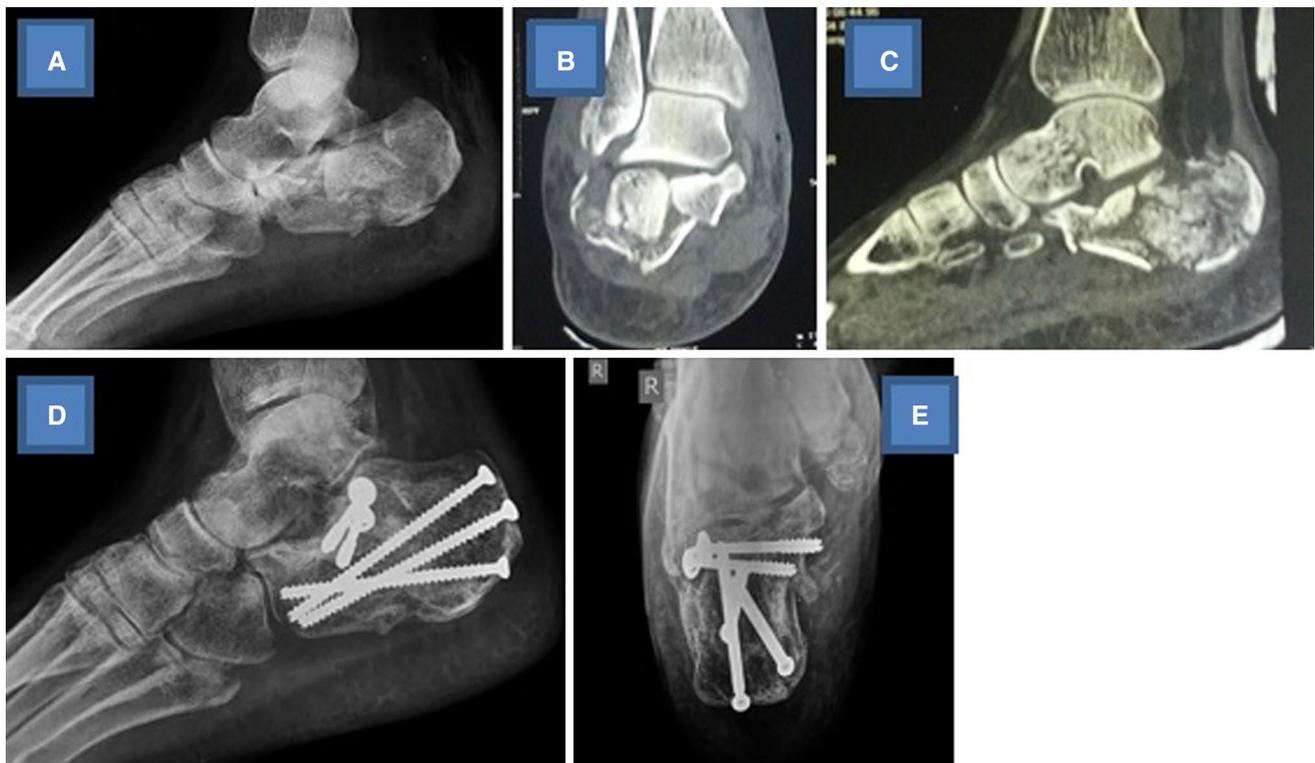
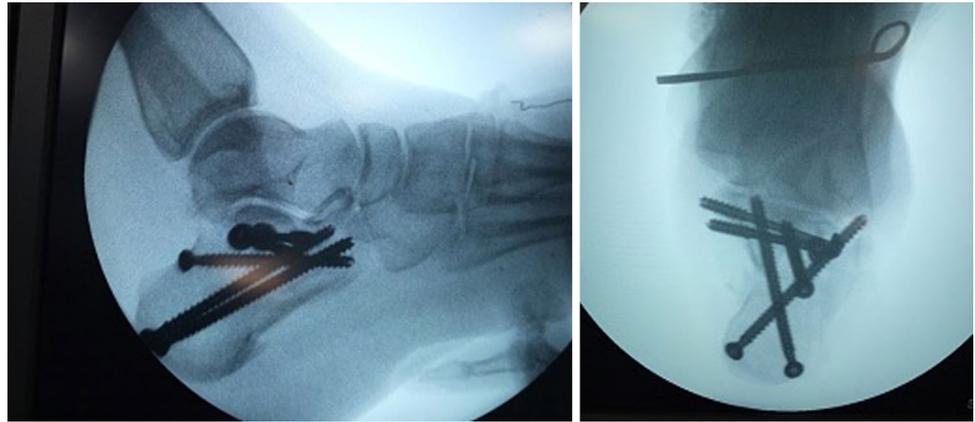
**Fig. 1** Approach to subtalar joint and reduction under direct visualisation (**a**) Sinus tarsi approach exposing the subtalar joint after retraction of peroneal tendon (**b**)



**Fig. 2** Temporary reduction with K wire fixation



**Fig. 3** K wires exchanged for 4 mm CC screws



**Fig. 4** Patient 1 **a** pre-operative radiograph showing DIACF. **b** Coronal section in CT scan showing Sander

American Orthopaedic Foot and Ankle Society Score (AOFAS score) at 24-month follow-up.

## Results

The mean pre-operative Bohler's angle was  $13^\circ$  (range of  $-5^\circ$  to  $20^\circ$ ). In two cases, the Bohler's angle was reversed. The mean post-operative Bohler's angle was  $31.4^\circ$  (range  $21^\circ$ – $40^\circ$ ). The mean Bohler's angle at the end of 12 months was  $31.1^\circ$  (range  $21^\circ$ – $40^\circ$ ) and maintained the same at

24 months (Table 2). The change in the Bohler's angle was noted in a patient who had sustained bilateral calcaneal fracture where the immediate post-operative values of  $34^\circ$  and  $36^\circ$  for right and left sides, respectively, decreased to  $30^\circ$  and  $35^\circ$  for right and left sides, respectively, at the end of 24 months. In all other cases, this angle was maintained. The mean Gissane's crucial angle was  $93.1^\circ$  (range  $90^\circ$ – $96^\circ$ ) pre-operatively. It was  $131.1^\circ$  (range  $110^\circ$ – $140^\circ$ ) post-operatively, and  $131.6^\circ$  (range  $110^\circ$ – $140^\circ$ ) at the end of 24 months. The same patient who had sustained bilateral calcaneal fracture and post-operative decline in Bohler's angle



**Fig. 5** Patient 2 **a–c** Coronal and sagittal sections in CT scan showing a Sander

**Table 2** Radiological parameters and values

Radiological parameter	Pre-operative mean value (range)	Post-operative mean value (range)	Mean value at 24 months
Bohler’s angle	13° (–5°–20°)	31.4° (21°–40°)	31.1° (21°–40°)
Gissane angle	93.1° (90°–96°)	131.1° (110°–140°)	131.6° (110°–140°)
Posterior facet angle	28.3° (12°–48°)	62.1° (45°–72°)	61.9° (45°–72°)
Calcaneal width	4.7 cm (4.45–4.82)	4.20 cm (3.86–5.43)	4.21 cm (3.86–5.43)
Posterior facet height	4 cm (3.24–4.5)	4.75 cm (4.29–4.98)	4.75 cm (4.29–4.98)
Calcaneal length	7 cm (6.79–7.98)	7.73 cm (7.12–8.29)	7.71 cm (7.12–8.29)

showed changes in Gissane’s angle at 24-month follow-up. The mean posterior facet inclination angle pre-operatively was 28.3° (range 12°–48°). The immediate post-operative mean was found to be 62.1° (range 45°–72°). At the end of 24 months, it was 61.9° (range 45°–72°), with changes noted in the same bilateral case (Fig. 6).

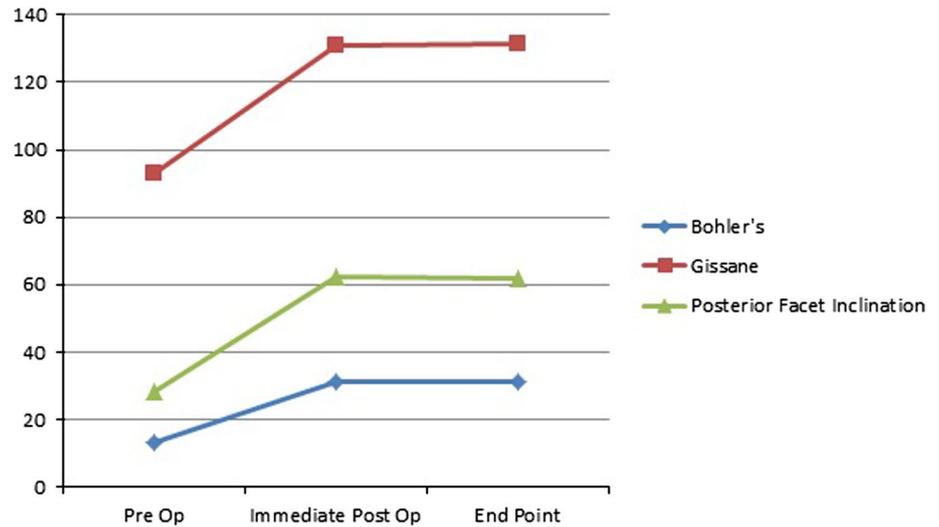
The mean calcaneal width pre-operatively was 4.7 cm (range 4.45–4.82 cm). The immediate post-operative mean was 4.20 cm (range 3.86–5.43 cm), and at the end of 2 years, the mean was 4.21 cm (range 3.86–5.43 cm). The increase in width was noted in the patient with bilateral calcaneal fracture. The mean height of the posterior facet pre-operatively was 4 cm (range 3.24–4.5 cm). The mean values at immediate post-op and at the end of 24 months were 4.75 cm (range 4.29–4.98 cm). The mean calcaneal length was 7 cm (range 6.79–7.98 cm) pre-operatively. The immediate post-operative mean was noted to be 7.73 cm (range

7.12–8.29 cm). At the end of 2 years, the mean was 7.71 cm (range 7.12–8.29 cm) (Fig. 7).

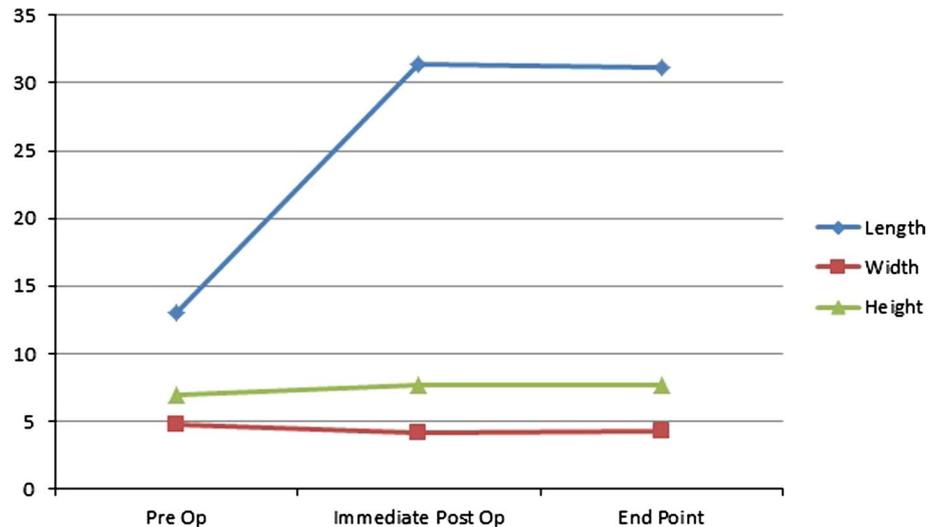
Functional outcome was analysed at the end of 24 months using AOFAS score. Excellent outcome (score 90–100) was seen in 28 fractures, good outcome (score 80–89) was seen in 12 fractures and fair outcome (score 65–79) was seen in 2 fracture. Poor outcome (score < 64) was not encountered, and the mean score was 90.10. When compared to the fracture severity, Sanders type 2 fractures had a better mean score of 91.05 in comparison with Sanders type 3 where the score was 86. Similarly, isolated unilateral fractures showed a mean score of 91.1, whereas bilateral fractures had mean score of 88.5 (Table 3).

Superficial wound complication was noticed in 2 cases out of 42 fractures (4.7%). Loss of sensation over the lateral aspect of foot, i.e. in the sural nerve innervation territory, was noted in one case. Heel widening was noted in

**Fig. 6** Line chart showing trends of the mean values for radiological angles



**Fig. 7** Line chart showing trends of the mean values for radiological measurements: Length, Width, and Height across Pre Op, Immediate Post Op, and End Point stages.



**Table 3** AOFAS score variation among different fracture patterns

Parameter	AOFAS
<i>Fracture type</i>	
Sander's type 2	91.05
Sander's type 3	86
<i>Fracture site</i>	
Unilateral	91.1
Unilateral with associated injuries	90
Bilateral	88.5

four cases. In a bilateral case, the right side was noted to be in varus alignment compared to left side. Surgical site infections, peroneal tendon subluxation, reflex sympathetic dystrophy (RSD) were not encountered in the analysis. No patient required a redo surgery or implant removal as the functional outcome was satisfactory.

## Discussion

There is definite ambiguity in the management of DIACF, and clinicians seek answers for certain questions. Is surgical management better than conservative? If so, what is the best modality of surgery available and what are the outcomes of the same? Although there has been literature suggesting that surgical management gives best outcome in terms of patient satisfaction, earlier return to work and lesser incidence of subtalar arthritis, studies also point out that the worst outcomes are also attributed to surgical management mainly due to wound healing complication [7, 10–12].

The UK heel trial which was a large volume multicentre trial stated that there is no benefit in surgical management [31]. The study was found to have significant selection bias, and the results and recommendation are questionable [32]. On the other hand, studies have shown that non-operative management has six times greater risk of needing a subtalar arthrodesis in long term when compared to surgical fixation [7, 10]. Recently published data from long-term randomised controlled trials on operative versus non-operative fixation with follow-up of more than 12 years concluded that there is slight benefit of surgery over the long term, and the authors do point out that the surgical techniques have improved over years [8, 33]. Hence, with the present day surgical techniques, the results could be better.

Minimally invasive techniques for fixation are being reported more in the recent past. They have advantages of lesser wound complications and earlier surgery in post-injury period than traditional ORIF [34]. There are various patient factors that need to be considered before surgical fixation as wound complications can be seen with pre-existing diabetes, poor nutritional status and immune-compromised

status [35, 36]. MIF has been advised as an alternative in these settings due to reduced wound complications [37].

Skeletally immature patients have shown good results with conservative management, and surgery is seldom needed [38]. Patients older than 60 years have doubtful functional benefit in surgical management although higher degree of patient satisfaction is still attributed to surgical fixation in these patients [7, 13]. We restricted our study population below the age group of 65 and excluded skeletally immature patients to avoid any bias in the functional outcome assessment. Patients less than 30 years have shown to have the best outcome following surgery, the average age of patients in our study was 31 years and this goes in accordance with the published literature on having better functional outcome scores [7].

In cases where there is significant articular comminution and anatomic reduction is not possible, primary subtalar arthrodesis gives the best possible outcome [10, 39–41]. Sander's types 3 and 4 have poor outcomes with both conservative and surgical management. The incidence of post-traumatic arthritis is more for these fractures with up to 23% chances in type 3 and 73% in type 4 [30, 40]. We attained excellent functional outcome in Sander's type 2 fracture with mean score of 91.05, Sander's type 3 fractures had a lower score in comparison with the mean score of 86 which is considered as good outcome and Sander's type 4 fractures were totally excluded from the study as they are known to have poor outcomes with high incidence of subtalar arthritis following surgery and are poor candidates for MIF [42].

Loss of calcaneal height can impact the functional outcome, and similarly Bohler's angle value less than 15 degrees has also shown to have poor outcomes [10, 43]. In our study, the mean Bohler's angle prior to surgery was 13 degrees which was restored to 31.1 degrees post-operatively and maintained at the end of follow-up. Apart from this, the other radiological parameters like calcaneal width, length, Gissane angle and posterior facet inclination angle were also restored. We aimed at attaining normal anatomic reduction whenever possible and having six different radiological parameters to match helped us ascertain that. Bilateral calcaneal fracture is a result of more significant trauma and has more propensities to complications like decreased range of movement and incidence of subtalar arthritis [43]. In our study, among eight patients, who sustained bilateral fractures, one patient had an alteration in the immediate post-operative Bohler and Gissane angle and heel widening with varus angulation. The functional outcome score as expected was lower in the bilateral cases with a mean score of 88.8 when compared to 91.1 achieved in isolated unilateral calcaneal fractures.

Wound complications were noticed in two patients which accounts for only 4.7% which in comparison with complication rates in ORIF as reported by other studies is

significantly lower [12, 17, 18] but in accordance with the wound complication rates in MIF [44]. These were superficial wound dehiscence which responded well with serial dressing alone. Heel widening and varus malalignment were noticed in two patients, but their functional outcome score was good. There are definite shortcomings in this study which includes a small study population, short follow-up of only 24 months and no comparative analysis with ORIF.

## Conclusion

Though DIACF is a challenging injury in terms of treatment and eventual functional outcome, surgical treatment has shown to have definite advantages over conservative management in most patients. Wound healing complication and late subtalar arthritis are the main causes that cast a doubt in treatment by surgical fixation. But long-term studies have revealed the upper edge of surgical management, and with the improved surgical techniques, the results may be even better. MIF has proven benefits of fewer wound complications and earlier intervention in post-injury period; our results showed similar outcomes with minimal wound healing complication and excellent functional outcome in the short-term analysis. Long-term analysis is required to identify the incidence of late complications like subtalar arthritis.

## Compliance with ethical standards

**Conflict of interest** None.

## References

- Talarico LM, Vito GR, Zyryanov SY (2004) Management of displaced intra-articular calcaneal fractures by using external ring fixation, minimally invasive open reduction, and early weight bearing. *J Foot Ankle Surg* 43:43–50
- McBride DJ, Ramamurthy C, Laing P (2005) The hindfoot: calcaneal and talar fractures and dislocations part I: fractures of the calcaneum. *Curr Orthop* 19:94–100
- Lindsay WRN, Dewar FP (1958) Fractures of the os calcis. *Am J Surg* 95:555–576
- Parmar HV, Triffitt PD, Gregg PJ (1993) Intra-articular fractures of the calcaneum treated operatively or conservatively: a prospective study. *J Bone Joint Surg Br* 75:932–937
- Nouraei MH, Moosa FM (2011) Operative compared to nonoperative treatment of displaced intra-articular calcaneal fractures. *J Res Med Sci* 16:1014–1019
- Thordarson DB, Krieger LE (1996) Operative vs. nonoperative treatment of intra-articular fractures of the calcaneus: a prospective randomized trial. *Foot Ankle Int* 17:2–9
- Buckley R, Tough S, McCormack R, Pate G, Leighton R, Petrie D, Galpin R (2002) Operative compared with nonoperative treatment of displaced intra-articular calcaneal fractures: a prospective, randomized, controlled multicenter trial. *J Bone Joint Surg Am* 84A:1733–1744
- Agren PH, Wretenberg P, Sayed-Noor AS (2013) Operative versus nonoperative treatment of displaced intra-articular calcaneal fractures: a prospective, randomized, controlled multicenter trial. *J Bone Joint Surg Am* 95:1351–1357
- Mitchell MJ, McKinley JC, Robinson CM (2009) The epidemiology of calcaneal fractures. *Foot (Edinb)* 19:197–200
- Csziy M, Buckley R, Tough S, Leighton R, Smith J, McCormack R et al (2003) Displaced intra-articular calcaneal fractures: variables predicting late subtalar fusion. *J Ortho Trauma* 17:106–112
- Coughlin MJ (2000) Calcaneal fractures in the industrial patient. *Foot Ankle Int* 21:896–905
- Howard J, Buckley R, McCormack R, Pate G, Leighton R, Petrie D et al (2003) Complications following management of displaced intra-articular calcaneal fractures: a prospective randomised trial comparing open reduction internal fixation with non-operative management. *J Orthop Trauma* 17(4):241–249
- Basile A (2010) Operative versus non-operative treatment of displaced intra-articular calcaneal fractures in elderly patients. *J Foot Ankle Surg* 49(1):25–32
- Tufescu TV, Buckley RE (2001) Age, gender, work capability, and worker's compensation in patients with displaced intra-articular calcaneal fractures. *J Orthop Trauma* 15:275–279
- De Boer AS, Van Lieshout EM, Den Hartog D, Weerts B, Verhofstad MH, Schepers T (2014) Functional outcome and patient satisfaction after displaced intra-articular calcaneal fractures: a comparison among open, percutaneous, and nonoperative treatment. *J Foot Ankle Surg* 30:1–8
- Schepers T, van Lieshout EMM, van Ginhoven TM, Heetveld MJ, Patka P (2008) Current concepts in the treatment of intra-articular calcaneal fractures: results of a nationwide survey. *Int Orthop* 32(5):711–715
- Veltman ES, Doornberg JN, Stufkens SAS, Luitse JSK, van den Bekerom MPJ (2013) Long-term outcomes of 1730 calcaneal fractures: systematic review of the literature. *J Foot Ankle Surg* 52:486–490
- Gougoulis N, Khanna A, McBride DJ, Maffulli N (2009) Management of calcaneal fractures: systematic review of randomized trials. *Br Med Bull* 92:153–167
- Rammelt S, Heineck J, Barthel S, Zwipp H (2009) Percutaneous fixation of intraarticular calcaneus fractures. *Technol Foot Ankle Surg* 8:70–76
- Kilkuchi C, Charlton TP, Thordarson DB (2013) Limited sinus tarsi approach for intraarticular calcaneus fractures. *Foot Ankle Int* 34(12):1689–1694
- Kline AJ, Anderson RB, Davis WH, Jones CP, Cohen BE (2013) Minimally invasive technique versus an extensile lateral approach for intra-articular calcaneal fractures. *Foot Ankle Int* 34(6):773–780
- Nosewicz T, Knupp M, Barg A, Maas M, Bolliger L, Goslings JC et al (2012) Mini-open sinus tarsi approach with percutaneous screw fixation of displaced calcaneal fractures: a prospective computed tomography-based study. *Foot Ankle Int* 33(11):925–933
- Weber M, Lehmann O, Sagesser D, Krause F (2008) Limited open reduction and internal fixation of displaced intra-articular fractures of the calcaneum. *J Bone Joint Surg Br* 90:1608–1616
- Tornetta P III (2000) Percutaneous treatment of calcaneal fractures. *Clin Orthop Relat Res* 375:91–96
- Stulik J, Stehlik J, Rysavy M, Wozniak A (2006) Minimally-invasive treatment of intra-articular fractures of the calcaneum. *J Bone Joint Surg Br* 88(12):1634–1641
- Park I, Song KW, Shin S, Lee JY, Kim TG, Park RS (2000) Displaced intra-articular calcaneal fractures treated surgically with limited posterior incision. *Foot Ankle Int* 21:195–205
- Schuberth JM, Cobb MD, Talarico RH (2009) Minimally invasive arthroscopic-assisted reduction with percutaneous fixation in the

- management of intra-articular calcaneal fractures: a review of 24 cases. *J Foot Ankle Surg* 48:315–322
28. Wang Q, Chen W, Su Y, Pan J, Zhang Q, Peng A et al (2010) Minimally invasive treatment of calcaneal fracture by percutaneous leverage, anatomical plate, and compression bolts—the clinical evaluation of cohort of 156 patients. *J Trauma* 69:1515–1522
  29. Tomesen T, Biert J, Frolke JPM (2011) Treatment of displaced intra-articular calcaneal fractures with closed reduction and percutaneous screw fixation. *J Bone Joint Surg* 93:920–928
  30. Sanders R, Fortin P, DiPasquale T, Walling A (1993) Operative treatment in 120 displaced intra-articular calcaneal fractures: results using a prognostic computed tomography scan classification. *Clin Orthop Relat Res* 290:87–95
  31. Griffin D, Parsons N, Shaw E, Kulikov Y, Kulikov Y, Hutchinson C, Thorogood M, Lamb SE, UK Heel Fracture Trial Investigators (2014) Operative versus non-operative treatment for closed, displaced, intra-articular fractures of the calcaneus: randomised controlled trial. *BMJ* 349:g4483
  32. Sharr PJ, et al (2015) Current management options for displaced intra-articular calcaneal fractures: nonoperative, ORIF, minimally invasive reduction and fixation or primary ORIF and subtalar arthrodesis: a contemporary review. *Foot Ankle Surg*
  33. Ibrahim T, Rowsell M, Rennie W, Brown AR, Taylor GJS, Gregg PJ (2007) Displaced intra-articular calcaneal fractures: 15 year follow-up of a randomized controlled trial of conservative versus operative treatment. *Injury* 38:848–855
  34. van Hove S, Poeze M (2016) Outcome of minimally invasive open and percutaneous techniques for repair of calcaneal fractures: a systematic review. *J Foot Ankle Surg* 55(6):1256–1263
  35. Harvey EJ, Grujic L, Early JS et al (2001) Morbidity associated with ORIF of intraarticular calcaneus fractures using a lateral approach. *Foot Ankle Int* 11:868–873
  36. Aldridge JM III, Easley M, Nunley JA (2004) Open fractures: results of operative treatment. *J Orthop Trauma* 18(1):7–11
  37. Arastu M, Sheehan B, Buckley R (2014) Minimally invasive reduction and fixation of displaced calcaneal fractures: surgical technique and radiographic analysis. *Int Orthop* 38(3):539–545
  38. Ceccarelli F, Faldini C, Piras F, Giannini S (2000) Surgical vs non-surgical treatment of calcaneal fractures in children: a long term results comparative study. *Foot Ankle Int* 21:825–832
  39. Thermann H, Hufner T, Schrott E, Held C, von Glinski S, Tscherne H (1999) Long-term results of subtalar fusions after operative versus non-operative treatment of os calcis fractures. *Foot Ankle Int* 20(7):408–416
  40. Sanders R (2000) Current concepts review: displaced intra-articular fractures of the calcaneus. *J Bone Joint Surg Am* 82:225–250
  41. Buckley R, Leighton R, Sanders D, Poon J, Coles CP, Stephen D et al (2014) Open reduction and internal fixation compared with ORIF and primary subtalar arthrodesis for the treatment of sanders type IV calcaneal fractures: a randomized, multicenter trial. *J Orthop Trauma* 28(10):577–583
  42. Giannini S, Cadossi M, Mosca M, et al (2016) Minimally-invasive treatment of calcaneal fractures: a review of the literature and our experience. *Injury*
  43. Loucks C, Buckley R (1999) Bohler's angle: correlation with outcome in displaced intra-articular calcaneal fractures. *J Orthop Trauma* 13(8):554–558
  44. Dooley P, Buckley R, Tough S, McCormack B, Pate G, Leighton R et al (2004) Bilateral calcaneal fractures: operative versus non-operative treatment. *Foot Ankle Int* 25(2):47–52