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ORIGINAL PAPER

Long-term outcome of first metatarsophalangeal joint fusion in the treatment of severe hallux rigidus

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Abstract
Aims This study was aimed to study the arthrodesis of the first metatarsophalangeal joint using an oblique interfragmentary lag screw and dorsal plate as an effective option for the treatment of hallux rigidus. Few researchers have studied the outcome of this surgical method over a long follow-up period.
Patients and methods We performed a retrospective review of 60 patients status post arthrodesis of the first metatarsophalangeal joint. The mean age was 68.5 years and average follow-up lasted for 47.3 months. Patients' satisfaction and functional outcomes were evaluated with the American Orthopaedic Foot and Ankle Society Hallux Metatarsophalangeal-Interphalangeal Scale, the foot and ankle questionnaire, the Functional Foot Index, and dynamic pedobarography.
Results Fusion rate of 93.3 % was recorded; 6.7 % of the cases ended up with a painless pseudarthrosis and required no additional surgery. Pedobarographic measurements demonstrated first ray weight bearing function restoration. More physiological foot plantar pressure patterns were observed. Concerning the postoperative outcomes, 71.7 % of the patients were very satisfied and 18.3 % were satisfied. The American Orthopaedic Foot and Ankle Society Hallux Metatarsophalangeal-Interphalangeal Scale increased postoperatively from 40.9 to 79.3.
Conclusion The arthrodesis of the metatarsophalangeal joint using transarticular screw and dorsal nonlocked plate is an effective method for the treatment of severe hallux rigidus with fair patient satisfaction rate and functional outcome.

Keywords Arthrodesis · Hallux rigidus · Fusion · Metatarsophalangeal joint · Pedobarography

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Introduction

Surgical intervention for the treatment of hallux rigidus includes a wide variety of options ranging from cheilectomy [1], arthrodesis [2], first metatarsal osteotomy [3], interposition arthroplasty [4], phalangeal osteotomy [5], excisional arthroplasty [6], and implant arthroplasty [7]. When treating the advanced stage of hallux rigidus, arthrodesis is a well-established procedure and provides very predictable and satisfying results [1, 7–11]. Over the years, many internal fixation techniques have been developed, including wires, screws, and plates [8, 12–15]. Nevertheless, it is not yet clear which surgical method and fixation device is ideal with regard to practicality and success rate.

The purpose of our study is to evaluate the first metatarsophalangeal (MTP) joint arthrodesis using a combination of a compression screw and a mini-compression nonlocking semitubular plate in terms of post-operative fusion rate, clinical progress, and functional outcome. In addition, the present study is intended to further explore the possible

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biomechanical basis of load redistribution over the metatarsals after the first MTP joint fusion by pedobarographic studies.

Patients and methods

Patients

We performed a retrospective study of 60 Caucasian patients who had undergone an isolated arthrodesis of the first MTP joint between December 2006 and April 2009. The study proposal was approved by the institutional board committee. All procedures were performed by the senior author using the same surgical technique. The patients' mean age was 68.5 years (range, 55–81). Of these 60 patients, 54 were women and six were men. All patients underwent unilateral surgery except one patient who had both sides operated at two different occasions giving a total of 61 feet. This patient was excluded from the pedobarographic study because the pedobarographic comparison with a non-operated foot was not possible.

The data collected included gender, age, previous foot surgery, comorbidities, smoking status, revision surgery, postoperative follow-up duration, malunion, and complications of internal fixation. The mean follow-up period was 47.3 months (range, 39–56). All operated feet had no previous hallux surgery but one foot which has underwent uneventful scarf operation for hallux valgus. Indications of MTP joint arthrodesis were (1) symptomatic hallux rigidus with an intractable pain isolated to the first MTP joint that was refractory to shoe modifications, use of rigid shoe inserts, nonsteroidal anti-inflammatory medications, and modification of activities, (2) radiological grade 3 hallux rigidus, and (3) pre-operative painful range of motion <30°. Contraindications for MTP arthrodesis included (1) patients in whom the absence of MTP joint motion is unacceptable (2) recent joint infection, (3) grade 2 or less hallux rigidus with >50 % of the metatarsal head articular surface intact (4) vascular insufficiency (4) peripheral neuropathy, and (5) a substantial restriction of range of motion (<30°) of the interphalangeal joint. In this study only patients with primary MTP joint arthrodesis were included. There were no patients with revision MTP joint arthrodesis.

Surgical technique and postoperative care

Arthrodesis of the first metatarsophalangeal joint was performed in supine position under regional anesthesia without exsanguinating the limb or using a tourniquet. A dorsal longitudinal incision was centered over the first MTP joint beginning at the middle of the proximal phalanx and extended 4 to 5 cm proximally. The incision was deepened along the medial border of the extensor hallucis longus tendon. A longitudinal capsulotomy and subperisostal preparation of the first MTP joint was performed preserving the capsule for later repair. After removing loose bodies and osteophytes, a joint debridement was carried out. A release of the articular capsule was conducted until getting a good plantar flexion of the proximal phalanx allowing the complete exposure of articular surfaces. A guidewire was drilled centrally in the first metatarsal head articular surface and directed proximally in the metatarsal bone. A cup-shaped reamer was used to create a convex metatarsal head surface with minimal necessary bone resection (Fig. 1a). After removing the guidewire, multiple drill holes were made in the prepared surface with a 2.0 mm drill bit. Another guidewire was inserted at the center of the articular surface of the base of the proximal phalanx and directed distally (Fig. 1b). A high-speed convex guided reamer was used to create the concave cup-shaped congruent surface of the proximal phalanx (Fig. 1c). In case of sclerotic surface, several drill-holes were made prior to the reaming. This surface matches the prepared metatarsal head surface (Fig. 1d). The surplus of bone remained after the preparation of the joint surfaces was removed with the rongeur allowing the coaptation of the cancellous joint surfaces.

The hallux was then placed in 15° to 20° of dorsiflexion in reference to the axis of the first metatarsal with a neutral rotation and an estimated valgus of 10 degrees. The position was held temporarily with a Kirscner wire which was drilled from the distal medial aspect through the proximal phalanx toward the distal lateral part of the metatarsal bone. A proper position was confirmed by placing a flat metal surface against the heel and the ball of the first metatarsal bone mimicking the weight-bearing status of the foot. The tip of the toe should look 5 to 10 mm upward, however, toe contact to the metal surface should be possible by gently pushing the toe downward. Under fluoroscopic control, the ideal position was stabilized with a lag compression screw across the joint replacing the Kirschner wire. Care was taken to ensure that the tip of the transarticular lag screw catches the far lateral cortex seeking stronger biomechanical purchase. Also, excessively protruding screw tip was deemed unacceptable. Next, a six-hole non-locked mini-compression plate (Charlotte® MTP Fusion System, Wright Medical, Memphis, TN) was bent dorsally and placed on the dorsal surface of the joint and fixed with four to six screws. A considerable intra-operative care must be taken while drilling and screw length selection to avoid injury to the nearby structures. After washing, the joint capsule was sutured with interrupted absorbable sutures. The tendon of the extensor hallucis longus was relocated and the overlying skin was then closed.

Post-operative and follow-up care

Dressing with tight bandage was applied post-operatively to protect the sutures and prevent the swelling. Weight bearing in postoperative shoes was allowed after the first

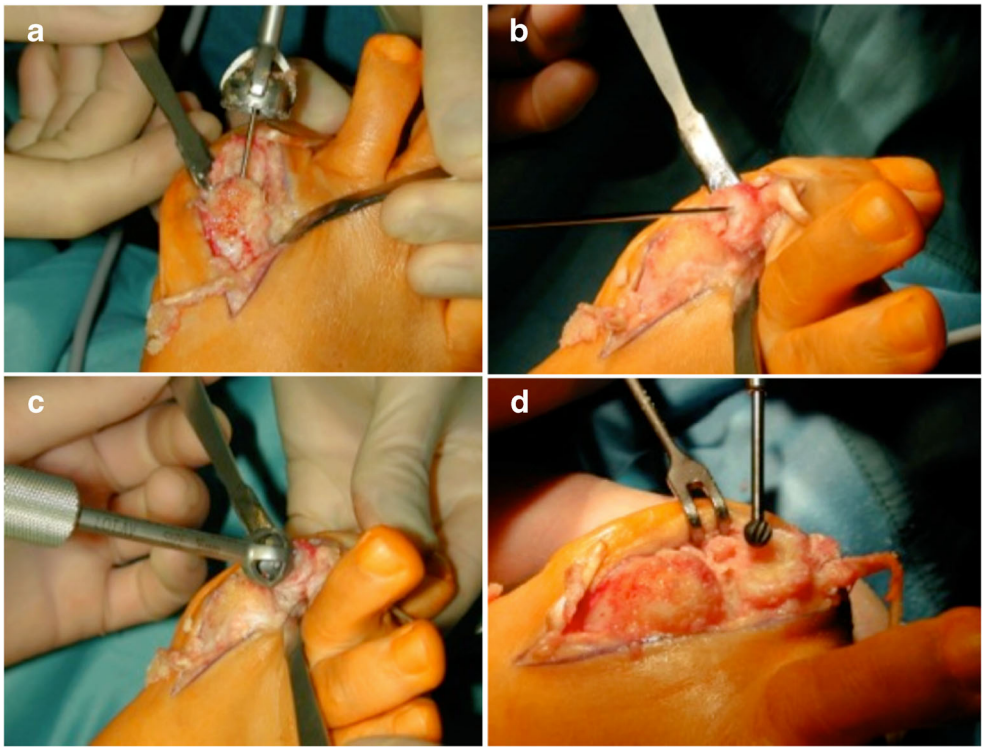

Fig. 1 Surgical steps of metatarsophalangeal (MTP) joint preparation for arthrodesis. (**a**) Guided concave reamer is used to create a regular hemisphere from the arthritic metatarsal head. (**b**) Base of proximal phalanx exposed and a central guidewire was inserted. (**c**) Dome-shaped reaming of the phalangeal articular surface of MTP joint. (**d**) Prepared MTP joint with concave digital side and convex metatarsal side is shown ready for adjustment and fixation

post-operative day. These protective shoes were required for six weeks. In general, follow-up visits were scheduled in two weeks, six weeks, three months and four to six months from the day of operation as dictated by clinical and radiological progress. X-rays were obtained to evaluate the union consolidation progress of the arthrodesis. The transition was allowed from the post-operative shoes into sneakers or post-operative comfortable low heel shoes within sixweeks on average. The resumption of athletic activities and prolonged walking can be allowed after four to five months post-operatively.

Functional outcome assessment

The following scores were used for the pre and postoperative clinical evaluation: the 100-point American Orthopaedic Foot and Ankle Society (AOFAS) Hallux Metatarsophalangeal-Interphalangeal Scale [16], Foot Function Index (FFI) [17, 18], and the post-operative result of the Foot and Ankle Questionnaire (FAQ) [19]. The subjective satisfaction was assessed by asking the patients to rate the overall and the cosmetic operative result in 4 grades: very satisfying, satisfying, acceptable, and unsatisfied. The scores of AOFAS Hallux Metatarsophalangeal-Interphalangeal Scale and FAQ were filled at the time of the follow-up examination by two independent investigators not involved in the primary surgical treatment. The FFI and satisfaction rating questionnaire were filled in by the patients prior to the clinical follow-up examination.

Radiological assessment

Weight-bearing antero-posterior and lateral view radiographs were obtained pre-operatively, at six weeks after surgery and at latest follow-up. Radiologic analysis included Hallux Valgus Angle (HVA), intermetatarsal angle (IMA), the dorsiflexion angle as well as the position of the tibial sesamoid in accordance to the American Orthopaedic Foot and Ankle Society guidelines [20, 21]. The radiographs were consistently interpreted by a person otherwise not involved in the clinical examination.

Pedobarographic assessment

Pedobarographic examination was conducted during the last follow-up visit. Plantar pressure assessment was performed on the appliance (emed® platform, Novel Inc., Munich, Germany). Software analysis was performed by emed measuring software. The forceplate sensor area measured 360 mm x 190 mm with resolution of 4 sensor/cm^2 and frequency of 50 Hz. At least five measurements were recorded for each foot. Patients were asked to walk barefoot normally with self-selected speed along a 12-metre-distance walkway. The forefoot was divided into three regions being the big toe, the first metatarsal head (MH_1) and the second metatarsal head (MH_2). The analysis was made by comparison of the operated foot and the non-operated one. The maximum force of the hallux, contact surface and contact time of the great toe represented the major analyzed parameters.

Results

Radiological results

Radiological union rate of 93.3 % was observed on the last follow-up. The measured HVA on weight bearing radiographs averaged 13.7° (±5.5°) with a mean IMA of 11.8° (±3.6°). The average dorsiflexion angle was 21° (±4°).

Functional results

The AOFAS score increased from 40.9 (±18.8) pre-operatively to 79.3 (±11.2) at the post-operative follow-up with the difference being statistically significant ($p = 0.00007$). The mean results of the FAQ at last follow-up were 89.4 points (±9.7). From post-operative patients' perspective, 43 patients (71.7 %) were very satisfied, 11 (18.3 %) were satisfied, and six patients (10 %) found the result acceptable. None of the patients was unsatisfied. All patients were satisfied with the cosmetic appearance of the foot after the operation. The median FFI score improved significantly from 38 (range, 0 to 80) to 8 (range, 0 to 59) ($p < 0.001$).

Pedobarographic examination

We compared the operated foot with the contralateral one using emed® platform system. The Maximal force increased in the operated foot with a statistical significance for the first toe and the MH_1. No statistically significant change was observed in maximal force with regard to the MH_2 (Table 1). The peak pressure was higher on the operated side with a statistically significant difference for the MH_1 while no significant changes were recorded for MH_2 and first toe. Contact surfaces of the operated feet did not demonstrate any significant changes as compared to the non-operated feet (Table 2). Operated feet showed significant reduction of first toe contact time (Table 3).

Complications

Based on the final follow-up radiographs (Figs. 2 and 3), four non-unions (6.7 %) were visualized (Fig. 4). None of them required a revision operation, as the MTP joints remained stable and asymptomatic with the implants in-place. Implant removal was done for two cases due to persistent subjective foreign body sensation. Deep wound infections requiring surgical intervention were not encountered. Two patients developed superficial wound healing disturbances responded to oral antibiotic therapy and repetitive dressings. Both healed fully without further complications.

Table 1 Pedobarographic maximal force values of first toe, first and second metatarsal heads for operated and non-operated feet

Maximal force (N)	First toe	MH_1	MH_2
Operated foot	138.3 ± 91.9	222.2 ± 83.3	198.0 ± 51.3
Contralateral foot	114.7 ± 85.7	182.5 ± 69.6	186.3 ± 46.9
p-value	0.031*	0.001*	0.080

* Statistically significant

N; newton, MH_1; first metatarsal head, MH_2; second metatarsal head

Table 2 Pedobarographic contact surface values of first toe, first and second metatarsal heads for operated and non-operated feet

Contact surface (m^2)	First toe	MH_1	MH_2
Operated foot	395.6 ± 235.0	610.8 ± 271.2	671.6 ± 280.0
Contralateral foot	396.9 ± 295.3	434.8 ± 258.0	620.8 ± 282.6
p-value	0.972	0.0001	0.163

m^2; squared meter, MH_1; first metatarsal head, MH_2; second metatarsal head

Discussion

The arthrodesis of the metatarsophalangeal joint is a well-established procedure in the treatment of severe hallux rigidus. Some authors consider it as the gold standard treatment [1, 8]. The first metatarsal head carries 50 % of the body weight during the second half of stance phase of gait cycle [22]. It is therefore crucial to maintain the load bearing capacity of the first ray within physiological ranges in order to prevent the lateral transfer of the forces toward lesser metatarsals. Overloaded lesser MTP joints often manifested by metatarsalgia [9]. The results of the pedobarography showed an increased maximal force for the first toe and the MH_1 on the operated foot. This demonstrates more load transfer back to the first ray sparing the lesser rays and the lateral foot, which goes in favor of the hypothesis of the therapeutic role of first MTP joint arthrodesis in terms of load redistribution [9].

The arthroplasty of the first MTP joint was advocated as an alternative to the arthrodesis in the treatment of moderate and severe stages of hallux rigidus. However, the results of

Table 3 Pedobarographic contact time values of first toe, first and second metatarsal heads for operated and non-operated feet

Contact time (ms)	First toe	MH_1	MH_2
Operated foot	36.3 ± 16.5	74.2 ± 6.6	80.0 ± 5.4
Contralateral foot	49.4 ± 271	75.8 ± 6.0	80.2 ± 5.4
p-value	0.002*	0.099	0.731

* Statistically significant

ms; millisecond, MH_1; first metatarsal head, MH_2; second metatarsal head

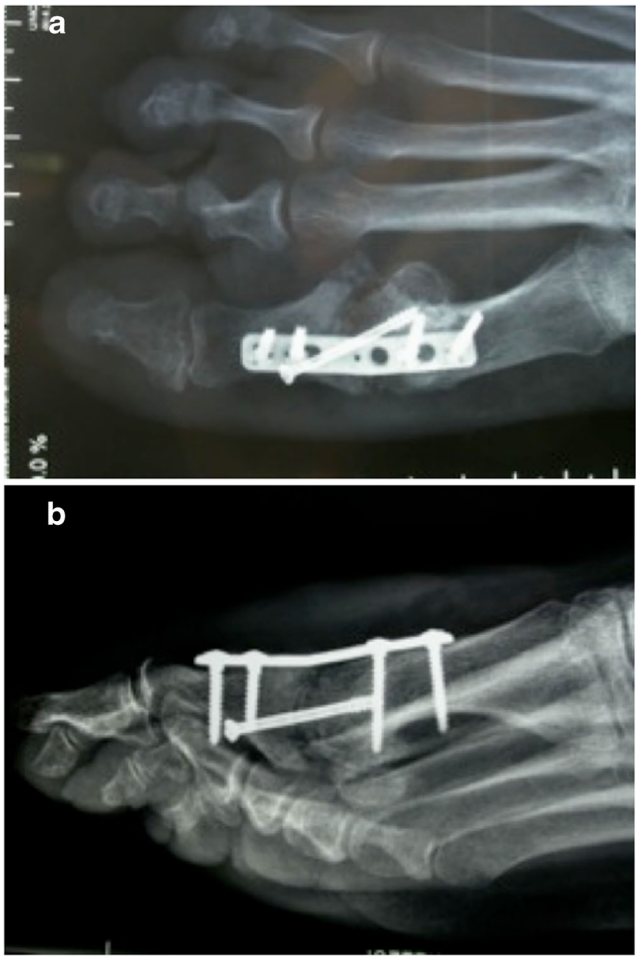

Fig. 2 Post-operative (**a**) dorsoplantar and (**b**) lateral views demonstrate well-aligned first metatarsophalangeal arthrodesis fixated by lag screw across the joint and low profile nonlocked plating

different studies showed that arthrodesis was a more predictable procedure than arthroplasty particularly in the long-term follow-up [7, 23]. Gibson and Thomson [24] had better pain relief and higher functional satisfaction in comparison to arthroplasty. At 24 months, pain improved in both groups but there were significantly greater improvements after arthrodesis ($p = 0.01$). Raikin et al. [10] found a significantly superior rating on the AOFAS score and visual analog scale (VAS) pain score in the arthrodesis group compared to the hemiarthroplasty group. The AOFAS score increased in our study post-operatively from 40.9 (±18.8) to 79.3 (±11.2) with statistically significant difference ($p = 0.00007$). The AOFAS scores following MTP arthrodesis in our patients were falling in the same range of the scores observed in similar studies [1, 25, 26]. Moreover, these AFOAS rates were relatively close to those obtained by Schneider and Jurenitsch [27] in normal population (88.3 ± 0.9 CI) for AOFAS hallux metatarsophalangeal-interphalangeal scale. Similarly, the FAQ averaged at the last followup 89.4 points showing a high satisfaction rate. Consistently, post-operative FFI of the participants showed a significant functional improvement as compared to their counterpart pre-operative scores.

The radiological poor union and the malpositioning of the MTP joint are considered the main concerns after first MTP joint fusion. For the preparation of the arthrodesis surfaces, we preferred the dome-shaped reamers because of the ease of use and the ability to reliably produce congruous joint surfaces. Dome-cup pair configuration of the opposing bony ends allows high degrees of adjustability in three-dimensional directions to easily achieve the final optimal alignment of the big toe [28]. Flat and tapered cut surfaces are technically easy and give a large surface area but severely restrict the choice of positioning angle [8]. The measured HVA averaged 13.7° (±5.5°). HVA values between 15° and 20° seem to give a good functional outcome after first MTP fusion [29–31]. The average dorsiflexion angle was 21° (±4°). Pydah et al. [32] obeserved a post-operative reduction of the IMA after first MTP joint fusion from 13.1° to 8.6°. Also Mann and Katcherian [33] described a reduction of this angle after first MTP joint arthrodesis. The mean IMA in our study was 11.8° (±3.6°). Thus the dome-shaped preparation of the surfaces allows a reproducible positioning of the arthrodesis approaching the normal physiological orientation of the foot.

In the pedobarography, we noticed a reduced contact time of the big toe in the operated foot. This could be attributed to the fusion of the MTP joint in a slight dorsiflexion of the big toe. Excessive dorsiflexion has been shown to lead to dorsal impingement and difficulties with shoe wear in some patients. Successful clinical outcomes depend largely on correct final positioning of the fusion [34]. Lewis et al. [35] found that more proximal placement of the plate led to increased final dorsiflexion angles and that the use of precontoured plates resulted in larger dorsiflexion angles at similar positions along the longitudinal axis of the first MTP joint than straight plates.

One of the main purposes of this study was to evaluate the union rate of the arthrodesis of the first MTP joint arthrodesis. In our series, 93.3 % union rate was recorded. In addition, the encountered cases of non-union (6.7 %) were well-tolerated by the patients and none of them experienced significant pain or instability mandating further intervention. The non-union rate in the present study appeared comparable to the rates of non-union observed in similar studies [8, 36, 37]. The analysis of the factors with potential unfavorable influence on the bone healing process like smoking and chronic comorbidities appeared of relatively insignificant effect in our study. Fusion rate in recent literature varies between 77 % and 100 % with the dorsal plating techniques and screw fixation [8, 11, 12, 37, 38]. Several fixation techniques and implants have been used for the fixation of the arthrodesis of the first MTP joint [8, 12–14, 39, 40]. Many authors have tried to determine the strongest and most reliable method of fixation of the arthrodesis. Dening et al. [14] showed that plate fixation alone results in significantly fewer non-unions than single screw fixation.

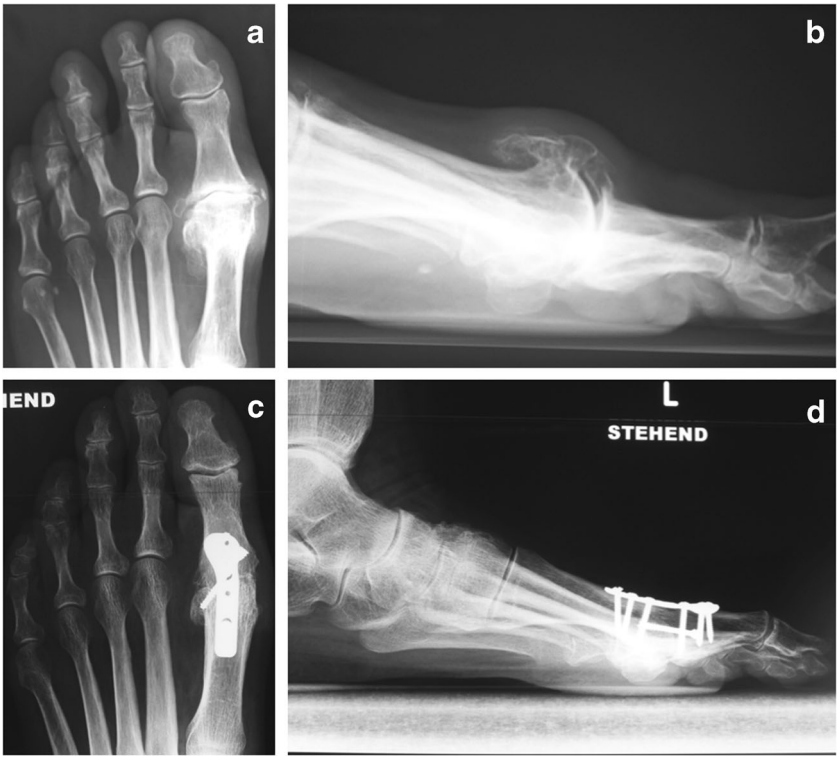

Fig. 3 Pre-operative radiographs (**a**) dorsoplantar and (**b**) lateral projections showing advanced osteoarthritic changes of the first metatarsophalangeal joint. Follow-up (**c**) dorsoplantar and (**d**) lateral radiographs with signs of fusion of first metatarsophalangeal joint

The comparison of the two crossed lag screws and the dorsal plate augmented with plantar lag screw fixation yielded no significant differences with regard to nonunion. Conversely, Hyer et al. [41] compared crossed screws and dorsal plates and observed an equivalent union rate and clinical outcome. Politi et al. [42] demonstrated, in a biomechanical analysis, that the most stable technique was the combination of machined conical reaming and an oblique interfragmentary lag screw and dorsal plate. The stability exceeded more than two times that of an isolated oblique lag screw. Dorsal plate alone and Kirschner wire fixation were the weakest techniques [42].

Intramedullary screw fixation of the first MTP joint fusion may be an option in certain situations such as failed procedures or severe deformities. It provides high-function outcomes with a low rate of surgical revisions combining adequate stability with appropriate cost-effectiveness, good fusion rate, and a low percentage of implant removals [40]. It, however, carries a potential risk of rotational instability,

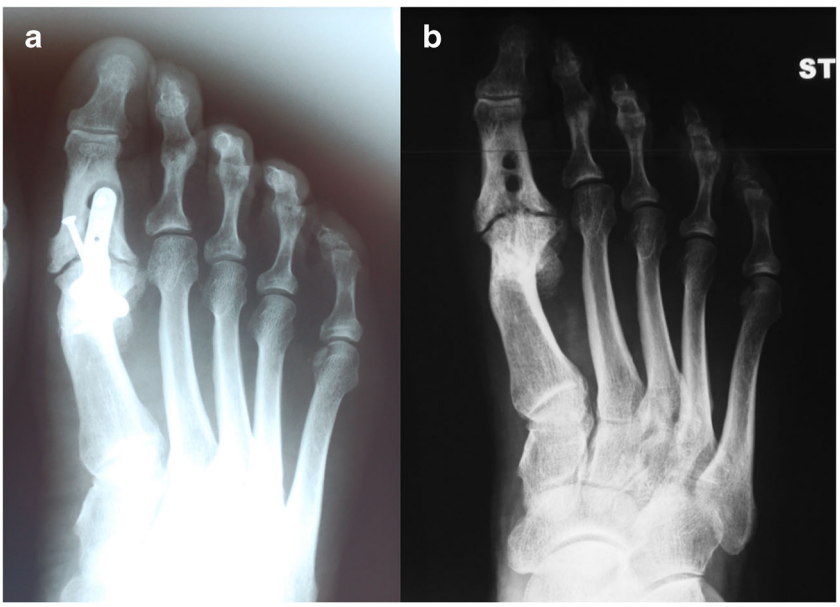

Fig. 4 (**a**) and (**b**) Radiological evidence of non-union of attempted first metatarsophalangeal joint arthrodesis

leading to possible malunion [43]. Locked plate technology is gaining popularity for procedures in the foot because of the high stability and low dislocation rate. These advantages are required particularly in the surgery of the osteoporotic bone [44]. Compared with nonlocking plates, locked hallux MTP arthrodesis plates exhibited significantly less plantar gapping and significantly greater stiffness in load-to-failure testing [13]. However, some authors found, in clinical studies, that a locked plate used for hallux MTP arthrodesis was associated with a tendency toward higher nonunion rates [37, 39].

Theoretically, using nonlocked semi-tubular plates rather than locked plates on top of lag screw fixation could be considered a limitation of the present study. Nevertheless, high union rate (93.3 %) was obtained. The cost of the precountered locking plate highly exceeds that of a semi-tubular nonlocking plate in our institution. Based on this information, the use of precountered locking plates may not always be justified. A non-union does not absolutely mean a bad result. All of the non-unions encountered in our study remained asymptomatic. The post-operative alignment and the pain reduction also largely influence the post-operative satisfaction of the patient.

Authors feel that arthrodesis of the first MTP joint using conical reaming for the joint surface preparation followed by an oblique interfragmentary lag screw and dorsal plate is a reliable method in the treatment of hallux rigidus. This technique is associated with high patient satisfaction rate and an improved functional result.

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Compliance with ethical standards

Conflict of interests None.

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