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Propulsive Metatarsalgia: a Comparative Study of Maceira's Osteotomy with and without Fixation

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SUMMARY

Background. Maceira's triple cut modified Weil osteotomy is indicated in the management of propulsive metatarsalgia. In this surgical procedure, the osteotomy will be usually stabilized with fixation. Our study is aimed at comparing the effectiveness of Maceira's triple cut modified Weil osteotomy stabilized with fixation and without fixation.

Methods. A retrospective individual cohort study was conducted from the data retrieved from 44 feet included of 40 patients, presented with propulsive metatarsalgia, who underwent "Maceira's triple cut modification of Weil osteotomy". In 29 feet, 57 osteotomies were performed without fixation, while in 15 feet, 56 osteotomies were performed along with the fixation. The mean follow-up period was 13.1 months and 12.4 months, respectively, in non-fixed and fixed groups. The patients were evaluated using AOFAS LIMS scale.

Results. In fixation group, the pre-operative mean scores were 42.47 ± 12.72 and the post-operative mean score was 70.8 ± 25.14, where as in non-fixation group preoperative mean score was 43.79 ± 13.20 and post-operative mean score was 81.59 ± 14.19. In both the groups there was improvement in the mean scores, which was statistically significant. But when compared amongst the fixation and nonfixation of osteotomy groups, there was no difference that was statistically significant ($p > 0.01$).

Conclusions. Maceira's triple cut modification of Weil osteotomy with or without fixation yields equal and effective results in patients with propulsive (3rd rocker) metatarsalgia.

KEY WORDS

Hallux valgus; metatarsalgia; metatarsophalangeal joint; osteotomy; toes.

BACKGROUND

Propulsive or third rocker metatarsalgia is one of the commonest painful condition of foot, with varying degrees of morbidity and disability. The incidence of metatarsalgia can vary between 5% and 36% (1) and it has preponderance for females (2). Metatarsalgia can be defined as a condition affecting the forefoot, which presents clinically with pain under the metatarsal heads due to the alteration in the plantar pressures as a result of the abnormal transfer of forces (3). It is considered as a symptom rather than a disease, but eventually patients develop painful intractable keratosis. On examination, keratosis can be seen over the sole of foot with palpable painful callosities under the metatarsal heads, which are the characteristic features of metatarsalgia. However, the exception being in propulsive metatarsalgia, where the plantar keratosis is more localized and palpable distally towards the toe, unlike just plantar to the metatarsal heads. The metatarsalgia is classified as primary metatarsalgia and secondary metatarsalgia. Primary metatarsalgia can be defined as the pain resulting from the anatomical abnormalities of the metatarsals and their relationship with each other and with the foot in general (4). The major cause of primary metatarsalgia include insufficiency of the first ray, disproportionately long second metatarsal bone and increased metatarsal declination angle (5). When the first ray is unable to bear the physiological load, the load will be transferred to the lateral lesser metatarsals, which leads to the propulsive or third rocker metatarsalgia. The noted causes of the hypermobility of first metatarsophalangeal joint include hallux valgus and pes planus (5). The disproportionately longer second metatarsal bone can affect the propulsive phase of the gait resulting in the third rocker metatarsalgia. This is because of less accommodative nature of the second metatarsal bone to the anatomical variation in comparison to the lateral metatarsals (4). The increased metatarsal declination angle is because of the excessive metatarsal plantarflexion, resulting in cavus foot, which in turn causes increased declination of the affected metatarsal, leading to the first rocker metatarsalgia (5).

The secondary metatarsalgia is due to the result of indirect overloading of the forefoot. It is associated with conditions like trauma involving the metatarsal head or plantar plate, where the metatarsal bones get shortened. The metatarsal bone can be plantar flexed resulting in the dislocation of metatarsophalangeal joint, resulting in pain. It is also observed in systemic inflammatory arthropathies such as rheumatoid arthritis, gout, psoriasis and in Achilles contracture with equinus. In inflammatory arthropathies, as a result of metatarsophalangeal joint synovitis, which induces the hyperextension of the metatarsophalangeal joint, this will result in the plantar overload under the metatarsal heads. Freiberg disease is the avascular necrosis of the metatarsal head commonly involving the second and third metatarsals. This is being the vascular etiology, mimics the secondary metatarsalgia (6, 7). Metatarsalgia as a result of the complications of prior forefoot surgeries is known as the iatrogenic metatarsalgia. In iatrogenic metatarsalgia due to the forefoot surgeries like in hallux valgus correction, lateral metatarsal osteotomy, there will be elevation of first metatarsal bone or excessive shortening of it (8), non-union and malunion causing overloading of adjacent rays which results in pain under the metatarsal heads (3).

A prompt clinical diagnosis and proper planning of management can resolve the symptoms with improvement in the biomechanics of the foot (9). The "Weil osteotomy" was named after Lowell Scott Weil and was popularized by Samuel Barouk, which is the gold standard for the surgical management of metatarsalgia. Later, the metatarsalgia was divided into "second rocker metatarsalgia" and "third rocker metatarsalgia". This knowledge has changed the principle of surgical management, by shortening the metatarsals by the osteotomy, aligned coaxial to the metatarsal bone line, thereby reversing the pathology of metatarsalgia, which results in relief of symptoms. The most popular surgical treatment of metatarsalgia is the "Weil osteotomy", as this technique is simple and also the results are predictable. However, the drawback of Weil osteotomy is the "floating toes", which occurs due to the plantar displacement of the metatarsal heads and is poorly tolerated. A defective surgical technique of Weil osteotomy leads to this floating toe, with uncontrolled shortening (> 3 mm) during the osteotomy (10). Ernesto Maceira came up with a modification of this surgical procedure, specific to "propulsive metatarsalgia" which is the triple cut modification of the "Weil osteotomy" (9). This results in controlled shortening, which is coaxial to the shaft of metatarsals and this also elevates the head of metatarsals, thereby preventing the floating toes (11).

A harmonic maestro curve in the metatarsal heads, from 1st to 5th metatarsals, maintains the forefoot biomechanics. A wide variety of implants are in use to stabilize the osteotomies, which range from simple Kirshner wire, cortical/cancellous screws to special implants like Schwartz snap-off compression pin, twist-off screws (11). The make of the implants also varies from stainless steel, titanium to bio-absorbable screws which are made of polymers of polylactic-co-glycolic acid (PGLA) (12). The diameter of the implants will also range from 1.6 mm to 2.4 mm. These all are aimed at the basic principle of stability by the "lag effect" across the osteotomy (12). There are different surgical techniques available, which focus on re-establishing the normal biomechanics and restoring the normal pressure distribution (13). These techniques involve realignment of the metatarsal head either by shortening or elevating. This can be achieved by performing the osteotomies commonly at the distal end of the bone like in

Weil osteotomy and various modifications of Weil osteotomy like triple cut Maceira's osteotomy (9) as in the present study or minimally invasive distal metatarsal metaphyseal osteotomy (DMMO) (14).
The present study aimed at comparing the effectiveness of the fixation and without fixation in Maceira's triple cut modified Weil osteotomy in propulsive metatarsalgia, with respect to functional outcomes and complications. We hypothesize that Maceira's triple cut modified Weil osteotomy with fixation and without fixation have comparable clinical outcomes.

MATERIALS AND METHODS

Study design

The present research is a retrospective individual cohort study, which involved, retrieving clinical case records, from our hospital.

Participants

The present study included 44 feet from 40 patients, who presented with propulsive metatarsalgia and underwent "Maceira's triple cut modification of Weil osteotomy" for "third rocker" propulsive metatarsalgia. The mean follow-up period was 13.1 months and 12.4 months, respectively, in non-fixed and fixed groups. All the surgeries were performed with the same surgical technique by two specialist foot and ankle surgeons. One surgeon among them fixed all the triple cut osteotomies, while the other did not fix any of the triple cut osteotomies which he operated on. The data collection was done by the first author of this study and the analysis of was done by four authors of this study after the detailed discussion. The statistical analysis was done by one of the consultant statisticians, available in our university.

Patient selection

All patients underwent thorough clinical evaluation in the form of gait evaluation, deformity assessment along with standing radiographs to confirm the diagnosis of propulsive metatarsalgia. These patients were given conservative line of management in the form of footwear modification, shaving of callosities and were put on physiotherapy modalities like stretching exercise program. There were no invasive methods, like local steroid infiltrations were done in any of the patients. The patients who failed to improve with the trial of conservative management for a minimum period of 6 months, were offered surgical treatment. The patients with "second rocker metatarsalgia", tightness of gastrocnemius, with a previous history of metatarsal fractures and surgical interventions in the foot were excluded from the present study. Also, patients with systemic illness like diabetes mellitus, rheumatoid arthritis, peripheral vascular diseases and peripheral neuropathy were excluded from the present study.

Clinical assessment

The patients were presented with complaints of pain, deformity, and limitation of activity in the affected lower limb. Each patient's gait was analysed, to determine the phase at which the pain generates. Pain developing in the propulsive phase of the gait cycle, indicating the third rocker metatarsalgia was documented. The deformities, such as claw toes were assessed in both standing and non-weight bearing positions, and fixity of these deformities was recorded at the corresponding joints. The plantar keratosis was noted and documented for its relationship with the metatarsal heads. The plantar keratosis is classically distal to the corresponding metatarsal heads in third rocker propulsive metatarsalgia unlike in second rocker metatarsalgia, where it is exactly on the metatarsal heads. The range of movement (ROM) at each joint was recorded. The footwear examination was explicitly done in each patient presenting with claw toes, secondary to metatarsalgia. The condition was diagnosed and documented as metatarsalgia in isolation or metatarsalgia with hallux valgus. Eventually, the quantification of disability of all the patients was evaluated and documented with the standardized questionnaire, based on the AOFAS lesser metatarsophalangeal-interphalangeal scale (LIMS) (15) at their first visit and then at the subsequent follow-ups during both the conservative and the surgical mode of management.

Radiological assessment

Standing plain radiographs of both feet were taken in all the patients (**figure 1 a**). Assessment of metatarsal parabola, which is a harmonious geometric progression of relative lengths, was assessed in dorsoplantar view, whereas, assessment of sloping of each metatarsal was done in lateral view. All the measurements were performed using DICOM multipurpose viewer (RAIM viewer version 2.5.0.511) software in digital radiographs. The hallux valgus deformity assessment was done using the hallux valgus angle (HVA), inter-metatarsal angle (IMA) along with this, the sesamoid subluxations were also recorded (16). Postoperatively, all the above parameters were reassessed and documented. The one year follow up with the AP weight bearing radiograph of bilateral feet showed maintenance of Mastero's harmonius curve bilaterally (**figure 1 b**).

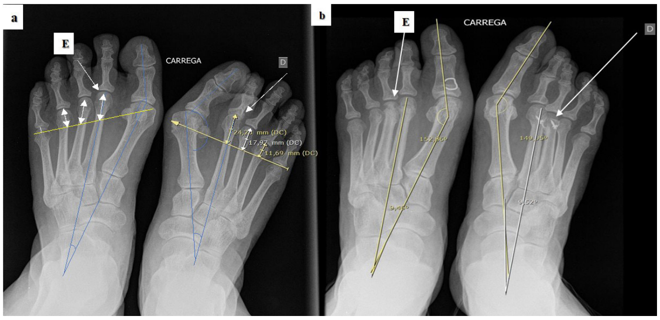

Figure 1. (a) Preoperative AP weight bearing radiograph of the bilateral feet with symptoms of metatarsalgia showing disturbed Maestro's harmonious curve with subluxation of 2nd metatarso-phalangeal joint on the right foot (D) in comparison to left foot (E). Symptomatic hallux valgus deformity of right (D) great toe. Radiological assessment of hallux valgus observed with hallux valgus angle and inter-metatarsal angle increased on right side (D), compared to the left side (E). **(b)** AP weight bearing radiograph of bilateral feet of one year follow up with no symptoms of metatarsalgia showing maintained Maestro's harmonius curve bilaterally. The Maceira's triple osteotomy not fixed on left (E) side and fixed on right side (D). Left side (E) hallux valgus corrected with distal Chevron osteotomy combined with Akin osteotomy showing improved hallux valgus angle of 31 degree (at 1 year) and intermetatarsal angle of 9 degrees. The right (D) side, hallux valgus correction not done with hallux valgus angle remained at 27 degrees (1-degree progress) after 1 year with intermetatarsal angle of 9 degrees.

Planning of osteotomy

Preoperatively, osteotomies were planned, considering Maestro's parabola criteria. Additional procedures such as excision arthroplasty, arthrodesis of the phalanges were planned as per the requirement of individual cases. Intraoperatively the hallux valgus deformity was corrected by appropriate osteotomies. In mild hallux valgus (intermetatarsal angle 10-15° and hallux valgus angle < 30°), "Chevron osteotomy" was done. In moderate hallux valgus (intermetatarsal angle > 15° and hallux valgus angle > 45°), "Scarf osteotomy" was done. After the correction of hallux valgus, to plan the number of triple cut osteotomies, the reassessment of the metatarsal parabola was done intraoperatively using fluoroscopy.

Operative technique

The patient was positioned supine; an ankle block was achieved after sedation. The ankle tourniquet was used for a bloodless field. The hallux valgus correction was done with appropriate osteotomies. Following this, reassessment of the position of metatarsal heads was done using fluoroscopy. Then the number of metatarsal heads to be addressed with Maceira's triple cut osteotomy was identified. Accordingly, a dorsal transverse incision was placed proximal to the involved metatarsophalangeal joints. The wound was deepened till the deep fascia, where extensor digitorum longus and brevis tendons were identified. A longitudinal incision was made in between them, taking care of the neurovascular structures. The capsule of the metatarsophalangeal joint was identified and incised in "T" fashion. The metatarsal head was levered and subluxated dorsally by using Hoffman's retractors on both sides of the metatarsal head, by releasing the collateral ligaments. Subsequently, the other toes were plantar flexed by the other hand of the surgeon, to well expose the metatarsal head. Similar exposure was carried out in all affected metatarsal heads and the Maceira's triple cut modified Weil osteotomy was performed as described below. It is essential to have a hand-held motorized long thin-bladed saw to achieve the controlled and precise osteotomies.

Steps of triple cut Weil osteotomy

First cut

The first cut (**figure 2 a**) was marked at the extra-articular part of the metatarsal head, just proximal to the articular cartilage with the electric cautery. An end-to-end bone cut was performed starting at a point around 2 mm inferior to the most dorsal aspect of the articular cartilage, with a saw blade angled around 25 degrees (**figure 2 a**), which is parallel to the weight-bearing plane of the foot. This step is unique in this modified Weil osteotomy, unlike in standard /traditional Weil osteotomy. It is mandatory to take diligent care to avoid damage to the metatarsal head's condyle and the flexor tendons on the metatarsophalangeal joint.

Second cut

It is a bone-to-bone cut performed, perpendicular to the ground, from dorsal to the metatarsal head's plantar aspect (**figure 2 b**). Here the extraction of a wedge of bone was planned through the osteotomy, as per the preoperative plan.

Third cut

This bone-to-bone cut is inclined as per the first cut (around 25 degrees) but started where the second cut has begun (**figure 2 c**). With the above three cuts, a wedge of bone was extracted (**figure 2 d**), and the cut end of the osteotomy was pushed together.

Fixation of the osteotomy

The distal end of the osteotomy is held in position with a guidewire across the osteotomy and fixed with an implant. In our osteotomies, 2.4 mm Herbert type cannulated screws and "snap-off screws" were used.

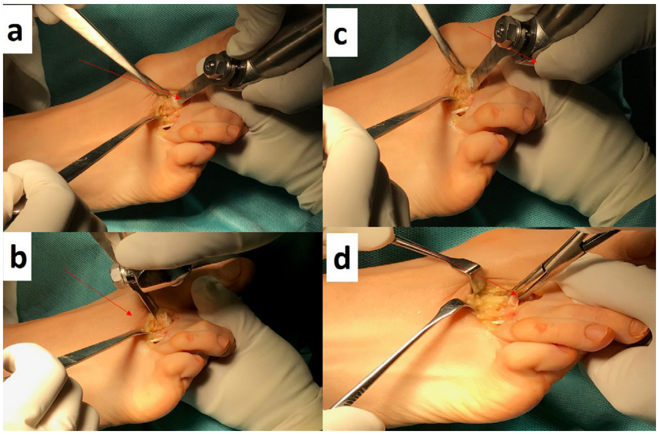

Figure 2. Triple cut osteotomy.

(**a**) First cut starting at a point around 2 mm inferior to the most dorsal aspect of the articular cartilage. The saw blade angled around 25 degrees. (**b**) Bone cut perpendicular to the ground, from dorsal to plantar aspect of Metatarsal head, to extract the exact amount of bone to be extracted as per the pre-operative plan. (**c**) Third cut of triple osteotomy inclined as per the first cut (around 25 degrees), but started from the point where the second cut had begun. (**d**) A cylinder of bone was extracted.

Osteotomy without fixation

After the triple cut osteotomy, in the non-fixation group, the osteotomised fragment is allowed to settle to the dependent position, after mimicking the foot's weight-bearing position in the operating table. The proximal migration of the metatarsal head was confirmed by the operating surgeon by fluoroscopy. In both fixation and nonfixation groups, after the completion of triple cut osteotomy, an additional procedure for correction of claw toes was performed either by excision arthroplasty or PIP joint arthrodesis by using Kirshner wires for the corresponding PIP joints.

The sequential osteotomies were performed similarly in the corresponding rays as per the pre and operative planning. When performing the osteotomy in the lateral rays, care was taken about the angle of the osteotomy, which varies according to the metatarsal's declination angle. Usually, the declination angle was increased as we progressed towards the lateral rays from the second metatarsal (11).

At the end of the procedure, the dorsal prominence of the metatarsal head was smoothened, which helps the MTP joints to achieve their full range of motion dorsally, without any restrictions. A thorough wash of the surgical site with saline was given, which aimed at avoiding any bone dust in the joint. The wound was closed, incorporating a capsulo-tendinous layer overcorrecting the toe in a plantarflexed manner. This step is crucial to avoid complications like floating toes. The subcutaneous layer is closed with 3-0 absorbable and skin with non-absorbable 3-0 suture material.

Postoperative management

A bulky cotton gauze dressing was applied, separating each toe and maintaining the toes in plantarflexion position, to control the oedema and to reduce the dorsal soft tissue retraction, thereby reducing the complications like "floating toes". This position of toes acts as "secondary bone fixation" as described by Maceira *et al*. (11). A forefoot offloading postoperative shoe was given and advised to bear weight and walk as tolerated. Irrespective of patients, with and without fixation, the postoperative care was similar for 14 days. After that, sutures were removed, depending on the wound healing. But in patients with claw toe corrections, the Kirshner wires were removed after 4 weeks, post-surgery.

Variables

Patients were followed up at regular intervals at 6 weeks, 12 weeks, 6 months, and 12 months, then for every 6 months. At each follow-up, the VAS score and AOFAS LIMS score were recorded. Radiological parameters were analysed and compared with preoperative findings. Radiographs were looked for complications like loss of fixation, non-union, and recurrence of deformity (**figure 3**).

Statistical methods

Repeated measures ANOVA test was used to compare the pain and activity limitation in the pre and postoperative period. Further analysis was done to compare the triple cut modified osteotomy with fixation and without fixation groups. Paired t-test was used for the estimation of hallux valgus correction. Whereas comparison between pre and postoperative status of the parabola correction were analyzed with the "Mcnemar test".

Ethics

The authors of this manuscript state that this research was performed as per the guidelines of international ethical standards suggested by Declaration of Helsinki (17) and approved by Institutional Ethics Committee of Clínica Creu Blanca (Reg Number 105/19) - IEC 354/2019; approval date: 03/06/2019.

RESULTS

Among the 44 feet, in 29 feet, 57 osteotomies were performed without fixation, while in 15 feet, 56 osteotomies were performed along with the fixation (**table I**). Among the 40 patients, 4 patients had bilateral involvement, making the total number sample size 44 (n = 44 feet). Among these 44

Figure 3. (a) Two-year follow up plain radiograph anteroposterior view showing bilateral feet, the triple cut osteotomy fixed on right side (D) and not fixed on left side (E). The left foot (E) showing radiological features of non-union of 2nd and 3rd metatarsal osteotomy sites, where the 4th metatarsal osteotomy showing union at osteotomy site. The hallux valgus correction done on left side (E) with distal chevron osteotomy fixed with a screw and "Akin" osteotomy fixed with metal staple. On right foot (D), the triple cut osteotomy fixed with "snap-off screws" showing healing of osteotomies. **(b)** 1-year post surgery for bilateral metatarsalgia operated with Maceira's triple cut osteotomy fixed with snap-off screws for the 2nd and 3rd metatarsal bilaterally with recurrence of symptoms showing subluxation of 2nd and 3rd metatarsophalangeal joint with disturbed Mastero's curve bilaterally with cross over 2nd toe.

feet, 40 feet (91%), presented clinically with hallux valgus deformity (**figure 1**) with metatarsalgia, and 4 feet (9%), presented with metatarsalgia alone. Among the 40 patients, who presented with metatarsalgia with hallux valgus, 32 feet had mild variety, 8 feet had moderate. Intraoperatively in both the mild and moderate hallux valgus patients, akin osteotomy was performed. Since all 44 feet had disturbed parabola per operatively, surgical correction was done to maintain the normal parabola. 113 triple cut osteotomies were performed in total. Out of these 113 osteotomies, 57 were not fixed and 56 were fixed. All patients followed up for a minimum period of 12 months. The mean follow-up time in the nonfixed group was 13.1 months and in the fixed group was 12.4 months. The AOFAS LIMS scores were improved from preoperative 43.79.47 ± 13.20 and 42.47 ± 12.72 to postoperative 81.59 points (SD 14.19; range 47-95) in the nonfixed group, whereas in the fixed group the score was 70.80 points (SD 25.14; range 25-95) ($p > 0.01$).

In both fixed and nonfixed groups, the pain reduction was significant (**table II**), from preoperative to the postoperative period, which had statistical significance ($p < 0.01$). However, the difference in pain was not statistically significant (**figure 4 A**), when compared between the two groups. ($p > 0.01$). The activity limitation (**table II**) improved from

Table I. Demographic data of study population.

Total number of feet (n)	Treatment	
	Maceira's Triple cut osteotomy without fixation (n = 29)	Maceira's Triple cut osteotomy with fixation (n = 15)
44	29	15
Mean age (years)	63	64
Gender Male:Female	2:27	3:12
Side Left:Right:B/L	14:10:5	6:5:4

Table II. Preoperative and postoperative pain and activity limitation in both the groups.

		Maceira's triple cut osteotomy without fixation		Maceira's Triple cut osteotomy with fixation	
		Preoperative	Postoperative	Preoperative	Postoperative
Pain	None	2 (6.9%)	16 (55.2%)	1 (6.7%)	7 (46.6%)
	Mild	16 (55.2%)	10 (34.5%)	6 (40%)	4 (26.7%)
	Moderate	10 (34.5%)	3 (10.3%)	8 (53.3%)	4 (26.7%)
	Severe	1 (3.4%)	0 (0%)	0 (0%)	0 (0%)
Activity limitation	None	0 (0%)	20 (69%)	0 (0%)	9 (60%)
	Mild	4 (13.8%)	5 (17.2%)	0 (0%)	1 (6.7%)
	Moderate	25 (86.2%)	4 (13.8%)	15 (100%)	5 (33.3%)
	Severe	0 (0%)	0 (0%)	0 (0%)	0 (0%)

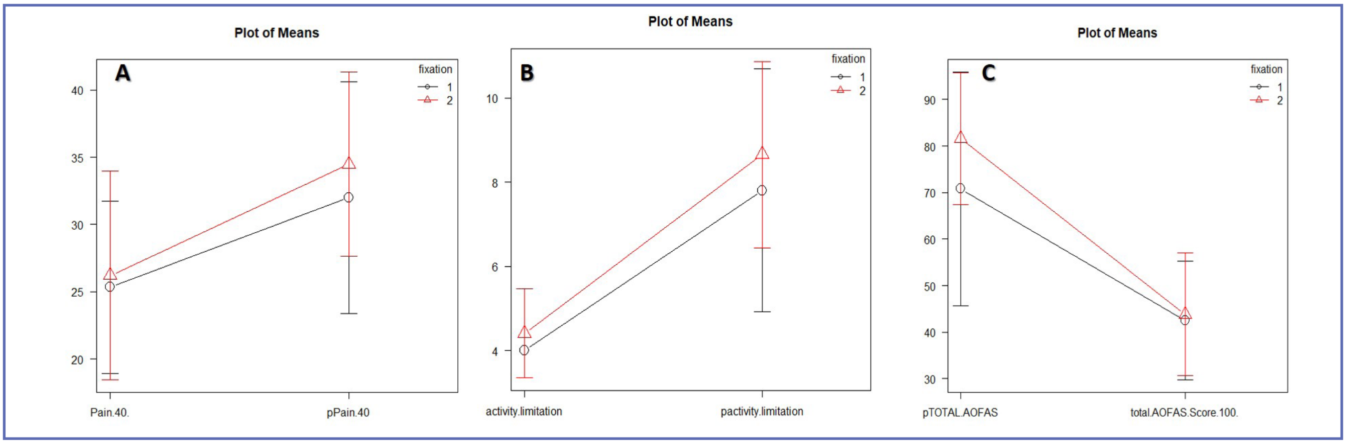

Figure 4. The comparison of fixation and non-fixation groups.

(A) Reduction of pain; **(B)** Activity limitation; **(C)** AOFAS score. In the present study, none of these compared parameters showed the statistical significance ($p > 0.01$).

preoperative to postoperative period significantly in both the groups ($p < 0.01$). But the activity limitation when compared postoperatively amongst the groups, there was no statistical significance (**figure 4 B**) ($p > 0.01$).

The AOFAS LIMS score (**table III**) improved from preoperative to postoperative status, which was statistically significant ($p < 0.01$), but post-operatively when the fixation group compared with the nonfixation group (**figure 4 C**), there was no statistical significance ($p > 0.01$). The hallux valgus (**table IV**) was evaluated radiologically by measuring the inter-metatarsal angle (IM angle) and Hallux Valgus angle (HV angle). The results of radiographic measurements from preoperative to the postoperative correction were compared and evaluated. The "paired t-test" was performed and this comparison was statistically significant ($p < 0.01$). The metatarsal parabola improvement from preoperative findings to postoperative maintenance (**table V**) was also statistically significant, which was evaluated with the "Mcnemar test" ($p < 0.01$).

The Mastero's metatarsal parabola (**table V**) was disturbed postoperatively, in 5 feet (33.3%), in the fixation group. whereas in the nonfixed group 6 feet (20.7%) showed disturbed parabola (**figure 3 b**). Loss of fixation was found in 5 feet (11%), out of which, in 3 feet had to undergo hardware removal due to soft tissue impingement. Non-union at oste-

Table III. Comparison of AOFAS LIMS score preoperative to postoperative in both the groups.

Grading	Points	Maceira's triple cut osteotomy without fixation		Maceira's triple cut osteotomy with fixation	
		Preoperative	Postoperative	Preoperative	Postoperative
Excellent	90-100	0 (0%)	14 (48.3%)	0 (0%)	4 (26.7%)
Good	75-89	0 (0%)	7 (24.1%)	1 (6.7%)	5 (33.3%)
Fair	60-74	4 (13.8%)	5 (17.2%)	0 (0%)	1 (6.7%)
Poor	0-59	25 (86.2%)	3 (33.4%)	14 (93.3%)	5 (33.3%)

Table IV. Comparison of Hallux valgus deformity in both the groups.

	Maceira's triple cut osteotomy without fixation		Maceira's triple cut osteotomy with fixation	
	Preoperative (Mean ± SD)	Postoperative	Preoperative	Postoperative
Hallux Valgus angle	38.25°	29.5°	33.86°	29.8°
Intermetatarsal angle	11.48°	8.77°	11.8°	10.26°

Table V. Comparison of status of Metatarsal Parabola Preoperative and Postoperative in both the groups.

Normal Metatarsal Parabola	Maceira's triple cut osteotomy without fixation		Maceira's triple cut osteotomy with fixation	
	Preoperative	Postoperative	Preoperative	Postoperative
Maintained	14 (48.3%)	23 (79.3%)	6 (40%)	10 (66.7%)
Disturbed	15 (51.7%)	6 (20.7%)	9 (60%)	5 (33.3%)

otomy sites (**figure 3 a**) were found on follow-up radiographs in 2 feet (4%) in the non-fixation group. But they were clinically asymptomatic. All the wounds were healed well, without any evidence of superficial or deep infection in both groups.

DISCUSSION

The head of metatarsal bones bears half of the body-weight of a person when the foot is in a plantigrade position. Normally, the first metatarsal bone bears half of the weight of the forefoot. Metatarsalgia can be due to a longer second metatarsal bone, which can contribute to the formation of pressure under the head of the metatarsal bone. The limited dorsiflexion of the foot due to heel cord contracture and ankle impingement can lead to the formation of diffuse metatarsalgia (18). The claw toe deformity can cause excessive weight bearing on the metatarsal head. In hallux valgus, when the proximal phalanx moves into the valgus, the splay between the first and second metatarsal increases. The base of the first metatarsal bone at the first cuneiform-first metatarsal joint also moves into the varus position and gets elevated. This leads to the transfer of weight from the first metatarsal head to the second metatarsal head. This results in the potential transfer of weight to the adjacent metatarsal head leading to the formation of callosity.

Metatarsalgia is considered as a symptom rather than a disease. The classical symptoms of metatarsalgia are pain at the sole, associated with the hyperkeratosis of skin below the head of metatarsal bones (18). The hypermobility of the first tarsometatarsal joint will contribute to the transfer of metatarsalgia (19). Thus the aetiology of the metatarsalgia may vary from anatomical abnormality to iatrogenic cause. Hence thorough examination of the sole and standing radiographs would be important tools for the accurate diagnosis and management of metatarsalgia (5). Initially, the metatarsalgia can be treated with the shaving of callosities, stretching exercises, shoe modification including insoles, and local steroid injections (20). Even unconventional treatment like massage therapy is well accepted by the patients, due to its low economical expenses and fewer adverse effects (21). If there is no improvement with the medical line of management, surgical intervention is advised (5). Initially, for the management of metatarsalgia, the surgical procedure, the distal osteotomy was suggested by Borggreve in 1949. Later, this was endorsed by Weil in 1992 (19). The Weil osteotomy became popular in Europe and was implemented by Barouk (22). Weil osteotomy is the procedure in which, the osteotomy is in parallel to the plantar surface of the head of the metatarsal. If it is internally fixed with screws, there will be the accomplishment of axial decompression (19). The surgical options also include osteotomy at the middle or proximal aspect of the metatarsal in cases of severe deformity, which require powerful deformity correction (13). In the last decade, minimally invasive "distal metatarsal metaphyseal osteotomy (DMMO) has gained momentum, as an alternative procedure for the traditional Weil osteotomy. This is a percutaneous, extra-articular metatarsal neck osteotomy without the internal fixation (14).

Rocker is the term, used in the gait cycle to the fulcrum, during its progression. The mechanical metatarsalgia is classified into second rocker metatarsalgia and third rocker metatarsalgia (20). The second rocker metatarsalgia is also known as midstance metatarsalgia or ankle rocker, where increased plantarflexion of the lesser metatarsals overloads the forefoot producing the metatarsalgia. The third rocker metatarsalgia is also known as propulsive metatarsalgia or forefoot rocker in which the forefoot acts as the third rocker and only the metatarsal heads and toes will be on the ground (20).

The present study has screened and included only the patients, who were clinically and radiologically diagnosed to have third rocker metatarsalgia. Espinosa *et al.* (9) stated that the triple cut modification of Weil osteotomy is a specific technique to address the third rocker metatarsalgia. For the treatment of third rocker metatarsalgia, the surgical option was recommended, only after the fair trial of conservative management failed for a minimum period of 6 months. In our study, the hallux valgus correction showed statistically significant improvement with the mean correction of the inter metatarsal (IM) angle (2.71°) and the hallux valgus (HV) angle (8.75°). This is comparable to the study by Biz *et al.* (23), where the mean IM angle correction was 5.95° and HV angle was 16.81°. In our study, the hallux valgus was divided as mild, moderate and severe, depending on the radiological measurements (IM angle and HV angle). The Cheveron osteotomy is performed in mild and Scarf osteotomy was performed in the moderate variety. This is in contrast to the study by Biz *et al*. (23), where the endolog technique was used to achieve the correction of hallux valgus.

Most of the patients with propulsive metatarsalgia will have insufficient first rays, which was evident in the present study. The patients presenting with abnormal parabola are good candidates to restore the forefoot physiological relationships with the Maceira's triple cut modified Weil osteotomy (9). In the present study, out of 44, 33 feet had a disturbed parabola in the preoperative state, the remaining 11 feet showed disturbed parabola after the correction of hallux valgus. Eventually, all 44 feet showed disturbed parabola after the correction of hallux valgus. Our study showed radiologically disturbed Maestro's metatarsal parabola (**table III**) in 6 patients (20.7%) in triple Weil osteotomy without fixation group and 5 patients (33.3%) in triple Weil osteotomy with fixation group. This finding is comparable to Biz *et al*. (14), where the ideal metatarsal parabola was obtained in 3 feet (3.2%) out of 93 feet. Biz *et al*. (14) concluded that, there is no correlation among having a harmonious Maestro's metatarsal parabola and the clinical outcome.

The patients with hallux valgus associated with the metatarsalgia, formed the major criteria in our patients. It is believed that the hallux valgus may be the cause or effect of metatarsalgia. Biz *et al*. (24), while analysing the first ray hypermobility in ballet dancers, could be able to make out the observation that, during the single stance of the dance, the dancers supported the body weight by using the second and third toes, with the first ray moving into the valgus, describing the development of metatarsalgia along with the hallux valgus deformity (9). It was reported that the conservative management is not satisfactory in the management of hallux valgus deformity. However, the exceptions are being the peripheral vascular disease, local infection and noncompliant patient population (25). Traditionally, among the hundreds of techniques of performing the osteotomies for the correction of deformities, Chevron and Scarf's osteotomies are the popular ones, which have the good functional outcomes. These open osteotomies are popular, because of their effectiveness combined with the reproducibility, resulting in the symptomatic relief with correction of the radiological parameters like hallux valgus angle, inter-metatarsal angle and distal metatarsal articular angle (DMAA). In our study, we performed Chevron and Scarf osteotomy in majority of the patients depending on the severity as assessed by the clinical and radiological means. Presently, the minimally invasive correction and stabilization of hallux valgus is in vogue, which evolved recently and are quite popular, with comparative results clinic-radiologically. They have good patient satisfaction as the techniques evolved lowering the complication rates (26). These techniques are surgically demanding from the surgeon's perspective with the steep learning curve.

The osteotomy technique recreates the biomechanics by the preservation of the relative length and position of interossei muscles concerning the centre of rotation of the MTP joint. Garcia *et al*. (15) in a retrospective study of the traditional Weil osteotomy, reported that there is no difference in functional outcome when osteotomies with and without fixation were compared. In our study, when the triple cut osteotomies were compared between the fixed and non-fixed groups, it was observed that there was no incidence of recurrent metatarsalgia. Our results also showed radiological features of non-union osteotomy in only 2 feet (4%) out of 29 nonfixed triple cut osteotomy feet. However, both these feet were asymptomatic. In our study, there were 5 feet showing loss of fixation amongst 15 fixed osteotomy feet. Out of these 5 feet, 3 feet were warranted for the hardware removal to settle down the symptoms. These results were comparable to the study by Garcia *et al*. (15), where the fixation of traditional Weil osteotomy had a higher incidence of revision surgeries in comparison to the non-fixation group.

The most important biomechanical aspect of triple cut osteotomy over the traditional Weil osteotomy is the intrinsic tendon's course with respect to the MTP joint. The course of intrinsic tendons is usually altered in traditional Weil osteotomy whereas, in triple cut osteotomy the course of the tendon is maintained., making the osteotomy stable.

Since the triple cut osteotomy without fixation had shown comparable functional outcomes with minimal complications, this can be considered as a valuable surgical option for the management of third rocker metatarsalgia. The triple cut Weil osteotomy prevents the stiff floating toe, which is one of the major complications observed in the traditional Weil osteotomy. It also reduces the duration of surgery and helps in better tolerance by the patients for early weight-bearing. The nonfixation of the triple cut osteotomy makes the metatarsal heads settle down to an appropriate position during the weight-bearing, thereby restoring a normal distribution of pressure within the forefoot (15). Further on, not fixing the triple cut osteotomy has an additional advantage of the reduction in the reoperation incidences for the hardware removal.

The present work is an attempt to know the need for fixation of the Maceira's triple cut osteotomy by the retrospective study, which is the first of its kind according to our knowledge. The main limitation of this study is the usage of AOFAS LIMS score for a short follow up. This research also has some limitations like, it is a retrospective study with a small follow-up period of less than two years and is performed in two institutions. The shorter follow up period made us not knowing about the late recurrences of the deformity. However, we are following up the same patients for a longer period of minimum 5-10 years. So we had adopted the AOFAS LIMS score for the assessment. The first ray pathology, which coexists with the metatarsalgia is seen in our study participants as well and this can be an another limitation. Any clinical and radiological parameters of the first ray pathology like recurrence of the hallux valgus deformity can alter the clinico-radiological results of the osteotomy.

But the strength of this study is that this is the first of its kind to compare retrospectively the need for fixation of Maceira's triple cut modified Weil osteotomy for the propulsive metatasalgia. The potential further research related to this study can be a randomized prospective trial with longer follow up is essential to clearly conclude about the need for fixation in a Maciera's triple cut modified Weil osteotomy.

CONCLUSIONS

Maceira's triple cut modification of Weil osteotomy with or without fixation yields equal and effective results in patients with propulsive (3rd rocker) metatarsalgia.

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DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

All the authors were equally involved in the conception and design of the first draft.

PRK, GLL, KAGN, AB: analysis and interpretation. PRK, BVM, GLL, MBA: data collection. PRK, KAGN, YLR, AB: statistical analysis. Writing the final manuscript was performed equally by authors, followed by the critical review. All the authors agree to be accountable.

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CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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