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Lateral column lengthening using Z osteotomy of calcaneus for adolescents with symptomatic flexible flat foot

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Abstract
Background: Flexible flatfoot (FFF) deformity is distinguished by the medial arch collapse, hindfoot valgus, forefoot abduction, and tightening of the gastrocnemius or gastrocnemius-soleus complex. The Z-osteotomy is a more current iteration of the Lateral Column Lengthening (LCL) and has promising results from existing research. This work aimed to evaluate the clinical and radiological results of double calcaneal Z osteotomy in symptomatic adolescent FFF patients.
Methods: This prospective cohort study was conducted on 20 adolescent patients with FFF deformity, at Benha university Hospitals and Al Mahalla general hospital. All patients were subjected to clinical and radiological evaluation, general and local examination.
Results: The postoperative evaluation revealed significant improvements in the lateral cerebral palsy (CP). The preoperative mean lateral CP angle was 6.76° (SD 3.407), which increased to 23.40° (SD 6.377) postoperatively. This resulted in a mean improvement of -16.640° and a percentage change of 246.15%, with a statistically significant difference in means (t = -14.099, $p< 0.001$). Similarly, the lateral tarsometatarsal (TMT) angle showed significant improvement postoperatively compared to its preoperative measurement. The mean angle preoperatively was 11.616° (SD 5.627), which decreased to 1.091° (SD 0.637) postoperatively, resulting in a percentage change of 90.6%. A statistically significant was found (t = 10.525, $p< 0.001$).
Conclusion: The proposed technique has been demonstrated to be a valuable contribution to the surgical correction of symptomatic flexible flatfoot, as it is straightforward, corrects all components of the deformity in a single session, and can be conducted in a secure manner by adolescents.

Keywords: Z osteotomy, lateral column lengthening calcaneus, adolescents, symptomatic, flexible flat foot

Introduction
Flatfoot is a frequent condition, especially among younger people. In children, most cases of flatfoot are symptom-free, flexible, and typically do not need treatment. Flexible flatfoot (FFF) deformity is characterized by the flattening of the inner arch of the foot, the turning of the hindfoot outward, the outward angling of the forefoot, and tightness in the gastrocnemius or gastrocnemius-soleus complex [1].
Nowadays, corrective procedures for FFF in adolescents may include methods like stabilizing the subtalar joint, repositioning the heel bone, lengthening the outer part of the foot, and reconstructing ligaments. Arthrodesis is recommended for patients who are unable to participate in daily routine activities due to pain, callosities, and discomfort while walking. Cotton osteotomy, gastrocnemius recession, and the initial tarsometatarsal fusion are additional procedures [2].
First, conservative methods are ineffective in alleviating the patient's symptoms; surgical procedures should be carried out. There is a wide range of surgical options available, including simple soft tissue procedures and more complex bone procedures like tarsal osteotomies, subtalar joint fusion outside the joint, and triple joint fusion [3].
Arthrodesis, medial displacement calcaneal osteotomy, spring ligament reconstruction, lateral column lengthening, and subtalar arthroereisis are all modern methods used to realign

FFF in adolescents. Further procedures include gastrocnemius recession, cotton osteotomy, and the initial tarsometatarsal fusion [4].

The Z-osteotomy is a more current iteration of the LCL and has promising results from existing research, which compares directly with other LCL osteotomy procedures regarding smaller graft needed, reduced healing time, non-union rate, reoperation rate, potential for greater correction, and improvement in talonavicular coverage [7].

The aim of the study was to assess the clinical and radiological results of double calcaneal Z osteotomy in symptomatic adolescent FFF patients.

Patients and Methods

This prospective cohort study was conducted on 20 adolescent patients, with FFF deformity was diagnosed, and Z Calcaneal Osteotomy was performed, at Benha university Hospitals and Al Mahalla general hospital, from January 2023 to February 2024. Informed written consent was obtained from all patients or their parents. The study was done after approval from the Ethics Committee on research involving human subjects of Benha faculty of Medicine.

Criteria of inclusion were patient presented with a symptomatic, painful FFF, age ≥ 10 years and less than 30 years old, forefoot abduction with hindfoot valgus, with no indications of diabetes mellitus or any risk factors that would prevent surgery, and the patient didn't have arthritis.

Exclusion criteria included patients less than 10 years old, those with rigid flatfoot, cerebral palsy (CP), or neuromuscular disorders, individuals with posterior tibial tendon insufficiency (PTTI), and those suffering from midfoot or hindfoot arthritis or generalized hyperlaxity.

All the studied patients were subjected to clinical and radiological evaluation, which was conducted in accordance with the subsequent protocol; the past history, which encompasses the medical history, history of previous trauma to the foot, and duration of the afflicted foot pain prior to surgery; general and local examination, which involved a meticulous evaluation of the affected foot; The evaluation of the neurovascular status of the extremity, in addition to the assessment of ankle and subtalar joint mobility, along with a heel raise test to confirm flexibility.

Preoperative scoring

A heel raise test is conducted to verify flexibility, in addition to the evaluation of ankle and subtalar motion. (AOFAS) score [8]. Visual Analogue Scale (VAS) The pain index is calculated to ascertain the discomfort both before and after the procedure [9]. In addition to evaluating ankle and subtalar motion, we conduct a heel raise test to verify flexibility.

Radiological evaluation

Prior to surgery in addition to the evaluation of ankle and subtalar motion and a heel raise exam to verify flexibility. Pre- and post-operative measurements of Meary's angle were implemented to evaluate the extent of flatfoot, and the talonavicular coverage angle (TNC) was measured to quantify forefoot abduction.

Z calcaneal osteotomy

Patient positioning was supine with a sandbag under the buttocks of the ipsilateral side. Before the surgery, a single intravenous injection of 1 gm of third-generation cephalosporin was given along with general or spinal anesthesia and a thigh tourniquet that was inflated 200 mmHg above systolic blood pressure. In the surgical steps, soft tissue lengthening was done by retracting the gastrocnemius muscle if the Silfverskiöld test came back positive. If the test came back negative, the Achilles tendon was lengthened through a percutaneous method. Realignment of the osteotomy followed, starting with a single lateral skin incision that is around 5 cm in length and runs parallel to the plantar surface over the peroneal tubercle.

Diathermy marked the osteotomy site in a Z shape. This approach is in the internervous plane between the superficial peroneal nerve and the sural nerve. If larger branches of either nerve are encountered, they should be protected and preserved. The peroneal ten dons are retracted plantarly, as needed. The lateral wall of the calcaneal neck is exposed, and small Hohman retractors can be positioned on the superior and inferior borders. The planned osteotomy is then outlined with a marking pen. The vertical ascending limb extends 1 cm posterior to the calcaneocuboid joint. and is directed upward. The horizontal limb began from the vertical ascending limb, and the oblique descending limb was subsequently formed by terminating 1 cm posterior to the posterior facet of the subtalar joint and leaving the capsule of the posterior facet undisturbed. The osteotomy was performed under imaging guidance using an oscillating saw or multiple drillings and osteotomies. Gently distract with a lamina spreader or Hunterman to extend the lateral column. The hindfoot is stabilized, and the forefoot is then adducted using the medial aspect of the talonavicular joint as a fulcrum. This, in combination with the use of the metal ruler, will facilitate mobilization of the osteotomy. This results in medial rotation of the distal part of the ''Z'' and an opening lateral wedge effect. The opening of the lateral portion of the osteotomy is usually between 5 and 10 mm. To rectify hindfoot valgus and restore normal hindfoot alignment, we medially slid the calcaneal tuberosity, resulting in a 0.5 cm to 1 cm medial translation.

We performed the fixation by securing 2-3 mm smooth wires through the calcaneocuboid joint and the calcaneal tuberosity. Then, the deep fascia was closed and the skin with interrupted sutures. The surgeon applied a slab below the knee to immobilize the patient.

Post-operative

Following discharge within 24 hours post-surgery, close monitoring of neurovascular status continued. Medications included a postoperative antibiotic regimen of third-generation cephalosporin subsequently, oral antibiotics were administered for a period of one week. Anti-oedematous medications and non-steroidal anti-inflammatory drugs were prescribed to the patient for the purpose of managing postoperative pain. Follow-up appointments were scheduled for one week, 2 weeks, 4 weeks, 3 months, and 6 months following the operation. At 2 weeks, during the course of one week. This patient was prescribed non-steroidal anti-inflammatory drugs and anti-oedematous medications to manage postoperative pain.

Postoperative rehabilitation involved a standardized program supervised by a physiotherapist starting at least 6 weeks after surgery. The primary objective of this regimen was to restore the extent of motion in the ankle and subtalar joints, engaging in proprioceptive exercises to fortify the

tibialis posterior tendon, and achieving consolidation of osteotomies and integration of bone grafts within 6 to 8 weeks postoperatively.

Postoperative evaluations at 6 months included assessing range of motion, applying the VAS score for pain, and using the ankle and subtalar motion (AOFAS) score to evaluate functional outcomes. Clinical photos were taken to document hindfoot valgus correction while standing. Radiological assessments, conducted after 6 months, included the degree of flatfoot improvement is evaluated by measuring the lateral Meary's angle in standing lateral view X-ray and the TNC angle in X-ray AP view to evaluate forefoot abduction improvement.

Statistical analysis

SPSS version 25 (IBM, Armonk, New York, United States) was used to manage data and conduct statistical analyses. Normality of quantitative data was assessed using the Shapiro-Wilk test and visual inspection. Numerical data were summarized with means and standard deviations or medians and ranges, while categorical data were presented as numbers and percentages. Changes in quantitative variables before and after surgery were compared using paired t-tests for normally distributed data and Wilcoxon signed-rank tests for non-normally distributed data. Spearman's correlation was employed to examine relationships between weight and post-operative outcomes. All statistical tests were two-sided, and findings with p-values less than 0.05 were considered statistically significant.

Case presentation

Case 1

A 13-year-old boy came in with symptoms related to his right foot, which exhibited FFF characterized by right absent arch, right prominent talar head, and severe heel valgus. Preoperative radiographs included a standing AP view of the right foot. X-rays at the three-month follow-up after surgery revealed a shift in the talus towards the inside, in contrast to the navicular and first metatarsal. Additionally, a standing lateral view indicated noticeable collapse of the arch; the calcaneal pitch angle improved to 23.5°, and the talonavicular coverage angle improved to 1.3 °. Clinical follow-up showed correction of the right arch to normal, with no more prominent talar head observed.

Figure 1

Case 2

A 10-year-old female presented with RT symptomatic FFF, had RT absent arch, prominent talar head and heel valgus. The preoperative radiographs obtained was standing AP view of the RT foot and The X-ray indicated that the talus was displaced medially in relation to the navicular and first metatarsal bones, while the standing lateral view of the right foot demonstrated obvious arch collapse. Preoperative RT foot had cerebral palsy (CP) 3 º, lat TM angle 23º, in AP Talonavicular coverage angle 5 º. 3 weeks postoperative, the graft in place fixed and maintained by k wire. At the final follow up, the CP angle 36º, in AP view the TN angle become 0.2 º. Standing lateral view showed satisfactory arch elevation. AP view showed congruent talonavicular joint. In the follow up photographs, arch correction to normal “No more prominent talar head” and neutral heel figure 2 results.

There were 15 females (60%) and 10 males (40%). The age of the patients ranged from eight to eighteen years, with an average age of eleven point forty-eight years old. There were 13 cases involving the left side (52%) and 12 cases involving the right side (48%). On average, patients were followed up for 18 months, with follow-up durations ranging from 16 to 36 months. The average duration of conservative treatment was 4.5 months, varying from 3 to 6 months. All patients underwent Achilles tendon lengthening. They were clinically and radiologically evaluated both before and after surgery, with an average follow-up period of 18 months, ranging from 6 to 36 months table 1.

Before surgery, 15 feet showed fair clinical condition, while 10 feet were assessed as poor. One female patient had good clinical status in both feet and no neuromuscular issues. Persistent and bothersome pain for both the child and parents prompted the decision to proceed with surgery. The clinical outcomes are presented below in table 2.

Before the surgery, all patients exhibited significant correction ($p< 0.001$) in all measured parameters during their latest visit post-surgery. Pain, which initially prompted the surgery, was completely resolved in every patient. Throughout the follow-up period, no difficulties were reported with wearing shoes. Postoperatively, 14 patients achieved excellent results (16-18 points), 9 patients achieved good results (13-15 points), and 2 patients achieved fair results (10-12 points); none of the patients had poor results (< 10 points). One patient with a fair clinical score experienced severe preoperative pain, which improved postoperatively. The arch, initially grade 3 (severe, no arch, convex medial border), improved to grade 2 (moderate, no arch, straight medial border). Preoperative heel misalignment of 20 degrees improved to 12 degrees postoperatively.

The average AOFAS scores were 68.56 ± 5.05 preoperatively, 86.40 ± 3.65 at three months postoperative, and 95.19 ± 1.00 at the maximum follow-up. Comparisons between these time points showed a significant increase in AOFAS scores ($p< 0.001$). The mean difference between preoperative and three-month postoperative scores was -17.84, corresponding to a 26.02% improvement. A significant increase in AOFAS scores was observed at three months postoperative compared to preoperative (P = 0.001). The mean difference between preoperative and maximum follow-up scores was -26.63, with a 30.82% improvement. A significant increase in AOFAS scores was noted at maximum follow-up compared to preoperative (P = 0.000). The mean difference between three-month postoperative and maximum follow-up scores was -8.79, reflecting a 9.23% improvement. A significant increase in AOFAS scores was found at maximum follow-up compared to three-month postoperative (P = 0.001) Table 3.

The postoperative evaluation revealed significant improvements in the lateral CP. The preoperative mean lateral CP angle was 6.76° (SD 3.407), which increased to 23.40° (SD 6.377) postoperatively. This resulted in a mean improvement of -16.640° and a percentage change of 246.15%, with a statistically significant difference in means ($t = -14.099$, $p< 0.001$). Similarly, the tarsometatarsal (TMT) angle showed significant improvement postoperatively compared to its preoperative measurement. The mean angle preoperatively was 11.616° (SD 5.627), which decreased to 1.091° (SD 0.637) postoperatively, resulting in a percentage change of 90.6%. This difference

in means was statistically significant (t = 10.525, P < 0.001). There was a notable and statistically significant enhancement in the angle of AP talonavicular coverage postoperatively compared to the preoperative measurement. A preoperative mean angle of 8.619 (SD 2.702) was improved postoperatively to 0.846 (SD.336) with percent of change 90.18%. The difference of means was statistically significant t= 14.836 *p*<0.001) table 4.

Discussion

Surgical intervention for FFF in children is typically considered for those with moderate to severe deformities who have not responded adequately to non-surgical treatments. The objectives of various surgical techniques proposed for treating FFF in children include elevating the medial arch and correcting both heel valgus and forefoot abduction [10]. Several surgical procedures are used to treat FFF in children, including the calcaneal stop procedure, arthrodesis, and Evan's osteotomy. Our comparison of results with previous studies indicated that Evan's osteotomy specifically addresses forefoot abduction but does not correct heel valgus. Therefore, it does not contribute to improving heel valgus following surgery [11].

This study explores a straightforward bone-based approach known as double calcaneal osteotomy, which achieves complete correction without requiring joint fusion. This is particularly beneficial for young patients. We present the results of using double calcaneal osteotomy to reconstruct severe FFF in adolescents, a procedure that has been seldom documented in previous literature.

Ebaugh and colleagues [12] In a recent study, a new surgical technique called the "extended Z-cut osteotomy" was proposed, which combines lateral column lengthening (LCL) and medial displacement calcaneal osteotomy (MDCO). This technique differs from traditional methods like the Griend osteotomy by using reverse vertical cuts. The study, conducted over the short-term with 25 patients and 25 feet affected by painful pediatric FFF deformity, showed significant clinical improvements. Patients experienced either complete absence of pain or substantial pain reduction, along with enhanced physical activity capabilities and reduced fatigue, as confirmed by radiological assessments. The AOFAS score, a measure of foot and ankle function, demonstrated a notable improvement (mean difference 95.19 ± 1, p < 0.001), reflecting advancements in both objective and subjective aspects of patient outcomes. Most patients reported minimal pain, and there was a decrease in the need for walking aids, resulting in increased maximum walking distances for many individuals. This successful outcome underscores the primary objective of enhancing quality of life through effective correction of deformities.

All the X-ray measurements showed clear improvement. On the side view, the calcaneal pitch angle improved by an average of 16.640 degrees with a small variation of 5.9 degrees, while the talar-first metatarsal angle improved by an average of 10.524 degrees with a variation of 5.66 degrees. On the top-down view, the talonavicular coverage angle improved by an average of 7.773 degrees with a small variation of 2.619 degrees. In terms of joint movement, our study achieved excellent outcomes, with all patients recovering full ankle and subtalar joint mobility within six months. Compared to other studies, our results were very similar in their effectiveness [13, 14].

The study found that Z calcaneal lengthening osteotomy effectively treats symptomatic FFF that doesn't respond to conservative treatments. This procedure led to an increase in the calcaneal pitch in every patient by carefully moving the front part of the heel bone upward. This improvement was seen as beneficial for both how the foot looks and how it appears on X-rays. The noticeable rise in the calcaneal inclination angle was directly linked to how well the osteotomy worked.

Using Z calcaneal osteotomy alone has several benefits. It allows for structural restoration of the arch without requiring additional soft tissue reconstruction. K-wires with Fixation instead of screws or Steinmann pins offers advantages such as cost-effectiveness, easier application, and eliminating the necessity for a follow-up surgery to take out the hardware.

Fortunately, there were no instances of the deformity returning in the study group, except for one foot that had an unsatisfactory outcome because the patient took off the cast prematurely (after only one month) and did not follow up regularly. Symptoms such as pain, fatigue, and reduced activity greatly improved after the surgery and continued to get better over the follow-up period, with no signs of getting worse. Radiological measurements taken postoperatively also showed no worsening up to the latest follow-up examination.

Our study had limitations as study was single centre study with relatively small sample size and lack of control study underwent the standard technique.

Table 1: Distribution of gender, age and side distribution in patient group

		Number (n=25)	%
Sex distribution	Female	15	60
	Male	10	40
Age	8 - 11y	14 feet	56
	12 - 18y	11 feet	44
Side distribution	Left	13	52
	Right	12	48

Table 2: Clinical results of the studied patients

	Preoperatively	Last visit
Excellent (%)	-	14(55.6%)
Good (%)	1 (2.8%)	9(36.1%)
Fair (%)	15 (58.3%)	2 (8.3%)
Poor (%)	9 (36%)	-

Data present as frequency (%).

Table 3: Comparison between pretreatment, Three-Month Postoperative and Maximum Follow-up mean values of AOFAS

Acne count ±SD X			Test Statistic	p- value	Sig
Preoperative	Three-Month Postoperative	Maximum Follow-up			
68.56±5.05	86.40±3.65	95.19±1	50	< 0.001	S
Multiple comparison (Bonferroni test)					
	MD	% of change	p- value	Sig	
Preoperative Vs Three-Month Postoperative	-17.84	26.02	0.001	S	
Preoperative Vs Maximum Follow-up	-26.63	30.82	0.000	S	
Three-Month Postoperative Vs Maximum Follow-up	-8.79	9.23	0.001	S	

X: Mean, SD: Standard Deviation, MD: Mean difference, p value: Probability value, S: Significant.

Table 4: Statistical analysis of radiological assessment

Measurement	Range	Mean	SD	Mean, Pre-Post	Percent of change	P
LCP, Pre (°), Post (°)	0 to 13, 10 to 38	6.76, 23.40	3.407, 6.377	-16.640±5.9	246.15	<0.001
LTMA, Pre (°), Post (°)	3 to 23, 0 to 2.3	11.616, 1.091	5.63, .6370	10.524±5.66	90.6	<0.001
AP TNCA, Pre (°), Post (°)	3 to 14, 0.2 to 1.5	8.619, .8456	2.7021, .336	7.773 ±2.619	90.18	<0.001

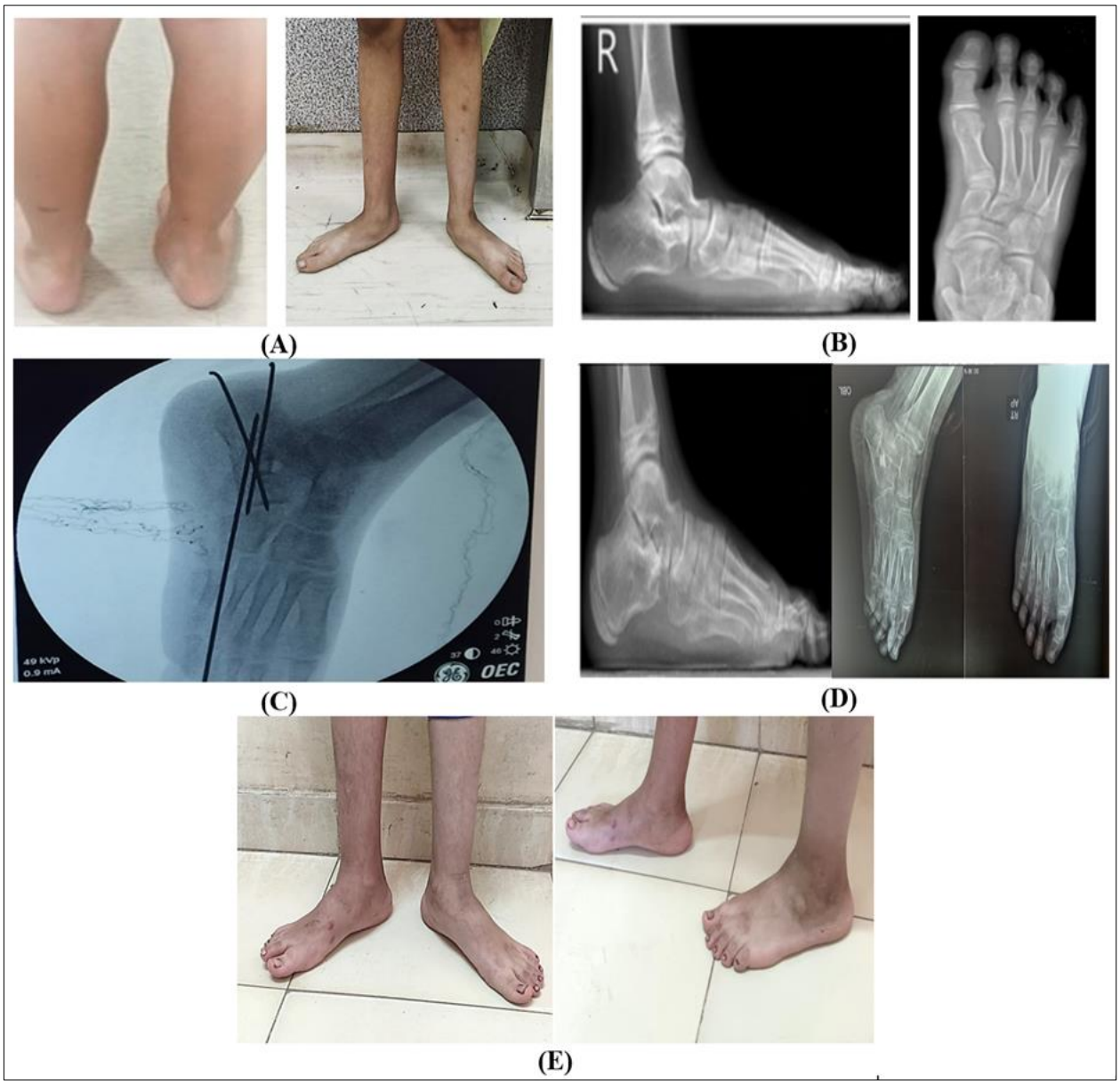

Fig 1: (A) Preoperative photograph, (B) Preoperative radiographs: Standing AP, Lat view, (C) Intraoperative Right foot X -Ray, (D) Right foot X -Ray final follow up, (E) RT foot final follow up photographic

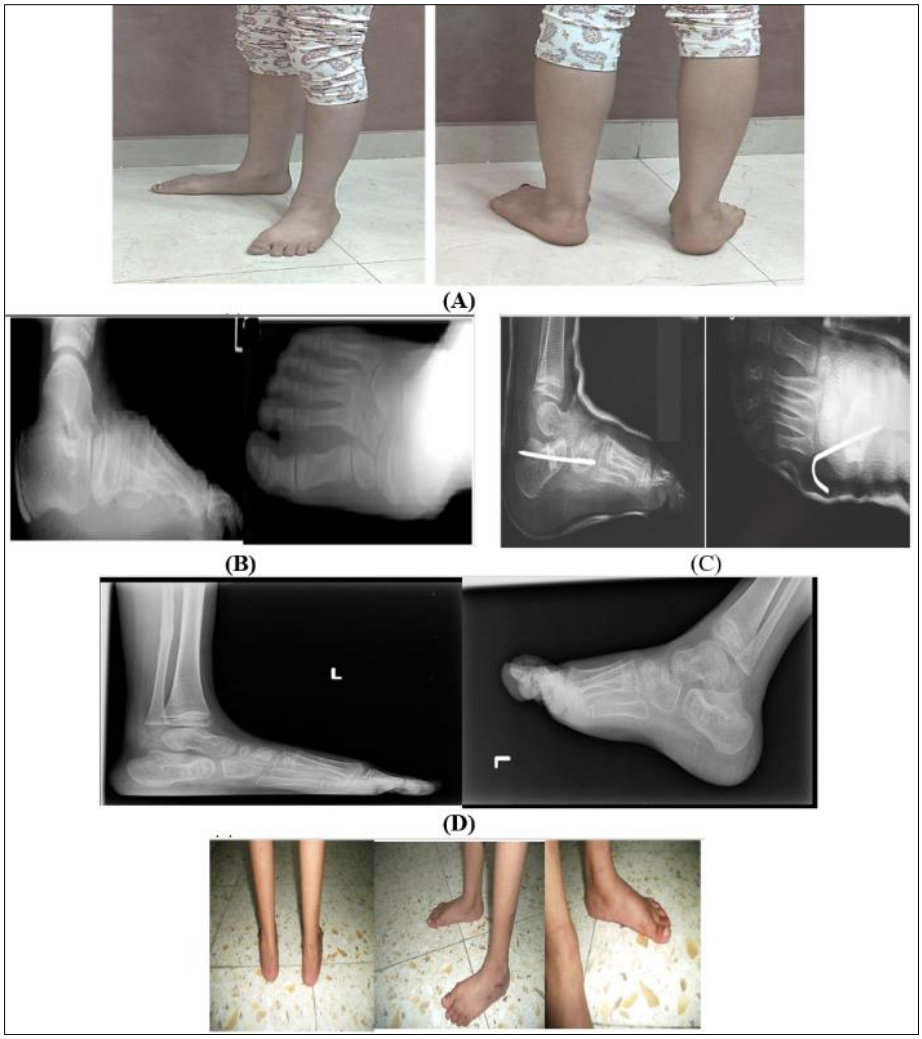

Fig 1: (A) Preoperative photographs, (B) preoperative RT foot X - ray AP and lateral, (C) postoperative RT foot X - ray AP and lateral, (D) RT foot X - ray AP and lateral final follow up, (E) Final follow up photograph

Conclusion

The suggested method has demonstrated significant benefits for surgically correcting symptomatic FFF. It is straightforward, addresses all aspects of the deformity in a single procedure, does not require joint fusion, and is safe for use in adolescents. However, it is advisable to conduct extended follow-up to further validate the efficacy of this technique.

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