Foot and Ankle Surgery 29 (2023) 466–474

Contents lists available at ScienceDirect

Foot and Ankle Surgery

journal homepage: www.journals.elsevier.com/foot-and-ankle-surgery

Coalition excision and corrective osteotomies versus coalition excision and arthroereisis in management of pes planovalgus with talo-calcaneal coalition in adolescents: A randomized controlled trial☆,☆☆

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ARTICLE INFO

Article history:
Received 13 May 2022
Received in revised form 5 March 2023
Accepted 24 June 2023

Keywords:
Coalition
Arthroereisis
Pes planovalgus
Talocalcaneal

ABSTRACT

Background: Talocalcaneal coalition is the most common cause of rigid flat foot in adolescents. It presents with recurrent ankle sprains, foot and ankle pain, and foot deformity. Management is still controversial. Multiple options were utilized during the last 40 years, including coalition excision only or coalition excision with hind foot arthrodesis or corrective osteotomies. However, the effect of arthroereisis after coalition excision is still questionable.

Patients and methods: Thirty feet in 28 patients with rigid flat foot due to talocalcaneal coalition, who presented to our institution between September 2018 and April 2020, were prospectively analyzed. Randomization was performed by random allocation using a computer-based system into two groups: group A for coalition excision and arthroereisis, group B for coalition excision and osteotomies. Functional and radiological outcomes and complications were recorded and analyzed using Statistical Package for the Social Sciences software.

Results: Thirty feet in 28 patients were included in the final analysis (15 feet in each group). One patient in each group had bilateral affection. The mean age was 14.5 years, and the mean follow-up duration was 24 months. At final follow-up, the mean AOFAS was 78.8 ± 4.04 in group A and 76.73 ± 4.66 in group B, while the FAAM scores were 80 ± 5 and 79 ± 3 in groups A and B, respectively. The complication rate was higher in group A, however with no statistical significance.

Conclusion: The combination of talocalcaneal coalition resection with either corrective osteotomies or arthroereisis had a significant improvement of functional and radiological outcomes in the management of rigid pes planovalgus.

1. Introduction

Tarsal coalition is a common cause of foot and ankle discomfort caused by the improper fusion of two or more tarsal bones. In adolescent, congenital tarsal coalition is a frequently ignored diagnosis. Different types of coalitions may be discovered during unrelated computed tomography (CT) or magnetic resonance (MR) imaging [1].

The actual prevalence of tarsal coalition is obscure; estimates range from < 1 % to approximately 1–2 % of the population [2]. Tarsal coalitions are further divided into fibrous, cartilaginous, and osseous coalitions based on the aberrant bridge morphology [3].

The onset of symptoms due to tarsal coalition is heterogeneous; however, patients with progressive ossification of the coalition are typically symptomatic in their second decade of life [3,4]. Most patients complain of discomfort or rigidity in their feet, which can occur as a result of trauma, weight gain, or increased sports activity

☆ Ethical Institutional review board approval was obtained from Ainshams university Hospital (FMASU MD 270/ 2018).
☆☆ Clinicaltrials.gov registration number (NCT05170698).

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https://doi.org/10.1016/j.fas.2023.06.007
1268-7731/

[5]. Physical examination frequently demonstrates decreased hind foot mobility, hind foot valgus, and lost foot arch [3,6].

The management of tarsal coalition is contentious, with no agreed-upon therapeutic protocol. It depends on a number of circumstances, including the size of the coalition and the related deformity.

Coalition excision and bone surgeries are the surgical options for rigid pes planovalgus. Medial displacement calcaneal osteotomy, lateral column lengthening, and opening wedge osteotomy of the medial cuneiform (Cotton osteotomy) are examples of bony corrective osteotomies [2].

Arthroereisis is a surgical procedure used to restore the medial foot arch and limit the movement of the subtalar joint without blocking it in individuals with flat feet. The word arthroereisis was derived by combining the Greek elements arthro- (joint) and -ereisis (to distract). In 1946, Chambers [2] described the impaction of a wedge-shaped bone block into the posterior facet of the calcaneus as the first example of subtalar joint “manipulation” in approaching flatfoot. In 1970, Lelièvre [7] developed the term “arthroereisis” to describe a similar technique, namely the insertion of a bone graft in the sinus tarsi that was secured by a temporary staple.

Subsequently, the concept of using an external synthetic implant in the subtalar joint was proposed. Variable implants have been used, which primarily differ in shape and material. Arthroereisis has been used for approximately 40 years; however, long-term studies are lacking, and its utility in tarsal coalition is currently being tested [2].

Rozansky [8] described a radiologic classification of 5 types of talocalcaneal coalition (Fig. 1) based on 3d CT reconstruction which depends on the shape of the bar in the subtalar joint and presence of fragmentation:

1-type I, linear coalitions (41 %).

2- Type II, linear coalitions with a posterior hook (17 %).

3-type III, shingled coalitions (15 %).

4- Type IV, complete osseous coalitions (11 %).

5- Type V, posterior coalitions (17 %).

In our study, 20 feet was type I,4 feet type III,3 feet type II and 3 feet type IV.according to Blitz classification [9] all feet in our study were type II.

2. Patients and methods

This was a prospective, randomized, parallel group study conducted in a single center. A total of 30 feet in 28 patients with rigid flat foot due to talocalcaneal coalition, who presented to our institution between September 2018 and April 2020, were prospectively studied. Random allocation using a computer-based system was used for randomization.

2.1. Inclusion criteria

All patients between the ages of 10 and 20 who had resectable talocalcaneal coalition and symptomatic rigid flat foot deformity were included in this study. In a coronal CT of the ankle, a resectable coalition was defined as the fusion between the middle facet of the calcaneus and the talus with a posterior facet involvement of < 20 % of the subtalar surface.

2.2. Exclusion criteria

Patients aged < 10 years old, those older than 20 years old, with nonresectable coalition, concomitant knee or hip deformity, neurological causes of deformity, double coalition, and previous foot surgery were excluded from this study.

2.3. Preoperative assessment

Complete history taking, local and general physical examinations, weight-bearing X-ray of the ankle and foot, and CT scan of the ankle in 3-mm slices were all part of the preoperative clinical and radiological patient evaluation (Fig. 2). Deformity was assessed by checking for hind foot valgus, medial arch loss, and forefoot abduction. The heel-rise test and range of motion of the subtalar joint were used to assess the deformity’s flexibility (Fig. 3). At the follow-up visit, a senior orthopedic resident used a goniometer to perform a range of motion assessment.

The major goal was to compare between the two groups as regards the degree of deformity correction, patient satisfaction, the incidence of complication, as well as functional assessment using the AOFAS, FAAM, and Foot and Ankle Disability Index (FADI).

Statement on human rights: The study received institutional review board approval, and all study participants provided informed consent after learning about the surgery, expected outcomes, and potential complications.

2.4. Surgical procedure

All patients were positioned prone on the table with the ipsilateral knee flexed to 90°. The arc of motion between the line from the first metatarsal head to the heel pad and the long axis of the tibia was used to calculate plantar flexion and dorsiflexion [1]. The arc of motion relative to the line drawn from the long axis of the lower leg bisecting the Achilles tendon was used to calculate subtalar motion if present [7].

Medial approach was done for coalition excision (Fig. 4) and lateral for arthroereisis. The application of the implant should be checked in lateral x ray of ankle and anteroposterior foot x ray. The surgical method is typically the same for all surgeons and is minimally invasive, with a lateral 1–4 cm incision made just anterior and inferior to the tip of the malleolus and parallel to the skin tension lines. Following sinus tarsi debridement, the hind foot is manually supinated and the foot is returned to its proper position. The arthroerisis implant should not cross the lateral border of talus in anteroposterior foot X ray and from posterior to anterior in lateral ankle X ray with no over distraction of subtalar. So undersize is better than over size in borderline cases (Fig. 5).

Group B underwent medial approach for coalition excision, lateral approaches for medial displacement calcaneal osteotomy or Evans (lateral column lengthening) osteotomy, and anterior approach for Cotton osteotomy. Evans osteotomy had an 8-mm iliac crest autograft; whereas Cotton osteotomy without fixation received a 5-mm autograft (Fig. 6). N o donor site morbidity was found in our study. Twenty-five feet received gastrocnemius recession based on Silverskoiled test after deformity correction.

2.5. Postoperative follow-up

For both groups, a below-knee slab was applied for 4 weeks. Antibiotics and analgesics were administered in the first 48 h postoperatively. Postoperative X-ray images were collected immediately after surgery, then every three months for two years. Except for the immediate postoperative period, standing X-rays were taken.

All patients were followed up every 3 months thereafter for a mean of two years. The following clinical and radiological evaluations were performed:

Clinically, the deformity was assessed by standing foot alignment: a line was drawn through the middle of the back of the calf muscle, and another line through the heel bisector, and the degree of valgus was measured using a goniometer pre- and postoperatively.

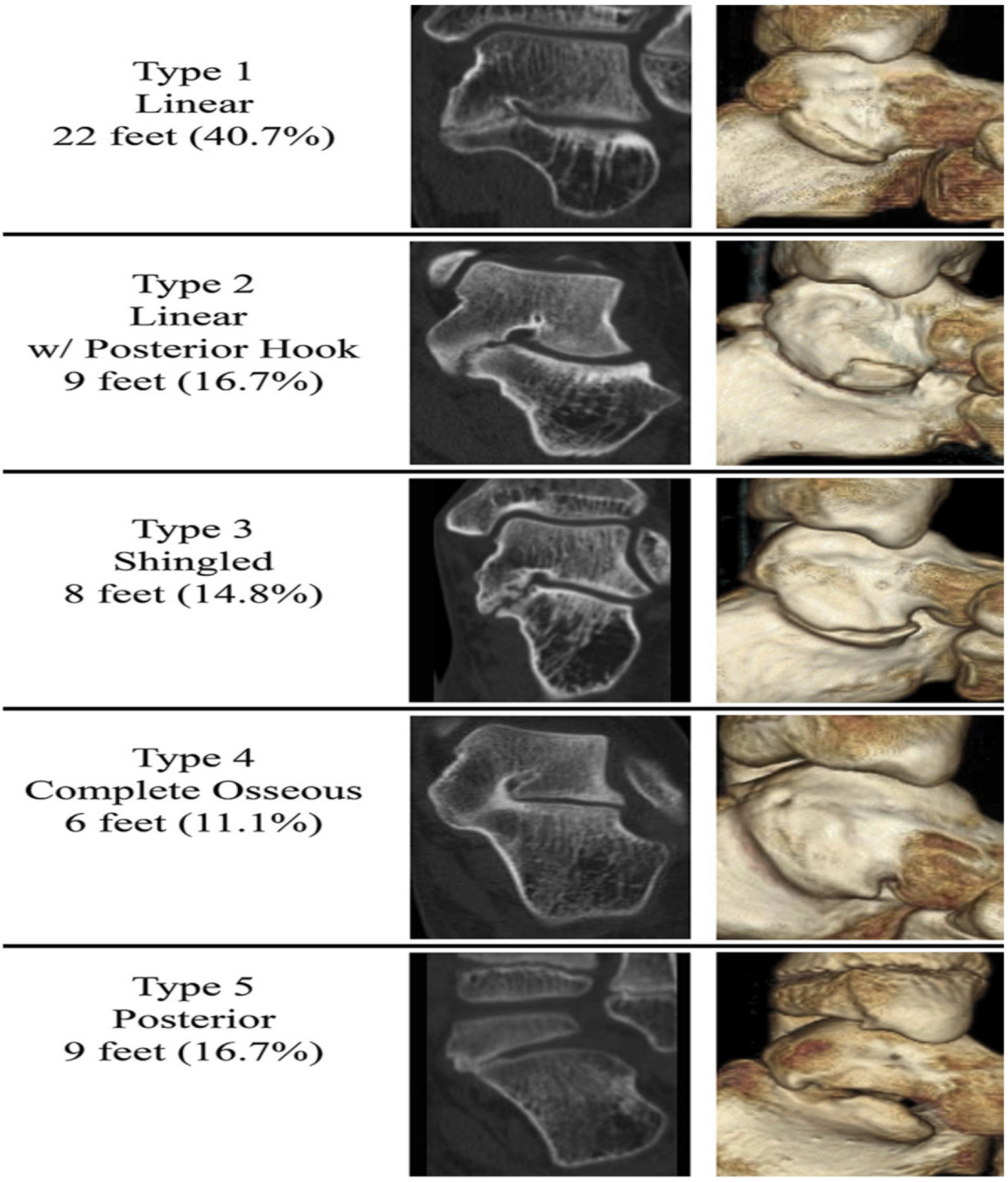

Fig. 1. Radiologic classification of talocalcaneal. Coalitions based on 3D reconstruction.

The range of motion of the ankle and subtalar joints was also assessed.

Forefoot abduction and foot arch were measured by talonavicular coverage angle, calcaneal pitch angle and Meary's angle.

For the subjective assessment, a questionnaire was completed to determine patient satisfaction and desire to undergo the surgery again in similar conditions. The various radiologic measures mentioned before were used to examine the radiological condition, whereas the AOFAS, FAAM, and FADI were used to assess the functional condition.

A P-value of < 0.05 was considered statistically significant. Statistical Package for the Social Sciences (SPSS ®25) was used to review, code, tabulate, and transfer the obtained data to a computer. Parametric numerical data were expressed as means, standard deviations, and ranges. Non-parametric data were presented as frequencies and percentages.

3. Results

We included 30 feet from 28 patients in our study (15 feet in each group). The mean follow-up duration was 24 (24±6.0) months. The mean age of the participants was 13.9±1.5 and 15.7± 2.46 years for groups A and B, respectively. Group A had a 2:1 female to male ratio, whereas that of group B was 2:3. The difference between both groups in terms of sex showed no statistical significance. Group B was distributed as follows: one foot of only calcaneal osteotomy, four

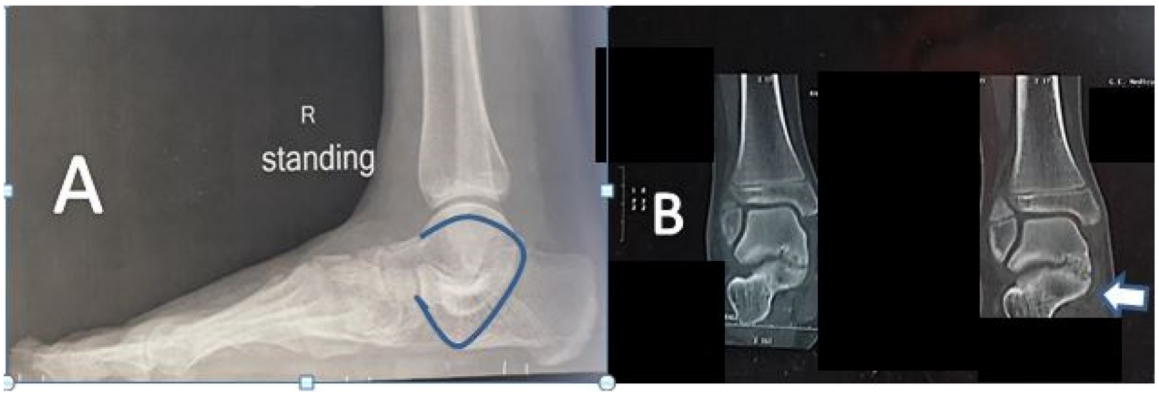

Fig. 2. a) Lateral standing view with continuous C sign (blue line), (b) coronal cuts of CT scan shows the coalition (white arrow).

Fig. 3. Heel rise test to assess flexibility of hind foot. With heel rise heel still in valgus that indicate rigid deformity.

feet of Evans osteotomy only, and ten feet of all osteotomies. The decision was based on the deformity's significant element. The flat arch with valgus less than 10 degrees was the key element in the Evans group. Only in one foot, the main deformity was heel valgus; hence calcaneal osteotomy was performed only once. Demographic data are presented in Table 1.

CONSORT flow diagram for study enrollment is shown in Fig. 7.

3.1. AOFAS, FAAM and FADI scores

Regarding the functional outcomes for the AOFAS, FAAM and FADI scores, both groups showed a statistically significant improvement compared with the preoperative score. At the end of the study period, no statistical difference was noted between both groups. Functional outcomes are shown in Table 2.

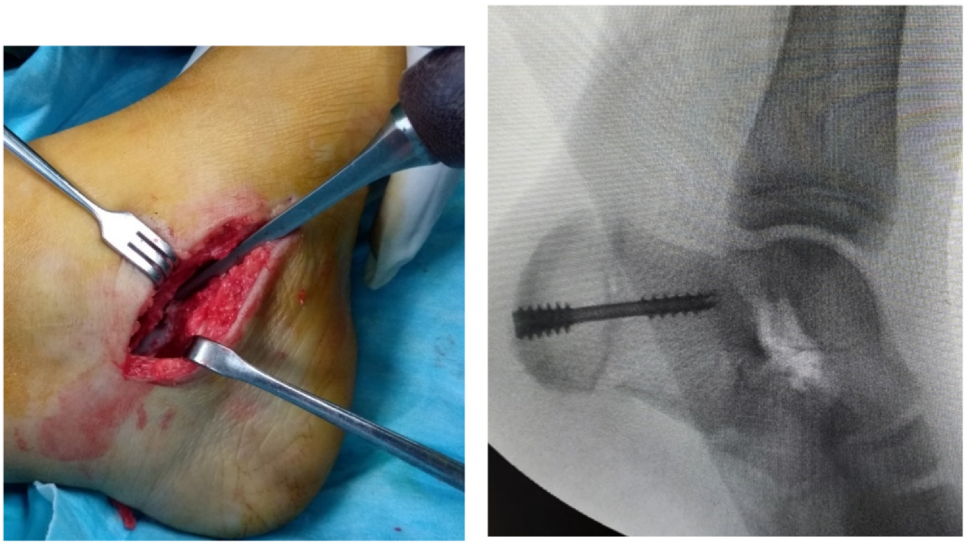

Fig. 4. Exposure and resection of coalition from medial incision and opening of subtalar joint.

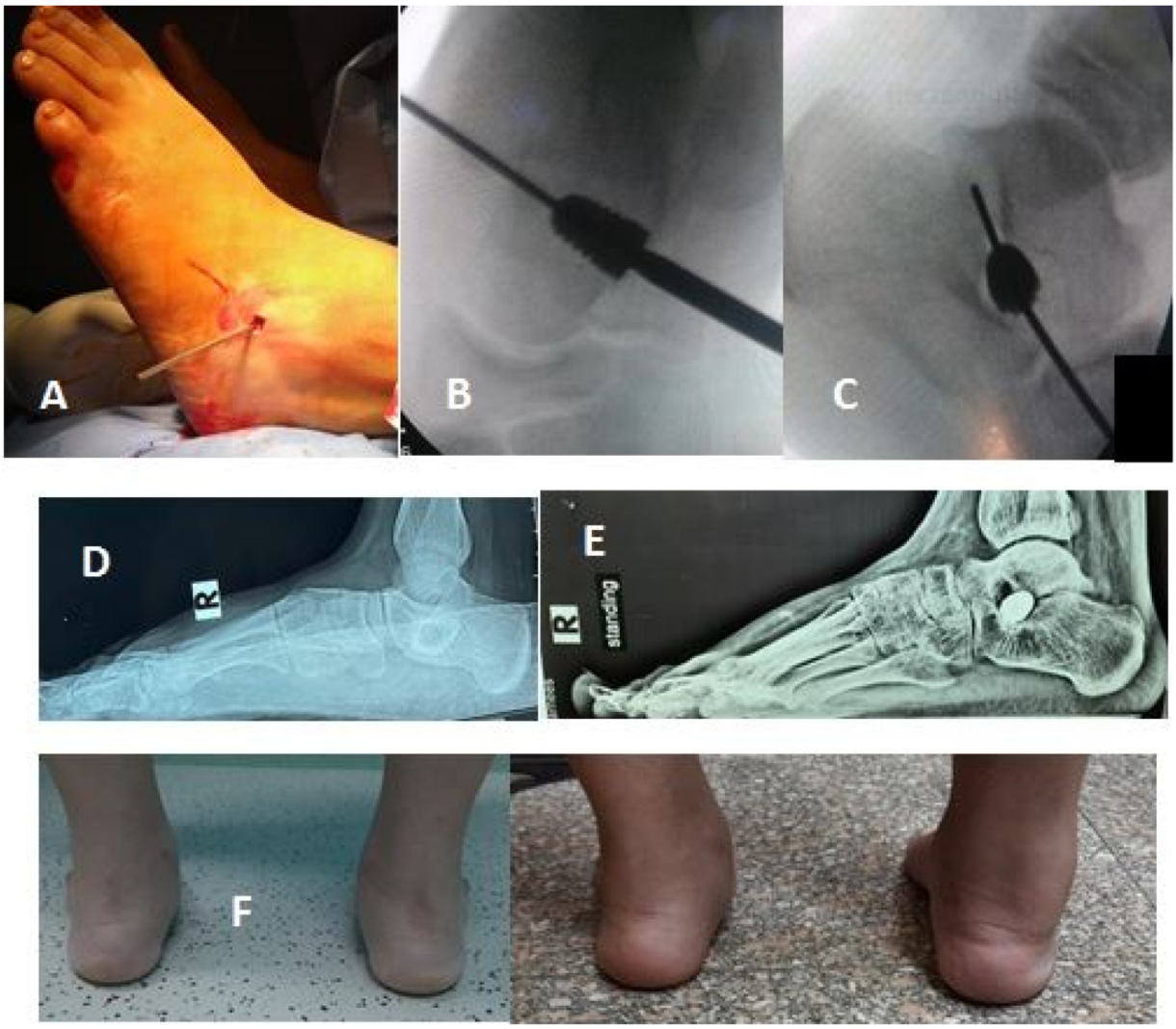

Fig. 5. A Lateral incision for arthroereiesis B: Intraoperative fluoroscopy showing accurate implant position in anteroposterior foot view C: Intraoperative fluoroscopy showing accurate implant position in lateral ankle view. D: Preoperative ankle x ray showing c sign, loss of arch E: 3month post-operative ankle x-ray showing improvement in meary`s and calcaneal pitch angle F: Pre and post clinical photo showing correction of valgus in RT side.

3.2. Heel valgus

In both groups, the heel valgus improved from 13.3° (3.7°) preoperatively to 2.5° (2.75°) postoperatively, with no statistically significant difference in improving the heel valgus between the two groups.

3.3. Complication rate

Despite the fact that group A had four times the number of complications as group B (4–1), nearly 25 % of group A developed complications, such as sinus tarsi pain in two cases and the need for implant removal in two cases due to severe pain and failure to accept the implant, while group B only had one case of wound infection that was resolved with conservative measures. There was no statistically significant difference between the two groups (Table 3). The two instances in group A who complained of sinus tarsi pain were handled with rest and analgesics, and the pain was alleviated within two weeks. The two individuals who required implant removal did so after failing all interventions for at least three months.

3.4. Satisfaction

No statistically significant differences were observed in the satisfaction rate between the two groups. Approximately 83 % of both groups had excellent results. In group A, unfavorable results were noted in two feet that developed sinus tarsi pain that necessitate implant removal and one foot had fair outcome. In group B, none of the feet had unfavorable results, and two feet had fair outcome (Table 4).

3.5. Radiological measures and range of motion

During the postoperative period, a significant improvement was noted in the calcaneal pitch angle, Meary's angle, and talonavicular coverage in both groups. In terms of rectifying these angles, no statistical significance was observed between the two groups (Table 5). The global range of motion difference between both groups was illustrated in (Table 6).

3.6. Pain level and analgesic requirement

In group B during the first 3 weeks post-operative the pain level and analgesic requirement were higher than group A. This was

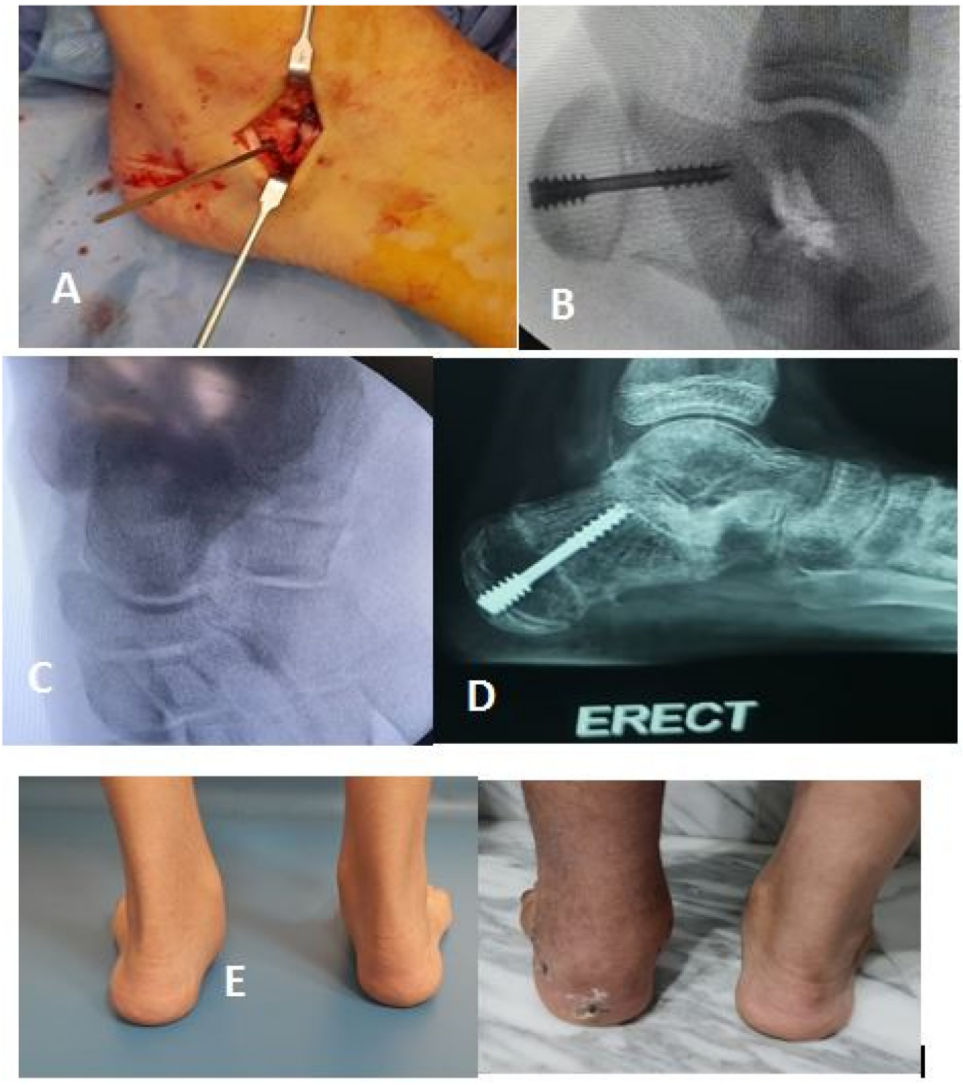

Fig. 6. A: Intraoperative osteotomies a: Evans osteotomy before distraction B: Intraoperative fluoroscopy lateral ankle view showing MDCO and Evans C: Intraoperative fluoroscopy AP foot view showing wedge graft in Evans osteotomy D: Lateral ankle erect view 3 months post-operative shows complete healing of osteotomies and improvement of Meary's and calcaneal pitch angle. E: Pre and postoperative photos of same patient showing valgus correction in left side.

Table 1
Demographic data of the participants N refer to the number of feet.

	Age		Gender			
			Male		Female	
	Mean	Standard deviation	No.	%	No.	%
Group A (N = 15)	13.93	1.35	5	33.3	10	66.7
Group B (N = 15)	15.73	2.46	9	60	6	40
P value	0.02		0.14			

attributed to the iliac crest harvest mainly and multiple osteotomies in this group. After that period the pain level and analgesic requirement were nearly similar between both groups during the follow up period.

4. Discussion

Talocalcaneal coalition is a condition where the talus and calcaneus fail to segment properly at the middle facet. It primarily affects adolescents. When conservative measures fail to relieve deformity and foot pain, surgery is recommended.[10] Surgical management remains questionable, and the best course of action has yet to be discovered.[10] Considering that multiple studies have revealed that coalition resection alone had resulted in poorer outcomes with increasing hind foot valgus, the combination of coalition resection and arthrodesis has become the primary surgical option.[7] Triple or double fusion and coalition excision resulted in good outcomes, especially in the adult population; however, long-term studies demonstrate an increase of stresses over the ankle joint, which may result in degenerative ankle disease. Multiple factors have been described as important in predicting outcomes and defining of the optimal operative intervention, age of the patient, size of coalition, pathology of coalition, degree of hind foot valgus, presence of talar beaking, the degree of the forefoot abduction and presence of degenerative changes within adjacent joints.[11].

When considering reconstruction, guidelines and a treatment algorithm that specifically consider the pes planus as a pathologic component of tarsal coalition have been recently proposed. [9] Coalitions are classified into three types based on whether or not they have pes planus or hind foot arthrosis. Pes planus or hind foot arthrosis are not associated with Type I coalitions. Type II coalitions are characterized by pes planus but no hind foot arthrosis. Type III

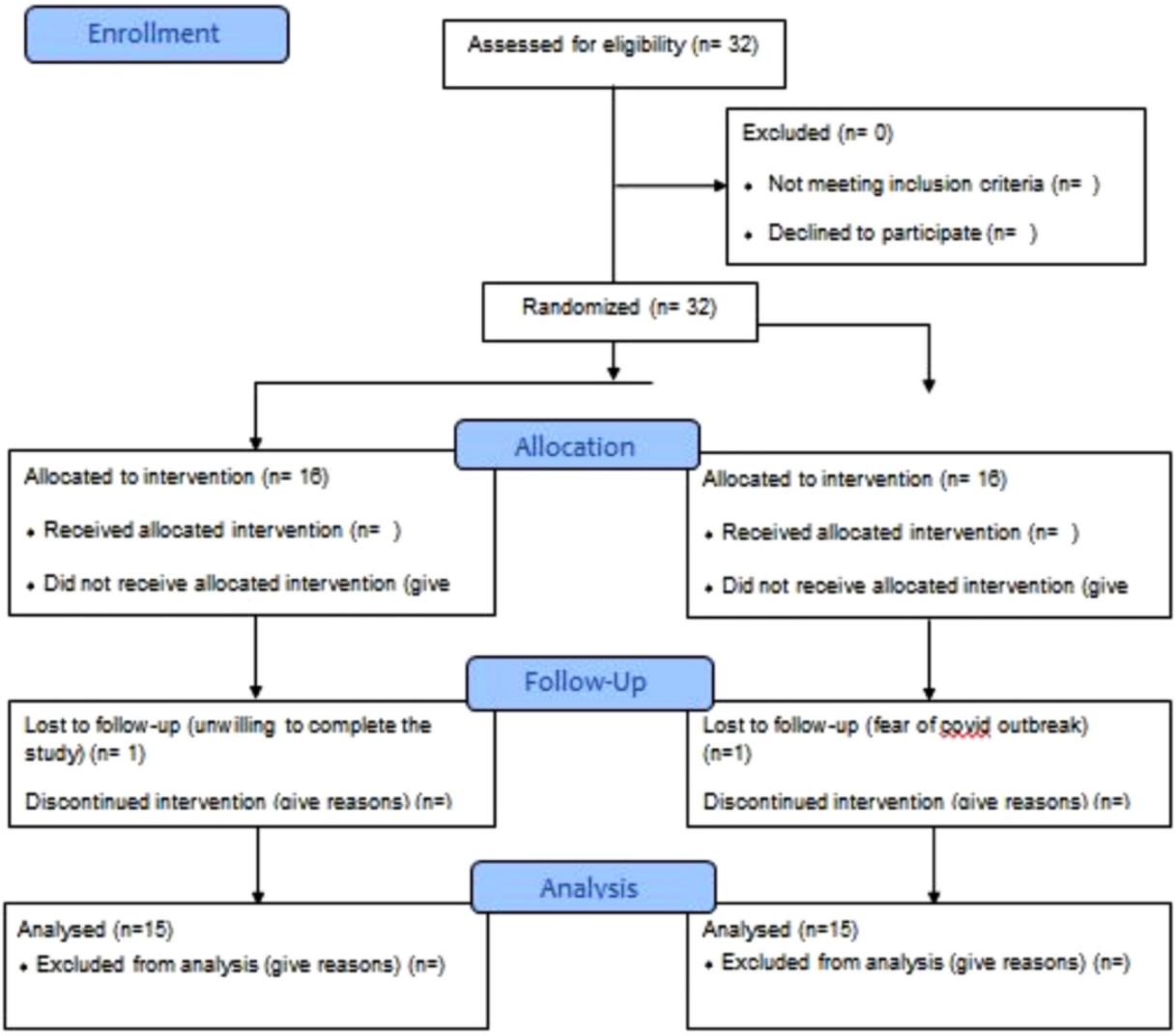

Fig. 7. Consort diagram for patients' enrollment in our study.

coalitions occur with pes planus and hind foot arthrosis this classification gave us a treatment algorithm for these cases Table 7.

Wilde et al. [12] reported that having more than 16 degrees of heel valgus was associated with a worse outcome after resection of coalition only.

Luhmann et al.[11], also reported worse outcomes with resection if hind foot valgus was more than 21 degrees. However, they did not advise against coalition excision because several patients had good results despite having more than 21 degrees of valgus. They described a third option that includes either a medializing calcaneal osteotomy or lateral column lengthening after coalition excision. If subtalar motion was significantly reduced after the coalition excision, a medializing calcaneal osteotomy was advised. Otherwise, lateral column lengthening was recommended instead.

Table 3
Showing difference in complication rate for both groups.

		Group A (N = 15)		Group B (N = 15)		X^{2*}	P value
		N	%	N	%		
Complications	Yes	4	26.7 %	1	6.7 %	2.16	0.33 NS
	No	11	73.3 %	14	93.3 %	FE	

Mosca et al.[13] used calcaneal lengthening osteotomy in conjunction with tarsal coalition resection and mentioned that management of valgus deformity and lost arch was just as important as coalition excision in terms of long-term outcomes. Their follow-up period ranged from two to fifteen years. They also performed only calcaneal lengthening osteotomies in unresectable coalition patients, but this result in short to intermediate pain relief.

Table 2
Showing preoperative and post-operative scores and functional outcomes.

	American Orthopedic Foot and Ankle Society's Ankle-Hind foot scale (AOFAS-AHS)			Foot and Ankle Ability Measure (FAAM)		
	Preoperative	one year post	Two year post	Preoperative	one-year post	2 year post
	Mean	mean	Mean	Mean	Mean	mean
Group A (N = 15)	57.93	78	78	65 %	80 %	80 %
Group B (N = 15)	51.73	76.7	76.73	64 %	79.5 %	79.5 %
P value	0.070.22		0.22	0.04	0.28	0.28

Table 4
Showing difference in satisfaction between both groups.

		Group A (N = 15)		Group B (N = 15)		X^{2*}	P value
		N	%	N	%		
Satisfaction	Excellent	12	80.0 %	13	86.7 %	2.08	0.60 NS
	Fair	1	6.7 %	2	13.3 %	FE	
	Poor	2	13.3 %	0	0.0 %		

El Shazly et al.[14] observed considerable improvements in the VAS and AOFAS in 30 feet treated with coalition excision and medial displacement calcaneal osteotomy, as well as a 75 % improvement in motion in 19 feet (73 %).[14] As a result of these studies, it was concluded that the management of valgus deformities, after coalition excision, is critical in achieving favorable functional outcomes and plantigrade foot.[10,13,15] Golshteyn and Schneider[16] reported that coalition resection was only effective in short or medium term and that a degree of valgus > 20° necessitated the use of other procedures. Subtalar arthrodesis should be avoided in children and adolescents to avoid probable growth disruption of the hind foot complex.[17] Consequently, they proposed extra-articular arthrodesis as the Grice method; however, this surgery is not often performed to date. Giannini et al.[15] reported better outcomes when resection is performed on patients aged 14 years old or younger 14 patients who underwent middle facet coalition resection in combination with arthroereisis. Interposition of the fat graft was commonly used in conjunction with coalition resection to prevent coalition recurrence. Furthermore, they reported 85.7 % reduction in postoperative pain, 92.8 % increase in range of motion, and correction of the associated valgus deformity. Their study and ours had nearly perfect outcomes for arthroereisis after a successful coalition excision. The main distinction was that their research was not comparative to other groups. Ghali et al.[18] reported that arthroereisis can be used as effective as an adjunctive procedure in

Table 5
Radiological outcomes.

	Group A (N = 15)		Group B (N = 15)		t*	P value
	Mean	SD	Mean	SD		
Calcaneal pitch pre	12.00	2.88	10.33	3.89	1.34	0.19 NS
Calcaneal pitch post	21.93	3.01	21.47	4.63	0.33	0.75 NS
t**	10.82		8.11			
P value	< 0.001 HS		< 0.001 HS			
	Mean	SD	Mean	SD		
Meary's angle lateral pre	10.47	2.36	9.87	1.60	0.82	0.42 NS
Meary's angle lateral post	2.07	1.75	2.73	1.58	1.10	0.28 NS
t**	10.95		21.22			
P value	< 0.001 HS		< 0.001 HS			
Meary's angle AP pre	15.40	3.78	16.07	4.88	0.42	0.68 NS
Meary's angle AP post	9.27	4.65	9.53	2.53	0.20	0.85 NS
t**	7.22		6.19			
P value	< 0.001 HS		< 0.001 HS			
	Mean	SD	Mean	SD		
Talonavicular coverage pre	14.87	3.36	15.67	4.50	0.55	0.59 NS
Talonavicular coverage post	5.27	3.20	4.07	3.59	0.97	0.34 NS
t**	8.60		10.56			
P value	< 0.001 HS		< 0.001 HS			

Table 6
Global motion score.

	Group A (N = 15)		Group B (N = 15)		Test value	P value
	Mean	SD	Mean	SD		
Global motion pre	3.00	2.54	0.67	1.76	2.61*	0.01 HS
Global motion 3 months	15.00	4.23	15.00	3.78	0.00**	1.00 NS
Global motion 6 months	6.67	2.44	7.20	2.60	0.58**	0.57 NS
Global motion 12 months	3.00	2.54	1.33	2.29	1.89**	0.07 NS
Test value	39.71		42.20			

Table 7
Blitz and Kernbach [9] proposed classification and surgical treatment algorithms for symptomatic middle facet talocalcaneal coalition.

Types of coalition	Associated Pathology	Intervention
I	TCC with no pes planus or hind foot arthrosis	Resection of the coalition
II	TCC with pes planus with no hind foot arthrosis	Resection ± flat foot reconstruction or appropriate foot arthrodesis in severe cases
III	TCC with pes planus and symptomatic subtalar arthrosis	Subtalar fusion ± flat foot
	TCC pes planus with symptomatic subtalar and talonavicular arthrosis	reconstruction or triple arthrodesis Subtalar and talonavicular fusion ±
	TCC pes planus with symptomatic subtalar, talonavicular, and calcaneocuboid arthrosis	Flat foot reconstruction or triple Arthrodesis Triple arthrodesis

management of tarsal coalition and in posterior tibialis tendon insufficiency, Because it is a simple procedure, the implant can be removed if complications arise, and it avoids foot osteotomies, allowing for early weight bearing.

In their retrospective investigation, Thomas et al.[19] reported that coalition resection results in an overall improvement in the VAS score after subtalar and calcaneonavicular coalition excision. Despite 33.8 % of the patients may require another surgery, the majority of patients can expect long-term pain relief without fusion. However, the study is retrospective in nature, with a mean age of 35.9 (range, 18–70) years.

Rigid pes planus was believed to be a contraindication to using arthroereisis as the primary surgical treatment because subtalar arthroereisis has mostly been utilized to treat flexible flatfoot.[20]. According to Zhou et al.,[17] the management of talocalcaneal coalition with flatfoot remains debatable. However, for a long-term outcome, two operative conditions should be noted: first, do not compromise the talocalcaneal joint's growth; second, cure the deformity by combining the excision of the coalition in a single-stage intervention. After acquiring motion at the subtalar joint through coalition excision, arthroereisis can be performed to address the deformity.[17].

To the best of our knowledge, this is the first prospective study that compares these two interventions in talocalcaneal coalition management. We found no statistical significance between both interventions in the functional and radiological outcomes, as well as foot alignment. Despite the fact that the arthroereisis group had a greater complication rate (up to 25 %), no statistically significant difference was found. This could be due to the small sample sizes in both groups, which is one of our study's potential limitations. Another limitation includes the short follow-up period, which is mainly due to the COVID-19 outbreak. Our study concludes that either arthroereisis or corrective osteotomies combined with coalition resection are suitable options for the management of rigid pes planovalgus with talocalcaneal coalition. Although arthroereisis had more complications in our study, it has minimal skin incision and low morbidity and can be utilized in mild to moderate cases of rigid pes planovalgus.

5. Conclusion

The combination of talocalcaneal coalition resection with either corrective osteotomies or arthroereisis showed a statistically significant improvement in functional and radiological outcomes as well as foot alignment. No statistically significant difference between both interventions was found in our study in the management of rigid pes planovalgus with tarsal coalition.

Financial disclosure

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interest

on behalf of all authors, the corresponding author declares no conflict of interest.

Declaration of interest

None.

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