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Special Article

The role of subtalar arthroereisis in flatfoot treatment: insights from weight-bearing computed tomography

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Abstract

Flatfoot is a common deformity in adult and pediatric populations, with a 5% incidence. The three-dimensional deformity and the dynamic joint behavior during weight bearing are better understood with weight-bearing computed tomography (WBCT), making it an essential tool for diagnosis and staging. There is consensus about the indication for arthroereisis in symptomatic flexible flatfoot or hindfoot valgus in pediatric or adolescent populations; however, no studies to date have evaluated the degree of three-dimensional correction achieved in adult patients with progressive collapsing foot deformity (PCFD) treated with arthroereisis. A retrospective analysis of nine adult patients with symptomatic flexible flatfoot (15 feet) submitted to arthroereisis, was performed. WBCT before surgery and four months after the procedure were reviewed. Subtalar and talonavicular joint alignment was analyzed through specific measurements (Inftal-suptal, Inftal-hor, posterior facet subluxation, medial facet subluxation, calcaneal pitch, Meary's angle, dorsal talar-1st metatarsal angle, and talonavicular angle). Inftal-hor, posterior facet subluxation, medial facet subluxation, Meary's angle, dorsal talar-1st metatarsal angle, and talonavicular angle reached statistically significant differences. The talonavicular coverage angle showed a more considerable improvement with a mean of 33º in the preoperative vs 23º in the postoperative ($p < 0.001$). Calcaneal inclination ($p = 0.195$) and Ifthal-suptal ($p = 0.656$) had no statistical differences. Subtalar arthroereisis is an effective three-dimensional correction procedure for adults with symptomatic progressive collapsing foot deformity.

Level of evidence: V, Therapeutic studies - investigating the results of treatment; Expert opinion.

Keywords: Subtalar Joint; Flatfoot.

Introduction

Progressive collapsing foot deformity (PCFD) is common in adult and pediatric populations, with an estimated incidence of 5% in the general population[1]. Hindfoot valgus, calcaneal pronation, forefoot abduction, and medial plantar arch flattering make this three-dimensional deformity challenging for foot and ankle surgeons[2,3]. In many cases, joint dynamic behavior during walking could be asymptomatic and not require any corrective interventions. Staged management is initiated when the pathology's progressive nature becomes symptomatic[4].

Conservative treatment includes shoe or insole modifications, physiotherapy, and changes in daily activities. In cases of conservative management failure, surgical treatment is considered. Options include tendon transfers, calcaneus or midfoot correction osteotomies, and subtalar or talonavicular joint arthrodesis, and, in some patients, arthroereisis appears to be a good option[5].

Over the years, subtalar arthroereisis has gained popularity in hindfoot valgus correction with a mechanical block of eversion. Inversion remains flexible, and the subtalar joint (STJ) remains unfused, thereby improving the secondary adaptation of the forefoot and hindfoot on uneven ground.

There have been several arthroereisis implants since its first description by Grice[6]. Vogler[7] classified the subtalar implants into three types, based on their biomechanical characteristics: axis-altering devices, impact-blocking devices, and self-locking wedges; the latter being the most used nowadays[8]. Several publications suggest that symptomatic flexible flatfoot or hindfoot valgus in pediatric or adolescent patients

Study performed at the Clínica Universidad de los Andes, Facultad de Medicina Universidad de los Andes, Santiago. Chile.

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is the main indication for this procedure[9]. Although weight-bearing radiographs are mandatory for the initial assessment and surgical planning, they have limitations in bone morphology and three-dimensional joint relationships[10,11].

Weight-bearing computed tomography (WBCT) has become a valuable tool to identify and optimize staging in foot and ankle deformities[12-14], solving the problem of conventional CT scans[11]. WBCT provides a better understanding of biomechanical behavior and foot anatomy in all planes by enabling more accurate extrapolation from static images[15]. At the same time, STJ valgus deformity, sinus tarsi, and/or subfibular impingement could be assessed[16].

After the first publication of WBCT in 2014[17], new radiological parameters have been described to understand PCFD better, like STJ orientation[15] associated with the talonavicular coverage angle[18].

The objective of this study is to present preliminary findings on the radiological correction observed in adult patients submitted to isolated arthroereisis, evaluated using WBCT, before surgery and four months postoperatively. We hypothesize that arthroereisis achieves adequate three-dimensional correction of the subtalar and talonavicular joints.

Methods

In this retrospective clinical study, pre- and postoperative changes were evaluated in adult patients with flexible PCFD submitted to arthroereisis. Subtalar joint, subtalar and talonavicular subluxation degrees were addressed with pre- and postoperative WBCT. Low-demand patients older than 18 years with symptomatic flexible flatfoot (subfibular impingement or medial pain) who have failed conservative treatment and have undergone arthroereisis as a primary procedure from June 2020 to June 2021 were included. Exclusion criteria were patients exhibiting a rigid STJ upon physical examination, previous history of foot and ankle surgery, known hindfoot or ankle osteoarthritis, patients requiring additional corrective osteotomy, or those in whom arthroereisis has been used as a complementary procedure to another surgical technique. The minimal follow-up period was 12 months. The analysis of the subtalar and midfoot orientation was performed on pre- and postoperative WBCT through the following radiological parameters.

Hindfoot alignment

A. Inftal-suptal: the angle formed by a tangent passing through the tibiotalar articular surface (talar surface) and the talar articular facet of the STJ at its point of greatest width (Figure 1a and 1b).

B. Inftal-hor: the angle formed by a tangent passing through the talar surface of the STJ at its point of greatest width and the horizontal (Figure 1c).

C. Posterior facet STJ subluxation: percentage of uncovering of the talar articular surface of the posterior facet of STJ concerning the calcaneal articular surface at its point of greatest width (Figure 2a).

D. Medial facet STJ subluxation: percentage of uncovering of the talar articular surface of the medial facet of STJ at its point of greatest width (Figure 2b).

E. Calcaneal pitch: the angle formed by a tangent passing through the horizontal plane and the inferior wall of the calcaneus.

Midfoot alignment

Talonavicular coverage: the angle between the articular surface of the head and the proximal articular surface of the navicular, measured on an axial reconstruction aligned with the foot axis that includes both structures in the imaging slices.

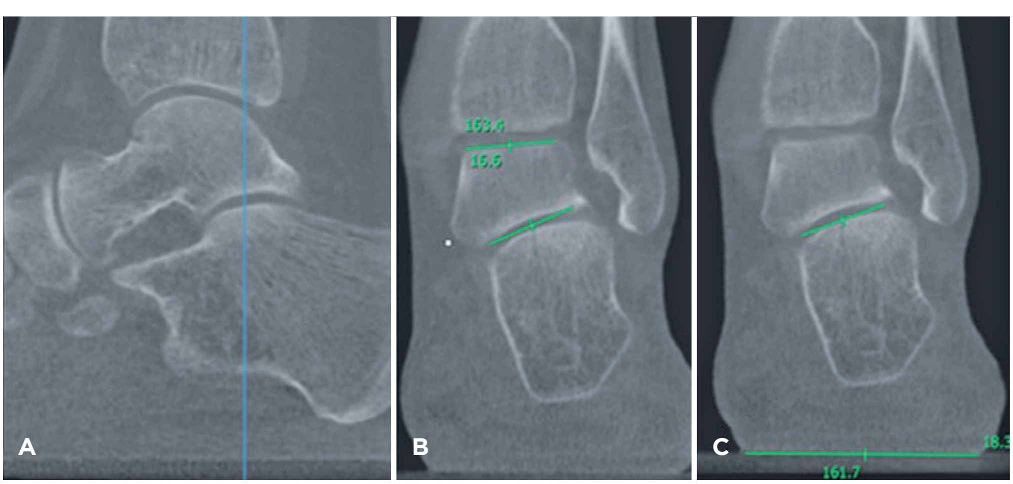

Figure 1. Angular measurements and subluxation parameters used in the three-dimensional assessment of the hindfoot using weight-bearing computed tomography (A). (B) Inftal-suptal. (C) Inftal-hor.

Lateral talar-1st metatarsal angle (Meary's angle): the angle between a line drawn along the longitudinal axis of the talus and the 1st metatarsal (1st metatarsal axis) in a reconstruction that includes both structures in the imaging slices.

Dorsal talar-1st metatarsal angle: a line is drawn down the longitudinal axis of the 1st metatarsal to form an angle with a second line along the longitudinal axis of the talar articular surface or talar neck, in an axial reconstruction aligned with the foot axis that includes both structures in the imaging slices.

Images were evaluated using the Enterprise Imaging XERO Viewer 8.1.2 software (Copyright (c) 2019 Agfa HealthCare N.V.). All measurements were performed by a single foot and ankle fellowship-trained in reconstruction. Reconstruction was performed on the foot anatomical axis in coronal, sagittal, and axial planes.

Statistical analysis

The variables were described with statistics measuring central tendency (medians, means, and percentages). To establish the type of distribution of the resulting data, the Shapiro-Wilk test was used. T-test or equivalent non-parametric Wilcoxon test was performed in the cases where the difference of pre- and postoperative variables measurements (Inftal-hor, Inftal-suptal, medial facet subluxation, posterior facet subluxation, calcaneal pitch, dorsal talar-1st metatarsal angle and lateral talar-1st metatarsal angle, midfoot alignment, talonavicular coverage angle) did not follow a normal distribution. All analyses considered an alpha of 5% ($p < 0.05$). The statistical analysis was performed using SPSS version 27. Due to the lack of existing literature or evidence to support a power calculation of our sample size for our intervention, the sample size was defined as the total number of patients operated on from June 2020 to June 2021 with pre- and postoperative WBCT. With the resulting data, a calculation of post hoc power was performed.

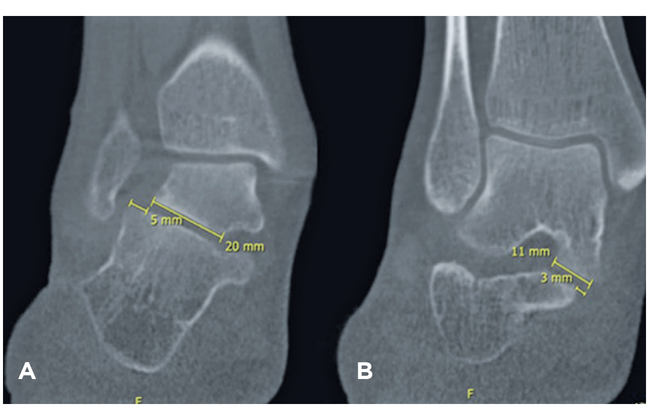

Figure 2. Subluxation measurements of the subtalar joint. (A) Posterior facet of the subtalar joint subluxation. (B) Medial facet of the subtalar joint subluxation.

Results

Nine patients were included, six of whom had bilateral surgery, totaling 15 feet (Table 1).

Thirteen feet showed a significant correction of the parameters evaluated. All the assessed measurements showed significant differences with pre- and postoperative WBCT comparatively, except the calcaneal pitch angle ($p = 0.195$) and Inftal-suptal ($p = 0.656$) which, with the numbers available, no significant difference could be detected, being the talonavicular coverage angle the one that showed the greatest change with a mean of 33º in the preoperative to 23º in the postoperative ($p < 0.001$). Table 2 summarizes the complete statistical analysis of the variables analyzed.

Clinical case

A 79-year-old male patient was diagnosed with PCFD. The patient presented a one-year history of pain associated with the posterior tibial tendon. Despite undergoing physical therapy and using orthotic insoles for eight months, he experienced minimal relief from his symptoms. A thorough physical examination revealed valgus positioning of the hindfoot, a flexible STJ with a positive heel rise test, and localized pain and inflammation along the posterior tibial tendon, exacerbated upon palpation of the retro-malleolar area (Figure 3a and 3b).

Weight-bearing computed tomography studies demonstrated a flatfoot deformity with no advanced signs of

Table 1. Demographic and clinical characteristics of the study population

Number of patients	Male sex, n (%)	Mean age, y	Bilateral side (%)
15	6 (40%)	39.06	6 (40%)

Table 2. Summary of the statistical analysis of the evaluated variables

	Preoperative (SD)	Postoperative (SD)	p
Iftal-hor	14.88 (4.99)	8.57 (3.81)	0.046
Iftal-suptal	16.986 (4.08)	10.373 (4.69)	0.656
Subtalar lateral medial facet	41.633 (15.8)	24 (10.55)	0.000
Subtalar lateral posterior facet	18.8 (6.58)	9.866 (6.82)	0.001
Calcaneal pitch	12.586 (5.82)	15.493 (6.63)	0.195
Dorsal talar-1st metatarsal angle angle	17.193 (9.8)	10.04 (5.34)	0.014
Meary's angle	21.426 (11.49)	13.893 (5.86)	0.003
Talonavicular coverage	33.994 (17.4)	23.7 (8.72)	0.001

SD: Standard deviation.

joint degeneration observed in the subtalar, tibiotalar, or talonavicular joints. Before the WBCT, all patients underwent radiographic evaluation using weight-bearing anteroposterior, lateral, and oblique views, as well as comparative Saltzmann radiographs. Notably, patients were not routinely studied with magnetic resonance imaging (MRI). The following angular measurements from the WBCT were: Dorsal talar-1st metatarsal angle at 18°, lateral talar-1st metatarsal angle at 13.8°, calcaneal inclination angle at 7.8°, talonavicular coverage angle at 44.2°, Inftal-hor at 18.3°, Inftal-suptal at 20.1%, with the subtalar lateral medial facet at 51%, and the subtalar lateral posterior facet at 22%.

Surgical technique

The patient was submitted to isolated arthrorisis for surgical correction while in a supine position with a bolster under the ipsilateral gluteus to maintain the lower extremity in a neutral position. The procedure was performed under local anesthesia with sedation. A 1 cm incision was made over the sinus tarsi (Figure 4), and a guiding K-wire was inserted toward the tip of the medial malleolus, with its position confirmed through fluoroscopic imaging. Accurate placement of the K-wire was verified through anteroposterior, lateral, and the Broden view projections.

Figure 3. Hindfoot valgus.

A cannulated trial was introduced through the guiding K-wire, advancing progressively to ensure a firm fit without excessive STJ distraction, which was confirmed on lateral-view imaging. The implant size was determined and positioned through the guiding K-wire (Figure 5a), ensuring it remained secure without distracting the STJ and aligned with the lateral contour of the talar neck in the anteroposterior view (Figure 5b and 5c). Notably, during the implant positioning, a clinical change in the three-dimensional disposition of the foot was observed, along with a noticeable limitation in the excursion of the STJ when forced into valgus. Following the procedure, the skin was closed with simple interrupted sutures, and a small adhesive dressing was applied to the surgical site to aid in the healing process (Figure 6). The patient was instructed to bear weight as tolerated immediately after the procedure, outfitted with a postoperative orthotic shoe, and scheduled for suture removal between the second and third postoperative weeks.

At the fourth month postoperative follow-up, the WBCT measurements were as follows: dorsal talar-1st metatarsal angle angle was 12.7°, lateral talar-1st metatarsal angle was 12.6°, the calcaneal inclination angle was 15.5°, and the talonavicular coverage angle was 10.5°, Inftal-hor 10.4°, Inftal-suptal 10.8°, subtalar lateral medial facet 43% and subtalar lateral posterior facet 20.7% (Figure 7).

The patient improved satisfactorily, and on the fourth-month control visit, he reported being able to perform all his daily activities. Notably, pain related to the posterior tibial tendon decreased significantly from 6/10 to 2/10 on the visual analog scale (VAS).

Discussion

Arthroereisis was first described by Grice in 1952[6] for treating flatfoot in children; however, it was abandoned due

Figure 4. Sinus tarsi approach.

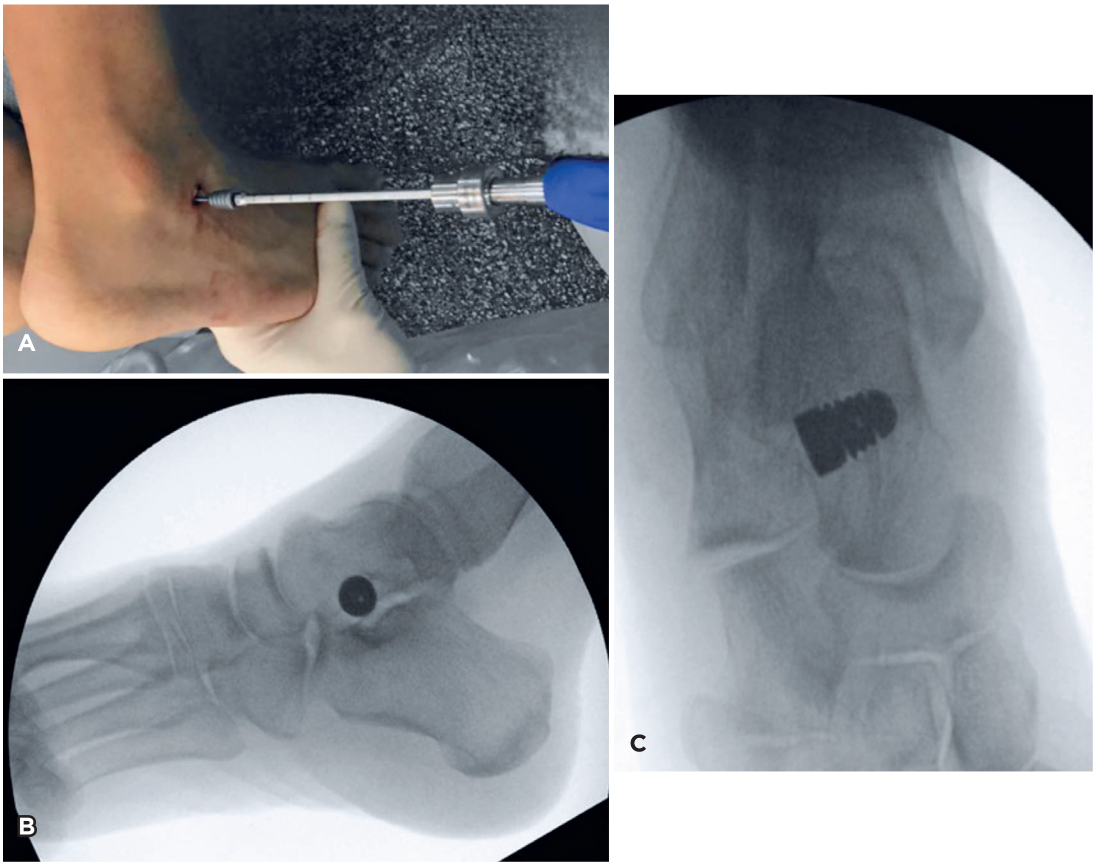

Figure 5. (A) Implant positioning. (B) Subtalar joint with no distraction. (C) Implant base aligned with the lateral contour of the talus neck.

Figure 6. Final aspect of the surgical site after closure with simple interrupted sutures and application of a small adhesive dressing to promote healing.

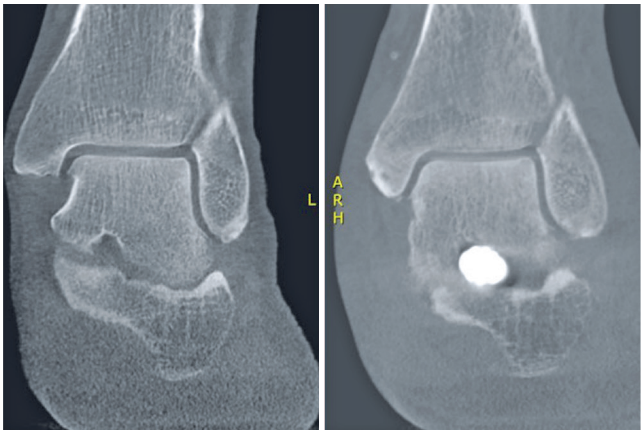

Figure 7. Weight-bearing computed tomography measurements at four months postoperatively, showing angles and subluxation percentages indicative of three-dimensional correction.

to the high rate of complications, loss of correction, and implants removal. Viladot[19] was the first to describe a sinus tarsi implant that showed success near 99% in the pediatric population, even without correction loss after removing hardware. Subsequently, Pisani[20] described the concept of glenopathy of the coxa pedis in which flatfoot generates an insufficiency of medial structures. This concept applies similarly in the pediatric and adult populations. Since the apex of the deformity is at the level of the STJ, generating an eversion and external rotation of the calcaneus leading to plantar flexion of the talar head, arthroereisis acts precisely at this site, providing a mechanical blocking of this phenomenon. Viladot et al.[21] studied 35 patients with flexible flatfoot deformity submitted to arthroereisis combined with soft tissue repair, demonstrating that 74% achieved good to excellent outcomes. Follow-up assessments using weight-bearing radiographs revealed significant correction in dorsal angle, Kite angle, Moreau-Costa-Bartani angle, and talonavicular coverage angle. One-third of the patients required implant removal due to associated pain.

Silva et al.[22] compared lateral column osteotomy and subtalar arthroereisis for Grade IIB adult-acquired flatfoot deformity. At 24 months, both achieved comparable radiological correction, but lateral column osteotomy showed superior clinical outcomes on the American Orthopaedic Foot and Ankle Society and VAS scales and a significantly lower complication rate (4.4% vs 20.6%). While subtalar arthroereisis provides a less invasive surgical approach, lateral column osteotomy demonstrated superior long-term functional outcomes in this study.

Stichnoth et al.[23] compared subtalar arthroereisis, medializing calcaneal osteotomy, and combined for adult flatfoot: all three significantly improved patient-reported outcomes and radiographic parameters. The combination provided superior radiographic correction, especially in severe cases. Pedobarographic analysis showed comparable gait in treated and untreated feet. While subjective improvements were similar, objective data favored subtalar arthroereisis and the combination, suggesting the latter as potentially superior for severe adult flatfoot.

Lewis et al.[24] studied a retrospective cohort of 212 feet treated with subtalar arthroereisis for stage 1 PCFD. Postoperative Foot and Ankle Outcome Scores demonstrated statistically significant improvements across all domains at a mean 2.5-year follow-up. A substantial 48.1% implant removal rate was observed, primarily due to persistent sinus tarsi pain. Comparing outcomes between patients with and without implant removal revealed no significant differences in functional measures at the final follow-up. These results suggest that subtalar arthroereisis provides clinically meaningful functional gains in stage 1 PCFD despite a high rate of subsequent implant removal.

Based on the literature and the author's experience, arthroereisis plays a crucial role in managing PCFD, not only in combined surgical interventions but also in isolation. This hypothesis aligns with the results demonstrated by three-dimensional measurements in WBCT.

Our study presents 15 feet with a good percentage of correction in 86.6 % of cases, despite requiring implant removal.

In our series, of the total variables evaluated, only 2 (posterior facet subluxation and calcaneal pitch) showed a non-normal distribution, showing significant differences for posterior facet subluxation in the analysis of WBCT pre- and postoperative ($p < 0.001$), with the Wilcoxon test. All the other variables followed a normal distribution, and their differences were evaluated with a t-test. Regarding the conventional parameters, the talonavicular coverage, the dorsal talar-1st metatarsal angle, and Meary's Angle showed significant changes in the WBCT at four months. When analyzing the variables that evaluate the subtalar joint orientation and the degree of peritalar dislocation (Iftal-hor, Iftal-suptal, subtalar lateral medial facet), all variables showed a statistically significant change ($p < 0.01$) from the preoperative measures with t-test, except for Iftal-suptal, which did not show significant differences ($p = 0.656$). In addition, our patients presented an incidence of symptomatic hardware of 20%; two patients required implant removal, one of those bilateral (3 feet), showing no improvements after one attempt at conservative treatment with local infiltration at six months. Fortunately, we did not obtain any loss of correction assessed by WBCT at the final follow-up of at least 24 months.

Additionally, and as the main objective of this novel study, we describe the behavior of the hindfoot assessed by WBCT four months after arthroereisis, focusing on the degree of three-dimensional correction achieved with this technique in adults, both in the subtalar and talonavicular joints. For our measures, it was decided to use the classically described variables, as well as the analysis of new measurements recently described and performed with WBCT for the evaluation of the subtalar joint such as the center of rotation of angulation of the deformity, including the subluxation of the medial and posterior facet of the STJ[25] together with the evaluation of the orientation of the STJ, according to the methods described (Iftal-hor, Iftal-suptal)[15]. Our report describes a significant three-dimensional correction of the variables measured at the subtalar and talonavicular joints level, except in two patients who did not achieve correction. Both required implant removal, and one was submitted to surgery with an Evans osteotomy and medial displacement calcaneal osteotomy, after which an adequate correction was achieved.

Our study is not without its limitations. Firstly, the absence of a comparative control group limits our ability to ascertain whether the percentage of correction achieved aligns with that observed in other interventions. Secondly, we could not establish a correlation between the functional scores (PROMIs) and the degree of correction attained in our patient cohort. Furthermore, this study represents a small case series, which restricts the strength of our conclusions and the establishment of a management protocol incorporating arthroereisis as a viable alternative. We also acknowledge that a four-month follow-up using WBCT may be relatively short, considering the chronic nature of this pathology. However, we believe this timeframe is sufficient to assess the foot's accommodation following surgical correction, as all patients commenced weight-bearing as tolerated in the immediate postoperative period.

The minimal invasiveness and short surgical time allow an early return to daily activities and do not burn any bridges for future treatment modalities. As discussed previously, the most striking complication is the potential hardware removal. The results are left unaffected. More evidence is still required to reach a better conclusion regarding arthroereisis in younger individuals. For the adult patient population, indications are even more confusing. Still, it seems reasonable to consider arthroereisis as a complement to other techniques to protect the medial soft tissue reconstructions or help improve corrective power associated with different kinds of osteotomies, or consider it as an isolated low-risk minimally invasive technique in patients who do not want aggressive reconstructions[26].

Conclusions

Subtalar arthroereisis is an effective treatment alternative for acquired flatfoot in adults, which achieves an adequate three-dimensional correction observed with WBCT in multiple parameters that affect both the orientation of the subtalar and talonavicular joints, achieving significant correction of all the parameters evaluated, except for the Iftal-suptal and the calcaneal pitch. Furthermore, we are continuing to study and monitor our patients with WBCT to expand our sample size and the results to be presented in future analyses.

Authors' contributions: Each author contributed individually and significantly to the development of this article: CO *(https://orcid.org/0000-0003-2574-9010), and OE, and EP Conceived and planned the activities that led to the study, wrote the paper, participated in the reviewing process. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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