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ORIGINAL ARTICLE

Retrospective Study

Pediatric flexible flatfoot: Does obesity influence the outcomes of arthroereisis?

Luca Monestier, Giacomo Riva, Mahfuz Latiff, Luca Marciandi, Elisa Bozzi, Alessandra Pelozzi, Andrea Pautasso, Giorgio Pilato, Michele Francesco Surace, Fabio D'Angelo

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Abstract

BACKGROUND

Childhood obesity has emerged in the last decades as an important public health problem worldwide. Although relationships between obesity and flatfoot have been shown, no studies have investigated the influence of obesity on arthroereisis outcomes.

AIM

To evaluate correlations between childhood overweight/obesity and clinical and radiographic outcomes after subtalar arthroereisis with self-locking implants.

METHODS

This retrospective study included one hundred and sixty-nine pediatric patients (10-14 years old) who underwent subtalar arthroereisis (PEEK PitStop® device) for severe flexible flatfoot. Exclusion criteria were additional procedures, revision of previous corrective surgeries, rigid flatfoot with severe deformity, and neurological or post-traumatic flatfoot. Preoperative/postoperative European Foot and Ankle Society (EFAS) and visual analogue scale (VAS) scores were determined; radiographic assessment was conducted on weight-bearing foot X-rays: Kite angle, first metatarsal-talus angle, Meary angle, calcaneal pitch angle and lateral

talo-calcaneal angle were analyzed.

RESULTS

EFAS and VAS scores improved post-operatively in the whole population. Only seven cases with complications were reported. Radiographic assessment revealed an improvement in all angles. Statistical analysis demonstrated that the impact of obesity was significant on arthroereisis outcomes: Relationships were reported between BMI and postoperative EFAS/VAS scores, postoperative calcaneal pitch angle, Kite angle, Meary angle and talo-first metatarsal angle.

CONCLUSION

Although arthroereisis represents a very effective and valid treatment for flatfoot both in normal weight and obese children, obesity significantly influences clinical and radiographic outcomes of arthroereisis, and obese children tend to perceive more pain and discomfort.

Key Words: Pediatric flatfoot; Obesity; Subtalar; Arthroereisis; Outcomes

Core Tip: Childhood obesity has emerged in the last decades as an important public health problem worldwide. It has been demonstrated that pediatric flatfoot is also related to obesity, showing a two-fold higher risk compared to normal weight children. While the relationship between obesity and flatfoot has been well established, only a few studies have reported the relationships between childhood obesity and arthroereisis outcomes and no studies have assessed the outcomes of self-locking implants and obesity. The aim of the present study is to evaluate correlations between childhood overweight/obesity and clinical and radiographic outcomes after subtalar arthroereisis with self-locking implants.

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INTRODUCTION

Childhood obesity has emerged in the last decades as an important public health problem worldwide. Recent data suggest that over 383 million individuals under 19 years of age may be affected in 2035, compared with over 175 million in 2020. The prevalence of obesity alone may increase from 14% to 24% of the population over the same period[1].

Childhood overweight/obesity is defined by body mass index (BMI) ≥ 25 kg/m² for overweight, and BMI ≥ 25 kg/m² for obesity, which is adjusted according to age and gender. While BMI between the 85th and 94th percentile is in the 'overweight' range, the BMI 95th percentile is in the 'obese' range[2].

Obesity is caused by excessive caloric intake; many factors may contribute including behavior, genetics, care and school environments, availability of affordable and healthy foods or beverages, and accessibility to places for physical activity[2,3].

As reported by the World Obesity Atlas in 2023, approximately 241 million children and adolescents (5-19 years old) are currently overweight or obese worldwide[1]. This scenario has been aggravated by the coronavirus disease 2019 pandemic; A recent study reported an 8.7% increase in childhood overweight and obesity during the pandemic[4]. The economic impact of childhood obesity is significant, including both the healthcare costs of treating obesity and its consequences and the impact of high BMI on economic productivity. The economic impact in the United States was $2.47 trillion, increasing from $1.96 trillion in 2020 to over $4 trillion in 2035[1].

Literature has demonstrated that childhood overweight/obesity may lead to adulthood disorders such as chronic diseases, mental health problems, diabetes, cardiovascular disease, and some types of cancer[5,6]. Moreover, children with overweight/obesity may have a higher risk of musculoskeletal disorders such as slipped capital femoral epiphysis, Blount's disease, and genu valgum, with an increased risk of fractures and musculoskeletal pain[7-11].

It has been demonstrated that pediatric flatfoot (pes planus) is also related to obesity, showing a two-fold higher risk compared to normal weight children[7,12-16]. Chen *et al*[14] found a significant difference in the prevalence of flatfoot between normal-weight (27%), overweight (31%) and obese (56%) children[14]. Cimolin *et al*[16] also reported a 70% rate of flatfoot in obese adolescents compared to 25% in the normal weight group[16].

The relationship between childhood obesity and flatfoot is still unknown. Mickle *et al*[17] asserted that higher rates of flatfoot in obese children may be explained by structural changes in the foot rather than the presence of thicker fat tissue under the midfoot region[17]. Moreover, Riddiford-Harland *et al*[18] showed that obese children have significantly greater medial midfoot fat pad thickness compared to leaner children, in non-weight and weight bearing: The authors concluded that the feet of obese children are both fat and flat[18]. These structural and morphological changes are asso-

ciated with compromised function in gait and activities[17,19].

In the treatment of pediatric flatfoot, subtalar arthroereisis has been reported as a minimally invasive, effective, and low-risk procedure[20-22]. Described firstly by Chambers[23] in 1946 and then by Lelievrè[24] in 1970, subtalar arthroereisis aims to limit subtalar eversion, to reposition the calcaneus and restore talocalcaneal divergence and talar head coverage, and not least restore the medial arch. Different devices for subtalar arthroereisis are currently used: From the first device proposed in 1974 by Subotnick[25] several implants have been introduced, differing essentially in material, shape and mechanism of action[25]. The implants were classified in 1987 by Vogler[26] into three types: Axis-altering prostheses, impact-blocking devices and self-locking implants[26].

While the relationship between obesity and flatfoot has been well established, only a few studies have reported the relationship between childhood obesity and arthroereisis outcomes. Pavone *et al*[27] reported results following calcaneostop implants[27], but no studies have investigated the outcomes of self-locking implants and obesity.

The aim of the present study is to evaluate correlations between childhood overweight/obesity and clinical and radiographic outcomes after subtalar arthroereisis with self-locking implants.

MATERIALS AND METHODS

One hundred and sixty-nine pediatric patients (10-14 years old) underwent subtalar arthroereisis between February 2020 and April 2022 at the Pediatric Orthopedics Unit of the ASST Settelaghi in Varese, the only pediatric orthopedic department in the whole Province of Varese (112000 inhabitants under 14 years old).

Surgery was indicated in patients presenting with flexible flatfoot, normal-aligned limbs and symptomatic flatfoot (foot pain during daily or sport activities, early muscle fatigue, disability in running or sport activity), severe grade (III-IV degree) or with critical malalignment of the hindfoot or a hindfoot valgus > 8°.

Exclusion criteria were introduced in order to reduce possible biases that may interfere with our purpose, which was to evaluate correlations between childhood obesity and outcomes after subtalar arthroereisis in flexible flatfoot in those aged < 10 years or > 14 years. Although there is no consensus on the age for surgery, performing subtalar arthroereisis before the age of ten may be too early, as nonsurgical management has been demonstrated to be efficient and should be pursued [28-30]; patients over 14 years were excluded because several authors have reported that the foot is defined 'mature' at the age of fourteen, with cessation of growth, closure of growth plates and stabilization of posture[31-33]. Patients undergoing additional procedures (gastrocnemius recession, hallux valgus correction, excision of accessory navicular bone, hemi-epiphysiodesis for genu varus/valgus) this criterion is crucial to reduce the effects deriving from other simultaneous procedures; revision of previous corrective surgeries for flatfeet; rigid flatfoot with severe deformity, neurological (*e.g.*, dystrophy), post-traumatic; unilateral surgery. From the original population of one hundred and sixty-nine patients, twenty-six were excluded using these criteria. Fifty-five patients were additionally lost at follow-up. Thus, eighty-eight children were finally included in this retrospective study. As bilateral surgery was performed for each patient, one hundred and seventy-two outcomes were assessed. Regular informed consent was obtained from all patients.

Thirty-one (35.2%) females and fifty-seven (64.8%) males were included in the study. Mean follow-up was 17.03 months (range 8.9-34.7).

Bilateral subtalar arthroereisis was performed in all cases using an anatomical PEEK PitStop® endorthesis (In2Bones, Memphis, TN, United States) (Figure 1). At the end of the procedure, a boot plaster was placed, and the patient was invited to walk immediately with canes. The cast was removed after three weeks, and the patient was free to walk with comfortable footwear; an exercise protocol was given to the patients to help return-to-walk. Activities with a high risk of ankle sprain (*i.e.*, running, jumping) were prohibited for the first two postoperative months: Only swimming and cycling were permitted.

Daily sport activities were allowed two months after surgery. Specific physiotherapy was indicated in the case of disability in walking or incomplete/unsatisfactory correction.

Clinical evaluation

Patients were assessed preoperatively and postoperatively at 20 days, 60 days, and at the time of the study (mean 17.03 months, range 8.9-34.7). Preoperatively, the weight, height, and BMI of each patient were also determined.

Clinical evaluation included the following: Valgus position of the heel in orthostatism, gait analysis, functional tests (Silfverskiold test, the toe rising test, Jack test), and footprint on the podoscope. Moreover, the European Foot and Ankle Society (EFAS) and visual analogue scale (VAS) scores were obtained preoperatively and postoperatively: These scores were chosen as they are universally validated, also in the Italian language[34-36]. The EFAS score concerns six items relating to activities of daily living and four relating to the performance in sports. The VAS scale is an instrument for measuring pain experienced by the patient.

Radiographic evaluation

Weight-bearing foot X-rays were obtained, analyzed and compared preoperatively and postoperatively with Synapse® software (FUJIFILM Medical Systems United States).

In the antero-posterior view, Kite angle (between lines drawn down the axes of the talus and calcaneus) and first metatarsal-talus angle (between longitudinal axes of first metatarsal and talar neck) were calculated. In the lateral projection, Meary angle (between the longitudinal axes of the talus and the first metatarsal), calcaneal pitch angle (between the calcaneal inclination axis and the supporting horizontal surface) and lateral talo-calcaneal angle (between axes of the talus and calcaneus) were analyzed.

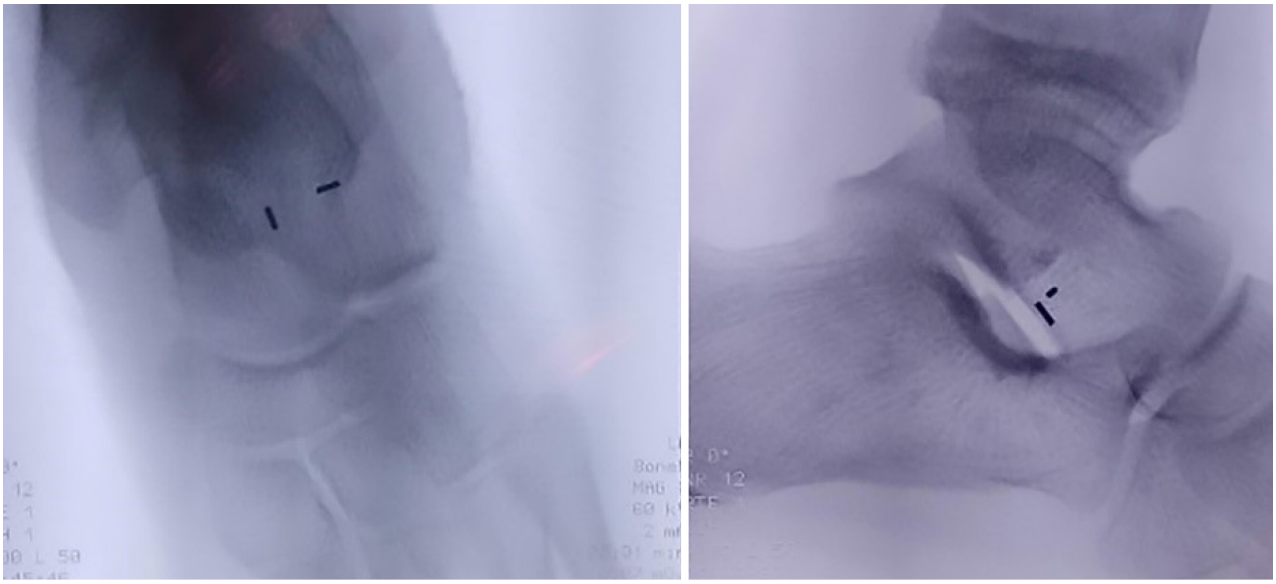

Figure 1 Postoperative X-rays of subtalar arthroereisis with the PitStop® PEEKdevice.

Statistical analysis

Data were analyzed using SPSS version 24.0 software (IBM, Armonk, NY, United States). The descriptive statistics were expressed by the use of means, SDs and frequencies. For the comparison of means, Student's *t*-tests were used with independent samples or with paired samples for the variables with normal distribution. In addition, statistical correlations between variables were identified by *t*-test; then, by means of linear regression, the trend of each parameter was analyzed as the other variables changed, obtaining R^2. Statistical significance was set at $P < 0.05$.

RESULTS

Mean age at surgery was 12.20 years (range, 10.15-14.48): Seventeen 10-year-old children (19.40%), twenty-four 11-year-old children (24.10%), twenty-two 12-year-old children (33.90%), nineteen 13-year-old children (17.80%), and six 14-year-old children (4.80%).

Mean BMI at the time of surgery was 20.69 (range: 14.08-29.34, SD: 3.44). Forty-two patients had a BMI < 18 kg/m² (23.8%), one hundred and twelve were normal weight (63.6%) and twenty-two were obese (22.6%).

The following PitStop® PEEK endorthesis sizes were used: Size 10 in four cases (2.3%), size 11 in thirty-three cases (18.8%), size 12 in seventy-two cases (40.9%), size 13 in sixty-three cases (35.8%), and size 14 in four cases (2.3%).

Clinical evaluation

EFAS and VAS scores are reported in Table 1. The mean preoperative EFAS score was 17.73 points (range, 2.00-40.00); postoperatively, the average score was 34.38 points (range, 18.00-40.00); as a result, the mean score increase was 16.65 points (range, 15.80-17.49, $P = 0.001$).

The mean preoperative VAS score was 6.38 points (range, 0.00-10.00); postoperatively, the average score was 1.98 points (range, 0.00-6.00); as a result, the mean score increase was 4.4 points (range, 4.04-4.75, $P = 0.001$).

A few complications were reported: Six cases had superficial wound dehiscence (3.4%) and only one case required implant removal by surgery after three years due to ankle sprain during national gymnastics games (1.2%). Normal weight children reported four of six dehiscences and implant removal, without any significant differences to obese patients ($P = 0.697$). Physiotherapy was indicated in thirty patients (34.1%) due to disability in walking or sports.

Radiographic evaluation

Radiographic data are reported in Table 2. The mean preoperative Kite angle was 25.11° (range, 10.00-39.00); postoperatively, the mean angle was 20.78° (range, 11.00-33.00); as a result, the average reduction was 4.33° (SD 3.52; $P = 0.001$); the mean preoperative first metatarsal-talus angle was 7.86° (range, 1.00-31.00); postoperatively, the mean angle was 4.99° (range, 0.00-15.00); as a result, the average reduction was 2.86° (SD 4.19; $P = 0.001$).

The mean preoperative Meary angle was 7.35° (range, 1.00-21.00); postoperatively, the mean angle was 3.44° (range, 0.00-18.00); as a result, the average reduction was 3.91° (SD 3.80; $P = 0.001$); the mean preoperative calcaneal pitch angle was 15.52° (range, 8.00-27.00); postoperatively, the mean angle was 18.83° (range, 7.00-33.00); as a result, the average increase was 3.31° (SD 2.38; $P = 0.001$); the mean preoperative talo-calcaneal angle was 37.52° (range, 28.00-54.00); postoperatively, the mean angle was 31.75° (range, 22.00-42.00); as a result, the average reduction was 5.77° (SD 4.55; $P = 0.001$).

Table 1 Preoperative and postoperative European Foot and Ankle Society and visual analogue scale scores

		Average	Min	Max	SD	SE	Sig ($P < 0.05$)
EFAS score	Pre	17.73	2.00	40.00	5.74	0.433	
	Post	34.38	18.00	40.00	4.08	0.308	
Δ EFAS		-16.65	-16.00	0.00	5.69	0.429	0.001
VAS score	Pre	6.38	0.00	10.00	2.48	0.187	
	Post	1.98	0.00	6.00	1.23	0.117	
Δ VAS		-4.40	0.00	-4.00	2.36	0.179	0.001

EFAS: European Foot and Ankle Society; VAS: Visual analogue scale scores.

Table 2 Preoperative and postoperative radiographic assessment

		Average	Min	Max	SD	SE	Δ value	SD	SE	Sig ($P < 0.05$)
Calcaneal pitch angle	Pre	15.52	8.00	27.00	3.18	0.240	3.31	2.38	0.179	0.001
	Post	18.83	7.00	33.00	4.37	0.330				
Talo-Calcaneal angle	Pre	37.52	28.00	54.00	4.32	0.329	-5.77	4.55	0.344	0.001
	Post	31.75	22.00	42.00	3.64	0.275				
Meary angle	Pre	7.35	1.00	21.00	4.02	0.303	-3.91	3.80	0.287	0.001
	Post	3.44	0.00	18.00	2.85	0.215				
Kite angle	Pre	25.11	10.00	39.00	5.22	0.394	-4.33	3.52	0.265	0.001
	Post	20.78	11.00	33.00	4.37	0.330				
Talo-M1 angle	Pre	7.86	1.00	31.00	4.32	0.330	-2.86	4.19	0.316	0.001
	Post	4.99	0.00	15.00	3.01	0.227				

Statistical analysis demonstrated a significant correlation between BMI < 25 kg/m² and BMI > 25 kg/m² ($P < 0.05$), and postoperative VAS: Normal weight patients 1.88 points; obese patients 2.64 points ($P = 0.001$); postoperative EFAS: Normal weight patients 31.09 points; obese patients 34.84 points ($P = 0.048$); postoperative Kite angle: Normal weight patients 20.32°, obese patients 23.95° ($P = 0.005$).

Relationships between BMI and postoperative EFAS score, postoperative VAS, postoperative calcaneal pitch angle, postoperative Kite angle, postoperative Meary angle and postoperative talo-first metatarsal angle were analyzed by linear regression: Postoperative EFAS score tended to decrease as BMI increased ($P = 0.001$; SE coefficient 2.081; R^2 corrected 0.095) (Figure 2A). Postoperative VAS score did not appear to be affected by BMI trends.

Postoperative calcaneal pitch decreased as BMI increased ($P = 0.001$; SE coefficient 2.493; R^2 corrected -0.007); the postoperative Kite angle also seemed to have a clinically agreeable behavior, as the angle tended to increase with increased BMI ($P = 0.003$; SE coefficient 1.802; R^2 corrected 0.003) (Figure 2B). Finally, the postoperative Meary angle tended to increase as the patient's BMI increased ($P = 0.001$; SE coefficient 2.563; R^2 corrected 0.067). No other statistically significant trends were detected.

DISCUSSION

Childhood obesity currently represents an important public health problem. Among other severe consequences, pediatric flatfoot has also been demonstrated to be related to obesity[7,12-15].

It has been shown that pediatric flatfoot (pes planus) is also related to obesity, with a two-fold higher risk compared to normal weight children[7,12-16]. The relationship between childhood obesity and flatfoot is still unknown. The structural and morphological changes reported in obese children with flatfeet are associated with compromised function in gait and activities[17,19].

In the treatment of pediatric flatfoot, subtalar arthroereisis has been reported as a minimally invasive, effective, and low-risk procedure[20-22].

Our study demonstrated that this surgical procedure is very effective in the treatment of symptomatic and flexible flatfoot: The EFAS score significantly increased and the VAS score significantly decreased after arthroereisis ($P < 0.001$), with general satisfaction in children and parents. Similarly, all angles measured significantly improved in the whole

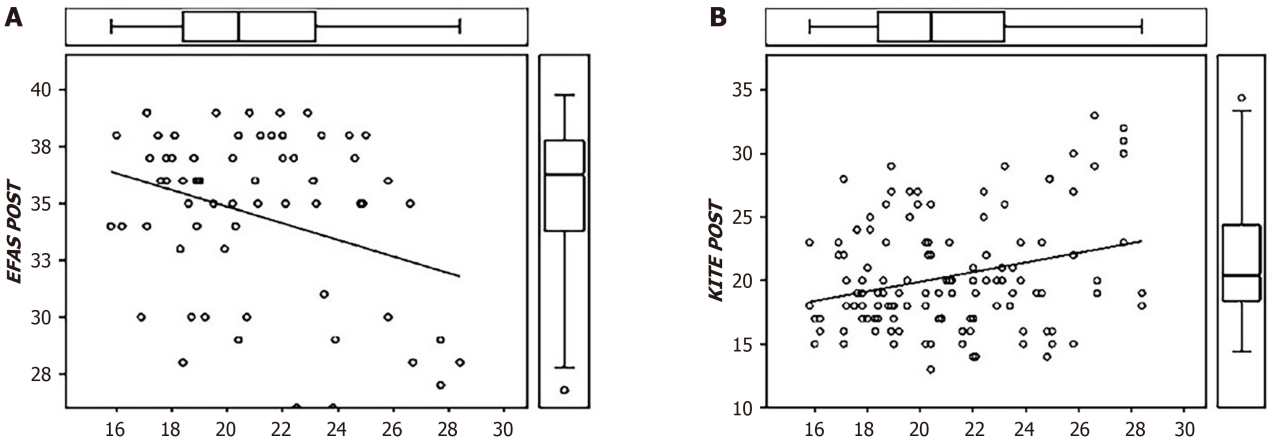

Figure 2 European Foot and Ankle Society/body mass index correlation and Kite angle/body mass index correlation. A: European Foot and Ankle Society/body mass index (EFAS)/body mass index (BMI) correlation: Postoperative EFAS score tended to decrease as BMI increased (P = 0.001; SE coefficient 2.081; R^2 corrected 0.095); B: Kite angle/BMI correlation: Postoperative Kite angle tended to increase with increased BMI (P = 0.003; SE coefficient 1.802; R^2 corrected 0.003). EFAS: European Foot and Ankle Society.

pediatric population (P = 0.0011). Our favorable results are similar to those reported in several other studies[37-44].

Regarding complications, we reported a rate of only 4.6%: The most common complication was superficial dehiscence treated with simple medications. Our results are in line with those from other studies, with complication rates ranging from 4.8% to 19.3%[20,45,46]. It is our opinion that superficial wound dehiscence is caused by the cast as sweating is frequent, leading to maceration of the skin surrounding the wound. Thus, we currently prefer not to use a cast but an ankle orthosis. The only case of implant removal was caused by an unpredictable traumatic event during gymnastics.

As demonstrated by the statistical analyses, obesity has a significant influence on both clinical and radiographic outcomes of subtalar arthroereisis: BMI over 25 kg/m² is significantly correlated with worse postoperative EFAS and VAS scores (P < 0.05). Also, postoperative angles show worse values in obese patients: Postoperatively, the calcaneal pitch, Kite angle, and Meary angle were significantly influenced (P < 0.05).

Few studies have reported the relationship between childhood obesity and the corrective potential of arthroereisis: Only Pavone reported results after calcaneo-stop implants[27], but no studies have reported the outcomes of self-locking implants.

As the goniometric improvements, with the exception of the Kite angle, were substantially similar in normal weight/overweight children, subtalar arthroereisis is effective in treating flexible flatfoot in both populations. However, the following question might arise: Is it worth performing this surgical procedure in overweight children? Based on our results, the answer is yes, and for two reasons. Firstly, the significant improvements in the postoperative EFAS score, VAS score and radiographic angles confirm that arthroereisis represents an effective and valid treatment of flatfoot even in this population; on the other hand, obese patients seem not to incur more complications than normal weight children, as complications were related to unpredictable factors.

Nevertheless, our results allow us to assert that subtalar correction due to arthroereisis requires greater effort in overweight children, resulting in poorer outcomes than normal weight patients as demonstrated by postoperative lower EFAS and higher VAS scores. Although good radiographic correction was obtained after subtalar arthroereisis, obese children tended to perceive more pain and discomfort midterm than their normal weight peers. These findings were confirmed by linear regression studies when evaluating the relationship between BMI and clinical-radiographic outcomes.

CONCLUSION

Subtalar arthroereisis is effective in treating flexible flatfoot both in normal weight and obese populations. Nonetheless, obesity significantly influences clinical and radiographic outcomes and obese children tend to perceive more pain and discomfort.

FOOTNOTES

Author contributions: Monestier L and Riva G were the patients' surgeons; Monestier L, Pelozzi A, Bozzi E, Latiff M and Marciandi L reviewed the literature and contributed to manuscript drafting; Latiff M and Pautasso A analyzed the imaging findings; Surace MF, Pilato G, D'Angelo F, Monestier L and Riva G were responsible for the revision of the manuscript for important intellectual content; All authors issued final approval for the version to be submitted.

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Informed consent statement: Regular informed consent was obtained from all patients. Informed written consent was obtained from the patients for publication of this report and any accompanying images.

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Data sharing statement: The authors confirm that the data supporting the findings of this study are available within the article.

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