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Functional evaluation of bilateral subtalar arthroereisis for the correction of flexible flatfoot in children: 1-year follow-up

Caravaggi Paolo[a,*], Lullini Giada[a], Berti Lisa[a], Giannini Sandro[b], Leardini Alberto[a]

[a] Movement Analysis Laboratory and Functional-Clinical Evaluation of Prostheses, Istituto Ortopedico Rizzoli, Via di Barbiano 1/10, 40136, Bologna, Italy
[b] First Orthopaedics and Traumatology Clinic, Istituto Ortopedico Rizzoli, via G.C. Pupilli 1, Bologna, Italy

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ABSTRACT

Background: Flexible flatfoot (FFF) is a common alteration of the foot diagnosed in the pediatric population causing pain and decreased quality of life. Surgical treatment via arthroereisis of the subtalar joint can be recommended when non-invasive options do not result in sufficient pain relief. While clinical outcome of subtalar joint arthroereisis is generally positive, no functional evaluation has thus far been reported following surgery.

Research question: The aim of this study was to assess the effects of two arthroereisis implants for the correction of bilateral FFF on foot and lower limb biomechanics during gait.

Methods: This is a prospective study following 13 children affected by bilateral symptomatic FFF. The patients underwent bilateral subtalar arthroereisis during the same surgery using two types of poly-L-lactide bioabsorbable implants: an expanding endo-orthotic implant, and a calcaneo-stop screw. Radiological parameters and gait analysis were performed preoperatively and at 1 year follow-up and compared to those from an age-matched normal-arched control population. Lower limb and multisegment foot kinematic analysis, along with EMG of the main ankle flexor/extensor muscles, were performed during level walking at comfortable speed. Paired non-parametric Wilcoxon signed-rank test was used to assess differences in radiological and kinematic parameters between pre-op and post-op assessments.

Results: All radiological parameters, and frontal-plane orientation of the rearfoot in double-leg standing were improved at 1-year follow-up in both implant groups (e.g calcaneo-stop: pre-op = 15 ± 7 deg; post-op = 6 ± 9 deg; $p < 0.01$). The endo-orthotic implant group showed significantly lower pronation/supination at the ankle and midtarsal joint. Activation of the tibialis anterior muscle was more physiological after surgery in both groups.

Significance: According to the present analysis, both implants appear effective in restoring physiological alignment of the rearfoot, however the endo-orthotic implant appeared more effective in restoring a more correct frontal-plane mobility of foot joints.

1. Introduction

Flexible flat foot (FFF) is a rather common pediatric foot deformity, usually asymptomatic, diagnosed in 10% of children [1]. The more evident morphological alterations characterizing FFF condition are the following: subtalar joint eversion; reduced medial longitudinal arch; calcaneus plantar flexion, and forefoot supination in weight bearing [2,3]. From a functional perspective, while normal feet pronate during the stance phase of gait and supinate during the propulsive phase [4], FFF is characterized by persistent foot pronation with inefficient propulsion during terminal stance, and thus abnormal function during loading response [5]. Altered foot pronation at foot contact also alters the biomechanics of lower limb joints, which may result in musculoskeletal injuries of the foot and leg [6,7].

Although the type of treatment for FFF is still a controversial issue in the orthopedic community [12], surgery can be recommended in case of symptomatic forms presenting pain along the medial side of the foot or in the leg and knee during gait, early muscle fatigue, gait alterations and Achilles tendon tightness [3,8,9]. According to the pathoanatomy of the FFF, surgical treatment can be performed via arthroereisis (Greek words for “joint raising”), arthrodesis or osteotomies. Arthroereisis of the subtalar joint is a widely used minimally-invasive procedure to

* Corresponding author.
E-mail addresses: paolo.caravaggi@ior.it (P. Caravaggi), giada.lullini2@unibo.it (G. Lullini), lisa.berti@ior.it (L. Berti), sandro.giannini@ior.it (S. Giannini), leardini@ior.it (A. Leardini).

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restrict excessive subtalar pronation by inserting an implant in the sinus tarsi [10]. This surgical procedure can be performed with different implants: impact block devices, also known as calcaneo-stop, which prevent anterior translation of the talus through the application of a screw in the inferior part of the sinus tarsi; axing-altering devices, and self-locking wedges that reduce pronation by impeding the contact between lateral process of the talus and the inferior part of sinus tarsi [9].

Calcaneo-stop is a widespread, reliable and effective implant; a study including 398 patients showed good results in clinical aspects and X-ray measures, absence of complications and restoration of normal foot function [2]. Normalization of footprint in 80% of treated patients was also reported with this technique [10]. Further studies reported improvements in clinical outcome when compared to healthy population [3,11]. An expanding poly-L-lactide (PLLA) endo-orthotic implant has also been proposed for surgical treatment of FFF. This has been shown capable to restore the normal foot structure and results in good clinical and radiographic outcomes [12], enduring at 18 months [13] and at 4 years follow-up [4]. These implants are available in different shapes and materials, either medical-grade metals or bioabsorbable polymers. Bioabsorbable implants however have some advantage as they do not require a second surgery to remove the implant following restoration of the correct rearfoot alignment, once skeletal maturity is reached [14].

Despite the large available clinical evidence, the choice of the best arthroereisis implant for the correction of symptomatic FFF condition is still debated, also due to a lack of quantitative data on the effects of different surgical options on foot and lower limb function [15]. To the best of the authors knowledge, no functional evaluation via gait analysis of the outcome of surgical correction of FFF by means of subtalar arthroereisis has thus far been reported in the literature. The aim of this study was assessing the kinematic effects of two types of bioabsorbable implants – expanding endo-orthotic implant and calcaneo-stop - for the arthroereisis of the subtalar joint in FFF. In particular we wanted to test the hypothesis that these implants are effective in limiting excessive foot pronation in a cohort of children with FFF condition by means of multi-segmental foot kinematic analysis.

2. Methods

13 children (11.3 ± 1.6 years; BMI 19.7 ± 2.8 kg/m^2) affected by bilateral symptomatic FFF eligible for arthroereisis of the subtalar joint, and a group of 10 normal-arched (rectus foot) healthy children (11.2 ± 2.4 years; BMI 19.1 ± 3.5) as control, were analyzed in the study. FFF patients underwent bilateral subtalar arthroereisis during the same surgery using two types of PLLA bioabsorbable implants: an expanding endo-orthotic implant for the left foot [8] (ENDO, top Fig. 1), and a calcaneo-stop screw for the right foot (CASTO, bottom Fig. 1). The endo-orthotic implant is an extra-articular expanding screw comprised of an internally-threaded cylinder for the insertion of a smaller screw, whereas the calcaneo-stop is a PLLA screw inserted in the calcaneal bone at the entrance of the sinus-tarsi and thus interfering with talar movements. Both screws are indicated for the surgical treatment of flexible flatfoot in children aged 8–14, and are designed for the arthroereisis of the subtalar joint as to restore physiologic alignment between talus and calcaneus [4,10]. Unless complications are present, a second surgery to remove PLLA screws is not needed, as these small constructs fully degrade and are reabsorbed after about 5 years from surgery [8,9].

The standard clinical assessment for the diagnosis of FFF condition is comprised of a physician examination and evaluation of radiological parameters from X-rays images. A 10-point VAS scale was used to assess the level of foot and ankle pain felt by patients in everyday activities, where 0 corresponds to no pain and 10 to the worst possible pain perceived. Jack test and toe standing test were used to assess the foot capability to rise the medial longitudinal arch via windlass mechanism and to restore frontal-plane rearfoot alignment. A podoscope was used to assess alterations in plantar contact area during double-leg standing. Meary's line and talocalcaneal angle were measured from lateral and frontal X-ray images of the patients' feet. Reference radiological parameters were from the literature [16–18]. The study was approved by the local Ethical Committee and parents' informed consent was obtained for the physician examination, the radiological evaluation and the kinematic data collection.

FFF patients were assessed pre-op and at an average follow-up of 1 year (12.5 ± 3.7 months). Functional evaluation was performed by means of kinematic and kinetic analysis of the main lower limb and foot joints during normal walking. Motion data collection implied a static acquisition in double-leg upright standing, and five trials of barefoot walking at self-selected speed. An 8-camera motion capture system (Vicon Motion Systems Ltd, Oxford, UK) was used to track markers on the lower limb [19], and on the foot [20,21] according to the Rizzoli Foot Model, at 100 Hz. 3D joint rotations were calculated using the Joint Coordinate System [22] between the following pairs of segments: shank-foot (ShFo); shank-calcaneus (ShCa, i.e. ankle-complex joint); calcaneus-midfoot (CaMi, i.e. midtarsal joint); midfoot-metatarsus (MiMe, i.e. tarso-metatarsal joint), and metatarsus-calcaneus (CaMe). Dorsi- / plantar-flexion, inversion/eversion and adduction/abduction rotations were calculated at each joint respectively in the sagittal, frontal and transverse plane. Medial longitudinal arch (MLA) deformation was estimated by tracking markers on the calcaneus and on the first metatarsal head [21].

Two force plates (Kistler, Switzerland) recorded ground reaction forces at 2000 Hz A wireless EMG system (Zerowire, Cometa, Milan, Italy) recorded the myoelectric activity of the gastrocnemius medial head and of the tibialis anterior muscles at 2000 Hz. Dynamic EMG data were automatically processed by a custom single-threshold algorithm as to obtain on-off patterns of muscle activity. A global temporal profile of activation was obtained for each muscle by calculating the percentage of muscular activity across all trials and all patients at each time frame of the normalized gait cycle [23]. Root mean square error (RMSE) of the EMG activation in each implant group with respect to control was used to assess alterations in EMG profiles due to arthroereisis in different phases of gait cycle.

All kinematic parameters were calculated as average across five trials for each subject. Post-hoc power analysis computed for foot joints range of motion (ROM) measures ($\alpha = 0.05$; effect size = 0.888) confirmed that 13 samples were sufficient to achieve a power of 0.815 for the statistical comparison between pre-op and post-op assessments. Non-parametric paired Wilcoxon signed-rank test was used to assess differences in radiological, clinical, kinematic and kinetic parameters between pre-op and post-op evaluations in each implant group ($\alpha = 0.05$). Non-parametric unpaired Mann-Whitney U test was used to assess differences between pre-op and post-op measurements and control (α 0.05). One-dimensional statistical parametric mapping [24] was used to determine differences in time-histories of intersegmental rotations between implant groups and corresponding control data.

3. Results

All radiological parameters and VAS of pain were significantly improved at 1-year follow-up in both implant groups. Pre-op Meary's line was 156.9 ± 7.4 deg and 161.8 ± 7.5 deg, respectively in the CASTO and ENDO group, and 168.8 ± 8.1 deg and 169.6 ± 5.6 deg at post-op (pre-op vs. post-op: $p < 0.001$; reference ≃ 180 deg). Talocalcaneal angle was 39.0 ± 6.4 and 38.3 ± 5.0 at pre-op, respectively in the CASTO and ENDO group, and 30.2 ± 3.9 deg and 31.1 ± 3.8 deg at post-op (pre-op vs. post-op: $p < 0.001$; reference = 15–30 deg). VAS of pain improved from 5.5 ± 1.0 and 5.4 ± 0.9, to 1.7 ± 0.8 and 1.6 ± 0.7, respectively in the CASTO and ENDO group (pre-op vs. post-op: $p = 0.002$).

No significant differences were detected in spatio-temporal and