Foot and Ankle Surgery 19 (2013) 56–61

Contents lists available at SciVerse ScienceDirect

Foot and Ankle Surgery

journal homepage: www.elsevier.com/locate/fas

Lengthening osteotomy of the calcaneus and flexor digitorum longus tendon transfer in flexible flatfoot deformity improves talo-1st metatarsal-Index, clinical outcome and pedographic parameter

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ARTICLE INFO

Article history:
Received 23 June 2012
Received in revised form 13 October 2012
Accepted 24 October 2012

Keywords:
Flatfoot
Calcaneus osteotomy
Tendon transfer
Talo-1st metatarsal angle
Talo-1st metatarsal index

ABSTRACT

Lengthening osteotomy of the calcaneus (LO) and flexor digitorum longus tendon (FDL) transfer to the navicular is one option for the treatment of flexible flatfoot deformity (FD). The aim of the study was to analyse the amount of correction and clinical outcome including pedographic assessment.

In a prospective consecutive non-controlled clinical followup study, all patients with FD that were treated with LO and FDL from September 1st 2006 to August 31st, 2009 were included. Assessment was performed before surgery and at 2-year-followup including clinical examination (with staging of posterior tibialis insufficiency) weight bearing radiographs (Talo-1st metatarsal angles (TMT)), pedography (increased midfoot contact area and force) and Visual Analogue Scale Foot and Ankle (VAS FA).

112 feet in 102 patients were analysed (age, 57.6 (13–82), 42% male). In 12 feet (9%) wound healing delay without further surgical measures was registered. All patients achieved full weight bearing during the 7th postoperative week. Until followup, revision surgery was done in 3 patients (fusion calcaneocuboid joint ($n = 2$), correction triple arthrodesis ($n = 1$)). 101 feet (90%) completed 2-year-followup. TMT dorsoplantar/lateral/Index and VAS FA scores were increased, and posterior tibialis insufficiency stage, pedographic midfoot contact area and force percentage were decreased (each $p < .05$).

All relevant parameters (stage of posterior tibialis insufficiency, TMT angles and Index, pedographic midfoot contact area and force percentage, VAS FA) were improved 2 years after LO and FDL transfer to the navicular in FD. The complication rate was low. This method allows safe and predictable correction.

1. Introduction

Lengthening osteotomy of the calcaneus and flexor digitorum longus tendon (FDL) transfer to the navicular screw is one option for the treatment of flexible flatfoot deformity (FD) [1–4]. The talo-1st metatarsal (TMT) angles (dorsoplantar and lateral), and the TMT-Index based on these angles have been introduced as relevant radiological parameters for assessment of flatfoot deformity [5]. The aim of the study was to analyse the amount of correction (for example talo-1st metatarsal-index (TMT-Index)), and clinical outcome including pedographic assessment.

2. Methods

2.1. Study design

In a prospective consecutive non-controlled clinical followup study, all patients with FD that were treated with lengthening osteotomy of the calcaneus and flexor digitorum longus tendon (FDL) transfer to the navicular for the treatment of FD based on the treatment algorithm (Table 1) from September 1st 2006 to August 31st, 2009 were included. No exclusion criteria were defined. Assessment was performed before surgery, and at 2-year-followup. The assessment included clinical examination (with staging of posterior tibialis insufficiency) radiographs with full weight bearing (TMT dorsoplantar, lateral, Index), pedography (midfoot contact area and force percentage in relation to available physiological pedographic data), and Visual Analogue Scale Foot and Ankle (VAS FA) [5,6]. The clinical assessment was performed by the two authors who were the director and assistant director of the orthopaedic department. For detection of potential weakness

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http://dx.doi.org/10.1016/j.fas.2012.10.006

Table 1
Treatment algorithm for pes abductoplanovalgus based in TMT-Index.

TMT-Index	Therapy
Grade 1 0 to −20	Wait, yearly control When posterior tibialis tendon insufficiency (classification see Table 2) physiotherapy In-shoe-orthosis based on pedography
Grade 2 −21 to −40	Lengthening osteotomy calcaneus Flexor digitorum longus transfer to navicular Reconstruction spring ligament and capsule talonavicular joint Reinsertion posterior tibialis tendon further distal and caudal than original insertion
Grade 3 −41 to −60	Gastrocnemius-slide Reduction and transfixation calcaneocuboid joint.
Grade 4 <−61	Complex (navigated) correction arthrodesis (for example double, triple, interposition arthrodesis calcaneocuboid joint) Flexor digitorum longus transfer to navicular Reconstruction spring ligament and capsule talonavicular joint Reinsertion posterior tibialis tendon further distal and caudal than original insertion Gastrocnemius-slide

TMT-index, Talo-1st metatarsal-index.

after gastrocnemius-slide, a test with single leg heel-rise for ten times was performed at followup.

2.2. Technique

This treatment was indicated following our treatment algorithm (Table 1).

First, a gastrocnemius-slide was performed as described [7,8]. A longitudinal medial 3 cm-skin incision was performed above the origin of the gastrocnemius tendon. The fascia was longitudinally incised, and the entire gastrocnemius tendon was cut directly at the origin of the tendon. Then, a medial approach with an incision directed from beneath the medial malleolus to the caudal margin of the 1st cuneiform was performed. The posterior tibialis tendon was detached from its insertion, debrided, and armed with a suture (Baseball-type stitch with Orthocord®, Depuy Mitek, Warsaw, IN, USA). The FDL was isolated and cut directly proximal to the knot of Henry under direct visualization. The tendon was armed with a suture (Baseball-type stitch with Orthocord®, Depuy Mitek, Warsaw, IN, USA). The talonavicular joint was opened and debrided. A bony canal was drilled in the navicular in a dorsal to plantar direction with a 4.5 mm drill. Then the lateral side was addressed through a lateral longitudinal incision directed from beneath the lateral malleolus to the lateral margin of the cuboid. The calcaneal lengthening osteotomy was performed with an oscillating saw 1.5 cm posterior to the calcaneocuboid joint and parallel to that joint. Before the osteotomy the calcaneocuboid joint was obened from the lateral side, debrided, reduced and transfixed with a 1.6 mm Kirschner wire that was inserted percutaneous and retrograde. The osteotomy was opened with a laminar spreader that was placed on two 1.6 mm Kirschner wires that were placed next to the osteotomy into the calcaneus. The opening of the osteotomy was performed until the dorsoplantar and lateral TMT angles as described below were 0° under fluoroscopy. During this assessment the foot and ankle were in neutral position in relation to the tibia and the foot was placed on a special board. This board has a special handle, and the board is pressed to the foot sole manually so simulate weight bearing. The amount of force/pressure simulating weight bearing was introduced by the surgeon in a non-standardized but subjectively driven manner. The gap size at the osteotomy site was measured. An autologous tricortical cortico-cancellous bone block with the corresponding same size was harvested from the ipsilateral pelvic rim using an oscillating saw. The bone block was inserted into the osteotomy and fixed by protruding the Kirschner wire that was used for the transfixation of the calcaneocuboid joint. This Kirschner wire was later bend and cut above the skin level. The osteotomized site was stabilized with a polyaxial locking plate with four 3 mm × 30 mm locking cancellous screws (R-Lock, Intercus, Rudolstadt, Germany). The plate was used for osteosynthesis of the osteotomy. The wire was used for transfixation of the reduced calcaneocuboid joint, and for initial retention of the bone block at the osteotomy site until the plate was placed. Then the medial side was completed. The talonavicular joint capsule and the spring ligament were sutured under tension (Mattress-type stich with Orthocord®, Depuy Mitek, Warsaw, IN, USA). The FDL was pulled through the navicular from plantar to dorsal. The posterior tibialis tendon was reinserted 1 cm more distal and plantar to its original insertion. The FDL was pulled towards the posterior tibialis tendon and fixed to that tendon. Drainages (10 Charrier) were inserted at the medial approach at the foot, and at the approached for the gastrocnemius-slide and pelvic rim. Bilayer closure followed, and dressing and an orthosis (Vacoped, OPED, Valley, Germany) were applied.

Postoperative treatment was performed in a walker-like orthosis (Vacoped, Oped, Valley, Germany) with 15 kg partial weight bearing for 6 weeks. The transfixing Kirschner wire was removed at 6 weeks before full weight-bearing without restrictions was allowed.

2.3. Radiographic assessment (Figs. 1 and 2)

Dorsoplantar and lateral digital radiographs in standing position with bipedal full weight bearing were obtained. The radiographs were measured digitally with a software (Medicad2, Hectec, Landshut, Germany). The Talo-1st metatarsal (TMT) angle was defined as the angle created between the axis of the 1st metatarsal and the talus. These axes were defined as the straight line between the centres of two circles that were placed in congruence with the outlines of the bones, one distal and one proximal at each bone. The TMT angles were defined to be negative for abduction in the dorsoplantar radiograph and for dorsiflexion in the lateral radiographs. The TMT-Index was defined as the sum of the dorsoplantar and lateral TMT angles [5].

2.4. Pedography

Standard dynamic pedography (three trials, walking, third step, mid stance force pattern) was performed as described before [9–11]. A standard platform (Emed AT®, Novel Inc., Munich, Germany and St. Paul, MN, USA) and software (Emed ST®, version 12.3.18, Novel Inc., Munich, Germany and St. Paul, MN, USA) was used. Both sides were measured. Computerized mapping to create a distribution into the following foot regions was performed with the standard software (Automask, version 12.3.18, Novel Inc., Munich, Germany and St. Paul, MN, USA): hindfoot, midfoot, 1st metatarsal head, 2nd metatarsal head, 3rd metatarsal head, 4th metatarsal head, 5th metatarsal head, 1st toe, 2nd toe, 3rd–5th toe. This mapping process does not include manual determination of landmarks [12]. The percentages of the midfoot contact area and force were compared with physiologic data [11].

2.5. Inter- and intraobserver repeatability

Bland and Altman plots and repeatability coefficients were used as measures of inter- and intraobserver repeatability for radiolog-

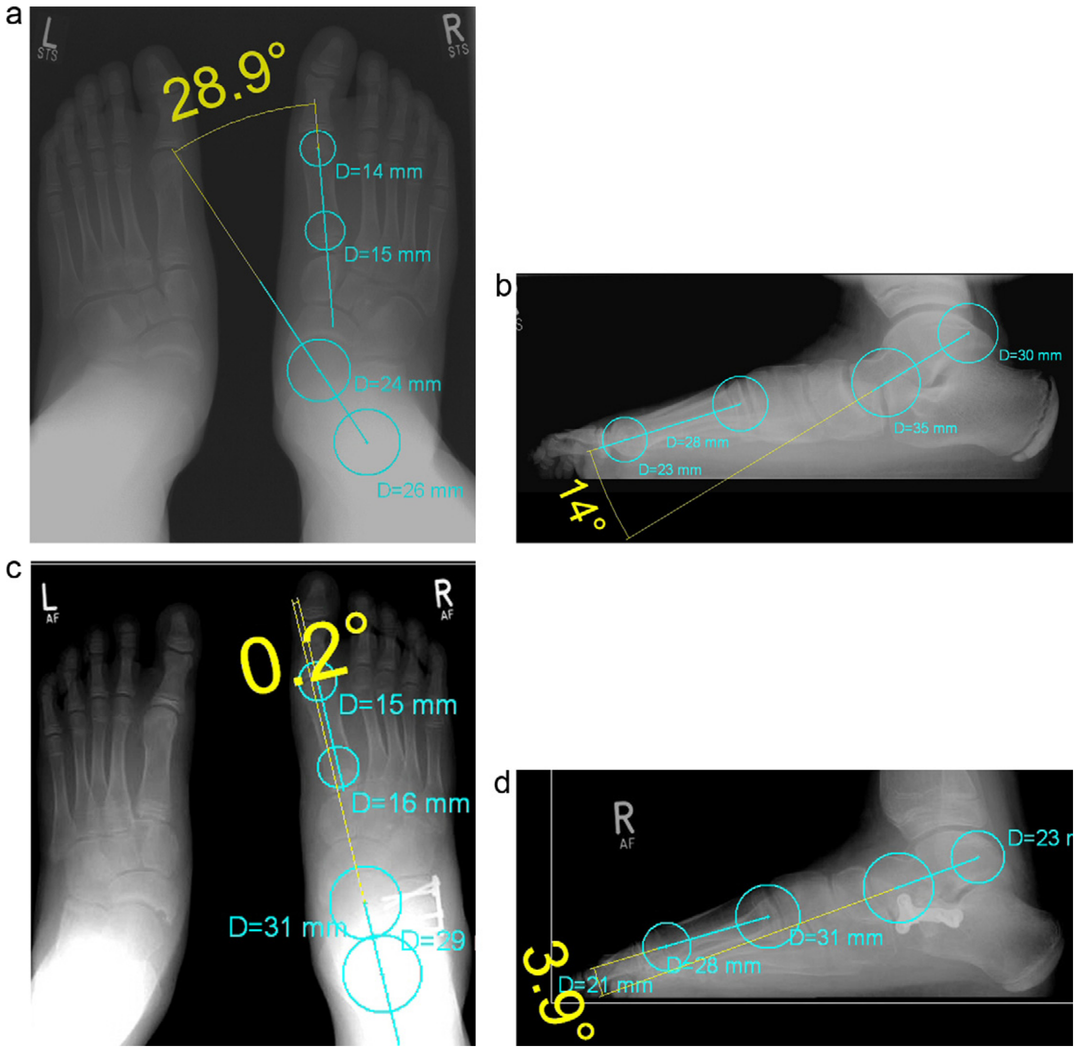

Fig. 1. (a–d) 13-Year-old male. Preoperative dorsoplantar TMT angle −28.9° (a) and lateral TMT angle −14° (b) resulting in a TMT-Index of −42.9°. At 2-year-followup, dorsoplantar TMT angle −.2° (c) and lateral TMT angle −3.9° (d) resulting in a TMT-Index of −4.1°. The measurements were performed with Medicad2 (Hectec, Landshut, Germany). The sizes of the circles are also shown. These sizes are not relevant because only the centre of the circle needs to be defined for the angle measurement.

ical measurements and assessment of posterior tibialis insufficiency stage [13]. The 95% limits of agreement represent a judgement of how well the measurements of the two reviewers (MR, SZ) agreed. By definition, the measurement error was smaller than the repeatability coefficient for 95% of the observations.

2.6. Statistics

An unpaired *t*-test was used for statistical comparison of VAS FA and TMT angles before surgery and at followup, and a Chi^2-test for all other parameters.

3. Results

112 feet in 102 patients were included in the study (age, 57.6 (13–82), 42% male). Table 3 shows the relevant preoperative parameters. In 12 feet (9%) wound healing delay at the lateral incision without surgical measures was registered. All feet/patients achieved full weight bearing during the 7th postoperative week. Until followup, revision surgery was done in 3 feet, twice fusion of the calcaneocuboid joint due to symptomatic arthritis of that joint and once correction triple arthrodesis due to symptomatic arthritis in the subtalar, talonavicular and calcaneocuboid joints.

101 feet (90%) completed 2-year-followup. The patients with revision surgery were excluded from the followup. Another eight feet were lost to followup. In comparison with the preoperative parameters, TMT dorsoplantar/lateral/Index and VAS FA scores were increased, and posterior tibialis insufficiency stage, pedographic midfoot contact area and force percentage were decreased at followup (Table 2, each $p < .05$). All osteotomies were considered to be healed with the bone block integrated. No subluxation of the calcaneocuboid joints was registered. No symptoms at the donor site at the pelvis were registered. All subjects completed the test for detection of potential weakness after gastrocnemius-slide successfully for both legs.

The pre- and postoperative inter- and intraobserver repeatability coefficients for the measurement of the TMT angles and the posterior tibialis insufficiency stage were >.75.

4. Discussion

In the flexible flatfoot deformity, osteotomies have a significant role in operative management by restoring more normal biomechanics, allowing tendon transfers to function successfully [1–

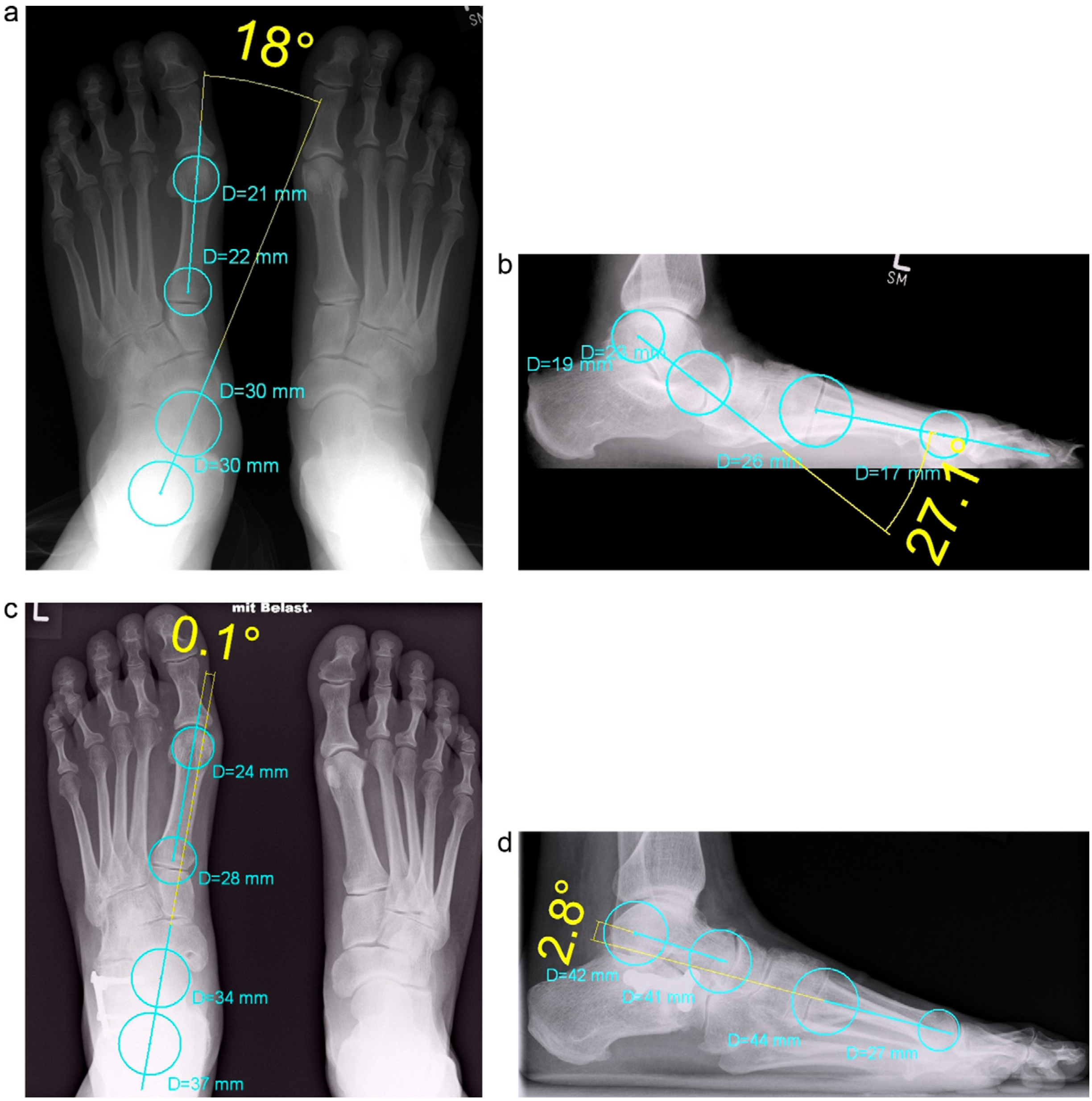

Fig. 2. (a–d) 47-Year-old female. Preoperative dorsoplantar TMT angle −18° (a) and lateral TMT angle −27.1° (b) resulting in a TMT-Index of −45.1°. At 2-year-followup, dorsoplantar TMT angle −.1° (c) and lateral TMT angle +2.8° (d) resulting in a TMT-Index of +2.8°. The measurements were performed with Medicad2 (Hectec, Landshut, Germany). The sizes of the circles are also shown. These sizes are not relevant because only the centre of the circle needs to be defined for the angle measurement.

4,14,15]. The options include lateral column lengthening, medial displacement calcaneal osteotomy, and combined double osteotomy technique [1–4,14,15]. The tight Lateral column lengthening has been used extensively for treatment of flexible flatfeet [1–4,14,15]. It has been shown clinically and radiographically to address all 3 components of the pes abductoplanovalgus deformity [2]. Lateral column lengthening is mostly used in combination with a medial soft tissue rebalancing procedure [2]. The mechanism of action is still speculative but clearly is not owing to tensioning of the plantar fascia as previously thought [2]. Despite the excellent correction of foot posture obtained by use of lateral column lengthening for FD, many clinicians have reservations about its use because of reported secondary increases in the calcaneocuboid joint pressures [2]. This increase in pressure has been shown to occur experimentally, increasing the potential risk of calcaneocuboid joint arthrosis [1]. To address the concern regarding potential calcaneocuboid arthrosis secondary to lateral column lengthening, calcaneocuboid joint distraction arthrodesis has been explored as an alternative technique [2]. The results show good initial correction, but the followup is extremely limited, and one study reported loss of correction over time [14,15]. Medial displacement osteotomy, in combination with flexor digitorum longus tendon transfer, can address all 3 components of FD [2]. It does not recreate the medial longitudinal arch in all patients, however [2]. The combination of double osteotomy technique with a FDL transfer showed good results without the evidence of calcaneocuboid arthrosis [2].

Our results are comparable to the literature regarding the clinical outcome [2,3]. Based on our treatment algorithm, no patient would require surgery at followup (Table 1, corrective surgery indicated when TMT-index $< -20°$). A real comparison of scores with the literature is not possible from a scientific point of view because most publications do not report results of a validated score as used in our study [16]. The complication rate was

Table 2
Posterior tendon insufficiency classification.

Stage 1	Single leg heel-rise possible, heel moves to varus during heel-rise
Stage 2	Single leg heel-rise possible, heel moves to neutral during heel-rise
Stage 3	Single leg heel-rise possible, heel stays in valgus during heel-rise
Stage 4	Single leg heel-rise not possible

favourably low. The only problems that were registered were wound healing delays at the lateral incision which could be partly caused by the relatively thick plates with a very stable locking mechanism that were inserted [17]. Still, we believe that adding a stable fixation is useful, and our healing of 100% supports this strategy, and finally all incisions healed. Adding a wire for transfixation the calcaneocuboid joint was performed to avoid subluxation during and after the correction. Subluxation of the calcaneocuboid joint is a frequent adverse effect which could induce arthrosis [1,2,4,18]. Three patients were converted to fusions which we consider as bad results. Two of these patients showed a typical arthrosis of the calcaneocuboid joint [2,14]. The radiological parameters were significantly improved. There are not many results comparable measurements reported [3]. Regarding the pedographic assessment, we could not find any comparable results in the literature except one single study with much lower case number ($n = 10$) [19]. We considered the increase of the midfoot contact area and force as relevant parameters which significantly improved.

We did focus but not limit the described treatment to adults and treated also children and adolescents. Children (e.g. Fig. 1) were treated like this when arthrorhisis with calcaneostop screw was considered to be not powerful enough and/or the remaining growth potential would not be sufficient [20,21]. In our point of view, there is a difference between the posterior tibial tendon insufficiency and flexibility of the deformity. Consequently, stage IV posterior tibialis tendon insufficiency is not principally combined with rigidity of the deformity. Consequently, the used posterior tibialis tendon insufficiency classification does only assess the function of the posterior tibialis tendon independently from the stiffness of the joints (Table 2). This is different to other less specific classifications [22,23]. We do believe that the function the of the posterior tibialis tendon does not highly correlate with joint stiffness, i.e. there are collapsed flat feet that are not stiff at all, and vice versa, there are stiff feet without any posterior tibialis tendon insufficiency. In our study, we did not observe any fixed deformities despite the high rate and degree of posterior tendon insufficiency (Tables 2 and 3). Therefore, we would like to emphasize the relevance of our introduced classification which is specific for posterior tendon dysfunction and independent from joint stiffness and/or fixed deformities. We emphasize, that the introduced treatment is not recommended for rigid deformity but could be successful for stage III and IV posterior tendon insufficiency combined with *flexible* deformity as shown by our results. In cases with rigid deformity we perform and recommend correction arthrodesis in addition to the soft tissue procedures [24,25]. Why was autograft used instead of allograft? In the local setting respectively the cultural environment, patients are very suspicious regarding allograft and prefer the risk and problems of autograft harvesting. Another local issue is cost and reimbursement. Furthermore, allograft is costly and not reimbursed by the insurances. In contrast, the cost of autograft is limited to additional surgery time and the cost of revision due to rather seldom complication which is much lower than the cost of allograft in the local setting. We always reinserted the posterior tibialis tendon and performed the augmentation with the FDL which might be considered as overtreatment in less severe cases. With this regimen, we achieved the presented results which seem to be favourable. Thus we believe that this uniform regimen is one successful option.

There are some shortcomings of the study such as missing control group, short followup time, and questionable reliability of the radiographic measurements and assessment of posterior tibialis tendon insufficiency. A missing control group is always a methodological shortcoming as in many other studies that we cannot invalidate. The followup time of 2 years for a modified technique seems appropriate. Nevertheless a longer followup would be desirable. The intra- and interobserver repeatability was sufficient (repeatability coefficients $>.75$) which is important to mention because most studies do not assess this important methodological issue [26]. We used a slight modification of determination of the 1st metatarsal axis. Hamel proposed to use the perpendicular line through the basis of the 1st metatarsal, and we used the connection of the proximal and distal bone centre [5]. We used this modification because we wanted to increase the accuracy of the defined bone axis. We could justify this method be sufficient repeatability coefficients which is lacking for Hamel's method as far as we know [5].

In conclusion, the described treatment of flexible flatfoot deformity with lengthening osteotomy of the calcaneus and flexor digitorum longus tendon transfer to the navicular improved all relevant parameters (stage of posterior tibialis insufficiency, TMT-Index, increased pedographic midfoot contact area and force, VAS FA) at 2-year-followup. The complication rate was low. This method allows safe and predictable correction.

Table 3
Parameters before surgery and at 2-year-followup.

Parameter/time	Before surgery ($n = 112$ feet)	2-Year-followup ($n = 101$ feet)	Statistical analysis test and result
Posterior tibialis insufficiency stage (for classification, see Table 2)	None, $n = 0$ (0%) Stage 1, $n = 0$ (0%) Stage 2, $n = 45$ (40%) Stage 3, $n = 55$ (49%) Stage 4, $n = 12$ (11%)	None, $n = 54$ (53%) Stage 1, $n = 27$ (27%) Stage 2, $n = 15$ (15%) Stage 3, $n = 4$ (4%) Stage 4, $n = 1$ (1%)	Chi^2-test, $p = .01$
TMT dorsoplantar	−20.1 (−41 to −12)	−6.4 (−12 to + 6)	*t*-Test, $p = .04$
TMT lateral	−15.7 (−36 to −5)	−3.2 (−8 to +5)	*t*-Test, $p = .05$
TMT-Index	−30.8 (−59 to −21)	−7.3 (−18 to + 8)	*t*-Test, $p = .02$
Pedography, percentage increased midfoot contact area	$n = 74$ (66%)	$n = 24$ (24%)	Chi^2-test, $p = .02$
Pedography, percentage increased midfoot force	$n = 68$ (61%)	$n = 18$ (18%)	Chi^2-test, $p = .01$
VAS FA	52.4 (16–94)	82.2 (54–100)	*t*-Test, $p = .05$

TMT, Talo-1st metatarsal angle. TMT dorsoplantar, negative value, dorsiflexion comparable to flatfoot; positive value, plantarflexion comparable to cavus foot; TMT lateral, negative value, abduction; positive value, adduction. TMT-Index = TMT dorsoplantar + TMT lateral. VAS FA, Visual Analogue Scale Foot and Ankle.

Conflict of interest

None of the authors or the authors' institution received funding in relation to this study.

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