G Model
FAS-1558; No. of Pages 8

ARTICLE IN PRESS

Foot and Ankle Surgery xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Foot and Ankle Surgery

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

Dynamic medial column stabilization using flexor hallucis longus tendon transfer in the surgical reconstruction of flatfoot deformity in adults

Jaeyoung Kim[a], Ji-Beom Kim[b], Woo-Chun Lee[b,*]

[a] Hospital for Special Surgery, New York, NY 10021, USA
[b] Seoul Foot and Ankle Center, Dubalo Orthopaedic Clinic, Seoul, Republic of Korea

ARTICLE INFO

Article history:
Received 22 October 2020
Received in revised form 30 November 2020
Accepted 20 December 2020
Available online xxx

Keywords:
Flatfoot
Medial column stabilization
Tendon transfer
Calcaneal osteotomy
Flexor hallucis longus
Deformity

ABSTRACT

Background: A common challenge in flatfoot reconstruction arises when there are multiple locations of collapse within the medial column. An extension of arthrodesis may lead to complications such as stiffness or adjacent joint arthritis. The purpose of this study was to report outcomes of flatfoot reconstruction using the dynamic medial column stabilization (DMCS) technique, which transfers the flexor hallucis longus (FHL) tendon to the first metatarsal base to support the entire medial column.

Methods: We retrospectively reviewed 14 consecutive patients (14 feet) who underwent DMCS as an adjunct to flatfoot reconstruction. In all cases, a medial displacement calcaneal osteotomy and gastrocnemius recession were performed to address hindfoot valgus deformity and heel cord tightness, respectively. Deformity correction was assessed using preoperative and postoperative weightbearing radiographs. The newly defined metatarsal-cuneiform articular angle (MCAA) and naviculo-cuneiform articular angle (NCAA) were measured to assess correction at each medial column joints. Clinical outcomes included the FFI and VAS scores. Any complications related to the surgery were investigated.

Results: All radiographic parameters significantly improved postoperatively. The sagittal plane correction occurred at all three joints within the medial column. Clinically, both FFI and VAS improved significantly at the final follow-up. One patient developed plantar pain under the first metatarsal head that may have been associated with the overtightening of the transferred tendon.

Conclusion: DMCS using FHL tendon transfer to the first metatarsal base was a useful technique for restoring the medial arch and correcting three planar deformities in the setting of flatfoot deformity.

1. Introduction

A flatfoot deformity in adults is a multiplanar deformity characterized by a progressive collapse of the medial arch, abduction of the forefoot, and valgus hindfoot alignment [1]. While literature supports operative intervention for patients who have failed conservative management, much controversy exists regarding the optimal surgical methods, especially when the deformity remains flexible [2,3].

As an elongation or attenuation of the posterior tibial tendon (PTT) has often been considered a major factor in the etiology of the flatfoot deformity [4], a combination of reconstructive procedures often included a tendon transfer to stabilize the talonavicular (TN) joint, in addition to lateral column osteotomies [5–10]. However, the capacity of flexor tendon transfer to the navicular has been scrutinized in recent studies [11–14], and the instability of the medial column distal to the TN joint frequently requires correction through an osteotomy or arthrodesis [15,16].

A collapse of the medial longitudinal arch can occur through the TN joint, naviculocuneiform (NC) joint, first metatarso-cuneiform (MC) joint, or a combination of the three. However, the location of the medial column instability is frequently unidentifiable at preoperative evaluation, while occasionally appreciable following surgery in the presentation of a secondary collapse. Furthermore, when there are multiple apices within the medial column, an extension of arthrodesis is often required, which can overload adjacent joints and stiffen the medial column [17].

In an attempt to fully address the deformities and achieve a stable medial longitudinal arch without sacrificing the joints, we devised a procedure which transfers the flexor hallucis longus (FHL) tendon to the first metatarsal base as an adjunct to flatfoot

* Corresponding author at: Seoul Foot and Ankle Center, Dubalo Orthopaedic Clinic, 764-30, Bang bae dong, Seochogu, Seoul 06554, Republic of Korea.
E-mail address: leewoochun@gmail.com (W.-C. Lee).

https://doi.org/10.1016/j.fas.2020.12.007
1268-7731/

Please cite this article as: J. Kim, J.-B. Kim and W.-C. Lee, Dynamic medial column stabilization using flexor hallucis longus tendon transfer in the surgical reconstruction of flatfoot deformity in adults, Foot Ankle Surg, https://doi.org/10.1016/j.fas.2020.12.007

reconstruction (Fig. 1). We hypothesized that this technique could efficiently restore the medial longitudinal arch as well as correct multiple components of flatfoot deformity and improve clinical outcomes. The purpose of this study was to introduce our technique of dynamic medial column stabilization (DMCS) with FHL tendon transfer to the base of the first metatarsal and to evaluate the outcomes of flatfoot reconstruction using this procedure.

2. Materials and methods

This was a retrospective study of prospectively collected data on consecutive patients who underwent flatfoot reconstruction combined with DMCS between 2017 and 2018. The DMCS was indicated in patients who presented with clinical symptoms of flatfoot deformity and radiographic evidence of medial column collapse combined with hindfoot valgus deformity. A patient with collapse at any location within the medial column (TN, NC, or MC joint) was indicated for the procedure. Patients with fixed deformity and radiographic evidence of advanced osteoarthritis at the constituents of the medial column were not considered candidates for this procedure.

The current study cohort included patients with a clinical and radiographic follow-up of a minimum of two years following surgery. Patients who were younger than 18 years old, received concurrent subtalar joint arthrodesis, lateral column lengthening, or total ankle arthroplasty were excluded from the study.

Ultimately, a total of 14 patients (14 feet) constituted our study cohort, with a mean age of 47.4 years (range, 23–69) and a mean body mass index of 23.7 kg/m^2 (range, 19.5–29.1). There were 13 females and one male. The mean follow-up period was 28.9 months (range, 24–37). Demographic data are shown in Table 1. Regarding the symptoms of the patients, ten had sinus tarsi pain, five had accessory navicular pain, five had sole pain, and two had medial pain along the course of PTT.

All patients failed conservative treatment, including non-steroidal anti-inflammatory drugs, physical therapy, and orthotics. In all patients, MDCO and gastrocnemius recession were performed to

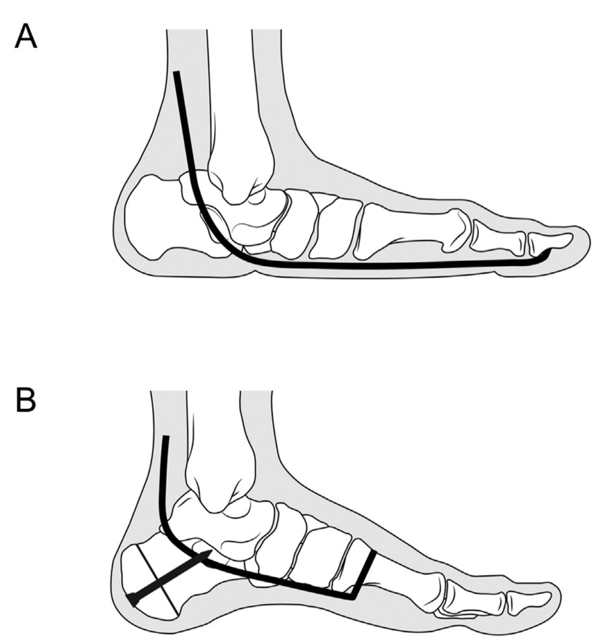

Fig. 1. Illustration of lateral weightbearing radiographs before (A) and after (B) the dynamic medial column stabilization. The flexor hallucis longus tendon is harvested from its distal end and transferred to the base of the first metatarsal bone, supporting the entire joints within the medial column.

address hindfoot valgus deformity and heel cord tightness, respectively. In one patient who presented severe PTT degeneration, debridement of the diseased tendon was carried out without flexor digitorum longus (FDL) tendon transfer. In five patients who presented with accessory navicular pain, the accessory bone was shelled out from the PTT, and the tendon was reattached in situ without advancement. Six patients underwent concurrent hallux valgus correction, and two underwent Weil osteotomy for second ray metatarsalgia. The local ethics committee approved the protocol of this study. Informed, written consent for the study was obtained from all patients.

2.1. Surgical technique

First, a coronal plane correction with MDCO was performed, and the wound was closed. A dorsally curved incision, approximately nine centimeters long, was made over the medial aspect of the foot from the midportion of the first metatarsal to the navicular tuberosity (Fig. 2A). The skin, subcutaneous layer, and deep fascia were elevated as a single layer. Careful dissection was performed to not injure the insertion of the tibialis anterior tendon or the medial branch of the superficial peroneal nerve. The abductor hallucis muscle was retracted plantarly, and the origin of the flexor hallucis brevis (FHB) was visualized and incised at the plantar aspect of the medial cuneiform. In this area, the FHL tendon is located just below the FHB origin. It can be easily identified without damaging the branch of the medial plantar nerve when the blunt dissection of soft areolar tissues is carried out after severing the tendinous origin of the FHB. Then, another two-centimeter long incision was made at the medial aspect of the proximal phalanx of the big toe, where the FHL tendon was visualized and detached (Fig. 2B). Then the FHL tendon was retrieved through the proximal wound (Fig. 2C). Locking sutures were placed at the end of the FHL tendon for handling. While the FHL tendon was pulled distally and medially, the connecting slip to the FDL was released from the FHL. The proximal two centimeters of the dorsum at the base of the first metatarsal were exposed, and the stability of the MC joint was evaluated. Dorsal instability of the joint was observed in all patients. With a small retractor placed at the lateral aspect of the first metatarsal, a tunnel was created at the base of the first metatarsal with a 5 mm sized reamer. The tunnel started about 12 mm distal to the MC joint from dorsal-distal to plantar-proximal direction targeting about 8 mm distal to the MC joint (Fig. 2D). The FHL tendon was passed from plantar to dorsal through the tunnel, then it was stabilized with a tenodesis screw with the ankle in about 10–20 degrees of plantarflexion, and the first metatarsal head was slightly pushed plantarward to prevent dorsiflexion at the MC joint (Fig. 2E). The FHL tendon was passed beneath the tibialis anterior tendon, and sutures were placed between the insertion of the tibialis anterior and the FHL for additional stabilization (Fig. 2F). Additional sutures were placed between the FHL and the adjacent tissues, including the capsule of the MC joint and thick fibrous tissues over the plantar medial aspect of the medial cuneiform. Wound closure was then achieved in a stepwise fashion.

Postoperatively, the patients were placed in a neutral position cast for six weeks. At six weeks postoperative, the cast was removed, and partial weightbearing was permitted. Patients were allowed to progress to full weightbearing as tolerated at 11 weeks after surgery. The postoperative protocol was uniform for all patients regardless of concomitant accessory navicular excision or gastrocnemius recession.

2.2. Radiographic assessment

Radiographic evaluation was performed to assess preoperative alignment and two-year postoperative correction of the

Table 1
Patient Demographics and Concurrent Procedures with Dynamic Medial Column Stabilization.

No.	Sex	Age	Side	BMI (kg/m^2)	Concurrent procedures	FU (mon)
1	F	50	R	20.1	MDCO, GR, DCMO	30
2	F	62	R	26.1	MDCO, GR, DCMO	25
3	M	32	R	23.5	MDCO, GR	37
4	F	54	L	20.5	MDCO, GR, PTT debridement	34
5	F	53	R	22.1	MDCO, GR, ANE	32
6	F	38	R	18.7	MDCO, GR, ANE	31
7	F	56	L	25	MDCO, GR, ANE	32
8	F	49	R	27.8	MDCO, GR, Weil	29
9	F	50	R	21.9	MDCO, GR, DCMO, ANE	25
10	F	69	R	20.3	MDCO, Weil	26
11	F	66	L	26.2	MDCO, GR, DCMO	28
12	F	35	R	19.6	MDCO, GR, ANE	24
13	F	23	L	26.6	MDCO, GR, DCMO	26
14	F	26	R	22.7	MDCO, GR, DCMO	24

R, right; L, left; BMI, body mass index; MDCO, medial displacement calcaneal osteotomy; GR, gastrocnemius recession; DCMO, distal chevron metatarsal osteotomy; PTT, posterior tibial tendon; ANE, accessory navicular excision; Weil, 2nd metatarsal Weil osteotomy; FU, follow-up.

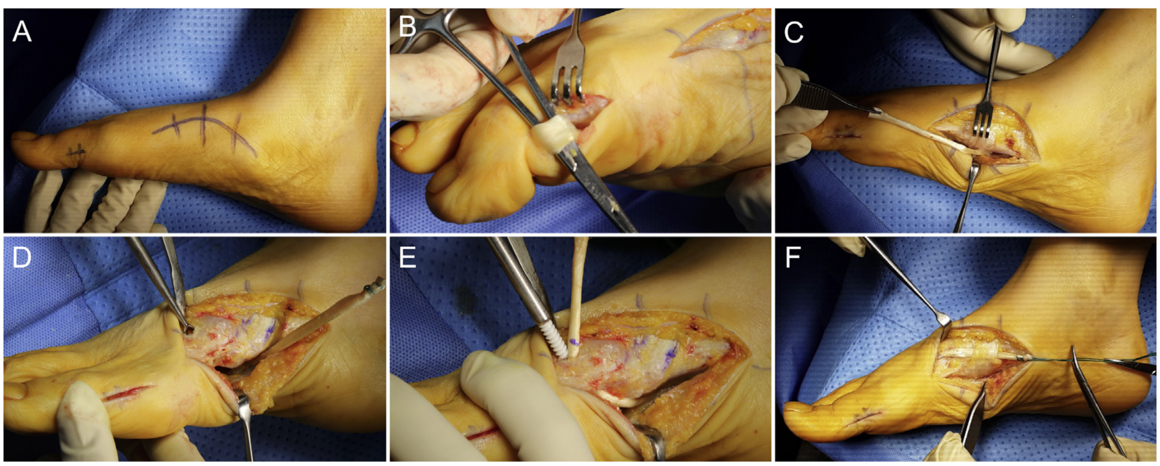

Fig. 2. Intraoperative images describe the dynamic medial column stabilization procedure. Site of the incision (A). Harvesting the flexor hallucis longus (FHL) tendon at its insertion with a separate incision (B). The FHL tendon was retrieved through the proximal incision. The length of the FHL tendon is sufficient enough to support the entire medial longitudinal arch (C). The tunnel was made at about one centimeter distal to the metatarsocuneiform joint (D). The FHL tendon was passed from plantar to dorsal through the tunnel. Then it was stabilized with a tenodesis screw (E). The FHL tendon was passed beneath the tibialis anterior tendon, and sutures were placed between the insertion of the tibialis anterior and the FHL for additional stabilization (F).

foot. The weightbearing foot anteroposterior (AP) view was used to measure the talonavicular coverage angle (TNC) [18–20]. On the weightbearing lateral view of the foot, the talo-first metatarsal angle (Meary's angle), medial cuneiform height, and calcaneal pitch angle (CP) were measured [18–20]. In addition, to assess correction at each medial column joint, the newly defined metatarsal-cuneiform articular angle (MCAA) and naviculo-cuneiform articular angle (NCAA) were measured (Fig. 3). The MCAA was the angle between the proximal articular surface of the first metatarsal bone and the distal articular surface of the medial cuneiform. The NCAA was an angle between the proximal articular surface of the navicular and distal articular surface of the medial cuneiform. Both MCAA and NCAA were deemed positive when there was a plantar sag within the medial column. To assess the amount of correction at each joint within the medial column, the amount of correction of each individual joint was calculated. A correction at the MC- and NC joint was assessed by changes of the MCAA and NCAA, respectively. A correction at the TN joint was calculated by subtracting the sum of changes of the MCAA and NCAA from changes in the Meary angle. Hindfoot alignment was analyzed with the hindfoot moment arm (HMA) and hindfoot alignment angle (HAA) in the alignment view [21].

All parameters were digitally measured using a metric software system. The radiographic measurement was performed by two independent observers for interclass correlation. The reliability of all radiographic parameters was determined. The intraclass correlation coefficient (ICC) was used for interobserver and intraobserver reliability.

2.3. Clinical evaluation

Patient-reported outcomes were determined using the Foot Function Index (FFI) and Visual Analogue Scale (VAS) for pain. FFI has been previously validated in a variety of scientific publications concerning foot and ankle surgeries [22]. All patients completed FFI and VAS preoperatively and at a minimum of two years following surgery. Complications related to surgery were recorded during the retrospective chart review. Additionally, patients were asked to document any discomforts associated with the harvest of the FHL tendon at their final follow-up.

2.4. Statistical analysis

Descriptive statistics are shown for numerical variables. The mean and standard deviations are reported when variables follow

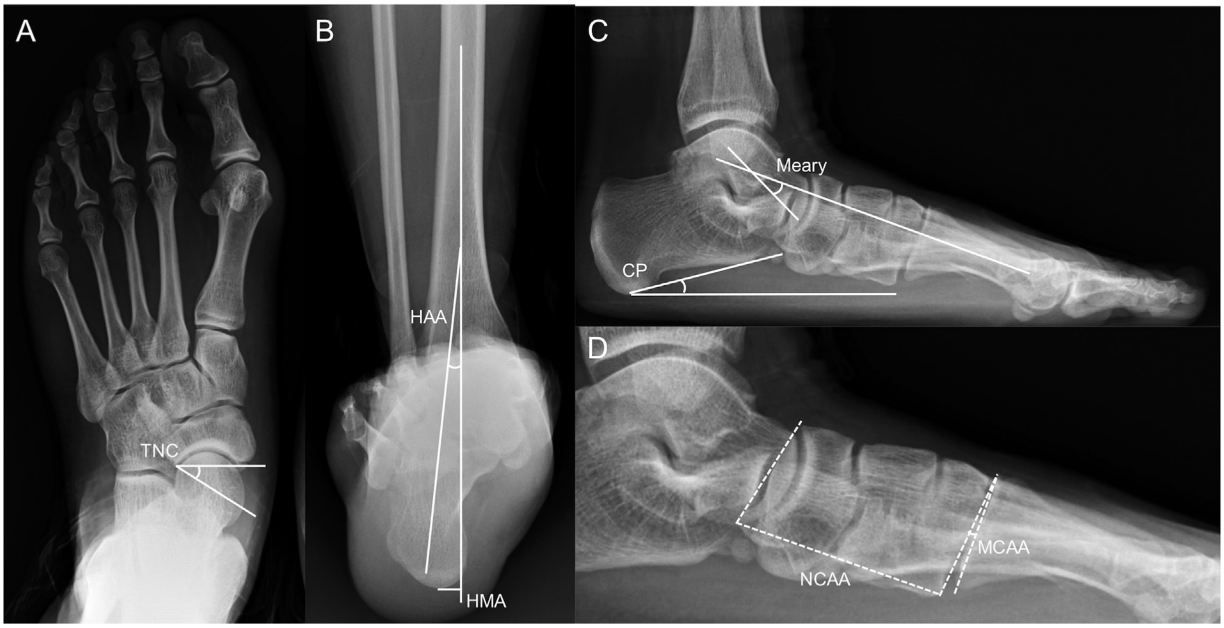

Fig. 3. Demonstration of radiographic measurements. (A) TNC (talonavicular coverage angle) was measured in weightbearing foot anteroposterior view. (B) HAA (hindfoot alignment angle, a negative value indicates valgus angulation) and HMA (hindfoot moment arm, a negative value when the calcaneus is lateral to the tibial axis) were measured in hindfoot alignment view. (C) The Meary (lateral talo-1st metatarsal angle, a positive value indicates planus), CP (calcaneal pitch angle) were measured in weightbearing foot lateral view. (D) In addition, the NCAA (naviculocuneiform articular angle) and MCAA (metatarsocuneiform articular angle) were measured in weightbearing foot lateral view.

a normal distribution. The Shapiro-Wilk test was used to assess the normality in the dataset. The Wilcoxon signed-rank test was used to analyze statistical significance in the difference between pre- and postoperative radiographic measurements and patient-reported outcomes. Statistical significance was determined as a p-value of less than 0.05. All statistical analysis was performed in Prism 8 for Mac (GraphPad, CA, US).

3. Results

All parameters measured on radiographs at a minimum of two years after surgery showed a statistically significant correction compared to the preoperative measurements. Preoperatively, the MCAA in 12 patients (86%) and the NCAA in all patients were observed to have a positive value, suggesting a large number of patients had multiple apices within the medial column. Postoperatively, both the MCAA and NCAA displayed correction with statistical significance (Table 2).

All three joints within the medial column demonstrated radiographic correction. The majority of correction within the medial column occurred at the TN joint (7.6 ± 6.1 degrees) followed by the NC joint (2.6 ± 0.9 degrees), and MC joint (1.3 ± 0.1 degrees, Fig. 4).

In the reliability analysis of the radiographic measurements, the ICC for interobserver comparisons ranged from 0.84 to 0.92, and the ICC for intraobserver comparisons, from 0.92 to 0.98 (Table 3).

Clinically, both FFI (from 55.2 ± 14.6 preoperatively to 13.4 ± 10 postoperatively, $p < 0.001$) and VAS (from 7.6 ± 1.1 preoperatively to 1.7 ± 1.1 postoperatively, $p < 0.001$) improved significantly at the final follow-up (Fig. 5).

With regard to complications following surgery, one patient developed plantar pain under the first metatarsal head that was not resolved until the final follow-up. The patient did not undergo additional surgery since her pain was manageable with a customized insole. None of the patients complained of discomfort related to FHL tendon harvest from the big toe.

Table 2
Comparison of the Radiographic Measurements Before and After Surgery.[*]

	Preoperative	postoperative	p-value
Foot anterior view			
TNC (°)	20.3 ± 7.8	14.9 ± 7.7	< 0.001
Foot lateral view[a]			
Meary (°)	24 ± 6.1	12.4 ± 5.2	< 0.001
NCAA (°)	7.6 ± 3.3	5.0 ± 2.4	< 0.05
MCAA (°)	1.4 ± 0.9	0.1 ± 0.8	< 0.001
Medial cuneiform height (mm)	8.9 ± 2.1	11.7 ± 2.3	< 0.001
CP (°)	17.5 ± 5.1	20.3 ± 4.7	< 0.001
Hindfoot alignment view[b]			
HMA (mm)	−6.1 ± 3.9	2.0 ± 4.9	< 0.001
HAA (°)	−8.2 ± 3.7	1.7 ± 3.9	< 0.001

TNC, talonavicular coverage angle; MCAA, first metatarso-cuneiform articular angle; NCAA, naviculo-cuneiform articular angle; Meary, lateral talo-1st metatarsal angle; CP, calcaneal pitch angle; HMA, hindfoot moment arm; HAA, hindfoot alignment angle.

[*] The values are given as the mean and standard deviation.

[a] The positive numbers in NCAA, MCAA, and Meary represent planus (plantar apex) arch.

[b] The negative numbers in HMA and HAA represent valgus alignment.

4. Discussion

In the current study, we examined the outcomes of flatfoot reconstruction using the DMCS technique, which was proposed to support the joints of the medial column by FHL tendon transfer to the first metatarsal base. The DMCS demonstrated a correction at all joints of the medial column and satisfactory three planar radiographic corrections without the need for arthrodesis of the joint (Fig. 6). All patients exhibited clinical improvements without a significant procedure-related complication within two-years of follow-up.

Traditionally, PTT dysfunction has been understood as the cause of flatfoot deformity in adults [4,23]. Therefore, the surgical management prioritized procedures that augment or substitute

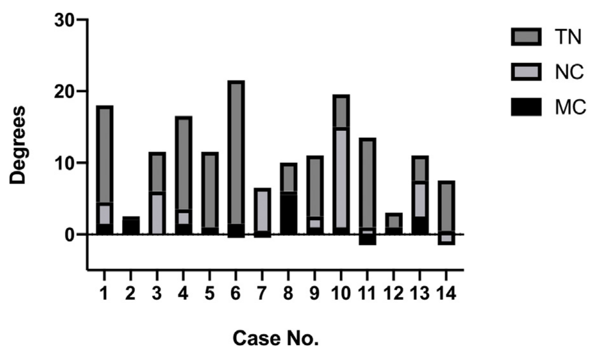

Fig. 4. The amount of correction obtained at each joint within the medial column. Overall, the largest amount of correction occurred at the talonavicular (TN) joint, followed by the naviculocuneiform (NC) joint and metatarso-cuneiform (MC) joint.

Table 3
Interobserver and Intraobserver Reliability of the Radiographic Parameters.

	Reliability (95% confidence interval)	
Measurement	Interobserver	Intraobserver
Foot anterior view		
TNC	0.88 (0.62 to 0.96)	0.98 (0.81 to 0.99)
Foot lateral view		
Meary	0.86 (0.57 to 0.96)	0.93 (0.77 to 0.98)
NCAA	0.84 (0.51 to 0.95)	0.96 (0.87 to 0.99)
MCAA	0.84 (0.47 to 0.95)	0.98 (0.92 to 0.99)
Medial cuneiform height	0.89 (0.67 to 0.96)	0.92 (0.58 to 0.98)
CP	0.92 (0.75 to 0.97)	0.98 (0.95 to 0.99)
Hindfoot alignment view		
HAA	0.86 (0.44 to 0.96)	0.96 (0.85 to 0.99)
HMA	0.84 (0.49 to 0.95)	0.97 (0.89 to 0.99)

TNC, talonavicular coverage angle; MCAA, first metatarso-cuneiform articular angle; NCAA, naviculo-cuneiform articular angle; Meary, lateral talo-1st metatarsal angle; CP, calcaneal pitch angle; HMA, hindfoot moment arm; HAA, hindfoot alignment angle.

the PTT function, most commonly FDL transfer to the navicular [5–9]. However, recent research has raised considerable uncertainty about the ability of deformity correction through FDL transfer [11–14]. Furthermore, additional procedures such as osteotomy or arthrodesis are often required to augment the medial column instability distal to the TN joint.

In many circumstances, there may be multiple apices within the medial column, and the source of medial column instability is not always readily appreciable preoperatively. The inability to correct all components of instability within the medial column may lead to secondary collapse after flatfoot correction, giving way to poor outcomes [17]. Although a medial cuneiform (Cotton) osteotomy has been reported to be effective in restoring medial longitudinal arch [24], its use in patients with instability at the MC or NC joint is limited [25]. A surgical extension of arthrodesis can be an option in the instance of multiple apices; however, this will lead to an overload of the adjacent joints and stiffen the medial column [17].

In an effort to address all deformities of the medial column joints without stiffening, we transferred the FHL tendon distal to the MC joint. As proven by the changes in the MCAA and NCAA, this produced correction at the MC and NC joint as well as TN joint and maintained correction during the follow-up period (Figs. 7 and 8).

In addition to sagittal plane correction, the DMCS demonstrated an ability to correct an axial plane deformity through the TN joint. Traditionally, forefoot abduction deformity was understood to be best addressed with lateral column lengthening (LCL) [7,26], since this offers correction through the Chopart joint with its proximity to the lever. However, due to the nature of non-anatomical lengthening, several concerns exist regarding LCL, such as stiffness, lateral column overload, and calcaneocuboid joint arthritis [27–30]. Furthermore, LCL is a sensitive procedure in which a titration of correction is mostly dependent on the surgeon's experience [26]. Therefore, we adopted MDCO in addition to DMCS to correct hindfoot valgus deformity as well as to protect the transferred FHL tendon at the medial column.

Whether the DMCS can substitute the role of the LCL is beyond the scope of this study. However, it is our belief that leaving a flexible medial column with DMCS is desirable in flatfoot correction since this will help adjustment of the foot on the ground even if the lateral column becomes stiff following LCL or subtalar arthrodesis.

FHL has demonstrated the functional ability in substituting an impaired Achilles tendon function in numerous investigations [31–35]. Besides, the FHL can provide a longer span than the FDL when it is harvested from its insertion. Therefore, we postulated that the FHL tendon transfer is a superior option to efficiently support the entire medial column when compared to the FDL. In our DMCS, the transferred FHL tendon runs from the sustentaculum tali, just beneath the TN joint, supporting the entire medial column through its insertion at the first metatarsal base. We believe it offers direct and dynamic support of the TN joint similar to the static support of the spring ligament (superomedial calcaneonavicular ligament) [36], conveying both sagittal and axial correction at the TN joint.

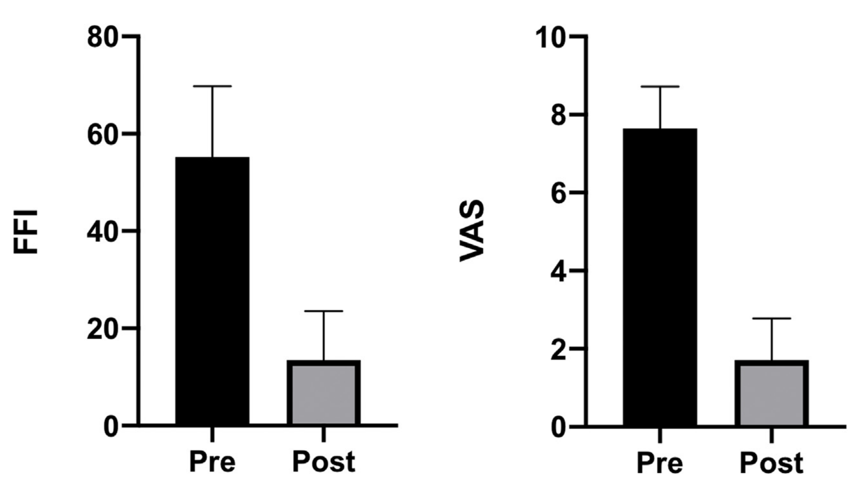

Fig. 5. Clinical outcomes before and after surgery. Both postoperative FFI and VAS revealed statistically significant improvements than preoperative ones (p-value for both FFI and VAS < 0.001). Abbreviations: FFI, foot function index; VAS, visual analogue scale.

Fig. 6. Radiographs before (A, B, and C) and after (D, E, and F) the flatfoot reconstruction with dynamic medial column stabilization (DMCS) showing three planar corrections including the axial (A and D), coronal (B and E), and sagittal plane (C and F). Note the radiographic improvement at each joint at the medial column before and after the DMCS (C and F).

Fig. 7. Pre- and postoperative radiographs of 62-year-old female (left) and 54-year-old female (right), both of which demonstrates successful three planar corrections after flatfoot reconstruction with dynamic medial column stabilization.

Harvesting the FHL may be associated with complications such as weakness of hallux plantarflexion strength or weakness of intrinsic muscles. However, we did not encounter those complications in our study cohort. This concurs with observations of previous studies that utilized the FHL for Achilles tendon diseases [32,37]. Theoretically, cock-up deformity of the big toe might occur following the harvest of the FHL at its distal insertional site. To remedy this probable complication, the initial approach included

Fig. 8. Pre- and postoperative radiographs of 50-year-old female (left) and 49-year-old female (right) demonstrate successful three planar corrections after flatfoot reconstruction with dynamic medial column stabilization.

leaving a distal tendon remnant for a potential soft tissue plication in the event of resulting cock-up deformity. However, as we have not encountered patients with this complication.

One patient from this study exhibited pain at the plantar side of the first metatarsal head, which developed upon weightbearing. We reason that too much tension on the transferred FHL may have resulted in excessive plantarflexion of the first metatarsal. After this observation, we took great care to control the tension of the construct by fixating the tendon at 10–20 degrees of ankle plantarflexion.

This study has several limitations. First, this was a retrospective study with a relatively small number of patients. However, this investigation aimed to report our technique and its preliminary outcomes with a minimum follow-up of two. Second, this study included a varying degree of preoperative deformity. Therefore, the indications for this procedure cannot be precisely clarified within the current study. Third, the concurrent procedures such as hallux valgus correction and accessory navicular excision may have affected the outcomes of the surgery. However, it is already well known that these procedures have minimal effect on arch parameters and abduction deformity of the foot. Fourth, although we examined the instability of the MC joint by measuring the MCAA with good reliability, this measurement only shows instability when there is a plantar gap and thus does not reflect the dorsal displacement of the first metatarsal relative to the cuneiform. However, we verified that instability in the form of a plantar gap or dorsal displacement was successfully corrected with this procedure (Fig. 9). Lastly, this study only reported the outcomes of DMCS with MDCO. Thus, the outcomes in combination with LCL or subtalar arthrodesis in more severe presenting deformities ought to be investigated, representing the hypothesis of our subsequent study.

In conclusion, this study reviewed and examined the outcomes of our DMCS technique in treating flatfoot deformity in adults. The DMCS offered satisfactory radiographic correction of the entire medial column joints without the need for arthrodesis; however, the long-term effect of permanent loss in the FHL function needs to be carefully observed. Furthermore, we recorded satisfactory patient-reported outcomes after a minimum follow-up of two years. We conclude that this technique represents a viable surgical option for patients with medial column instability with multiple apices.

Fig. 9. Radiographs are showing the correction at the metatarsocuneiform joints. Either form of the instability, plantar gapping (A, asterisk), or dorsal displacement (C, arrowheads) corrected after the dynamic medial column stabilization (C and D).

Conflict of interest

Authors here have nothing to disclose. No one of the authors has got any financial support from the outside parties with regard to this subject.

Acknowledgement

We thank Jesse Seilern (Medical university of Vienna, Austria) and Oliver Hansen (Hospital for Special Surgery, New York) for his thoughtful review of the manuscript, Min Jung Park & So Yoon Lee for the illustration.

References

[1] Deland JT. Adult-acquired flatfoot deformity. J Am Acad Orthop Surg 2008;16:399–406.
[2] Mosier-Laclair S, Pomeroy G, Manoli A. Operative treatment of the difficult stage 2 adult acquired flatfoot deformity. Foot Ankle Clin 2001;6:95–119.
[3] Hiller L, Pinney SJ. Surgical treatment of acquired flatfoot deformity: what is the state of practice among academic foot and ankle surgeons in 2002? Foot Ankle Int 2003;24:701–5.
[4] Johnson KA, Strom DE. Tibialis posterior tendon dysfunction. Clin Orthop Relat Res 1989;196–206.
[5] Chadwick C, Whitehouse S, Saxby T. Long-term follow-up of flexor digitorum longus transfer and calcaneal osteotomy for stage II posterior tibial tendon dysfunction. Bone Joint J 2015;97:346–52.
[6] Wacker J, Hennessy M, Saxby T. Calcaneal osteotomy and transfer of the tendon of flexor digitorum longus for stage-II dysfunction of tibialis posterior: three- to five-year results. J Bone Joint Surg Br 2002;84:54–8.
[7] Chan JY, Greenfield ST, Soukup DS, Do HT, Deland JT, Ellis SJ. Contribution of lateral column lengthening to correction of forefoot abduction in stage IIb adult acquired flatfoot deformity reconstruction. Foot Ankle Int 2015;36:1400–11.
[8] Conti MS, Jones MT, Savenkov O, Deland JT, Ellis SJ. Outcomes of reconstruction of the stage II adult-acquired flatfoot deformity in older patients. Foot Ankle Int 2018;39:1019–27.
[9] Myerson MS, Corrigan J. Treatment of posterior tibial tendon dysfunction with flexor digitorum longus tendon transfer and calcaneal osteotomy. Orthopedics 1996;19:383–8.
[10] Day J, Kim J, Conti MS, Williams N, Deland JT, Ellis SJ. Outcomes of idiopathic flexible flatfoot deformity reconstruction in the young patient. Foot Ankle Orthop 2020;5:2473011420937985.
[11] Spratley EM, Arnold JM, Owen JR, Glezos CD, Adelaar RS, Wayne JS. Plantar forces in flexor hallucis longus versus flexor digitorum longus transfer in adult acquired flatfoot deformity. Foot Ankle Int 2013;34:1286–93.
[12] Vaudreuil NJ, Ledoux WR, Roush GC, Whittaker EC, Sangeorzan BJ. Comparison of transfer sites for flexor digitorum longus in a cadaveric adult acquired flatfoot model. J Orthop Res 2014;32:102–9.
[13] Arangio GA, Salathe EP. A biomechanical analysis of posterior tibial tendon dysfunction, medial displacement calcaneal osteotomy and flexor digitorum longus transfer in adult acquired flat foot. Clin Biomech 2009;24:385–90.
[14] Hui H-e J, Beals TC, Brown NA. Influence of tendon transfer site on moment arms of the flexor digitorum longus muscle. Foot Ankle Int 2007;28:441–7.
[15] Day J, Conti MS, Williams N, Ellis SJ, Deland JT, Cody EA. Contribution of first-tarsometatarsal joint fusion to deformity correction in the treatment of adult-acquired flatfoot deformity. Foot Ankle Orthop 2020;5:2473011420927321.
[16] Johnson JE, Sangeorzan BJ, de Cesar Netto C, Deland JT, Ellis SJ, Hintermann B, et al. Consensus on indications for medial cuneiform opening wedge (Cotton) osteotomy in the treatment of progressive collapsing foot deformity. Foot Ankle Int 2020 1071100720950739.
[17] Kadakia AR, Kelikian AS, Barbosa M, Patel MS. Did failure occur because of medial column instability that was not recognized, or did it develop after surgery? Foot Ankle Clin 2017;22:545–62.
[18] Lamm BM, Stasko PA, Gesheff MG, Bhave A. Normal foot and ankle radiographic angles, measurements, and reference points. J Foot Ankle Surg 2016;55:991–8.
[19] McCormick JJ, Johnson JE. Medial column procedures in the correction of adult acquired flatfoot deformity. Foot Ankle Clin 2012;17:283–98.
[20] Perry MD, Mont MA, Einhorn TA, Waller JD. The validity of measurements made on standard foot orthoroentgenograms. Foot Ankle 1992;13:502–7.
[21] Saltzman CL, El-Khoury GY. The hindfoot alignment view. Foot Ankle Int 1995;16:572–6.
[22] SooHoo NF, Samimi DB, Vyas RM, Botzler T. Evaluation of the validity of the Foot Function Index in measuring outcomes in patients with foot and ankle disorders. Foot Ankle Int 2006;27:38–42.
[23] Stein BE, Schon LC. Posterior tibial tendon dysfunction in the adult: current concepts. Instr Course Lect 2015;64:441–50.
[24] Aiyer A, Dall GF, Shub J, Myerson MS. Radiographic correction following reconstruction of adult acquired flat foot deformity using the cotton medial cuneiform osteotomy. Foot Ankle Int 2016;37:508–13.
[25] Tankson CJ. The Cotton osteotomy: indications and techniques. Foot Ankle Clin 2007;12:309–15.
[26] Thordarson D, Schon LC, de Cesar Netto C, Deland JT, Ellis SJ, Johnson JE, et al. Consensus for the indication of lateral column lengthening in the treatment of progressive collapsing foot deformity. Foot Ankle Int 2020 1071100720950732.
[27] Cooper PS, Nowak MD, Shaer J. Calcaneocuboid joint pressures with lateral column lengthening (Evans) procedure. Foot Ankle Int 1997;18:199–205.
[28] Ellis SJ, Joseph CY, Johnson AH, Elliott A, O'Malley M, Deland J. Plantar pressures in patients with and without lateral foot pain after lateral column lengthening. JBJS 2010;92:81–91.
[29] Ellis SJ, Williams BR, Garg R, Campbell G, Pavlov H, Deland JT. Incidence of plantar lateral foot pain before and after the use of trial metal wedges in lateral column lengthening. Foot Ankle Int 2011;32:665–73.
[30] Oh I, Imhauser C, Choi D, Williams B, Ellis S, Deland J. Sensitivity of plantar pressure and talonavicular alignment to lateral column lengthening in flatfoot reconstruction. J Bone Joint Surg Am 2013;95:1094.
[31] Tashjian RZ, Hur J, Sullivan RJ, Campbell JT, DiGiovanni CW. Flexor hallucis longus transfer for repair of chronic Achilles tendinopathy. Foot Ankle Int 2003;24:673–6.
[32] Den Hartog BD. Flexor hallucis longus transfer for chronic Achilles tendonosis. Foot Ankle Int 2003;24:233–7.
[33] Wegrzyn J, Luciani J-F, Philippot R, Brunet-Guedj E, Moyen B, Besse J-L. Chronic Achilles tendon rupture reconstruction using a modified flexor hallucis longus transfer. Int Orthop 2010;34:1187–92.
[34] Schmidtberg B, Johnson JD, Kia C, Baldino JB, Obopilwe E, Cote MP, et al. Flexor hallucis longus transfer improves achilles tendon load to failure in surgery for non-insertional tendinopathy: a biomechanical study. JBJS 2019;101:1505–12.
[35] Wapner KL, Pavlock GS, Hecht PJ, Naselli F, Walther R. Repair of chronic Achilles tendon rupture with flexor hallucis longus tendon transfer. Foot Ankle 1993;14:443–9.
[36] Taniguchi A, Tanaka Y, Takakura Y, Kadono K, Maeda M, Yamamoto H. Anatomy of the spring ligament. JBJS 2003;85:2174–8.
[37] Coull R, Flavin R, Stephens MM. Flexor hallucis longus tendon transfer: evaluation of postoperative morbidity. Foot Ankle Int 2003;24:931–4.