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Subtalar joint kinematics and arthroscopy: insight in the subtalar joint range of motion and aspects of subtalar joint arthroscopy

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Publication date
2012

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Citation for published version (APA):

Beimers, L. (2012). *Subtalar joint kinematics and arthroscopy: insight in the subtalar joint range of motion and aspects of subtalar joint arthroscopy*. [Thesis, fully internal, Universiteit van Amsterdam].

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CHAPTER 4

Computed tomography-based measurements on the range of motion of the talocrural and subtalar joints in two lateral column lengthening procedures

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Foot and Ankle International, In Press

ABSTRACT

Background Lateral column lengthening (LCL) has become an accepted procedure for the operative treatment of the flexible flatfoot deformity. Hindfoot arthrodesis via a calcaneocuboid distraction arthrodesis (CCDA) has been considered a less favourable surgical option than the anterior open wedge calcaneal distraction osteotomy (ACDO), as CCDA has been associated with reduced hindfoot joint motion postoperatively. The talocrural and subtalar joint ranges of motion were measured in patients who underwent an ACDO or CCDA procedure for flatfoot deformity.

Methods CT scanning was performed with the foot in extreme positions in five ACDO and five CCDA patients. A bone segmentation and registration technique for the tibia, talus and calcaneus was applied to the CT images. Finite helical axis (FHA) rotations representing the range of motion of the joints were calculated for the motion between opposite extreme foot positions of the tibia and the calcaneus relative to the talus.

Results The maximum mean FHA rotation of the talocrural joint (for extreme dorsiflexion to extreme plantarflexion) after ACDO was $52.2^\circ \pm 12.4^\circ$ and after CCDA $49.0^\circ \pm 12.0^\circ$. Subtalar joint maximum mean FHA rotation (for extreme eversion to extreme inversion) following ACDO was $22.8^\circ \pm 8.6^\circ$, and following CCDA $24.4^\circ \pm 7.6^\circ$.

Conclusion An accurate CT-based technique was used to assess the range of motion of the talocrural and subtalar joints following two lateral column lengthening procedures for flatfoot deformity. Comparable results with a considerable amount of variance were found for the range of motion of the ACDO and CCDA procedures.

INTRODUCTION

Acquired degenerative flatfoot deformity is a problem frequently seen in adults and may lead to a painful foot with progressive planovalgus deformity. The most common cause for the unilateral adult acquired flatfoot is incompetence of the posterior tibial tendon (PTT) and the supporting medial ligaments.⁴ Intermediate (stage two) incompetence of the PTT is described as the loss of normal alignment of the foot but with the associated flatfoot deformity remaining flexible.^{6,10} Surgical treatment for the stage two PTT insufficiency usually includes a flexor digitorum longus (FDL) tendon transfer in combination with a bony procedure to realign and stabilize the hindfoot passively. Current bony procedures include the lateral column lengthening procedure, the medial displacement calcaneal osteotomy, or a double osteotomy technique. The rationale for the lateral column lengthening procedure is to restore the medial longitudinal arch by realigning the foot around the talus, thereby correcting the hindfoot valgus and neutralizing the forefoot abduction.^{4,9} Evans described an anterolateral open wedge calcaneal distraction osteotomy (ACDO) just proximal to the calcaneocuboid joint for lateral column lengthening.³ Another surgical option for lateral column lengthening is a calcaneocuboid joint distraction arthrodesis (CCDA). Both techniques showed significant improvement in the postoperative radiographic parameters of the foot and AOFAS clinical scores.^{5,7,11-16,18,19} Following CCDA for flexible flatfoot deformity, one might expect a decreased tarsal and thus decreased subtalar joint range of motion. This could possibly lead to a symptomatic hindfoot. Therefore, surgeons might prefer the ACDO over the CCDA, as the ACDO procedure preserves calcaneocuboid joint motion resulting, theoretically, in better hindfoot function. On the other hand, there might be an effect on the subtalar joint range of motion with the ACDO procedure as the anteroposterior length of the calcaneus is increased and thereby the length and/or the function at the calcaneal facets of the subtalar joint is disturbed. The effect of the two different LCL procedures on the talocrural and subtalar joint ranges of motion in-vivo was not previously described. The purpose of this study was to describe the range of motion of the talocrural and subtalar joints of patients who underwent the anterior calcaneal distraction osteotomy (ACDO) or the calcaneocuboid distraction arthrodesis (CCDA) for the operative treatment of flexible adult acquired flatfoot. An accurate computed tomography-based bone registration technique was used for this purpose.

METHODS

The study was approved by our Medical Ethical Committee. Patients with a flexible adult acquired flatfoot that had been treated surgically by a lateral column lengthening procedure

were selected at random from the hospital database (Table 1). These patients received a study information package by mail. Ten patients (nine female, one male) agreed to participate and signed informed consent prior to participation. The first group consisted of five patients that had been treated with a calcaneocuboid distraction arthrodesis (CCDA) for symptomatic flexible adult acquired flatfoot deformity. The second group consisted of five patients that had been treated with an anterior open wedge calcaneal distraction osteotomy (ACDO) for flatfoot deformity. The two groups were operated on serially in time, i.e. the CCDA group was operated in the early phase and the ACDO patients were operated on more recently. All surgery was performed by the same foot and ankle surgeon (JWKL). Pre-operatively, patients complained of pain in the medial and/or lateral hindfoot. The patients were able to walk approximately 15 to 30 minutes. On pre-operative physical examination, patients exhibited a subluxation of the forefoot in relation to the hindfoot (peritalar dorsolateral subluxation), resulting in increased hindfoot valgus. Typically, the patients were not able to perform the single heel rise test on the symptomatic foot due to insufficiency or pain of the PTT. In all cases, complete manual correction of the hindfoot valgus deformity and peritalar dorsolateral subluxation was easily possible, thus assuring that the patient had a flexible flatfoot deformity.

Surgical technique

In the anterior calcaneal open wedge distraction osteotomy (ACDO), a lateral skin incision was made to expose the lateral calcaneus and the anterior calcaneal process. Following identification of the calcaneocuboid joint, the calcaneocuboid joint was temporary fixated using a single K-wire. The calcaneal open wedge osteotomy was made at approximately 20 mm posterior from the calcaneocuboid joint line. The anterior calcaneal osteotomy cut was made perpendicular to the long calcaneal axis. Care should be taken to leave the medial cortex of the calcaneus intact to act as a semi-rigid hinge. Using a laminar spreader, the anterior calcaneal osteotomy was opened up. For distraction, an autogenous tricortical bone graft of approximately 10 mm originating from the os ilium was used. The osteotomy was usually fixated with an X-plate and screws bridging the graft (Figure 1A and 1B). The calcaneocuboid distraction arthrodesis (CCDA) was performed through an identical lateral skin incision centered a little more distally over the calcaneocuboid joint. Following identification of the calcaneocuboid joint, all cartilage was removed. For calcaneocuboid distraction, an autogenous tricortical bone graft of approximately 10 mm originating from the os ilium was placed between the calcaneus and cuboid. The distraction arthrodesis was fixated using a H-

shaped plate and screws (Figure 2A and 2B). In both LCL procedures, an additional augmentation of the PTT was performed in the same operating session. For augmentation of the PTT, the insertion of the PTT to the navicular tuberosity was identified. The abductor hallucis muscle was reflected in a plantarward direction with release of the flexor hallucis brevis muscle, exposing the plantar aspect of the foot. The FDL was retrieved, working from proximal to distal as this is considered to be more safe with regard to damaging the medial plantar nerve. At the level of Henry's knot, the FHL and the FDL were sutured together. Then the FDL tendon was released proximally. The talonavicular joint was identified together with the spring ligament. In three patients, repair of the medial capsulo-ligamentous structures was performed at this stage. The PTT was excised in case of severe involvement and loss of function. A 6.0 mm drill hole was made through the navicular bone for passage of the FDL tendon. The FDL tendon was pulled through the drill hole from plantar to dorsal and was firmly sutured on to itself and the periosteum of the navicular bone on the dorsal side. An additional lengthening of the Achilles tendon is most often necessary (Table 1). In that case, a percutaneous technique was used for Achilles tendon lengthening. The postoperative treatment and rehabilitation protocol was the same for both LCL procedures. A non-weightbearing lower leg cast was provided for four weeks followed by a weightbearing lower leg cast for another four weeks. With radiographs showing signs of bony consolidation at eight weeks postoperatively, patients were allowed full weightbearing without a cast. Support at this stage was provided by use of a walker brace.

Measuring the range of motion

For accurate assessment of talocrural and subtalar joint ranges of motion in-vivo following the lateral column lengthening procedure, a validated CT-based bone contour registration technique was used.^{1,17} In summary, the patients were positioned supine on the CT scanner table with the lower leg fixed on to a supporting platform and the foot fixated to a radiolucent footplate. For computer segmentation of the tibia, talus and calcaneus, the first series of CT images with normal radiation dose (150 mAs) was made with the foot in the neutral position relative to the lower leg. Subsequently, low radiation dose CT scans (26 mAs) were acquired with the foot in eight extreme positions using a cranially directed force applied to the footplate at eight different points. The external load (i.e. sand bags) was applied to the footplate through a system of a single pulling wire and pulleys to force the foot in the extreme position (Figure 3). The maximum external load that was applied was the maximum load that was tolerated by the patient. The eight extreme foot positions resulting from the load applied

to the footplate were: dorsiflexion, combined eversion-dorsiflexion, eversion, combined eversion-plantarflexion, plantarflexion, combined inversion-plantarflexion, inversion, combined inversion-dorsiflexion. CT scanning was performed starting from dorsiflexion (assigned position one) and continued in a clockwise order to end with position eight for the right foot. In case of a left foot, CT scanning was performed in each of the eight extreme foot positions starting from dorsiflexion (assigned position one) and continued in a counterclockwise order (position eight, position seven, etc). Semi-automated computer bone segmentation and automatic registration of the distal tibia, talus and calcaneus in the CT image sets was performed.¹

Description of joint kinematics

The range of motion in the talocrural and subtalar joints was defined as the motion between two extreme positions. For each subject, ranges of motion were calculated of the tibia and calcaneus relative to the fixed talus from extreme dorsiflexion (DF) to extreme plantarflexion (PF), from extreme eversion (EV) to extreme inversion (IN), from extreme eversion-dorsiflexion (EVDF) to extreme inversion-plantarflexion (INPF), and from extreme eversion-plantarflexion (EVPF) to extreme inversion-dorsiflexion (INDF). For quantitative analysis, the range of motion of the talocrural and subtalar joints were expressed by a finite helical axis (FHA) with a rotation about this helical axis (θ) and a translation along this axis (t).²⁰ The FHA's were represented in a right hand rule XYZ-coordinate system that coincided with the geometric principal axes of the talus.¹ The origin of the coordinate system was the geometric centroid of the talus. Each FHA rotation was decomposed into three rotation components relative to the coordinate axes of the talus by using the attitude vector.²⁰ The rotation components facilitate the clinical interpretation of the range of motion of the talocrural and subtalar joints.¹⁷ The three rotation components are plantarflexion-dorsiflexion, inversion-eversion, and internal rotation-external rotation. No statistical analyses were performed for comparison of the outcome between the two patient groups.

RESULTS

The mean age at surgery was 59 years in the ACDO patients and 54 years in the CCDA patients. Follow-up ranged from six months to more than nine years (mean four years and six months) (Table 1). In the ACDO group the mean follow-up was 29 months, in the CCDA group the mean follow-up was 79 months. All osteotomies and arthrodeses had fused and no early complications had occurred. The postoperative pain at the lateral fourth and fifth

tarsometatarsal joints was noted as a late complication of these lengthening procedures. At time of follow-up, the mean AOFAS score for the ACDO patients was 85 points (SD 14) and 76 points (SD 23) for the CCDA patients. The patients rated their own overall result of operative treatment as Excellent in two cases, Good in seven cases and Poor in one case. In all patients, the ACDO or CCDA procedure was combined with augmentation of the PTT using the flexor digitorum longus (FDL) tendon (Table 1). In case of a fixed pes equinus deformity after the ACDO or CCDA procedure, an additional percutaneous Achilles tendon lengthening was performed in seven patients. In two ACDO patients an additional first tarsometatarsal joint arthrodesis was performed to stabilize and correct the flattened medial arch of the foot. In two other ACDO patients an additional proximal first metatarsal osteotomy combined with a distal soft tissue procedure was performed to correct hallux valgus deformity. In three patients (in one ACDO and two CCDA patients), a secondary resection arthroplasty of the fourth and fifth tarsometatarsal joints was performed for treatment of persistent pain at these two joints in a later stage.

Helical axis range of motion

The mean finite helical axis (FHA) rotation θ was 52.5° (SD 12.4°) for the talocrural range of motion from extreme dorsiflexion to extreme plantarflexion in the ACDO patients, the mean FHA rotation θ was 49.0° (SD 12.0°) for talocrural range of motion in the CCDA patients (Table 2). If dorsiflexion and plantarflexion was combined with inversion or eversion of the foot, the FHA range of motion was smaller. For the subtalar joint, in both groups the mean FHA rotation θ was calculated for extreme eversion to extreme inversion of the foot. The maximum mean FHA rotation θ for the subtalar joint was 22.8° (SD 8.6°) in ACDO patients, and 24.4° (SD 7.6°) in CCDA patients respectively (Table 2). If eversion and inversion was combined with dorsi- or plantarflexion of the foot, then the FHA range of motion was smaller. FHA translations were small and variable for talocrural and subtalar range of motions with means ranging from 0.0 to 2.2 mm in the two groups (Table 2).

Rotation components of the range of motion

For extreme dorsiflexion to extreme plantarflexion of the foot, the motion in the talocrural joint is a combination of plantar flexion, inversion and some internal rotation if dissolved about the principal axes of the talus (Figure 4A). These talocrural joint motions can be considered as coupled motions. For foot dorsiflexion to plantar flexion, there is very little

motion in the subtalar joint. For joint motion from extreme eversion to extreme inversion, there is a comparable amount of inversion and internal rotation of the subtalar joint for the ACDO and CCDA patients (Figure 4B). For joint motion from extreme eversion-plantarflexion to extreme inversion-dorsiflexion and for extreme eversion-dorsiflexion to extreme inversion-plantarflexion, the three rotation components for the talocrural and subtalar joints were also comparable between the two groups (Figure 4C and 4D). Notice that with considerable inversion-eversion in the subtalar joint, there is also a substantial amount of internal-external rotation within the joint (Figure 4B, 4C and 4D).

DISCUSSION

An accurate CT-based technique was used to evaluate the in-vivo range of motion of the talocrural and subtalar joints in patients who were treated with a lateral column lengthening procedure and PTT augmentation for flexible adult acquired flatfoot deformity. In this study, comparable results were found in the ACDO and CCDA patient groups for the talocrural and subtalar joint range of motion. It must be emphasized that there was considerable variation in outcome between the patients within each group. In addition, the patient groups only consisted of 5 eligible patients each as these are low volume procedures. Furthermore, as the ACDO procedure is more commonly carried out nowadays, the CCDA group would hardly increase in size over time and the difference in follow-up periods would also increase. Therefore, with the small number of patients in both groups for the above mentioned reasons no statistical analyses were performed and no statistically supported conclusions could be drawn from this study. All patients in the current study were operated by the same surgeon. The reason that the two surgical techniques were used by the one surgeon is explained as follows. In the past, patients with acquired flatfoot deformity that did not respond to conservative treatment were advised correction through a calcaneocuboid distraction arthrodesis with percutaneous lengthening of the Achilles tendon and medial soft tissue augmentation. The results of this technique reported in 2006 by Krans et al. were discussed as having a less favourable outcome than after a lengthening procedure through a distraction osteotomy of the anterior calcaneus as reported by Hintermann et al. earlier.^{5,7} Based on these reports, from then onwards patients were operated with lengthening of the lateral column using an anterior calcaneal distraction osteotomy (ACDO). This was combined with the same medial soft tissue procedures and if necessary, other additional procedures. There are some limitations to this study. Using the two surgical techniques in different time periods also implies that the follow-up times are different. For the CCDA patients the mean follow-up time

was larger than for the ACDO patients; 79 and 29 months respectively. Although there was a 50 month difference in follow up between the two groups, the early CCDA patients did not do worse compared to the ACDO patients in terms of talocrural and subtalar joint range of motion. Moreover, as clinical results might deteriorate over time for several reasons, there also was no difference in AOFAS scores between the two groups. Therefore, it can not be stated that the difference in follow up time between the two groups automatically resulted in worse results for the group of patients that were operated first (i.e. the CCDA patients). Another limitation is that preoperative measurements of the talocrural and subtalar joint range of motion were not available for comparison.

The talocrural and subtalar joint range of motion were reported earlier for a group of 20 non-matched normal subjects (mean age 26.3 years, range 22 to 35 years) using the same CT scanning technique and research protocol.¹ The talocrural joint range of motion (extreme dorsiflexion to extreme plantarflexion) following the CCDA procedure in the five patients (49.0 ± 12.0 degrees) was smaller compared to the normal subjects (63.3 ± 11.0 degrees). Subtalar joint range of motion (extreme eversion to extreme inversion) was smaller following both LCL procedures (ACDO 22.8 ± 8.6 degrees; CCDA 24.4 ± 7.6 degrees) as compared to the normal subjects (37.3 ± 5.9 degrees). It should however be kept in mind that extreme foot positions that result in end positions of the joint (extreme dorsiflexion, extreme plantarflexion, extreme eversion, etc) may not be required for normal function in activities of daily living. In addition to that, ankle and hindfoot surgery might reduce the range of motion of the joints. However, this reduction might not be of importance for a normal function of the ankle and foot of the individual subject that has been operated on. Lundgren et al. studied hind-, mid- and forefoot joint motion in volunteers during walking on a flat surface using invasive bone markers.⁸ From the data of the in-vivo measurements during walking in the five volunteers by Lundgren et al., helical axis rotations could be calculated by conversion of the sagittal, frontal and transverse plane rotations. For the talocrural joint during walking, the mean helical axis rotation was 18.7 degrees (± 3.5 degrees). The mean helical axis rotation for the subtalar joint was 13.9 degrees (± 2.0 degrees). In the present study, the postoperative individual helical axis rotations for the talocrural and subtalar joint range of motion were larger than the results for normal walking from the study by Lundgren et al.⁸ Measuring the total range of subtalar joint motion (rotations about the helical axis for subtalar joint motion from maximum eversion to maximum inversion) in ten cadaveric specimens, DeLand et al. found an average of 30% loss of subtalar joint range of motion following isolated calcaneocuboid arthrodesis

with a 10 mm lengthening fusion.² In our patients, the mean subtalar range of joint motion was 61% (22.8/37.3 degrees) for the ACDO patients, and 65% (24.4/37.3 degrees) for the CCDA patients of the mean range of subtalar joint motion as measured in the group of 20 normal subjects.¹ Although DeLand et al. used cadaveric specimens, the results from the present in-vivo study seem to resemble their results.

In summary, an accurate CT-based technique was used to assess the range of motion in the talocrural and subtalar joints in patients who underwent a calcaneocuboid distraction arthrodesis (CCDA) or an anterior open wedge calcaneal osteotomy (ACDO) procedure for flexible adult flatfoot deformity. Although a substantial variance was noted in both patient groups, the procedures yielded comparable outcomes with regard to the range of motion of the talocrural and subtalar joint. Further in-vivo studies should be conducted to assess the actual reduction of the talocrural and subtalar joint ranges of motion following specific surgical procedures.

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TABLES

Table 1
Patient demographics.

Patient	Sex	Side	Age at Surgery	Procedure	Plate Fixation (Removal)	PTT Augmentation	Additional Procedures	Late Procedures	Follow-up (months)
1	Female	Right	29	CCDA	Yes (Yes)	FDL Tendon	None		110
2	Female	Left	60	CCDA	Yes (Yes)	FDL Tendon	Achilles Tendon Lengthening		104
3	Female	Right	66	CCDA	Yes (Yes)	FDL Tendon	Achilles Tendon Lengthening		74
4	Female	Left	55	CCDA	Yes (Yes)	FDL Tendon	Achilles Tendon Lengthening	Resection Arthroplasty TMT-4 and TMT-5	16
5	Female	Left	59	CCDA	Yes (Yes)	FDL Tendon	Achilles Tendon Lengthening	Resection Arthroplasty TMT-4 and TMT-5	90
6	Female	Right	51	ACDO	No	FDL Tendon	Achilles Tendon Lengthening, TMT-1 Arthrodesis		55
7	Female	Right	63	ACDO	No	FDL Tendon	Proximal MT-1 Osteotomy, DSTP, Achilles Tendon Lengthening		53
8	Female	Right	63	ACDO	Yes (No)	FDL Tendon	TMT-1 Arthrodesis		6
9	Female	Right	55	ACDO	Yes (No)	FDL Tendon	Proximal MT-1 Osteotomy, DSTP	Resection Arthroplasty TMT-4 and TMT-5	19
10	Male	Left	63	ACDO	Yes (No)	FDL Tendon	Triceps Tenotomy		11

CCDA=Calcaneocuboid Distraction Arthrodesis, ACDO=Anterior Calcaneal Distraction Osteotomy, FDL=Flexor Digitorum Longus, DSTP= Distal Soft Tissue Procedure, MT=Metatarsal, TMT=Transmetatarsal

Table 2
Finite helical axis (FHA) rotation and translation values for the talocrural and subtalar joint ranges of motion between the extreme foot positions for the anterior calcaneal distraction osteotomy (ACDO) and the calcaneocuboid distraction arthrodesis (CCDA) patients.

Direction of joint movement	FHA rotation θ ($^{\circ}$)				FHA translation t (mm)					
	ACDO		CCDA		ACDO		CCDA			
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.		
Extreme dorsiflexion to extreme plantarflexion	Talocrural joint		52,2	12,4	49,0	12,0	1,4	0,6	0,5	0,6
	Subtalar joint		8,6	6,4	4,7	2,4	-0,6	0,8	0,1	1,2
Extreme eversion-dorsiflexion to extreme inversion-plantarflexion	Talocrural joint		47,3	12,0	44,9	11,6	1,3	0,1	0,7	0,6
	Subtalar joint		15,7	4,4	18,1	5,5	-0,3	0,5	-0,4	0,8
Extreme eversion to extreme inversion	Talocrural joint		18,2	9,6	16,5	7,9	0,0	1,0	0,5	1,2
	Subtalar joint		22,8	8,6	24,4	7,6	0,5	0,7	0,4	0,4
Extreme eversion-plantarflexion to extreme inversion-dorsiflexion	Talocrural joint		44,4	11,2	36,0	8,3	-0,1	0,6	-0,2	0,4
	Subtalar joint		17,2	8,5	20,0	10,0	2,2	0,9	1,3	0,6

S.D. = standard deviation

FIGURES



Figure 1 A Preoperative lateral weightbearing radiograph of the foot showing the pes planus deformity in a patient with flexible acquired flatfoot deformity.



Figure 1 B Postoperative lateral weightbearing radiograph showing correction of the flatfoot deformity through an anterior calcaneal osteotomy using a screw for fixation. In addition, a first tarsometatarsal joint arthrodesis was performed. The medial arch of the foot is restored postoperatively as shown by the increased navicular to ground distance.



Figure 2 A Preoperative lateral weightbearing radiograph of the foot showing the pes planus deformity in a patient with flexible acquired flatfoot deformity.



Figure 2 B Postoperative lateral weightbearing radiograph showing correction of the flatfoot deformity through a calcaneocuboid distraction arthrodesis with the use of an X-plate and screws for fixation of the arthrodesis. The medial arch of the foot is restored postoperatively as shown by the increased navicular to ground distance.



Figure 3 Patient laying on the CT scanner table with the lower leg fixed on to a supporting platform and the foot fixated to a radiolucent footplate. CT scans were acquired with the foot in eight extreme positions using a cranially directed force applied to the footplate at eight different points. Here the foot was forced in extreme dorsiflexion using an external load (i.e. sand bags) applied to the footplate through a system of a single pulling wire and pulleys.

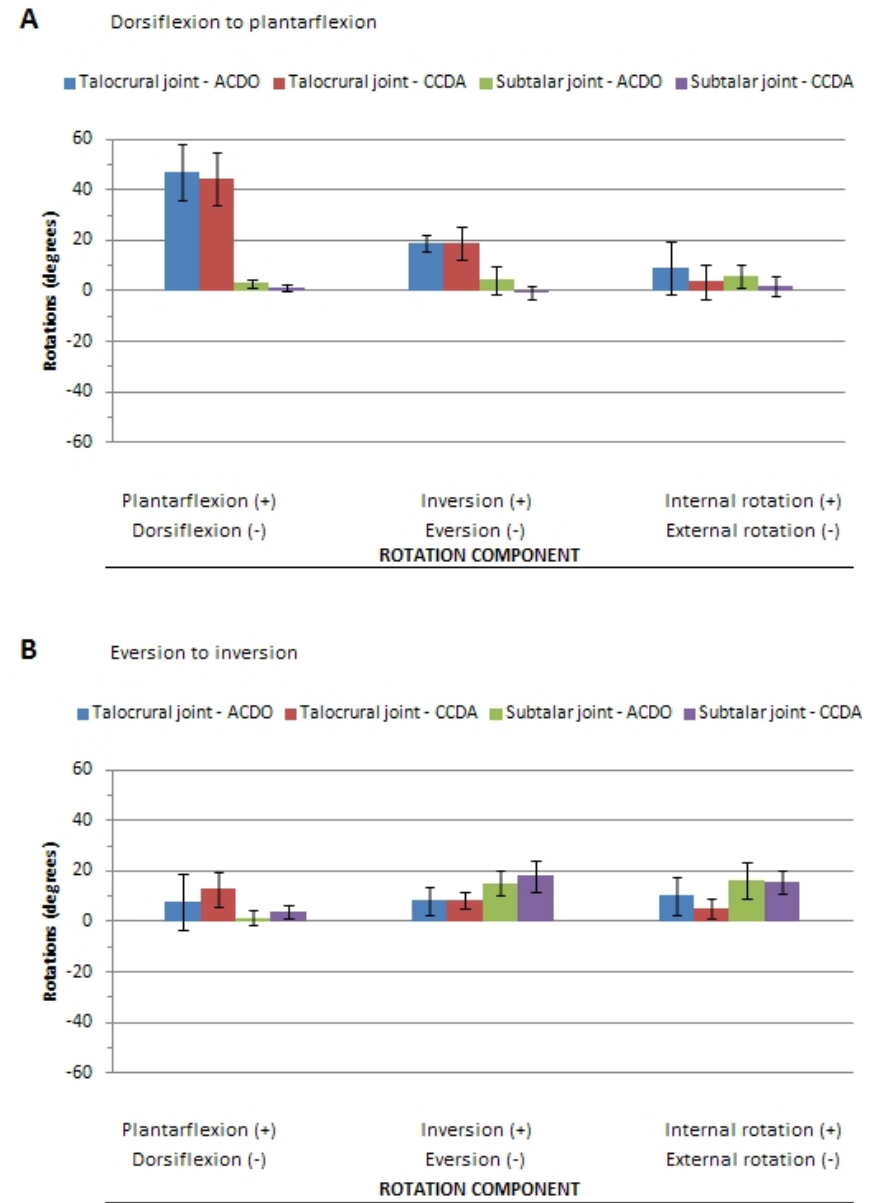


Figure 4 A - D The three rotation components for the talocrural and subtalar joint ranges of motion for the ACDO and CCDA patients. Figure 4 A shows the rotation components for ankle and subtalar joint range of motion from extreme dorsiflexion to extreme plantarflexion of the foot, figure 4 B from extreme eversion to extreme inversion.

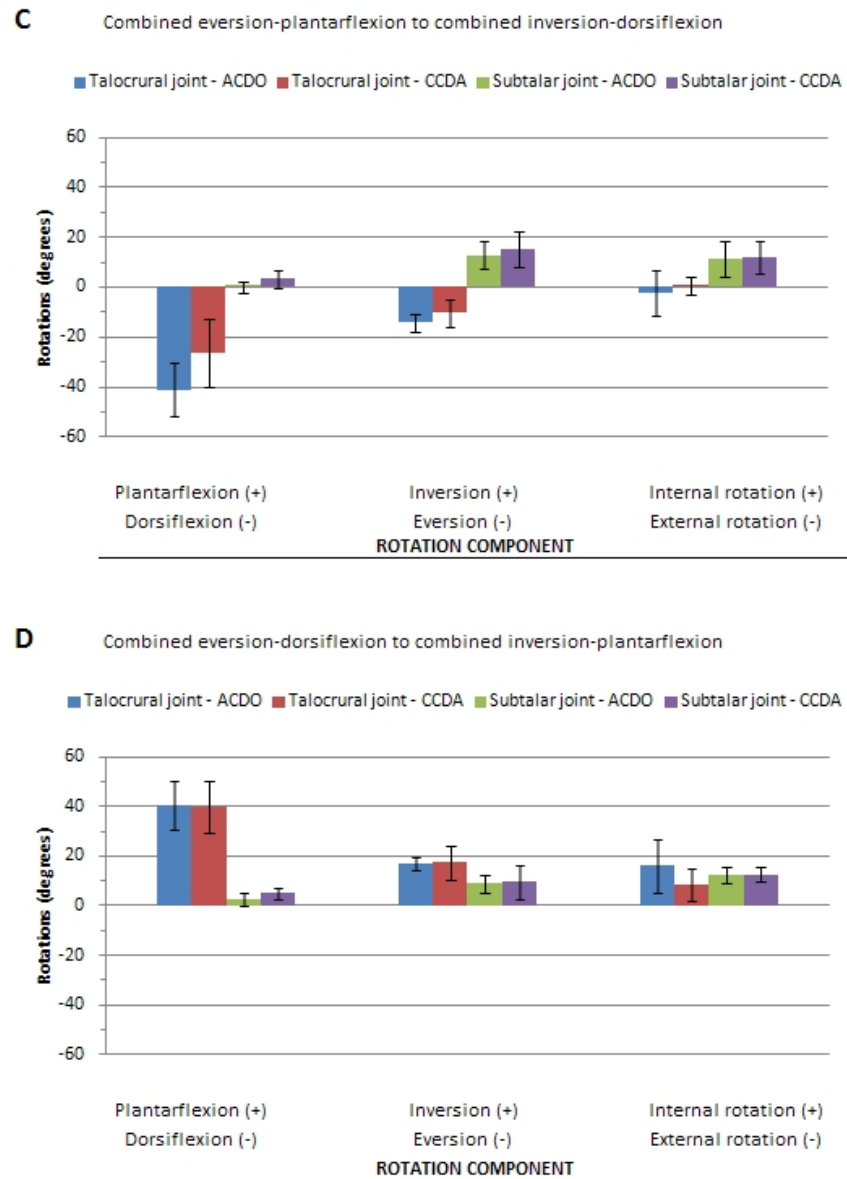


Figure 4 C shows the rotation components for ankle and subtalar joint range of motion from extreme combined eversion-plantarflexion to extreme combined inversion-dorsiflexion and figure **4 D** from extreme combined eversion-dorsiflexion to extreme combined inversion-plantarflexion.

Overview of subtalar arthrodesis techniques – options, pitfalls and solutions

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Foot and Ankle Surgery 2010;16(3):107-116

This research was co-funded by the Minimally Invasive Surgery and Interventional Techniques program, Delft University of Technology, Delft, The Netherlands. The program had no involvement in the study design, the collection, analysis and interpretation of data; in the writing of the manuscript; and in the decision to submit the manuscript for publication.