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Gait characteristics and functional outcomes during early follow-up are comparable in patients with calcaneal fractures treated by either the sinus tarsi or the extended lateral approach

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ABSTRACT

Background: To overcome the substantial functional loss after calcaneal fractures (CF), surgical treatment currently consists of two strategies, namely the commonly used extended lateral approach (ELA) and the less invasive sinus tarsi approach (STA). Despite the comparable anatomical restoration, the biomechanical and functional outcome of these strategies during early rehabilitation has not yet been investigated.
Research question: To evaluate changes in gait characteristics and functional development in patients with CF treated by either STA or ELA.
Methods: A total of 56 patients with unilateral CF were included in this retrospective study. 26 patients were treated by ELA while 30 patients underwent surgery through the STA. Functional and biomechanical measurements were performed at follow-up periods of three and six months. Foot and ankle kinetics and kinematics were extracted using instrumented gait analysis with a multi segment foot model. Physical and mental components of the Short Form 36 (SF-36) and total scoring of the AOFAS hindfoot scale were used for functional evaluation. Statistical analysis was performed using Mann Whitney and Student's t-test. Effect sizes of group differences were calculated using Cohen's d.
Results: Comparisons between ELA and STA showed no significant difference regarding the biomechanical and functional outcome. Within-group comparisons showed significant ($p < 0.05$) improvements from three to six month follow-up. Ankle joint and hindfoot kinematics showed increased mobility during walking of up to 34% and 26%, respectively. Maximum ankle joint moment also improved by up to 34% while vertical ground reaction force increased by 8%. Functional outcome only revealed significant changes in the physical component of SF-36.
Significance: ELA and STA treatments revealed comparable functional improvements in patients with unilateral intraarticular calcaneal fractures during early rehabilitation. The less invasive STA provides adequate restoration of dynamic foot function and could serve as a viable alternative to the commonly used ELA.

1. Introduction

Fractures of the calcaneus lead to severe functional impairments of dynamic foot function which often cause high morbidity, large time periods (up to three years) of working disability, and high rates of socioeconomic costs [1–3]. According to the German Social Accident Insurance, calcaneal fractures (CF) have a continuous prevalence of approximately 28% among traumatic ankle and foot injuries and are still rated as the second-most incident in foot accidents [4]. Displaced intraarticular fractures are usually treated by an early operative intervention after reduction of swelling, while conservative treatments of these fractures comprise the risk of subtalar posttraumatic osteoarthritis as well as hindfoot malalignment. The standard surgical strategy is the extended lateral approach (ELA), which uses an L-shaped incision with an open reduction and internal fixation (ORIF) by an interlocking plate [3,5]. Although great achievements have been made in the surgical treatment of CF, the functional outcome in many cases still remains unsatisfactory regarding wound complications, anatomic

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reconstruction, and dynamic foot function [5–7]. Previous gait analysis findings demonstrated walking abnormalities in patients after CF. These are present in the form of decreased foot mobility with prolonged dorsal extension during stance phase as well as reduced weight acceptance and joint moments at the affected leg. However, in most of these studies only small populations with a large time span in follow-up measurements (6–48 months) were analysed and almost no information is available regarding gait changes in the very early period after surgery [2,8–11]. The observed functional limitations after CF are thought to occur due to pain and joint stiffness but may also be explained by changes in calcaneus geometry and incongruities of the subtalar joint surface [2,12–14]. The far less invasive sinus tarsi approach (STA) was introduced in the last decade. This method uses a small incision over the subtalar joint, protecting the peroneal tendons and exposing the subtalar joint to obtain a clear view for reduction of the important joint surface of the calcaneus. The correct length and hindfoot axis of the calcaneus is restored via the “Westhues maneuver” while the reduction is controlled via intraoperative 3D scans. Cannulated screws are used for bone fixation. In comparison to the ELA, several benefits of the STA have already been proven, such as shorter surgery duration and less wound complications while presenting comparable anatomical restoration [5,10,11]. However, to what extent this treatment strategy may provide any advantage to the common ELA procedure in terms of functional outcome, and how functional outcome develops at a very early stage after surgery have not yet been investigated. Therefore, the main research objective of this study was to use instrumented gait analysis to evaluate biomechanical and functional changes in patients with intraarticular CF treated by the STA or the ELA. We hypothesise that patients treated by the less invasive STA show a superior biomechanical and functional outcome compared to patients treated by ELA. We further hypothesise that both treatment groups show biomechanical and functional improvements from the three months to the six months follow-up.

2. Methods

2.1. Study population and follow-up

Between 2012 and 2017, a total of 56 consecutive patients with unilateral intraarticular CF were retrospectively included in this prospective clinical study and divided into two subgroups depending on the surgical treatment (Fig. 1). This was the result of a 2015 shift in treatment policy at the Department of Foot and Ankle Surgery from the ELA to the less invasive STA technique. 26 patients (19 male, 7 female) underwent ORIF using ELA while 30 patients (26 male, 4 female) were treated by the STA controlled by intraoperative 3D scans. Study inclusion criteria were an age between 18 and 65 years, unilateral injury and surgically treated intraarticular CF (fracture type: joint depression or tongue type). Exclusion criteria were open CF, bilateral fractures, any diseases influencing walking ability, complex regional pain syndrome, polytrauma or other injuries of the lower extremity. Patients fulfilling the inclusion criteria were informed about the study protocol and written consent was obtained. After surgical treatment, all patients completed a standard aftercare period consisting of approximately 8–10 weeks of partial weight-bearing and subsequent rehabilitation care. Approximately three months after surgery, when full weight-bearing was regained, patients returned to the hospital for baseline evaluation of biomechanical and functional data. As most of the healing process occurs within an early postsurgical period, patients were reassessed six months after surgery [15,16]. This clinical study was conducted in accordance to the guidelines of the Declaration of Helsinki of the World Medical Association, approved by the local ethics committee (Bavarian Medical Association, Nr.11041) and registered in the German Clinical Trials Register (DRKS00003485).

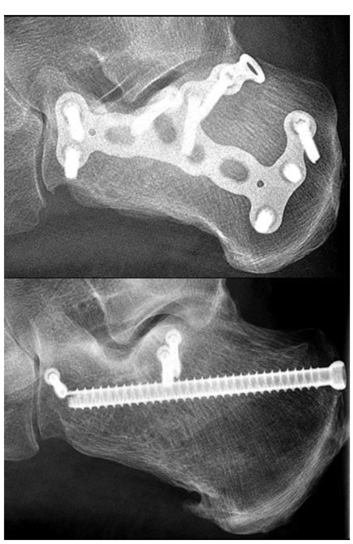

Fig. 1. Radiologic capture (lateral view) of the fractured calcaneus treated by ELA using angular- stable plate fixation (top) or STA using cannulated screw fixation (bottom).

2.2. Functional outcome

Regarding patient reported outcome measures (PROMs), the ankle-hindfoot scale of the American Orthopaedic Foot and Ankle Society (AOFAS) and the Short Form 36 questionnaire (SF-36) were utilised [17]. The AOFAS is a 100-point scale with subjective and objective components including pain, function and alignment. The SF-36 is a subjective questionnaire including several sections such as vitality, physical function, bodily pain and mental health. For this survey, the physical (PSS) and mental (MSS) summary scales were extracted and used for further analysis.

2.3. Instrumented gait analysis

To evaluate biomechanical changes and efficacy of surgical techniques an instrumented gait analysis was performed at three and six months after surgery. To measure foot and ankle kinematics and kinetics, the multi-segment Oxford Foot Model (OFM) was used [18]. Measurements were realised using an eight-infrared-camera system (Vicon MX-T20, Oxford, UK) at a sampling frequency of 200 Hz. Synchronous kinetic analysis was performed by two embedded force plates (AMTI OR6-7-2000, Watertown, USA). A total of 42 reflective markers were placed on anatomical landmarks according to the OFM marker protocol. During each measurement, patients walked over a 15 m walkway while a total of five valid gait trials (single foot contact on force plate) were averaged and processed for further evaluation. Key gait parameters of the fractured side were extracted and analysed during stance phase. To investigate dynamic mobility of the foot complex, maximum values for hindfoot dorsal extension with respect to the tibia and hindfoot eversion were analysed. For a more functional analysis of active ankle joint mobility, sagittal range of motion (ROM) of the hindfoot was analysed during push off phase. Absolute ROM for hindfoot eversion during stance phase was also investigated. Kinetic analysis of weight-bearing capacity during stance phase was evaluated by the maximum vertical ground reaction force and the maximum ankle joint moment [19,20]. Furthermore, spatial-temporal parameters such as walking speed, cadence, and step length were included in our analysis.

2.4. Statistical analysis

Data comparison of gait parameters and functional scores within and between groups was performed using SPSS version 19.0 (SPSS Inc.,

Table 1
Patient demographic data for both treatment groups presented as mean (standard deviation).

	ELA-Group (n = 26)	STA-Group (n = 30)	P value
Age (y)	49.8 (10.3)	52 (10.6)	0.39
Body mass (kg)	77.7 (13.5)	80.9 (14.6)	0.36
Height (cm)	175.4 (7.5)	176.8 (8.4)	0.54
BMI (kg/m^2)	25.2 (3.7)	25.7 (3.5)	0.49
Sanders Classification (Type II/III)	12/14	19/11	0.28
Affected side (left/right)	12/14	20/10	0.09
Operating time (min)	126 (27)	94 (24)	< **0.001**

Chicago, USA). Normal distribution of all datasets was checked by Shapiro-Wilk test. *t*-test for independent samples, Mann Whitney test and Chi-squared test were used to determine differences of variables between surgical treatment groups. Regarding within-group comparisons, t for dependent samples and Wilcoxon signed rank test were utilised. All findings were considered statistically significant at $p < .05$. To measure the magnitude of a treatment effect for significant differences between groups, the effect size was calculated using Cohen's d.

3. Results

No significant differences were found between ELA and STA for patient demographics, anthropometrics and fracture classification. Average operation time was significantly reduced by up to 30 min ($p < 0.001$, Table 1). PROMs showed comparable results between treatment groups for both the three and six month follow-up periods (Table 2). The SF-36 physical score improved significantly from month 3 to month 6 for ELA by 12% and for STA by 14%. AOFAS scores also showed an improvement for both groups without reaching statistical significance. The SF-36 mental component was similar for both groups and at both time points. Spatio-temporal parameters showed a significant change within both groups during the follow-up period. Cadence was significantly improved for both groups at six months (ELA: 109 ± 9 steps/min; STA: 103 ± 9 steps/min) compared to 3 months (ELA: 101 ± 12 steps/min; STA: 97 ± 10 steps/min). Significant changes ($p < 0.05$) in walking speed were also observed between the three (ELA: 0.94 ± 0.27 m/s; STA: 0.93 ± 0.21 m/s) and six months measurements (ELA: 1.18 ± 0.24 m/s; STA 1.09 ± 0.2 m/s). Moreover, step length was significantly increased ($p < 0.05$) after six months (ELA: 0.61 ± 0.2 m; STA: 0.65 ± 0.08 m) in both groups when compared to three months (ELA: 0.59 ± 0.11 m; STA: 0.61 ± 0.09 m). Between groups only cadence was slightly larger at six months in the ELA group compared to the STA group ($p = 0.04$, $d = 0.66$). For all other spatio-temporal parameters between group differences were smaller than $d = 0.4$ and were not significant. Results of kinetic and kinematic parameters and between-group comparisons are listed in Table 3 and Fig. 2. Ankle ROM at push off significantly increased by 30% for ELA and by 34% for STA within the follow-up period. Also, subtalar ROM increased significantly for ELA (25%) and for STA (28%). No changes over time were found for maximum hindfoot eversion and maximum ankle dorsal extension during stance phase. Between groups only subtle differences were observed. At three months, maximum ankle dorsal extension was approximately 3° (26%) larger for STA compared to ELA ($p = 0.04$, $d = 0.55$). At six months, maximum hindfoot eversion was 3° (90%) larger for STA group compared to ELA ($p = 0.02$, $d = 0.62$). For all other kinematic parameters between group differences were smaller than $d = 0.48$ and were not significant. Kinetic analyses showed an improvement in weight-bearing capacity for both groups during the follow-up period. Maximum ankle joint moment increased by about 30% and maximum vertical ground reaction forces increased by about 5% for both groups. Differences between groups were all smaller than $d = 0.5$ and were not statistically significant.

4. Discussion

The objective of this study was to evaluate early biomechanical and functional changes after surgical treatment of unilateral intraarticular calcaneus fractures. To our knowledge, this study is the first that objectively compares these changes between a soft tissue sparing sinus tarsi procedure (STA) and the more commonly used extended lateral approach (ELA). The observed improvements in functional outcome over time reflect a successful rehabilitation process for both patient groups. No clinically important differences were found between the two surgical techniques. The AOFAS outcomes in our study are in agreement with several meta-analyses which generally demonstrated a good clinical rating without any differences between STA and ELA procedures [21]. Although, these studies investigated patients with CF at significantly longer follow-up periods (> one year) our results suggest that a certain functional threshold is already achieved at an early stage after surgical treatment [2,10,22–24]. Contradictory results were found regarding the SF-36 physical summary scale (PSS) after three and six months, since both groups clearly fell outside the range of patients with a longer follow-up period [2,10,23,24]. The only comparable outcome was found in a study by Hirschmüller et al., who investigated patients with unilateral CF more than one year postoperatively. However, these patients suffered from high rates of wound complications and revision surgery which might explain the lower rates of physical function [11]. Regarding the mental summary score, the current study is consistent with other studies and also the normal healthy population in Germany. This confirms that mental health remains almost unaffected in patients with CF even early after trauma [10,11,23,25].

Gait analysis demonstrated notable changes during the follow-up period but not between surgical treatments. In this context, similar or even higher walking speeds were found for both groups when compared to the results of other studies [2,9–11]. This may be explained by the fact that long-term posttraumatic issues that affect walking speed, such as secondary osteoarthritis in the subtalar and calcaneal cuboid joints, are still absent during early follow-up [26]. Cadence was the only parameter that showed a significant difference between surgical approaches. However, this difference was only visible at six month follow-up and was relatively subtle ($d = 0.55$) and may not affect clinical practice. Gait kinematics revealed comparable improvements in ankle and subtalar ROM for ELA and STA groups, indicating an onset of a better dynamic foot and ankle mobility. However, foot mobility still

Table 2
Within- and between-group comparison for ELA and STA approaches for functional outcome mean (standard deviation) values during the three and six month follow-up.

	ELA		STA		P values			
	3 Months	6 Months	3 Months	6 Months	Within ELA	Within STA	ELA vs. STA 3 Months	ELA vs. STA 6 Months
AOFAS	73 (11)	79 (11)	75 (10)	79 (12)	0.06	0.07	0.44	0.77
SF-36 PSS	38 (9)	43 (9)	36 (9)	42 (10)	**0.009**	< **0.001**	0.47	0.85
SF-36 MSS	54 (9)	53 (8)	57 (8)	57 (7)	0.61	0.61	0.31	0.1

Table 3
Within- and between-group comparison (ELA and STA) for mean (standard deviation) kinetic and kinematic parameters during the three and six month follow-up.

	ELA		STA		P values			
	3 Months	6 Months	3 Months	6 Months	Within ELA	Within STA	ELA vs. STA 3 Months	ELA vs. STA 6 Months
M_{max} stance (Nm/Kg)	0.88 (0.36)	1.33 (0.27)	0.95 (0.38)	1.32 (0.32)	**0.003**	< **0.001**	0.46	0.89
GRF 1st Peak (%BW)	103 (9)	109 (10)	101 (5)	105 (6)	**0.002**	< **0.001**	0.31	0.06
GRF 2nd Peak (%BW)	98 (3)	104 (7)	99 (5)	104 (7)	**0.001**	< **0.001**	0.17	0.73
Ankle DE_{max} stance (°)	12.1 (6.5)	12.7 (3.7)	15.2 (4.6)	14.7 (4.3)	0.73	0.69	**0.04**	0.07
Ankle ROM push off (°)	8.4 (4.5)	11.8 (5.3)	9.8 (4.7)	14.8 (6.8)	**0.002**	< **0.001**	0.31	0.08
Hindfoot EV_{max} stance (°)	2.2 (5)	3.7 (4.5)	4.3 (7.3)	7.1 (5.5)	0.09	0.11	0.23	**0.02**
Hindfoot ROM stance (°)	4.2 (2.4)	6.3 (4.3)	5.2 (2.9)	6.9 (3.3)	**0.004**	**0.02**	0.29	0.95

M_{max}, Maximum ankle moment; GRF, Ground reaction force; DE, Dorsal extension; ROM, Range of Motion; EV, Eversion.

remained limited even after six months since hindfoot motion in both groups was reduced by up to half of the normal mobility during stance phase [27]. This might be likely related to the high rates of soft tissue swelling but also to residual incongruences of the articular surface at the subtalar joint. During normal walking, the calcaneus is initially in a slight inversion followed by an eversion during full weight-bearing and a subsequent inversion around terminal stance. This varus-to-valgus interchangeis almost absent in our patients.. Furthermore, an almost permanent eversion throughout the whole stance phase was observed, which tended to even increase in both groups after six months. These results reflect those of Hetsroni et al. who also found longer subtalar eversion and decreased range of motion in patients with unilateral CF

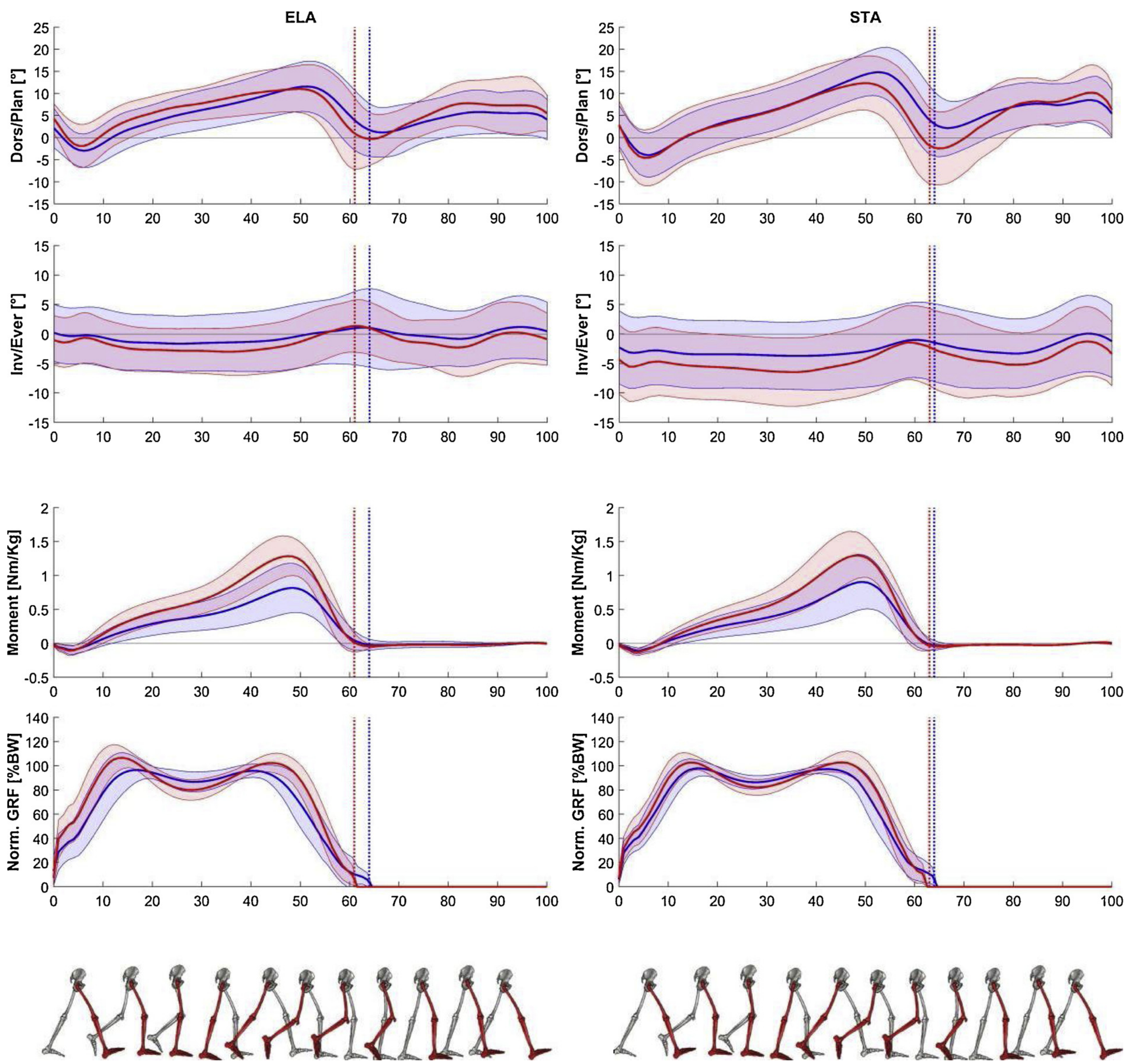

Fig. 2. Ankle and hindfoot kinematics, ankle joint moment and normalised vertical ground reaction force (mean ± 1 standard deviation) for the ELA group (left column) and the STA group (right column) during the three months (blue) and six months (red) follow-up period. Dotted vertical lines indicate the end of stance phase (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

[10]. Generally, these alterations indicate the functional deficit to create sufficient stability along the longitudinal arch and to lock the tarsal joints to create adequate push off [27]. Considerably higher ranges of sagittal and subtalar ankle motion were found compared to other studies that investigated patients with CF [2,8–10]. As patients in these studies walked notably slower than in our study, this may indicate that these impaired foot and ankle joint kinematics may not only be attributed to walking speed. This is supported by the findings of Hetsroni et al. who compared surgically treated patients with CF and healthy controls at similar walking speeds, and still found noticeable deviations regarding subtalar joint kinematics [10]. This would suggest that limited hindfoot eversion during stance is primarily influenced by abnormal joint function and decreased activity rather than by walking speed [26]. Improvements in maximum vertical ground reaction forces and ankle joint moments indicate an enhanced weight-bearing capacity and an increase in muscle strength capacity, mainly in the ankle plantar flexors during the early rehabilitation period [28,29]. Similar results regarding maximum ground reaction force were reported in surgically treated patients [9] and also for patients treated conservatively [30]. These findings suggest that patients in the early phase after surgical treatment have already achieved a certain weight-bearing capacity that is almost comparable to those with a considerably longer follow-up. However, even six months after surgery, ankle moments and ground reaction forces remained clearly reduced compared to normative values and are somewhat comparable with those of patients with total ankle replacement [31]. This might be related to the long period of disuse and immobilisation after surgery (˜ 8–12 weeks), which causes muscle atrophy, decreases muscle strength and changes mechanical properties of the Achilles tendon. [8,32]. The biomechanical assessment of gait in patients after CF revealed that functional outcome was almost similar between ELA and STA under investigation. Treatments were almost comparable, despite some small differences in foot and ankle kinematics. Only maximum ankle dorsal extension at three months and maximum hindfoot eversion at six months were significantly larger in the STA group [27]. However, as these kinematic changes remained considerably small, biomechanical advantages might not have any clinical impact. This is supported by other clinical studies who found a comparable anatomical reconstruction of joint surfaces and calcaneal restoration using both strategies [5,14]. Intraoperative 3D scans during surgical treatment using the STA had an important influence regarding the comparable results between both strategies. Clinically, this imaging method proved to be a valuable assistance for anatomical reconstruction of the calcaneus and should always be used for operative care. This study has some limitations. The overall sample size in both groups is relatively small regarding comparisons of surgical techniques. Patients were only investigated over a very short follow-up period which is unable to reflect long-term adaptions in patients with CF. This should be taken into account, since a complete recovery after CF is not finished even one year after surgery [31]. The STA cannot be entirely compared to the ELA since in CF of Sanders type IV only insufficient stabilisation especially of the processus anterior of the calcaneus would be achieved by screw fixation alone. In these types the ELA with plate osteosynthesis would be always of advantage. To address the potential effect of fracture severity, we subsequently ran a statistical analysis using ANOVA regarding surgical treatment (ELA & STA), fracture type (Sanders II & Sanders III) and interaction on all outcome parameters. No significant effects were found in our analysis, which provides some confidence that our findings were not biased by fracture severity. As no radiologic evaluation was performed during the follow-up, no information was obtained regarding the maintenance of the anatomical restoration of the joint surfaces. We can only assume that the mechanical competence of both techniques was sufficient to maintain alignment as we were unable to identify any pain exacerbation or functional deficits in both patient groups. Marker-based foot model data should be interpreted cautiously due to soft tissue artefacts. Since a substantial rate of swelling around the ankle joint was still present, this may have had some influence on foot kinematics. Finally, the analysis of joint moments can be seen as critical, as this parameter was only obtained based on a single rigid-body approach. Although this has a crucial impact on joint power estimations, calculations of ankle joint moments proved to be unaffected [33]. In conclusion, our findings could not confirm that the less invasive STA is superior to the ELA regarding functional performance or mobility until six months post-surgery. Nonetheless, we also provided evidence that the STA showed no disadvantages regarding dynamic foot function during walking or patient reported mental health and physical activity. From a biomechanical perspective and with regard to the comparable positive course of healing, the STA thus proved to be a viable alternative in the very common fracture types of Sanders II and III. In combination with intraoperative 3D scans, this surgical procedure might be a viable alternative method which should be further established regarding future surgical treatment in patients with intraarticular CF.

Conflict of interest disclosure

None.

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