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Comparison of Plantar Pressure Distribution During Walking After Two Different Surgical Treatments for Calcaneal Fracture

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A B S T R A C T

The aim of our study was to compare gait in terms of foot loading and temporal variables after 2 different operative approaches (the extended lateral approach [ELA] and sinus tarsi approach). Twenty-two patients who sustained an intra-articular calcaneal fracture underwent plantar pressure distribution measurements 6 months after surgery. Measurements were performed while patients walked on the pedobarography platform. The values of dynamic variables were significantly lower on the operated limb in the ELA. In the sinus tarsi approach, no differences were observed between the operated and uninjured limbs (UIN) at peak pressure and at maximal vertical force. The values of temporal variables (contact time of the foot and of the heel) between the operated and UIN differed in the ELA. The hypothesis that differences in foot load between operated and UIN will be more significant in the ELA was confirmed. Our results showed that the differences in loading and temporal variables between the operated and the UIN persisted 6 months after surgery in both methods. The operated limb was less loaded, with the tendency to shift the load toward the midfoot and forefoot. After the less invasive sinus tarsi approach, the dynamic and temporal variables on the operated limb were nearly the same as those on the healthy one. The sinus tarsi surgical approach can be recommended for treatment of displaced calcaneal fractures.

For displaced fractures, surgical treatment is preferred (1–3). The 2 most commonly used approaches are extended lateral approach (ELA) and less invasive sinus tarsi approach (STA). The results of fracture treatment are assessed in several ways; clinical examination results may not always be consistent with radiographic images and computed tomographic results (4). Nevertheless, it is quite common that, despite the satisfactory results of clinical examination, abnormalities in the gait pattern remain noticeable after surgery (5). Therefore, we attempt to use other instrumentation methods to evaluate treatment outcomes. Such methods include pedobarography, which allows plantar pressure analysis at various time intervals after surgery (5,6). With this method, abnormalities in the plantar pressure distribution between the uninjured and operated limbs (OPE) while walking can be confirmed. Such abnormalities include shortened stance phase, delayed timing of peak pressure under the hallux and second toe, lateral load shift at the midfoot, and decreased toe pressures in OPE (6).

One aspect of physiological walking is symmetry in the action of the lower limbs and symmetry of the ground reaction forces (7). A high degree of loading symmetry between the left and right feet during walking in healthy subjects have been observed (8,9). However, differences between dynamic parameters calculated from the right and left lower limbs have been reported frequently (10,11). A comparison of these parameters in healthy and OPE was previously used to determine the degree of asymmetry of walking in patients after calcaneal injury (8,12,13). Gait asymmetry after successful surgical treatment of displaced ankle fractures was characterized by plantar pressure distribution differences between uninjured and OPE (14).

The purpose of this study was to compare the plantar pressure distribution in the stance phase after 2 different operative approaches. Our primary aim was to measure plantar pressure distribution and to analyze the temporal variables of the stance phase during walking in both groups of patients. The secondary aim was to determine the recommendation for calcaneal fracture surgical treatment. We undertook a retrospective cohort study to compare outcomes in patients who had undergone ELA with those who had undergone STA for calcaneal fracture. Nevertheless, we expected a lower peak pressure under the operated foot, regardless of the selected operative procedure. With the less invasive STA, we expected a tendency to resume symmetry between both limbs in terms of temporal variables sooner after surgery.

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Patients and Methods

The aim of our study was to compare gait in terms of foot loading and temporal variables after 2 different operative approaches. The secondary aim was to determine the recommendation for intra-articular calcaneal fracture surgical treatment.

Patients

All consecutive patients with intra-articular calcaneal fracture from January 2014 to June 2016 were contacted and volunteered to participate in this study. Inclusion criteria were age ≥18, unilateral injury, and fractures classified preoperatively by computed tomographic scanning as Sanders type II or type III. Patients in whom previous illnesses or injuries affecting the gait were known were excluded from the study.

The mean age of the patients (N = 22) was 45 ± 11.75 (range 25 to 68) years, the mean height was 1.78 ± 0.05 (range 1.68 to 1.85) m, and the mean body mass was 79.5 ± 11.07 (range 65 to 95) kg. The operative approaches for patients who were gradually coming in alternated regularly regardless of the physical characteristics of patients so that the first patient was operated on using ELA and the next using STA. The age of patients in the ELA group (n = 12) was 39.4 ± 5.54 (range 27 to 48) years, height 1.77 ± 0.06 (range 1.68 to 1.85) m, body mass 76.33 ± 11.19 (range 55 to 92) kg. The age of patients in the STA group (n = 10) was 51.6 ± 13.62 (range 25 to 68) years, height 1.79 ± 0.04 (range 1.72 to 1.84) m, body mass 83.3 ± 9.64 (range 65 to 95) kg.

The surgery was performed within 2 weeks after the injury by the same orthopedic surgeon specializing in foot and ankle surgery. Postoperative mode had been set for all patients equally.

Six months after operative treatment, patients were consecutively contacted to participate in the measurement. It was performed between July 2014 and December 2016. The patients were familiarized with the design of the measurement and they signed an informed consent. Analysis of plantar pressure distribution while walking was then performed. All experiments were approved by the institutional review board of the Technical University of Liberec and conducted in accordance with the Declaration of Helsinki.

Plantar Pressure Analysis Protocol

Measurement of the plantar pressure distribution and pressure values was performed while walking on the pedobarography measurement platform (EMED®-c50/R; Novel, Munich, Germany). The scanning frequency was 50 Hz.

The actual measurement was preceded by a 5-minute training walk over a measurement platform. The measurement was then initiated, aimed at analyzing the plantar pressure distribution during the stance phase while walking. The participants were asked to walk barefoot at a self-selected speed that they use in everyday life, over a platform embedded in the floor. They took at least 3 steps before and after the platform to ensure recording of a step in full gait. The measurement was repeated until a total of 5 individual steps of OPE and 5 individual steps of uninjured limbs (UIN) were recorded.

For each step, loading variables and temporal variables were calculated. The mean of 5 steps for each variable was used to compare OPE and UIN. The loading variables normalized to body mass included peak pressure, representing the maximum pressure recorded under the whole foot, maximum vertical force, vertical force time integral, and peak pressure under the heel. The temporal variables included the contact time of the whole foot with the ground, and contact time, when the heel was in contact with the ground. Other variables included the percentage of the time when the center of pressure (CoP) is in the heel zone, midfoot zone, forefoot zone and toes zone, the maximal velocity of CoP, and the average velocity of CoP.

Table 1
Basic physical characteristics of 2 groups of patients operated by different surgical approaches

	ELA (n = 12)		STA (n = 10)		*p* Value*
	Mean ± SD	Median	Mean ± SD	Median	
Age (y)	39.4 ± 5.54	40	51.6 ± 13.62	53	.02†
Mass (kg)	76.3 ± 11.19	77	83.3 ± 9.64	86	.16
Height (m)	1.77 ± 0.06	168	1.79 ± 0.04	178	.55
BMI	24.3 ± 2.51	25	26.2 ± 3.53	27.2	.21

Abbreviations: BMI, body mass index; ELA, extended lateral approach; SD, standard deviation; STA, sinus tarsi approach.
* Mann-Whitney *U* test. † $p \leq .05$.

Assessors

Surgery, fracture classification and clinical examination was done by a doctor of medicine (J.P.), biomechanical measurement was done by a senior researcher (S.J.), and data processing and evaluation was done by senior researchers (S.J. and M.J.). Preparation of the Discussion and Conclusions was performed with the cooperation of all authors.

Statistics

Data analyses were performed using STATISTICA software (version 12.0; StatSoft Inc., Tulsa, OK). The normality of the data distribution was assessed by the Kolmogorov-Smirnov test. Because the data were not normally distributed, the Mann-Whitney *U* test was used to determine the differences in basic physical characteristics between the groups. To compare OPE and UIN limbs, the Wilcoxon paired test was used. Statistical level significance was defined at 5% ($p \leq .05$).

Results

The comparison of groups according to basic characteristics is shown in Table 1. A statistically significant difference between patients operated on using the STA and patients operated on using an extensive lateral approach (ELA) was found in their age ($p = .02$), patients operated with ELA were younger, although the surgical treatments alternated regularly regardless of the physical characteristics of patients. For mass, height, and body mass index, the difference was not significant ($p > .05$).

Comparison of plantar pressure variables between the operated and UIN after 2 different surgical approaches (ELA and STA) 6 months after the surgery is shown in Table 2. In the OPE, the contact time of the foot

Table 2
Comparison of plantar pressure variables between operated and uninjured limbs after 2 different surgical approaches

	ELA (n = 12)				STA (n = 10)			
	OPE Mean ± SD	UIN Mean ± SD	*p* Value*	*r*	OPE Mean ± SD	UIN Mean ± SD	*p* Value*	*r*
CT (ms)	861.4 ± 163.4	877.6 ± 157.5	.20	0.37	876±.1 163.6	905.8 ± 165.7	.03	0.68
PPrel	4.71 ± 1.17	6.21 ± 1.73	.01	0.75	5.62 ± 2.11	6.27 ± 1.89	.24	0.37
MVF_{rel}	10.63 ± 0.56	11.13 ± 0.76	.01	0.77	11.46 ± 1.05	11.81 ± 1.13	.14	0.47
CTH (ms)	661.2 ± 142.7	553.0 ± 119.2	<.01	0.84	635.9 ± 181.3	593.6 ± 117.7	.51	0.21
PPHrel	3.73 ± 0.64	4.21 ± 0.60	.03	0.61	3.69 ± 1.23	4.21 ± 0.94	.02	0.73
FTIrel	6.59 ± 0.73	7.28 ± 0.65	<.01	0.82	7.36 ± 1.02	7.91 ± 1.31	.01	0.85
CoP trajectory (%)								
Heel	30.14 ± 5.17	23.52 ± 5.34	.02	0.66	24.83 ± 5.61	23.62 ± 5.94	.28	0.34
Midfoot	37.24 ± 10.35	22.63 ± 6.67	.00	0.86	37.72 ± 15.10	25.11 ± 5.71	.07	0.56
Forefoot	28.39 ± 12.21	48.01 ± 9.45	.01	0.79	30.72 ± 12.66	45.24 ± 10.37	.02	0.73
Toes	4.23 ± 3.05	5.85 ± 4.25	.03	0.83	6.72 ± 2.008	6.02 ± 2.56	.33	0.31
CoP velocity ($m•s^{-1}$)								
v_{max}	0.95 ± 0.356	0.687 ± 0.193	.03	0.63	0.792 ± 0.192	0.775 ± 0.277	.80	0.08
v_{ave}	0.280 ± 0.031	0.271 ± 0.035	.05	0.81	0.283 ± 0.042	0.273 ± 0.050	.09	0.57

Abbreviations: CoP, center of pressure; CT, contact time with the ground; CTH, contact time of the heel with the ground; ELA, extended lateral approach; FTI, force time integral relativized to body weight; MVF_{rel}, maximal vertical force relativized to body weight; OPE, operated leg; PP_{rel}, maximum pressure per body weight; PPH_{rel}, maximum pressure under the heel relativized to body weight; *r*, Cohen effect size; SD, standard deviation; STA, sinus tarsi approach; UIN, uninjured leg; v_{ave}, average velocity; v_{max}, maximal velocity.
* Wilcoxon test.

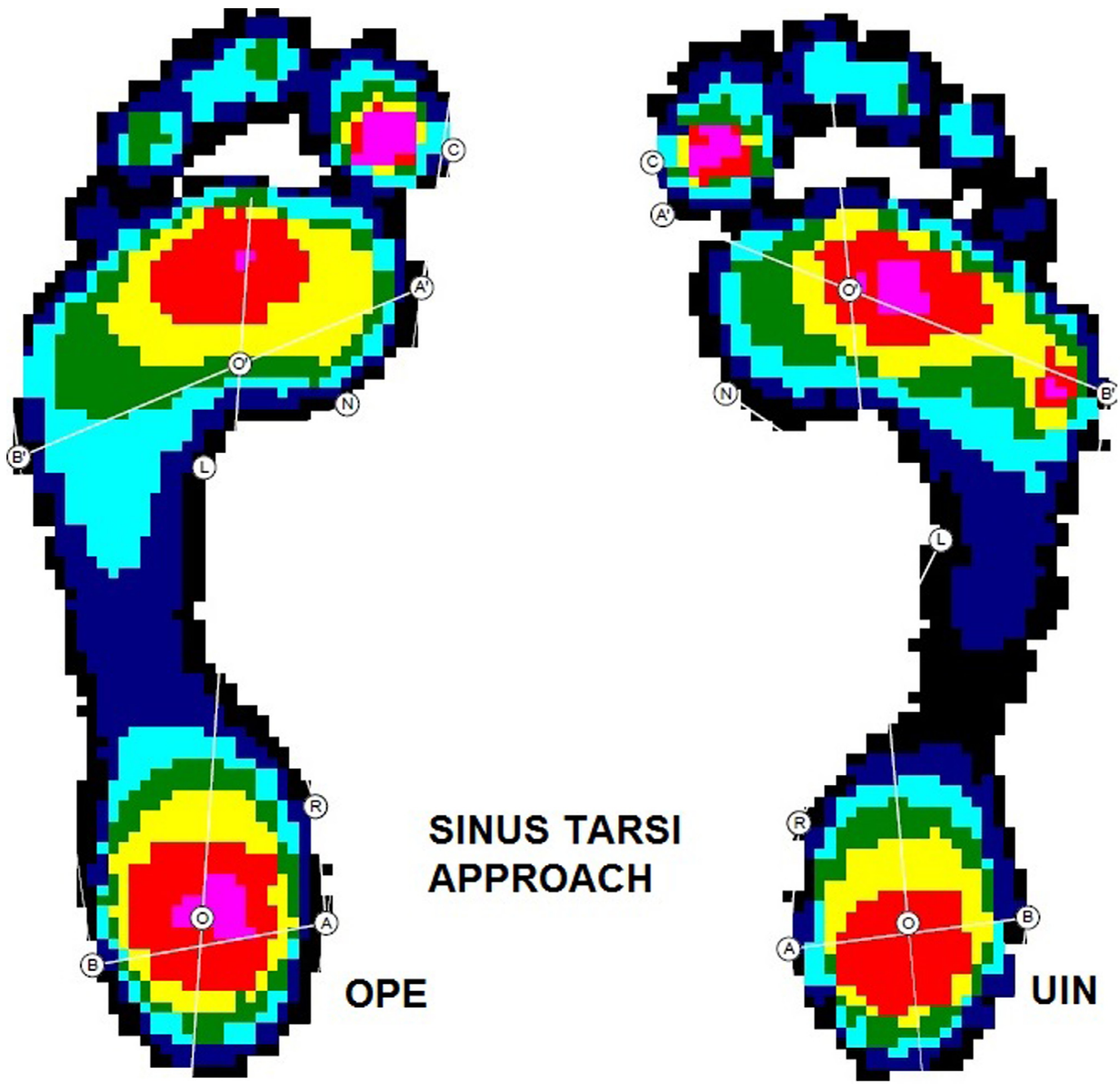

Fig. 1. Plantar pressure distribution after the sinus tarsi approach.

with the ground was shorter after both approaches (in STA by 3% and in ELA 2%). This difference was statistically significant in STA ($p = .03$). In contrast, the contact of the operated heel with the ground was longer in comparison with the uninjured heel after both approaches (in STA by 7% and in ELA by 20%). In ELA, this difference was statistically significant ($p < .01$).

Peak pressure values were higher for both surgical approaches on the UIN (in STA by 10.4% and in EXT by 24.2%) (Figs. 1 and 2); for EXT, this difference was statistically significant ($p = .01$). At maximum vertical force, the values on the OPE were lower (in STA by 3.0% and in EXT by 4.5%). In EXT, this difference was statistically significant ($p = .01$). Peak pressure values under the heel were statistically significantly higher on the UIN in both approaches, with STA exhibiting a difference of 12.4% ($p = .03$) and EXT 11.2% ($p = .02$). Force time integral values on the OPE were lower compared with the UIN for both operative approaches. In STA, this difference was 7% ($p = .01$) and in EXT 10% ($p < .01$).

The CoP trajectory was different for both limbs in both surgical approaches as well. In ELA, the percentage of CoP was longer during the stance phase on the OPE in the heel ($p = .02$) and midfoot ($p < .01$) areas. The phase in which CoP was in the forefoot and toes area was shorter in ELA in the OPE ($p = .01$ and $p = .03$). In STA, there was a decrease in CoP representation in the forefoot zone in the OPE ($p = .02$). In the other zones, the CoP remaining on the OPE was longer; however, with respect to the UIN, the differences were not statistically significant ($p > .05$). There was no significant shift to lateral in CoP trajectory for either surgical approach, but patients operated with ELA tended more to flat foot on the OPE (Fig. 2). In ELA, there were statistically significant differences

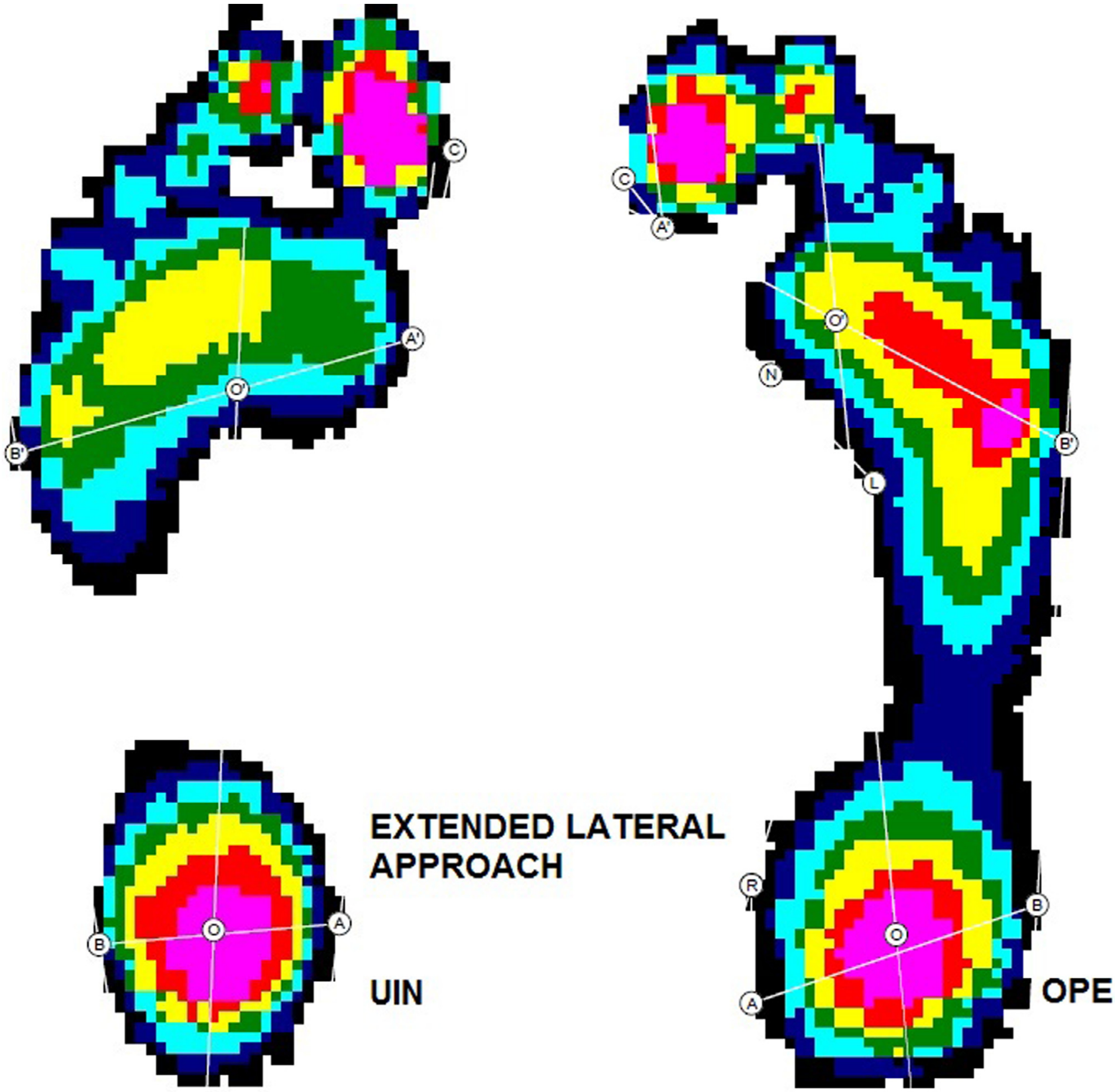

Fig. 2. Plantar pressure distribution after the extended lateral approach. OPE, operated leg; UIN, uninjured leg.

between the limbs in the CoP velocity, both at the maximum ($p = .03$) and the average ($p = .05$) velocity. In STA, these differences between the 2 limbs were not statistically significant ($p > .05$).

Discussion

The aim of our study was to compare gait cycle in terms of plantar pressure distribution and temporal variables after ELA and STA for intra-articular calcaneal fracture. Six months after surgical treatment of calcaneus fracture, statistically significant differences ($p \leq .05$) between the OPE and the UIN in most of the observed variables (except contact time with the ground) were found in the extensive surgical approach. These side-to-side differences have been reported in the literature to remain for quite a long time after surgery (8,15). In the less invasive STA, the OPE and the UIN values were statistically significantly different only at contact time with the ground, peak pressure under the heel, force time integral, and CoP trajectory in the forefoot.

At the contact time of the whole foot with the ground, the difference between the OPE and UIN was not statistically significant in ELA (1.85%; $p > .05$). This result is surprisingly different from previous studies (4,6), which reported significantly decreased stance duration in the OPE compared with the UIN. In STA, the contact time with the ground was shorter in the OPE (3.28%) than in the UIN ($p = .03$), which corresponds with the values in patients treated with the ELA described in the literature (4,6,8).

The contact of the heel with the ground was significantly ($p < .01$) longer in the OPE than in the UIN in the ELA ($\leq$19.57%). In STA, the percentage differences were smaller (7.13%) and they were not statistically significant. The contact time for the total foot was significantly shorter for the OPE than for the UIN. In our patient group (N = 22), the duration of contact of the operated heel with the ground was longer in 16 patients (STA in 5 patients and ELA in 11 patients). This finding is because of the slower but also lower loading of the injured heel. In the remaining 6 patients (STA in 5 patients and ELA in 1 patient), the time of the step on the heel of the OPE was shorter according to previous study (16) and the step was directed more toward the medial or anterior part of the foot. Thus, unlike the UIN, the stance phase and medial heel contact of the OPE was shortened (6).

As for dynamic parameters, the OPE values were lower than those for UIN regardless of the selected approach. The peak pressure measured under the whole foot during the stance phase was significantly different ($p = .01$) between both limbs in the ELA, in which the OPE values were 24.15% lower. Previous study did not demonstrate these differences >4 years after the surgical treatment (6). In STA, the peak pressure values in the OPE were lower by 10.37%. No statistical significance of this difference was established ($p > .05$). We consider this insignificant difference, measured 6 months after the surgery, to be very positive.

At the peak pressure under the heel, the differences between the OPE and the UIN in both surgical approaches were significant ($p \leq 0.05$) in our study. The percentage differences were similar between the approaches (STA 12.22%; ELA 11.22%), with lower values on OPE. This finding is consistent with previous studies (4,15). This finding points to the fact that 6 months after surgeries performed by both surgical approaches, the patients—with respect to maximum pressure under the heel—tended to step more and more cautiously on the injured heel. This overall trend of a load shift toward lateral regions of the injured limb is supported by differences in other areas. This factor indicates a persisting deviation of the gait pattern long after fracture (8). On the OPE, in contrast with the UIN, plantar pressure is shifting toward the forefoot after injuries of the heel bone. Pressure under the midfoot is increased, and pressure drop under the heel occurs at the same time (4,12,15); in some cases, pressure under the forefoot is increased as well (17). The displacement of pressure toward the midfoot can be explained by the limited range of motion in the subtalar and tibiotalar joints (18). There was no significant shift to lateral in plantar pressure distribution. Post-traumatic changes after this type of injury may lead to a breakdown of the longitudinal arch and result in a flat foot, often combined with hindfoot varus or valgus (15).

In terms of time in specific zones (heel, midfoot, forefoot, and toes) and in terms of both maximum and average CoP velocity, the CoP trajectory was significantly different in the OPE and the UIN in ELA. With this approach, CoP in the OPE in the heel and midfoot zones was longer compared with the UIN. In contrast, in the forefoot and toes zones, CoP was significantly longer in the UIN. In the STA, a statistically significant difference was observed only in the forefoot zone where CoP was found on a percentage basis longer in the UIN than in the OPE. This fact is likely to be related to the overall CoP shift toward the forefoot and relieving the heel owing to persistent pain in the area under the heel of the foot when stepping. The load time shortening also corresponds with a significantly higher average and maximum CoP velocity values on the OPE compared with the UIN we found in the ELA.

One aspect of physiological walking is symmetry in the action of the lower limbs and symmetry of the ground reaction forces (7). A high degree of loading symmetry between the left and right feet during walking in healthy subjects has been observed (8,9).

In general, lateralization of peak pressure distribution and temporal parameters presented in our study for the ELA group are similar with the values found in the literature (6,8,12,15). For the STA group, values of the OPE and the UIN limbs are more symmetrical than in ELA.

Based on the conducted temporal and dynamic parameters analysis, the STA seems to be the more appropriate surgical method. Patients who had been operated on through this approach showed less significant differences in the observed variables measured on the OPE and the UIN 6 months after surgery. In contrast, the ELA may worsen the conditions for restoring walking symmetry owing to increased scarring on the lateral side of the heel, limiting the talocalcaneal joint mobility or by impairing the mobility of the peroneal tendons in the lateral ankle.

The results of this study show that, after postoperative treatment of Sanders type II or type III calcaneal fractures, the differences in load between the OPE and the UIN persisted at 6 months after the surgery. Regardless of the selected surgical approach, patients tended to load the OPE differently than the UIN, including a tendency to shift the load toward the midfoot and forefoot.

After a less invasive STA, the OPE was loaded similarly to the healthy one. In terms of the time parameters of foot contact with the ground when stepping, and in terms of load dynamics, no later than 6 months after the operation there was symmetry of the load in the area below the heel in patients after STA. Our results supported the hypothesis that plantar pressure distribution differences between OPE and UIN are greater in the ELA than in the STA at 6 months after surgery.

Limitations of this study include that the participants were not homogenous in terms of age, they have not filled out an AOFAS, and the follow-up period could be longer (i.e., 12 to 18 months). Because patients with unilateral intra-articular fracture were coming to the hospital with their injury between January 2014 and June 2016 continuously, it was not possible to randomize selection of the surgical approach owing to a relatively small incidence of this injury in the hospital catchment area to influence the age characteristics of the patients operated on using ELA and STA, because surgical approaches were chosen alternately regardless of the physical characteristics of patients. In the group that was operated on using ELA and that was significantly older ($p = .02$), there were also young patients (minimum age of 25 years), similar to the STA group (minimum age of 28 years). Owing to the low frequency of this injury and considering the capabilities of the surgical department, it was not possible to conduct the measurements in a larger group of patients. The generalizability of these results should be considered carefully. Another limiting factor in this study is that the participants walked at their preferred speed. Because the measurement was taken at a relatively early stage of recovery, it was not possible to influence the walking speed in the selected group of patients. The study was performed only in a group of patients and not in a group of healthy subjects, but according to previous studies the human gait in healthy adults is symmetrical (7).

In conclusion, despite our appreciation of the limitations of our investigation, we believe that the results of this study could be useful in the future for calcaneal fracture treatment and it is possible to recommend the STA surgical approach for treatment of displaced fractures of the calcaneus, in which decreased pain owing to the limited extent of the surgical approach should be considered. The results could be used in the development of future studies that focus on the same or similar conditions.

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References

1. Buckley RE, Tough S, McCormack R, Pate G, Leighton R, Petrie D, Galpin R. Operative compared with nonoperative treatment of displaced intra-articular calcaneal fractures: a prospective, randomized, controlled multicenter trial. J Bone Joint Surg Am 2002;84:1733–1744.

2. Ibrahim T, Rowsell M, Rennie W, Brown AR, Taylor GJ, Gregg PJ. Displaced intra-articular calcaneal fractures: 15- year follow-up of a randomised controlled trial of conservative versus operative treatment. Injury 2007;38:848–855.
3. Jiang N, Lin QR, Diao XC, Wu L, Yu B. Surgical versus nonsurgical treatment of displaced intra-articular calcaneal fracture: a meta-analysis of current evidence base. Int Orthop 2012;36:1615–1622.
4. Hirschmüller A, Konstantinidis L, Baur H, Müller S, Mehlhorn A, Kontermann J, Grosse U, Südkamp NP, Helwig P. Do changes in dynamic plantar pressure distribution, strength capacity and postural control after intra-articular calcaneal fracture correlate with clinical and radiological outcome? Injury 2011;42:1135–1143.
5. Schepers T, Van der Stoep A, Van der Avert H, Van Lieshout EM, Patka P. Plantar pressure analysis after percutaneous repair of displaced intra-articular calcaneal fractures. Foot Ankle Int 2008;29:128–135.
6. Hetsroni I, Ben-Sira D, Nyska M, Ayalon M. Plantar pressure anomalies after open reduction with internal fixation of high-grade calcaneal fractures. Foot Ankle Int 2014;35:712–718.
7. Hamill J, Bates BT, Knutzen KM. Ground reaction force symmetry during walking and running. Med Sci Sports Exerc 1983;15:170.
8. Rosenbaum D, Lübke B, Bauer G, Claes L. Long-term effects of hindfoot fractures evaluated by means of plantar pressure analyses. Clin Biomech 1995;10:345–351.
9. VanZant RS, McPoil TG, Cornwall MW. Symmetry of plantar pressures and vertical forces in healthy subjects during walking. J Am Podiatr Med Assoc 2001;91:337–342.
10. Kaufman KR, Miller LS, Sutherland DH. Gait asymmetry in patients with limb-length inequality. J Pediatr Orthop 1996;16:144–150.
11. White SC, Gilchrist LA, Wilk BE. Asymmetric limb loading with true or simulated lower limb-length differences. Clin Orthop Relat Res 2004;421:287–292.
12. Jansen H, Frey SP, Ziegler C, Meffert RH, Doht S. Results of dynamic pedobarography following surgically treated intra-articular calcaneal fractures. Arch Orthop Trauma Surg 2013;133:259–265.
13. Öcgüder A, Gok H, Heycan C, Tecimel O, Tonuk E, Bozkurt M. Effects of custom-made insole on gait pattern of patients with unilateral displaced intra-articular calcaneal fracture: evaluation with computerized gait analysis. Acta Orthop Traumatol Turc 2012;46:1–7.
14. Becker HP, Rosenbaum D, Kriese T, Gerngross H, Claes L. Gait asymmetry following successful surgical treatment of ankle fractures in young adults. Clin Orthop Relat Res 1995;311:262–269.
15. Besch L, Radke B, Mueller M, Wredenhagen MD, Waroga D, Hilgert RE, Mathiak G, Oehlert K, Seekamp A. Dynamic and functional gait analysis of severely displaced intra-articular calcaneus fractures treated with a hinged external fixator or internal stabilization. J Foot Ankle Surg 2008;47:19–25.
16. Rammelt S, Amlang M, Barthel S, Gavlik JM, Zwipp H. Percutaneous treatment of less severe intraarticular calcaneal fractures. Clin Orthop Relat Res 2010;468:983–990.
17. Contreras MEK, Muniz AMS, Souza JBD, Avila AOV, Borges Junior NG, Barbosa DRF, Kroth LMM, Filho MR. Biomechanical evaluation of intra articular calcaneal fracture and clinical radiographic correlation. Acta Ortop Braz 2004;12:105–112.
18. Allmacher DH, Galles KS, Marsch JL. Intra-articular calcaneal fractures treated nonoperatively and followed sequentially for 2 decades. J Orthop Trauma 2006;20:464–469.