INTRA ARTICULAR CALCANEAL FRACTURES: A CLINICAL AND BIOMECHANICAL ANALYSIS

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ABSTRACT

Objective: Verify the variables of plantar pressure distribution of patients submitted to surgical procedure for calcaneal fracture, and correlate them with two different surgical approaches. Method: The authors studied 15 patients between 20 and 53 years of age (average 40.06 yrs.) who had intra-joint calcaneal fractures, submitted to surgical treatment by means of two different approaches: the lateral and the sinus tarsi. The authors checked the plantar pressure distribution by correlating these variables with the two different surgical approaches. The plantar pressure distribution was assessed using the Pedar System (Novel, Gmbh, Munich, Germany), by checking the maximum peak of the hindfoot and forefoot pressure on the affected and the normal sides. Results: the mean maximum pressure of the hindfoot plantigram in both approaches showed no statistical difference (t=0.11; p=0.91), as well as the mean maximum pressure of the forefoot plantigram (t=-0,48; p=0,64). Conclusion: The authors have concluded that there were no significant statistical differences between the average maximum peak of the hindfoot and forefoot pressure on the affected side as compared to the normal side, and these variables have showed no differences when compared to the surgical approach used.

Keywords – *Calcaneal fracture; Plantar pressure distribution; Biomechanic*s

INTRODUCTION

Most studies on the subject of intra-articular fractures of the calcaneus have only seek to evaluate the topic from a clinical point of view, with well-established criteria for such evaluation and imaging through radiography and CT. The biomechanical studies, in turn, tend to characterize variables in experimental models and anatomical specimens (cadaver parts), which provides tests with high sensitivity without, however, evaluating real situations of this type of trauma[1-7].

Meanwhile, studies such as those of Kitaoka et al.[8], Siegmeth et al.[9], and Contreras et al.[10] have included the clinical aspects that are relevant to fractures of the calcaneus.

This study aims to verify the variables of the distribution of plantar pressure in patients undergoing surgical treatment of fractures of the calcaneus and to correlate them with two different surgical approaches.

METHODS

This is an experimental study. All patients selected for this study underwent surgical treatment of unilateral intra-articular fractures of the calcaneus. After the rehabilitation period, patients with at least 24 months of follow-up underwent evaluation of plantar pressure distribution.

The sample consisted of 15 patients of both sexes who were submitted to surgical treatment of

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Study conducted at the Department of Orthopedics and Traumatology, Hospital Governador Celso Ramos, Florianópolis, SC, at the Biomechanics Laboratory at the Universidade do Estado de Santa Catarina, and the University Pablo De Olavide-Seville, Spain.
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intra-articular fractures of the calcaneus, operated at the Hospital Governador Celso Ramos (HGCR) from January 1996 to October 2002. Of the 15 patients, 10 were operated on via lateral access and five through the sinus tarsi access. During this period, 128 patients (134 feet) were operated for fractures of the calcaneus. Of these, 15 patients fit the criteria adopted for this study.

The inclusion criteria were:

a) Patients with at least 24 months of follow-up;

b) Patients with fractures in only one foot, since we use the opposite side, characterized as normal, as the control group;

c) Only the cases of type II and III, classified through computed tomography by Sanders, 1989;

d) Cases that had complete documentation, which included pre- and postoperative X-rays and computed tomography;

e) Cases of patients who agreed to sign the informed consent form for research and consent for photography and video.

We used descriptive statistics to analyze the quantitative parameters of the sample. To compare the sample means, we used the paired Student's t-test for dependent and related samples and the Student's t-test for independent samples assuming unequal variances. We used linear correlation to correlate the sample data. The level of significance was set at 5% ($\alpha = 0.05$).

The study was approved by the Ethics Committee on Human Research of the Hospital Governador Celso Ramos (HGCR) and the Universidade do Estado de Santa Catarina (UDESC).

SURGICAL TECHNIQUE

We used two different surgical approaches for the surgical treatment of intra-articular fractures of the calcaneus, the direct lateral approach and the sinus tarsi approach, which we called the short approach. For both approaches the patient is placed in full lateral decubitus, with the limb to be operated up and the opposite limb in 30 degrees of hip flexion and 90 degrees of knee flexion, freely supporting the limb to be operated on the surgical table. The fixation of fractures is performed with Kirschner wires and/or screws. Plates are not used.

Lateral approach

Routine asepsis and antisepsis are adopted, blood is drained, and a rubber band tourniquet is used.

The lateral access is performed through an incision that begins anterior to the posterior calcaneal tuberosity and runs one and a half centimeters distally below the lateral malleolus, making a small curve before ending over the extensor digitorum brevis muscle (Figure 1).

Dissection of the cutaneous branch of the sural nerve is carefully performed, repaired with cardiac tape. The sheath of the peroneal tendons is then identified and raised along with the periosteum of the lateral surface of the calcaneus. Generally, it is necessary to cut the fibulocalcaneal ligament, thereby exposing the lateral wall of the calcaneus and the talocalcaneal joint. Previously, the extensor digitorum brevis muscle is disinserted and the calcaneocuboid joint is exposed.

Sinus tarsi approach (short approach)

The skin incision begins immediately anterior to the cutaneous projection of the peroneal tendons, and with a slight curve, it is directed medially to the edge of the extensor tendons of the toes (Figure 2). The extensor digitorum brevis muscle is folded distally to expose the calcaneocuboid joint, and then the fat is cleaned out of the sinus tarsi. Once the joint capsule is opened, the joint is cleaned for better viewing. In some cases, the interosseous ligament must be cut in order to facilitate visual access to the medial aspect of the calcaneus. The sinus tarsi has no articular surface, therefore cartilage denotes the presence of previously diverted fragments.

The control by radioscopy assists in verifying the reduction of the fracture. Cleaning and hemostasis are performed after emptying the tourniquet, a suction drain (in all cases) is placed and the operative wound is closed in layers. All patients used a plaster splint for 15 to 20 days.

Postoperative period

The suction drain is removed in 24 hours. Antibiotic therapy is performed with the first dose 30 minutes before incision, repeating after four hours, and then every eight hours until completing 24 hours, when it is interrupted.

The patient is discharged on the first postoperative day with anti-inflammatory drugs or oral analgesics. He/she is required to return to the clinic three days after discharge. The plaster splint remains for 20 to 30 days, and plantar and dorsal flexion movements are stimulated shortly thereafter. Kirschner wires that were placed percutaneously are removed between 60 and 80 days. Full weight-bearing is permitted only with 90 days in all cases.
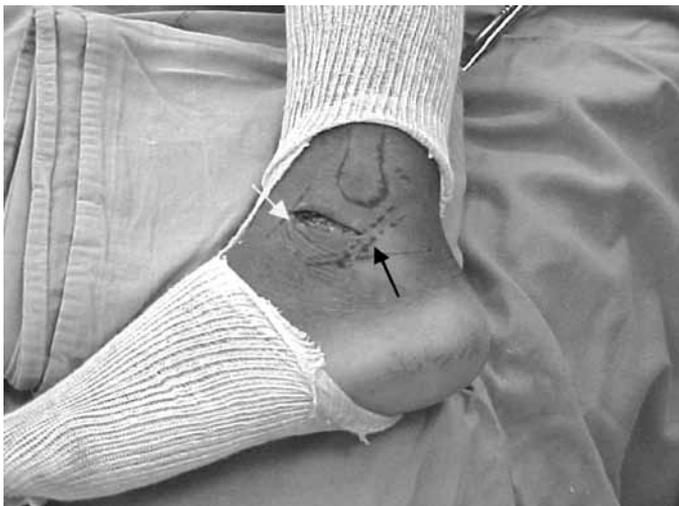
Source: HGCR-SC

Figure 1 – Photograph showing cutaneous incision on the lateral approach of patient number 8. The arrow indicates the path of the peroneal tendons.

INSTRUMENTATION AND EVALUATION OF PLANTAR PRESSURE

To evaluate the distribution of plantar pressure, the Pedar System produced by Novel (GmnH, Munich, Germany) was used.

Patients were instructed to walk a distance of 10 meters with a natural cadence, using their own casual footwear. The data from the initial and final footfalls were discarded, utilizing only the data from the three central footfalls, thus eliminating the acceleration and deceleration phases of gait. The frequency of acquisition was 50 Hz. Five gait trials were collected for each sub-

Source: HGCR-SC

Figure 2 – Photograph showing the cutaneous incision for short approach in patient number 14. The white arrow shows the lateral edge of the extensor retinaculum and the black arrow, the path of the peroneal tendons.

ject. The three trials with the lowest standard deviation were selected for the calculation of the pressure peaks.

RESULTS

The patients' ages ranged between 20 and 53 years, with an average of 40.06 years and a standard deviation of ± 8.08. Fourteen patients (93.3%) were male and one was female (6.6%). Seven patients (46.6%) had a fractured left calcaneus and eight (53.3%) had the right side affected.

The cause of the fracture had its frequency distribution divided into falls from a height in 12 cases (80%), falling from standing height in one case (6.6%), falling from a skateboard in one case (6.6%), and a jet ski accident in one case (6.6%).

Associated injuries occurred in four patients (26.6%), one being a fracture of the radial head, two with fractured spine, and one with a fracture of the distal third of the ipsilateral tibia.

According to the Essex-Lopresti classification (1951) for intra-articular fractures of the calcaneus, we had six patients (40%) with tongue-type fractures and nine (60%) with joint depression type fracture.

The evaluation by the Sanders classification of 1989 regarding the types of fracture is represented by the frequency distribution in Table 1.

Table 1 – Distribution of absolute and relative frequency of fracture types according to the Sanders et al. classification.

Sanders classification	Frequency	
	Absolute	Relative
II A	2	13.30%
II B	6	40.00%
III AB	2	13.30%
II AC	1	6.66%
III BC	4	26.66%
Total type II	8	53.33%
Total type III	7	46.66%
Total	15	100%

The mean preoperative Böhler angle was 9.73 ± 15.09 and in the late postoperative period, 24.6 ± 7.66. These values were compared by paired t-test, which showed a statistically significant difference between them (t = -4.29, p = 0.0007).

The mean Gissane angle was 117.06 ± 9.44 preoperatively and 120.06 ± 8.80 in the late postoperative period. These values were compared by paired t-test, showing that there is no statistically significant difference between them (t = -1.08, p = 0.29).

The mean values found in the sample for the clinical index of the American Orthopaedic Foot and Ankle Society (AOFAS) was 86.40 points.

The lateral surgical approach was used in 10 patients and the anterior approach in five.

Table 2 quantitatively describes the values for each patient, the mean peak maximum hindfoot and forefoot pressure on the operated and normal sides, measured in kPa, and the surgical approach and the operated side.

Table 3 shows the descriptive statistics of mean maximum pressures of the pressure-measuring insoles of the hindfoot on the operated side and the normal side. We compared these averages by Student's t-test for independent samples, finding no statistically significant difference between these values (t = 0.66, p = 0.51).

Table 4 presents the descriptive statistics of mean maximum pressures of the pressure-measuring insoles of the forefoot on the operated side and the normal side and compares these means by Student's t-test for independent samples, showing no statistically significant

Table 2 – Description of the individual values of mean peak maximum hindfoot and forefoot pressure on the operated and normal sides (kPa). Description of the surgical approach used and the operated side.

Record #	Name	Approach	Side Op.	PMPR op	PMPR nl	PMPA op	PMPA nl
194499	JLS	L	R	65	50	110	92
208322	ANC	L	R	269	230	260	290
216795	LCR	L	R	190	190	140	160
199958	REZ	L	R	290	90	210	110
200531	VH	L	R	90	95	140	97
215828	JJS	L	L	160	160	240	210
221298	JAD	L	L	180	200	140	220
194370	RS	L	L	167	170	182	210
205796	ADK	L	L	190	210	260	240
125525	RAS	L	L	170	180	160	165
215744	AL	C	R	250	230	190	170
215379	WP	C	R	117	90	227	190
222935	ACSO	C	R	200	180	200	190
221272	DAN	C	L	160	190	330	430
223587	ES	C	L	140	160	80	140

Source: Biomechanics Laboratory – UDESC-CEFID
Side Op. = Side operated, R = Right, L = Left
L = lateral approach, C = sinus tarsi approach
PMPR op = Mean maximum pressure of the pressure-measuring insole of the hindfoot of the operated side
PMPR nl = Mean maximum pressure of the pressure-measuring insole of the hindfoot of the normal side
PMPR op = Mean maximum pressure of the pressure-measuring insole of the forefoot of the operated side
PMPR nl = Mean maximum pressure of the pressure-measuring insole of the forefoot of the normal side

Table 3 – Comparison of mean maximum peak pressures found in the hindfoot pressure-measuring insole on the operated side and the normal side.

t-test: two samples assuming different variances

	PMPR op	PMPR nl
Mean	175.86	161.66
Variance	3,801.98	3,048.80
Number of cases	15	15
Degrees of freedom	28	
T	0.6644	
Two-tailed P (t ≤ t)	0.51183	
Two-tailed critical T	2.04840	

PMPR op = Mean maximum pressure of the pressure-measuring insole of the hindfoot of the operated side
PMPR nl = Mean maximum pressure of the pressure-measuring insole of the hindfoot of the normal side

Table 4 – Comparison between the mean maximum peak pressures found in the pressure-measuring insoles of the forefoot of the operated side and the normal side.

t-test: two samples assuming different variances

	PMPA op	PMPA nl
Mean	191.26	194.26
Variance	4,336.35	7,186.06
Number of cases	15	15
Degrees of freedom	26	
T	-0.1082	
Two-tailed P (t ≤ t)	0.9146	
Two-tailed critical T	2.0555	

PMPA op = Mean maximum pressure of the pressure-measuring insole of the forefoot of the operated side
PMPA nl = Mean maximum pressure of the pressure-measuring insole of the forefoot of the normal side

Table 5 – Comparison of mean maximum peak pressures found in the pressure-measuring insoles of the hindfoot of patients operated on through the lateral and short approaches.

t-test: two samples assuming different variances		
	PMPR op	
	Lateral approach	Short approach
Mean	177.1	173.4
Variance	4,681.21	2,762.8
Number of cases	10	5
Degrees of freedom	10	
T	0.1158	
Two-tailed P (t ≤ t)	0.9100	
Two-tailed critical T	2.2281	

PMPR op = Mean maximum pressure of the pressure-measuring insole of the hindfoot of the operated side.

Table 6 – Comparison of mean maximum peak pressure values found in the pressure-measuring insoles of the forefoot of patients operated on through the lateral approach and the short approach.

T-test: two samples assuming different variances		
	PMPA op	
	Lateral approach	Short approach
Mean	184.2	205.4
Variance	3.025,28	7,995.8
Number of cases	10	5
Degrees of freedom	6	
T	-0.4861	
Two-tailed P (t ≤ t)	0.6441	
Two-tailed critical T	2.4469	

PMPA op = Mean maximum pressure of the pressure-measuring insole of the forefoot of the operated side

difference between these values (t = -0.10, p = 0.91).

Table 5 examines the mean maximum pressures of the pressure-measuring insoles of the hindfoot of feet operated by the lateral approach and the short approach. A comparison of the means by Student's t-test for independent samples shows that there is no statistical difference between the two approaches (t = 0.11, p = 0.91).

Table 6 examines the mean maximum pressures of the pressure-measuring insoles of the forefeet of feet operated by the lateral approach and the short

approach. A comparison of the means by Student's t test for independent samples shows that there is no statistical difference between the two approaches (t = -0.48, p = 0.64).

DISCUSSION

There is no consensus in the literature regarding the surgical approach. Since Lenormant and Wilmoth[11] and Palmer[12], the lateral approach has been widely used. Pennal and Yadav[13], Bezes et al.[14], with a sample of 257 cases, Letournel[15], Melcher et al.[16], Gell and Flemister[17] used the lateral approach as described by Palmer[12], or with a modification in its obliquity, and described a broad view of the posterior facet and calcaneocuboid joint. In our country, Salomão et al.[18], Santin et al.[19], Köberle et al.[20], Moraes Filho et al.[21], and Contreras et al.[10] used the lateral approach, with different methods of osteosynthesis. The lateral approach has the advantage of creating excellent exposure of the posterior and anterior facet, and the calcaneocuboid joint. Using a spatula, you can reach the medial side, but the reduction of the sustentacular fragment is indirect. The peroneal tendon sheath is lifted along with the periosteum and its reconstruction is not always anatomically possible, and may lead to a decreased range of excursion for these tendons. The fibulocalcaneal ligament must be sectioned and is very difficult to reinsert. This is an important anatomical structure and there is insufficient research on its absence in the evolution of calcaneal fractures.

The lateral approach described in this study is similar to that used by Bezes et al.[14]. An important modification of the lateral approach is described by Benirschk and Sangeorzan[22], performing a proximal vertical extension, making the approach L-shaped and thus expanding its visual field. Sanders et al.[23], Crosby and Fitzgibbons[24], Loucks and Buckley[25], and Harvey et al.[26] have reported on their experience with this approach and, except for the last, who found 8.2% of skin necrosis, the other authors have reported complication rates similar to that of authors using other approaches[27]. Wiley et al.[27] reported on a modification in the lateral approach described as a "smile" incision for better exposure of the sinus tarsi, the anterior process, and the calcaneocuboid, using as surface parameters: the posterosuperior apex of the calcaneus, anterior to the lateral border of the Achilles tendon; the inferior edge of the inferior calcaneous to the end

of the fibula; the anterior process of the calcaneus in the calcaneocuboid joint. The main complication of this approach would be the sural nerve injury, which was 8% in this study and does not constitute an absolute contraindication according to the authors. The medial approach, first described by McReynolds[28], was studied and rescued by Bordeaux[29], and since then, the medial approach has been used in isolation or associated with the lateral approach, as described by Zwipp et al.[30] and Kundel et al.[31] in the first 100 cases of their series. In our country, Köberle et al.[20] and Moraes Filho et al.[21] used the medial approach when they were not successful in reducing using only the lateral approach.

Sclamberg and Davenoport[32] described an approach through the sinus tarsi, allowing for direct access to the subtalar and calcaneocuboid joints. Andermahr et al.[33,34] studied the vascular anatomy of the calcaneus and concluded that the approach through the sinus tarsi has a lower risk of vascular injury than the lateral and medial approaches, through which comes 90% of the irrigation of the calcaneus. Fernandes[35] reported on 38 cases, all treated surgically with sinus tarsi approach, of which three cases (7.89%) had superficial tissue damage. Ebraheim et al.[36] evaluated the results obtained using the short approach in 99 patients (106 feet), with only four cases (3.8%) of superficial infection and one case (0.9%) of deep infection. They evaluated the advantage of directly approaching the posterior facet and the anterior and lateral aspect, with the limitation of indirect reduction of the posterior tuberosity of the sustentaculum of the talus. The short approach was used in five cases in our study and we had one case (6.6%) of deep infection with this approach (patient 3). This patient had significant swelling of the foot and, although there were no signs of compartment syndrome, we believed that there would be some degree of tissue damage irrespective of the approach used. The patient obtained 95 points using the AOFAS clinical criteria, showing that there was no clinical harm because of the infection.

Carr[37] performed an extensive review of approaches with small incisions that were less than 6 cm (percutaneous, lateral, medial and combined), correlating the fracture pattern according to the AO classification and the surgical technique. It was concluded that despite the small incisions, the potential risks persist, the limited exposure requires a deep knowledge of the anatomy of the lesion and

fixation methods. Experience with the expanded lateral approach is the basis for using small incisions.

The strength of the synthesis materials for the calcaneus was explored by several authors. Wang et al.[4] performed an experimental study in 20 cadaver legs obtained by limb amputation. Through axial load, they experimentally created 12 intra-articular fractures of the calcaneus. Specimens were randomly divided into two groups, which were submitted to open reduction and internal fixation. In the first group, fractures were fixed with a plate and screws from lateral to medial through a lateral approach. The second group also received a longitudinal screw from posterior to anterior. With a universal testing machine, axial load tests were conducted until the syntheses failed. They reported that the group receiving longitudinal screws had greater axial strength than that fixed only with the lateral plate.

Redfern et al.[38] and Stoffel et al.[39] used models of intra-articular fractures in parts of cadavers to compare fixation using locking or non-locking plates in biomechanical studies testing strength, deformity, and workload. Redfern et al.[38], in experimental models with Sanders type IIB fractures, found no advantages between the fixation with locking plates or the traditional fixation with non-locking plates. Stoffel et al. demonstrated that locking plates fostered better fixation with smaller irreversible deformities during cyclic loading and require a higher load to fail. When they compared the final deformity and the work to create the gap between the two plates, no statistically significant differences were found. Richter et al.[40] developed this study with synthetic models and concluded that fracture fixation with a lateral plate and locking screws fostered greater stability than the standard plate without locking screws, especially in the simulation of cyclic loading.

Few authors have studied the distribution of plantar pressure in fractures of the calcaneus in the clinic. Most papers report on experimental studies. Siegmeth et al.[9] performed a comparison between a group of patients treated by a conservative method, and other through surgery (all by the same approach). Conducted a thorough clinical and baropodometric comparison using the Pedar system. Gildone et al.[41] used an electronic baropodometer to evaluate the results of surgical treatment of calcaneal fractures using a specific technique. Contreras et al.[10] studied the distribution of plantar pressure in patients with surgically treated calcaneal fractures using the F-Scan system.

We chose the Pedar system for this study because it is an instrument with greater data reliability according to the literature.

According to Hughes et al.[42], the reliability coefficient increased as the number of steps in data collection increased, working with mean pressure data. Due to the great variability of biological data, we used the average of the best three footfalls (those with the lowest standard deviation) as the parameter for the value that expresses the kinetic variable.

Segal et al.[43] demonstrated the effect of walking speed in different plantar regions in individuals without pre-existing pathologies using the Pedar system. They concluded that in the hallux and calcaneus peak plantar pressure increases linearly according to speed.

We found no significant change between the mean peak pressure in the pressure-measuring insoles of the hindfoot, the operated side (late postoperative) and the normal side. There was also no change in the same variables in the pressure-measuring insoles of the forefoot. Siegmeth et al.[9] reported that the pressure on the calcaneus is 14% lower in the surgical group than in the normal group and that the pressure in the midfoot is 27% higher in the surgical group and 55% higher in the conservative treatment group than in the normal group. The time-force integral is increased by 21% in the surgical group and 10% in the conservative group in relation to the control group.

In the hallux, there is a 25% decrease in the values of this variable when compared with those of normal feet. Contreras et al.[10], found significant differences using the F-Scan system between the contact areas, force, and average pressure of the fractured hindfoot and the fractured forefoot, with the fractured side having higher values.

Research on the asymmetry index between normal foot and the affected foot, in the case with intra-articular calcaneal fracture, could extend the correlation between variables of the distribution of plantar pressure and clinical-radiographic variables. This index would be an important tool for providing continuity to this study that may reveal with further, deeper analysis other characteristics of plantar distribution and, in turn, the subject's gait pattern.

CONCLUSIONS

There was no statistical difference between the mean maximum peak pressure of the hindfoot and forefoot of the fractured side in the late postoperative period when compared with the normal side. There was no statistical difference between the surgical approaches used and the mean maximum peak pressure of both the hindfoot and forefoot in the late postoperative period.

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