ARTICLE IN PRESS
JCLB-03279; No of Pages 6
Clinical Biomechanics xxx (2011) xxx–xxx
Contents lists available at ScienceDirect
Clinical Biomechanics
journal homepage: www.elsevier.com/locate/clinbiomech

Plantar pressure distribution after tibiotalar arthrodesis

Reinhard Schuh [a,b,*], Jochen Gerhard Hofstaetter [e], Stefan Gerhard Hofstaetter [c], Samual B. Adams Jr. [d], Karl-Heinz Kristen [e], Hans-Joerg Trnka [b]

[a] Department of Orthopaedic Surgery, Medical University of Innsbruck, Anichstrasse 35, 6020 Innsbruck, Austria
[b] Foot and Ankle Center Vienna, Alserstrasse 43/8D, 1080 Vienna, Austria
[c] Department of Orthopaedic Surgery, Klinikum Wels-Grieskirchen, Grieskirchnerstrasse 42, 4600 Wels, Austria
[d] Division of Orthopaedic Surgery, Duke University Medical Center, 27710 Durham, NC, USA
[e] Department of Orthopaedics, Vienna General Hospital, Medical University of Vienna, Waehringer Guertel 19-21, 1090 Vienna, Austria

ARTICLE INFO

Article history:
Received 10 May 2010
Accepted 2 February 2011

Keywords:
Ankle arthrodesis
Plantar pressure distribution
Ankle osteoarthritis

ABSTRACT

Introduction: Arthrodesis is a well-established treatment option for end-stage osteoarthritis of the ankle. Osteoarthritis of the ankle can alter plantar pressure distribution. However, surprisingly little is known about the effect of ankle arthrodesis to alter plantar pressure distribution. The purpose of this study was to determine plantar pressure distribution in a selected group of patients with unilateral arthrodesis of the ankle joint.
Methods: 20 patients with an average age of 60 years who underwent isolated unilateral ankle arthrodesis using a 3-crossed screw technique by a single surgeon were included. After a mean of 25 months (range 12–75 months) post surgery plantar pressure distribution was determined in five regions of the foot. The outcome was evaluated clinically, using the American Orthopaedic Foot and Ankle Society hindfoot score, as well as radiographically. The contralateral normal foot was used as a control.
Findings: Comparing the foot that underwent tibiotalar arthrodesis to the contralateral normal foot, differences were found in the peak pressure and maximum force in the toe region and the lateral midfoot region. In addition, a decrease in the contact time in the forefoot region and a decrease of the contact area in the toe region of the operated foot were identified. The other regions did not show a significant difference. The mean American Orthopaedic Foot and Ankle Society score of the operated leg was 79 (range 46–92) at the last follow up, and the mean fixation angle of the arthrodesis on lateral weight bearing radiographs was 90° (range 86°–100°).
Interpretation: Our results indicate that arthrodesis of the ankle joint can provide high levels of function with minimal changes in the plantar pressure distribution.

1. Introduction

It has been reported that 15–20% of the population in Europe and North America suffer from some forms of osteoarthritis and that approximately 10% of all cases involve the ankle joint. (Glazebrook et al., 2008; Lawrence et al., 1998) Osteoarthritis (OA), is a progressive disorder of the joints caused by gradual loss of cartilage and resulting in the development of bony spurs and cysts at the margins of the joints. Inflammation of the synovial membrane of the joint is common late in the disease. Its cause is unknown but may include chemical, mechanical, genetic, metabolic, and endocrine factors.

Ankle OA is a debilitating condition that results in functional limitations and a poor quality of life (Saltzman et al., 2006). It also leads to altered gait patterns and three-dimensional kinematic behavior of the hindfoot, the forefoot, and the entire lower limb as well as plantar pressure distribution (PPD) (Beyaert et al., 2004; Horisberger and Valderrabano, 2009; Rhys et al., 2006; Wu et al., 2000).

Measurements of plantar pressure provide critical information of foot and ankle function during gait and other functional activities. The data obtained from this established technique are used for the evaluation and management of patients with a wide variety of foot impairments (Orlin, 2000).

To assess the functional load-bearing aspect of the feet during walking, there are two established measurement approaches. The first approach measures the total ground reaction force of the tread, whereas the second approach uses pressure platforms.

In contrast to measurements with a force platform, plantar pressure analysis provides detailed information about the whole foot contact and loading during the stance phase of gait (Sinclair et al., 2009). Horisberger et al. found in a cross-sectional pedobarographic study of 120 patients with unilateral end-stage ankle OA decreased

* Corresponding author at: Department of Orthopaedic Surgery, Medical University of Innsbruck, Anichstrasse 35, 6020 Innsbruck, Austria.
E-mail address: reinhard.schuh@uki.at (R. Schuh).

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doi:10.1016/j.clinbiomech.2011.02.001

loading parameters in terms of peak pressure as well as maximum force for the total foot and for certain regions of interest in comparison to the unaffected side (Horisberger and Valderrabano, 2009).

The goal of any treatment in ankle OA is to alleviate pain and improve function. The two major surgical treatment options for endstage OA of the ankle are tibiotalar arthrodesis and total ankle replacement. The relative benefits of total ankle arthroplasty and ankle fusion continue to be one of the most debated topics in foot and ankle surgery (Haddad et al., 2007). Previous studies revealed that tibiotalar arthrodesis affects foot kinematics in terms of temporospatial gait parameters as well as ground reaction force (Beyaert et al., 2004; Piriou et al., 2008; Wu et al., 2000). A number of authors have studied plantar pressure changes after various types of hindfoot arthrodesis (e.g. subtalar arthrodesis, subtalar distraction arthrodesis, and triple arthrodesis) (Czurda et al., 2009; Diezi et al., 2008; Rammelt et al., 2004).

The specific aims of this study are (1) to determine if there is an altered plantar pressure and force distribution between the operated and the non-operated normal contralateral foot, (2) to assess clinical results, using the American Orthopaedic Foot and Ankle Society (AOFAS) hindfoot score, and (3) to compare the radiographic results of patients who underwent ankle arthrodesis for the treatment of isolated unilateral osteoarthritis of the ankle.

2. Methods

2.1. Patients

We retrospectively identified patients who underwent isolated ankle arthrodesis by the senior author (HJT) between 06/1997 and 01/2008. In order to get a homogenous patient population, only patients who underwent unilateral isolated tibiotalar arthrodesis with a three crossed screw technique were selected (Kennedy et al., 2006). Patients with differing fixation techniques (blade plate, additional staples, etc.) as well as patients in whom additional surgical procedures at the foot and ankle were performed at the same time or if neuropathic foot deformities were present were excluded. Furthermore only patients with a normal contralateral foot were included. A total of 20 patients (7 men/13 women) with a mean age of 60 years (range: 45–70 years) at the time of arthrodesis met the inclusion criteria (see Table 1). Indications for surgery were post-traumatic OA in 18 patients (85%), avascular necrosis of the talus in one patient (5%), and primary OA in another patient (5%). The minimum time for clinical and radiographic follow-up was 12 months (mean: 25 months; range: 12–75 months). The study was performed with the approval of our institution's Human Subjects Review Board, and all participants signed an approved informed consent form.

2.2. Surgical technique and post-operative mobilization

For the anterior approach, a 10-cm longitudinal incision 1 cm lateral to the tibialis anterior tendon was performed. After the cartilage was removed, the joint surfaces were apposed while maintaining a neutral position of the ankle. Then three guidewires for the 7.3 mm cannulated self-cutting cancellous compression screws (Synthes GmbH, Salzburg, Austria) were inserted across the joint under fluoroscopic visualization. The operated feet of the patients were initially kept non-weight bearing. After one week, full weight bearing of the operated foot in a full contact cast starting below the knee (Celecast, Lohmann & Rauscher GmbH) was allowed. Eight weeks postoperatively the cast was removed and radiographic as well as clinical examinations were performed. Patients received a multimodal rehabilitation program starting on average of 10 weeks after surgery. The program included lymphatic drainage of the lower extremities, the mobilization of the knee joint and the tarsal joints, strengthening exercises and gait training. The mean duration of the program was six weeks. Patients received one treatment session a week.

Table 1
Demographics of the patients included in the study.

Age mean (SD)	60 (8.8)
Sex (male/female)	7/14
Body mass index mean (SD)	28.2 (3.4)
Height mean (SD)	169 (7.6)
Weight mean (SD)	80.3 (10.7)
Follow-up (months) mean (SD)	25 (16.0)

2.3. Experimental procedures

The plantar loading parameters were assessed using an EMED capacitive pressure measurement platform (Novel GmbH, Munich, Germany). The platform has a total area of 610 mm × 323 mm enclosing a 240 mm × 380 mm sensor area. It includes a total of 1760 sensors, providing a resolution of two sensors/cm^2. The sampling rate of the platform was fixed at 60 Hz, and it auto-triggered on the first contact. The platform has a maximum measurable force of 67,000 N with a hysteresis of less than 3%. Because of the depth of the platform of 18 mm, the test arrangement enclosed the platform in the center of a polyethylene mat with a length of 5 m; the whole arrangement including the platform and mat was on ground-level. Patients were able to walk over the platform in both directions. To represent the most natural gait patterns, the midgait method has been chosen for pedobarographic assessment (Orlin, 2000; Putti et al., 2008). This setting provides high validity and reproducibility. Five measurements per foot were recorded to perform reliable measurements (Orlin, 2000). Data were collected and stored for further analysis. Analysis of the records was performed with the EMED/D software. An average of the five data sets was calculated by the software, and the foot was divided into geometric regions of interest according to the anatomic areas of the toes, forefoot, medial midfoot, lateral midfoot, and hindfoot (see Fig. 1). The total foot was also considered in the calculation. The following variables for each region were generated by the software: peak pressure (kPa), maximum force (N), and contact area (cm^2). According to Orlin et al., these parameters have the highest clinical relevance (Orlin, 2000). Previous studies have revealed the high reliability and validity of measurements provided by this pedobarographic assessment device (Orlin, 2000; Putti et al., 2008).

2.4. Clinical assessment

At the final follow-up with each patient the American Orthopaedic Foot and Ankle Society (AOFAS) hindfoot score (Kitaoka et al., 1994) was obtained. This outcome measurement assesses pain, function, hindfoot motion, and alignment. The maximum score is 100 points.

2.5. Radiographic assessment

We obtained anteroposterior and lateral weight bearing radiographs at each clinical review until radiographic and clinical union was reached. Radiographic union was defined as bridging trabeculae across the fusion site (Moeckel et al., 1991). We defined delayed union as continued symptoms and radiographic evidence of incomplete fusion 6 months after surgery and nonunion as radiographic evidence of failure of fusion 1 year after surgery (Kennedy et al., 2006). We determined the sagittal position of the arthrodesis on the lateral view by measuring the long axis of the tibia in relation to the plantar surface of the foot (see Fig. 2a) at the final follow-up (Mazur et al., 1979). The frontal alignment was determined by the angle formed *between* the long axis of the tibia and

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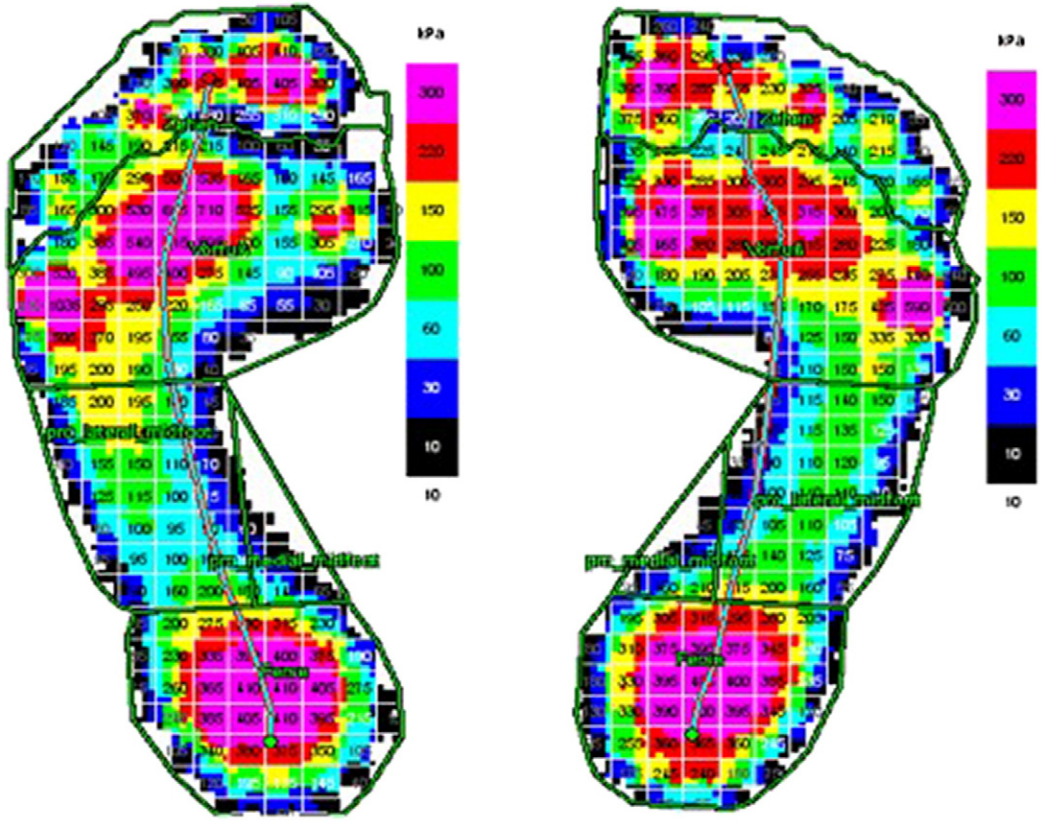

Fig. 1. Plantar pressure distribution of a patient 21 months after isolated arthrodesis of the right ankle. The foot is divided into the regions of interest hindfoot, medial midfoot, lateral midfoot, forefoot, and toes.

a line perpendicular to the articular surface of the talus as described by Wood and Deakin (Wood 2003).

2.6. Statistical analysis

Statistical comparison of the pedobarographic measurements were made between the operative foot and the contralateral foot with the use of a paired sample t-test with an alpha level of 0.05. The analysis was performed using SPSS 16.0 for Mac OS X (SPSS Inc, Chicago, IL) and the level of significance was set at alpha <0.05.

3. Results

In the toe region of the foot that underwent tibiotalar arthrodesis peak pressure, maximum force and contact time showed decreased values in comparison to the control side ($P = 0.023$; 0.022; and 0.035). In the lateral midfoot region of the operated foot there was significant increased peak pressure and maximum force compared to the not operated foot ($P = 0.036$; and 0.010). Contact time showed decreased values in the forefoot region of the operated foot ($P = 0.001$). The assessment of maximum force revealed no statistically significant difference for the total object, the hindfoot region, the medial midfoot

Fig. 2. Anterior, posterior and lateral standing weight bearing radiograph of the ankle. The sagittal alignment was measured by calculating the intersection of the long axis of the tibia (a) and the plantar surface (b). The frontal alignment was measured by the angle (d) formed of the long axis of the tibia (b) and a line perpendicular (a) to the articular surface of the talus (c) as described by Wood and Deakin.

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and the forefoot region respectively between the operated and the contralateral normal foot. Also, the evaluation of contact time and contact area did not reveal any changes between the operated and the non affected side for the total object, the hindfoot region and the medial midfoot region. The highest loads (peak pressure and maximum force) occurred in the forefoot region.

The pedobarographic results are illustrated in Table 2 and Fig. 3.

The mean AOFAS hindfoot score was 79 (range, 46–92) at the last follow up. Two patients (9.6%) had an excellent score (90–100), 15 patients (75.0%) had a good score (75–90), two patients (9.6%) had a fair score (50–74), and one patient (4.8%) had a poor score (see Table 3).

The mean sagittal hindfoot alignment on lateral standing radiographs was 90° (±2.3) and ranging from 86° to 100°. A total of 84.3% were within 5° of the mean value. None of the patients demonstrated union in more than 10° plantarflexion or dorsiflexion. The mean frontal hindfoot alignment was 3° of the valgus position. All of the patients met the radiographic inclusion criteria as defined by Kennedy et al. for ideal arthrodesis, in fact less than 5° varus and 10° valgus position (see Table 4) (Kennedy et al., 2006).

Nonunion and delayed union did not occur in any of the patients. None of the patients experienced a deep infection, a wound breakdown, or hematoma. One patient developed a superficial wound infection that was treated successfully with oral antibiotics.

4. Discussion

Here we present the first study that investigates plantar pressure distribution after tibiotalar arthrodesis. The analysis showed decreased peak pressure, maximum force and contact area in the toe area of the operated foot as compared to the contralateral foot. This result might indicate limited plantarflexion resulting from the loss of ankle motion during the push off phase of gait. Additionally, there was increased peak pressure and maximum force in the lateral midfoot region of the operated foot compared to the contralateral foot, which is an indication for a higher load of the lateral aspect of the midfoot during midstance. No statistically significant differences for peak pressure of the hind-, mid- and forefoot regions between the operated and the not affected side were identified. The results of the plantar pressure assessment revealed no statistically significant differences between the operated and the unaffected foot for maximum force and peak pressure of the regions total foot, hindfoot, medial and midfoot, and forefoot.

Ankle OA is a debilitating condition that results in functional limitations and a poor quality of life (Saltzman et al., 2006). In a recent study Glazebrook et al. (2008) demonstrated that patients who suffer on end-stage osteoarthritis of the ankle had severe pain, diminished health-related quality of life, limited physical function and diminished physical ability to fulfill occupational duties.

Recent attention has been focused on alterations of plantar pressure distribution in patients with affections of the ankle joint. In a pedobarographic study of Horisberger et al. dynamic plantar pressure distribution was assessed in 120 patients who suffered from isolated unilateral osteoarthritis of the ankle. This study revealed decreased maximum force and contact area for the whole osteoarthritic foot in comparison to the unaffected side. In addition, the authors found decreased peak pressure for the hindfoot and the toe region. Based on the results of their study, the authors concluded that affection of the ankle leads to alterations of plantar pressure distribution.

These alterations may be interpreted as an attempt by the patient to reduce the weight load, and therefore pain, upon the ankle. In particular, this may be true for the decreased maximum force in the total foot and the hindfoot area (Horisberger and Valderrabano, 2009).

Our results also indirectly strengthen this hypothesis. Since arthrodesis is an effective procedure to eliminate pain due to osteoarthritis patients of the present study presented no major differences concerning the overall loading parameters of the operated foot and the healthy foot. This might indicate that patients loaded both feet equally.

Another factor explaining the plantar pressure alteration in ankle OA patients may include the atrophy of the muscles surrounding the ankle. Patients with end-stage ankle OA show a substantial muscle weakness as well as reduced joint moments and ground reaction forces (Valderrabano et al., 2006).

In the patients of the present study the mean sagittal hindfoot alignment on lateral standing radiographs was 90°, and 84.3% of them were in between 5° standard deviation from neutral dorsiflexion. The mean coronar hindfoot alignment was 3° of the valgus position. According to Kennedy et al. (2006) all of the patients met the inclusion criteria for normal arthrodesis concerning the coronal plane.

We do think that the absence of alterations of plantar pressure is due to the almost ideal alignment of the arthrodesis and the elimination of pain due to osteoarthritis in the patients of the present study.

However, because of the small sample size and the absence of normalization to body weight we failed to prove direct correlation between hindfoot alignment and plantar pressure distribution.

Patients of the present study reached a mean AOFAS score of 79 points. These results highly correspond to recent results in literature (Buchner 2003; Culpan et al., 2007; Haddad et al., 2007; Kennedy et al., 2006; Rhys et al., 2006; Smith and Wood 2007). A biomechanical study by Wayne et al. (1997) revealed that peak pressure in the subtalar and talonavicular joint does not increase substantially if fixation of the arthrodesis is performed in neutral sagittal alignment.

Table 2
Pedobarographic results of the operated and nonoperated foot. The plantar pressure parameters are presented as mean xx (SD yy).

	Operated foot	Nonaffected foot	P value
Total object			
Maximum force (N)	641.9 (259.7)	643.9 (242.9)	0.976
Peak pressure (kPa)	882.2 (151.1)	875.7 (145.0)	0.537
Contact area (cm^2)	126.7 (154.3)	129.1 (18.2)	0.250
Contact time (msec)	970.3 (179.5)	929.6 (281.3)	0.469
Hindfoot			
Maximum force (N)	505.1 (88.1)	493.5 (114.5)	0.515
Peak pressure (kPa)	352.3 (155.8)	328.0 (104.7)	0.551
Contact area (cm^2)	33.6 (5.4)	32.6 (3.4)	0.260
Contact time (msec)	608.7 (190.1)	606.2 (172.5)	0.906
Lateral midfoot			
Maximum force (N)	173.8 (89.1)	132.1 (69.4)	0.036*
Peak pressure (kPa)	167.4 (71.6)	135.7 (51.6)	0.010*
Contact area (cm^2)	22.3 (5.8)	21.1 (6.7)	0.164
Contact time (msec)	612.0 (189.5)	592.8 (167.0)	0.339
Medial midfoot			
Maximum force (N)	31.8 (31.2)	23.3 (19.2)	0.090
Peak pressure (kPa)	138.4 (61.4)	106.3 (41.0)	0.269
Contact area (cm^2)	4.0 (2.5)	3.9 (3.2)	0.943
Contact time (msec)	429.0 (226.2)	429.1 (186.0)	0.996
Forefoot			
Maximum force (N)	678.3 (159.4)	673.7 (123.5)	0.916
Peak pressure (kPa)	595.0 (285.4)	588.0 (254.8)	0.814
Contact area (cm^2)	51.0 (6.0)	51.6 (6.3)	0.327
Contact time (msec)	779.0 (172.2)	829.4 (286.4)	0.001*
Toes			
Maximum force (N)	143.1 (90.5)	190.1 (83.0)	0.023*
Peak pressure (kPa)	268.3 (133.1)	384.7 (183.3)	0.022*
Contact area (cm^2)	17.0 (6.2)	19.8 (5.3)	0.035*
Contact time (msec)	683.9 (187.4)	737.5 (136.6)	0.125

* Statistically significant difference that was revealed by the paired t-test.

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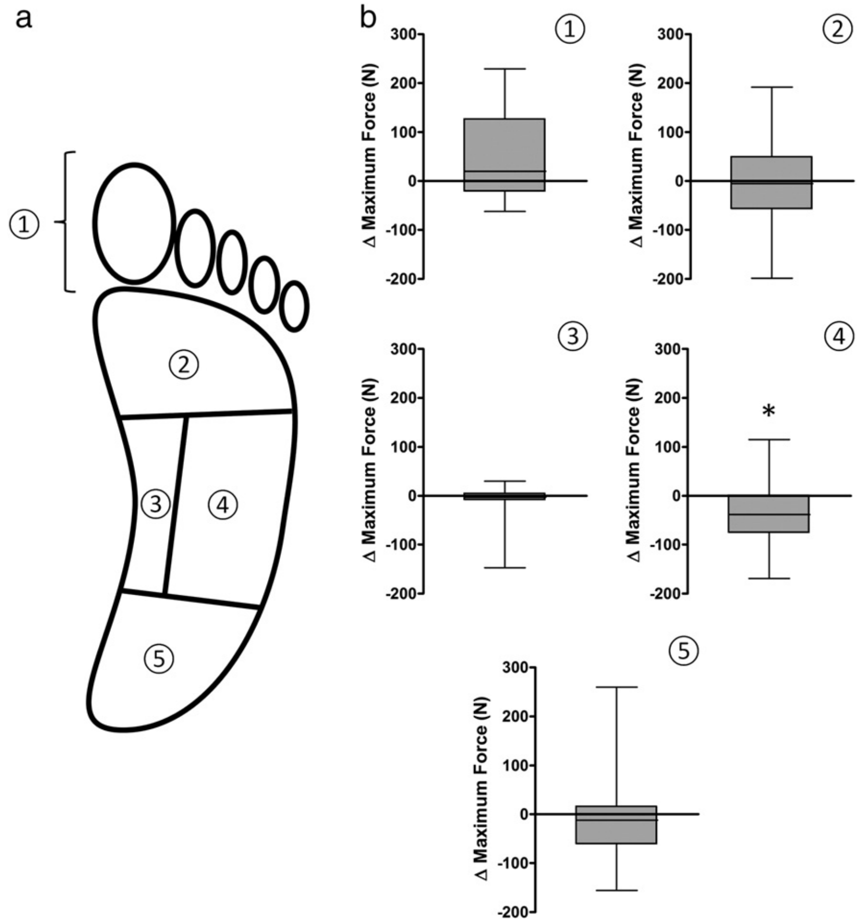


Fig. 3. Mean difference of maximum force between the operated and the nonoperated foot. The boxplots are presented for the following regions of interest: hindfoot, lateral midfoot, medial midfoot, forefoot and toes. The star (*) indicates statistically significant difference.

They found that the peak pressure of these joints increases considerably if the arthrodesis is in equinus position. Another previous report has described increased midfoot and hindfoot load after ankle arthrodesis (Suckel et al., 2007). Beyaert et al. (2004) found in a kinematic study on patients who underwent ankle arthrodesis an earlier forward displacement of ground reaction force compared to a healthy control group. The authors concluded that this displacement leads to high stress on the mid-tarsal joints during stance phase of gait. Patients of the present study did not show higher loads in terms of peak pressure or maximum force in the hindfoot or forefoot region of the operated foot compared to the normal foot. All arthrodesis were fixed in neutral sagittal position. However, there was increased load in the lateral midfoot region of the operated foot. This might indicate a lateralization of force transmission in the stance phase of gait in patients with tibiotalar arthrodesis.

Suckel et al. (2007) found increased load of the medial column of the foot after fusion in a dynamic in vitro model of titiotalar arthrodesis. They suggested shoe modification in order to improve the load distribution of the foot. In contrast to these results our in vivo study revealed increased peak pressure and maximum force of the region of the lateral midfoot in the foot that underwent arthrodesis compared to the not operated foot.

Table 3
This table represents the results of the AOFAS score and radiographic assessment. The values are given as mean, standard deviation (SD) and range. In addition, the ideal alignment for tibiotalar arthrodesis according to Kennedy et al. is presented.

	Mean	STD, (range)
AOFAS score	79	12.26, (64–92)
Sagittal alignment	90°	2.3°, (86°–100°)
Coronal alignment	2° valgus	3.2°, (4° varus–8° valgus)

There are a number of limitations of this study. First, because of the retrospective nature of this study we were not able to obtain preoperative pedobarographic data of our patients. Secondly, our data might not be generalizable to other techniques, particularly those with other fusion positions.

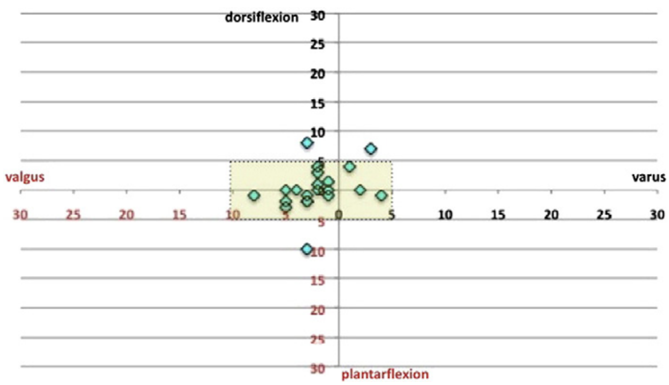
However, our single-technique ankle arthrodesis in a single-surgeon population resulted in high reliability.

According to Horisberger et al. in order to avoid the highly disturbing inter-subject variances, this study was performed with an intra-individual comparison design (Horisberger and Valderrabano, 2009). Gait velocity seems to affect plantar pressure distribution (Rosenbaum et al., 1994). In the present study plantar pressure assessment was performed using the mid-gait method because it is the most favorable way to represent normal gait patterns (Orlin, 2000; Putti et al., 2008). Patients were instructed to walk at normal speed and keep their velocity constant. Putti et al. (2008) showed that this reveals repeatable results. However, gait velocity was not recorded.

Another limitation represents the lack of normalization of the plantar pressure data to body weight. Therefore, an analysis of the correlation between the clinical and radiographic data and plantar pressure parameters was not possible.

Further research is necessary to determine if there is a difference concerning plantar pressure distribution between patients who underwent total ankle arthroplasty or ankle arthrodesis respectively for the treatment of end-stage ankle osteoarthritis. Also, the aim of

Table 4
Recommended alignment for tibiotalar arthrodesis according to Kennedy et al..The mean sagittal alignment of the patients of the present study is presented in column three, and standard deviation in column four. Ideal alignment is presented graphically. The yellow background indicates the optimal alignment.



	Ideal position[1]	Mean	STD
Sagittal alignement	5° dorsiflexion – 5° plantarflexion	0°	2.3°
Coronal alignement	5° valgus – 10° varus	3° valgus	2.8°
Total object			
Maximum force (N)		1.9 (463.0)	
Peak pressure (kPa)		−6.6 (48.2)	
Contact area (cm²)		2.4 (17.4)	
Contact time (msec)		−40.7 (252.8)	
Hindfoot			
Maximum force (N)		−24.2 (167.9)	
Peak pressure (kPa)		−11.6 (88.0)	
Contact area (cm²)		−1.0 (2.3)	
Contact time (msec)		−2.8 (109.0)	
Lateral midfoot			
Maximum force (N)		−31.8 (62.0)*	
Peak pressure (kPa)		−41.7 (114.7)*	
Contact area (cm²)		−1.2 (5.1)	
Contact time (msec)		−19.3 (168.0)	
Medial midfoot			
Maximum force (N)		−32.1 (71.0)	
Peak pressure (kPa)		−8.53 (29.69)	
Contact area (cm²)		−0.02 (3.2)	
Contact time (msec)		0.09 (176.0)	
Forefoot			
Maximum force (N)		−7.0 (621.0)	
Peak pressure (kPa)		−4.6 (191.8)	
Contact area (cm²)		0.6 (8.3)	
Contact time (msec)		50.3 (192.0)*	
Toes			
Maximum force (N)		116.3 (748.0)*	
Peak pressure (kPa)		47.0 (229.2)*	
Contact area (cm²)		2.8 (13.4)*	
Contact time (msec)		53.5 (153.2)	

* $p<0.05$.

our future research will focus on prospective investigations of plantar pressure distribution in patients with end-stage osteoarthritis of the ankle and postoperative changes when they undergo either tibiotalar fusion or total ankle replacement.

5. Conclusions

Tibiotalar arthrodesis and total ankle replacement (TAR) are the major surgical treatment options for ankle arthritis (Gougoulias and Maffuli, 2010; Haddad et al., 2007). Arthrodesis has been historically the most commonly-applied surgery for osteoarthritis of the ankle. In-vitro studies revealed that arthrodesis affects kinematics of the foot and ankle more severely than artificial joint replacement. Our results support the belief that ankle arthrodesis might not affect kinematics in terms of plantar pressure distribution for most areas of the foot.

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Please cite this article as: Schuh, R., et al., Plantar pressure distribution after tibiotalar arthrodesis, Clin. Biomech. (2011), doi:10.1016/j.clinbiomech.2011.02.001