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ORIGINAL ARTICLE

Pedobarographic assessment of 17 patients with ankle arthrodesis

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KEYWORDS
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Abstract
Aim: The aim of this study is to compare and analyse the changes in plantar pressure whilst walking, in patients with ankle arthrodesis by means of kinetic and kinematical motion analysis and plantar support studies.
Patients and method: We studied 17 patients (14 males and 3 females) with post-traumatic ankle arthrodesis (13 right side and 4 left side) with a minimum follow up of three years (3-9 years). There were no other associated lower extremity pathologies. The mean age was 40 years (26-54 yrs.) and mean weight 89kg (54-117kg). A physical examination and pedography was performed (Emed®, Novel, Munich, Germany). The foot was divided into 6 zones and we compared the fused one with the control.
Results: The fused ankle had lower total pressures, vertical forces and support area compared to the non-fused. On the other hand, the support time was greater in the fused ankle. Pressures on the heel, midfoot and forefoot were higher in the fused side. We confirmed higher pressures in the forefoot and toes in the external and central part of the fused side.
Conclusion: Pressures on the midfoot and internal and central part of the forefoot are greater after an ankle arthrodesis due to changes in the plantar arch that release support from the heel and the first toe.
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PALABRAS CLAVE
Pie;
Tobillo;
Artrodesis;
Marcha;

Valoración pedobarográfica de 17 pacientes intervenidos con artrodesis de tobillo

Resumen
Objetivo: evaluar la concordancia y la reproducibilidad en las observaciones de las líneas de radiotransparencia del componente protésico humeral en las hemiartroplastias cementadas de hombro.

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Presión plantar

Material y método: cinco observadores han evaluado 128 radiografías obtenidas de 32 hemiartroplastias cementadas de hombro en dos momentos del seguimiento evolutivo en proyecciones anteroposterior y perfil de escápula, con una reevaluación a las 3 semanas. Se han evaluado las líneas de radiotransparencia en 7 zonas alrededor del implante en las interfaces cemento-hueso y cemento-implante. Se han clasificado las radiotransparencias en cuatro categorías según el tamaño en milímetros. Se han evaluado los resultados con el método estadístico kappa.
Resultados: en el estudio de la reproducibilidad intraobservador se han obtenido para las interfaces implante-cemento y cemento-hueso índices kappa de 0 a 0,6. En el estudio de la concordancia entre observadores para cada una de las zonas e interfaces el 65%de los índices kappa obtenidos oscilan entre 0 y 0,4. La capacidad intraobservador de seguimiento en el tiempo de un mismo paciente se ha evaluado por el porcentaje de respuestas posibles de cada observador que ha oscilado entre el 85 y el 90%.
Conclusiones: hay un bajo índice de concordancia y reproducibilidad al analizar las radiotransparencias tanto en la interfaz hueso-cemento como en la de cemento-implante. También hay un bajo índice de errores al analizar la evolución de las radiotransparencias en dos radiografías del mismo implante obtenidas en dos momentos diferentes en el tiempo.
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Introduction

The treatment of post-traumatic arthrosis is one of the most controversial and debated aspects in orthopaedic ankle surgery. Even in the era of prostheses, arthrodesis of the ankle has a place among the clinical possibilities, as in cases of painful joints, with alteration of the position and marked limitation in mobility, this treatment leads to stability and pain-free weight-bearing capacity. Arthrodeses in the foot must be understood as actions to normalize support and eliminate pain.[1,2] Following Sanchís Olmos[3] we consider that arthrodeses are "those surgical procedures intended to block a joint totally by completely eliminating its mobility. It is a functional, not anatomic, concept and its purpose is purely mechanical" which led Vaquero González[4] to consider it "a mobilizing intervention".

Nowadays the main indication for this kind of surgery is considered to be a painful, rigid ankle with functional alterations, non-responsive to conservative treatment, resulting from a previous fracture, infection, osteonecrosis or arthrosis. Ankle arthrodesis has been considered as a salvage surgery in patients with moderate and intense pain, severe functional alteration and a deformity of the hindfoot, providing the tibial-talus joint is affected.[5-9] Moreover, approximately 1% of people suffer from arthrosis in the ankle joint[10] and, of these, almost three quarters of cases are a consequence of traumatic injury with fractures of the ankle or torn ligaments.[11]

The goal of ankle arthrodesis is to eliminate pain by achieving a stable fixation with an anatomically aligned hindfoot and ankle.[12] It is a procedure that obtains very good results in disabled foot and in arthropathy of the ankle and can be considered as an alternative to save the joint versus amputation in neuropathic, diabetic, degenerative or rheumatoid limbs. In addition, it resolves a serious problem without affecting daily activities. The fixation of the talotibial fibular joint is compensated for with a greater mobility of the adjacent joints, the knee and tarsal joints. In our paper, we attempt to analyze plantar pressure during gait on the side subjected to surgery in order to compare it with the healthy side and the years of its course.

Patients and methodology

We included in our study patients who had suffered an accident at work and, as a result, required arthrodesis of the ankle, and who had accepted to have all the tests required by the study. Those patients without could not be assessed, or did not wish to be assessed, were excluded, as were those patients with bilateral trauma, those with prosthetic joints in either of the lower limbs or with joint surgery related to mobility or with the weight-bearing axis in either of the lower limbs.

The 17 patients finally analyzed presented a mean age of 40 years (range 26-54 years); fourteen were male and three were female; 13 right ankles versus 4 left ankles were operated on. The mean weight of the patients was 89 kg (range 54-117 kg). Fourteen of the patients were regular smokers.

The kinds of fracture found were a tibial pilon fracture in 10 cases, in 6 a bimalleolar fracture and on one occasion, it was a consequence of osteochondritis. Eleven were closed lesions and 6 open fractures corresponding, according to the Gustillo-Anderson classification, in 5 cases to grade I, and one was grade III.

Following their accidents, 14 patients were given an open reduction with internal fixation of the lesion; one patient was stabilized with an external fixator, one had a primary arthrodesis and another was made stable with a transcalcanear Steinmann pin. The time elapsed until arthrodesis was performed was 39 months from the first

surgical procedure (range 204-6 months). The patients included in the study presented a minimum course of 3 years (range 3-9 years).

The surgical technique used was open surgery with cannulated compression screws, in all 17 patients. In 9 of the operations, crest graft was added to favour consolidation.

Following their surgery, the patients remained immobilized with a plaster boot for three months, with weight-bearing allowed after 2 months if the radiographic check-ups allowed this. With respect to deambulation aids, 80% could move around without crutches, 11% needed the assistance of walking stick and 9% needed two walking sticks at the time of the review. When they were asked about the use of ortheses or insoles for a more comfortable gait, 7 patients indicated that they used them regularly. The type of orthesis used in 6 patients was a pre-shaped insole and one required a lift of 2 cm.

Clinically, we evaluated the varus-valgus stability of the ankle: with the knee flexed at 20°, varus-valgus stability was verified manually and was considered normal when the articulation showed an opening of less than 2 mm with respect to the contralateral side; medium laxity was when the opening was between 2 and 5 mm, moderate laxity between 5 and 10 mm and severe laxity when it was greater than 10 mm. We analyzed the mobility of the sub-talar joint; the heel was mobilized and the degree of passive inversion/eversion of the posterior part of the foot was evaluated. Rotation of the foot was obtained with the patient in supine position and the patella facing the zenith; using a goniometer, the angle between the medial edge of the foot and the vertical was measured. Neutral position was given by rotation of the contralateral leg.

Sagittal mobility of Chopart's joint was assessed with the patient seated: the goniometer was placed on the longitudinal axis of the medial part of the tibia and the first metatarsal and the active mobility was measured.

Using a measuring tape, the perimeter of the calf was measured, 5 cm distal from the anterior tuberosity of the tibia in order to identify the atrophy in the gastrocnemius. As for the dissymmetry between the limb operated on and the control leg, this was determined with the subject standing barefoot. A line was drawn between the posterior iliac crests. Wooden lifts of known thickness were placed under the arthrodesed foot until the iliac crests were balanced.

Analysis of plantar pressure during gait. We studied plantar support with the foot bare, using a pedobarographic platform. The patients stood on a pedobarographic platform (Emed®, Novel, Munich, Germany) to analyze the distribution of the pressure on both feet. The pressure distribution during gait was later evaluated. The values obtained for the foot operated on and for the healthy foot used as the control were analyzed.

Patients first passed with the right foot and then with the left foot pressing down on the platform at a speed they considered normal. This was done three times and all readings were recorded unless an anomaly was observed, in which case we had them repeat the test. In this way, we obtained dynamic and static plantar support data.

Each plantar imprint was divided into 6 regions (heel, midfoot, internal area of the forefoot, the central area of the forefoot, the external area of the forefoot and the toes) to obtain the mean pressure in each of these areas (fig. 1). With the results obtained, we carried out a statistic description of all the variables studied and we analyzed the frequency of each of the variables. We analyzed the biomechanical variables comparing the arthrodesed side and the healthy side using Mann-Whitney's U test for non-parametric groups.

Results

The mean time until onset of a radiographically visible consolidation of the arthrodesis was three months.

The complications in this series were two cases of superficial infection that remitted with lavage and oral antibiotic treatment; the provision of spongy bone from the iliac crest in another case and it was necessary to operate on one patient for a re-arthrodesis. We removed the osteosynthesis material from 3 patients. Atrophy of the calf was detected as all of the patients presented an average of 2 cm less in their calf perimeter compared with the healthy side.

Of the seventeen patients studied, only one reported a sensation of instability in the sagittal plane. The mean inversion obtained in the twenty patients was 6° (range 0°-18°) and eversion was 5° (range 0°-20°). Three patients presented an external rotation, with a mean of 6° (range 5°-10°). Four patients had a similar rotation on the contralateral side; the rest, ten, presented the arthrodesed foot in internal rotation, with a mean of 8° (range 3°-15°). The mobility of Chopart's articulation in the coronal plane for patients with an ankle arthrodesis was 10° (range 0°-30°). Of these, 6° were plantar flexion (range 0°-30°) and 4° of dorsal flexion (range 0°-10°).

Five presented shortening of the limb operated on with respect to the contralateral one, with a mean of 1.25 cm (range 0.5-2 cm).

Thirteen of the seventeen patients operated on (76%) presented inflammation in the arthrodesed ankle, more marked at the end of the day. For their part, five patients (30%) indicated hyperkeratosis in the foot operated on, requiring regular attention from a chiropodist. The distribution of this hyperkeratosis was two on the head of the 5th metatarsal, the internal plantar arch, the head of the 1st metatarsal and the proximal inter-phalangeal area of the 4th toe. As for scarring, only one patient reported occasional itchiness, the remainder only indicated alterations in the pericicatricial pigmentation.

We saw that the foot operated on presented less total pressure, force, and total support area that the unoperated foot. The weight-bearing time, on the other hand, was greater in the operated foot (table 1).

The pressure in the heel, midfoot and forefoot, taken together, albeit not significant, were greater in the arthrodesed foot (table 2). By studying the three areas of the forefoot and the toes, we saw that, without reaching significance, the internal portion of the forefoot and the weight-bearing on the toes were lower in the arthrodesed foot while they increased in the central and external portions of the forefoot (table 3) (figs. 1 and 2).

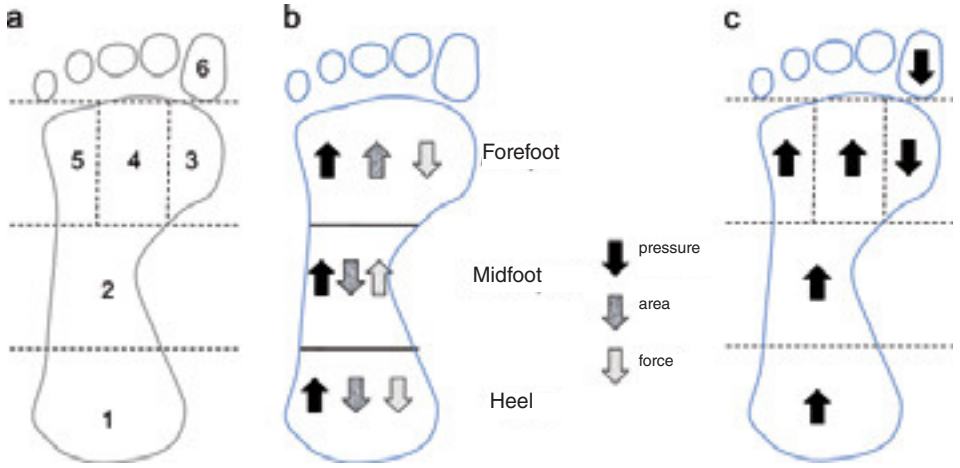

Figure 1 a) Division of the sole of the foot into six areas. b) Increase or reduction in the forces, areas and pressures comparing the operated side with the control side. c) Increase or reduction in the pressure comparing the operated side with the control side.

Table 1 Plantar support parameters in the foot with arthrodesis and the contralateral foot

Group	Total pressure		Total force		Total area		Total weight-bearing time	
	X	SD	X	SD	X	SD	X	SD
Operated on	706.47	254.01	970.18	196.41	130.05	16.87	1,298.00	183.3
Not operated on	747.35	242.40	999.06	189.26	183.88	20.26	832.94	193.77

Table 2 Plantar pressure, force and weight-bearing area in three areas of the foot

Foot area	Pressure		Force		Area	
	X	SD	X	SD	X	SD
Heel						
With arthrodesis	399.12	87.08	745.76	207.59	63.35	24.33
Without arthrodesis	333.53	91.11	825.82	247.23	69.82	23.56
Midfoot						
With arthrodesis	271.18	95.17	894.82	196.82	95.00	19.19
Without arthrodesis	232.41	103.62	873.29	190.72	100.29	26.53
Forefoot						
With arthrodesis	621.82	282.02	918.94	199.44	75.18	23.71
Without arthrodesis	617.35	206.21	968.52	165.00	60.18	16.97

Discussion

We have considered a study of ankle arthrodesis as a consequence of traumatic injury in the workplace. Albeit small, the population under study engages in normal daily life providing no great effort is required. We must not forget that, in all cases, the aetiology was the result of serious accidents with an uncertain functional future.

In our study we have always compared the operated ankle against its contralateral, unoperated limb, on many occasions referred to as healthy, and we have used this limb as the control leg, although we know it may suffer from pathology, radiographic changes and compensatory modifications or biomechanical alterations as a consequence of the arthrodesis of the other ankle. Nonetheless, this seems to us to be more reliable than to look for an external control group.

When footwear is used, they can all walk pain-free on regular terrain and arthrodesis has allowed them to return to their previous occupations and recreational activities. The specific problems referred to, within daily activities, following ankle arthrodesis include climbing stairs, rising from a seat, walking on irregular surfaces and running. Patients generally have a low level of satisfaction as they are forced to need assistance or to wear permanently altered footwear.

The results of Buck et al.[13] reflect that a vagus position of the ankle is advantageous and provides a more normal gait. For their part, Said et al.[14] analyzed the gait in 11 patients: those who could walk best had their ankle position at a right angle with a discreet equine inclination and a pseudo-dorsiflexion of 5° or more and pseudo plantar flexion of 20° or more, taking advantage of the rest of the mediotarsal joints. An arthrodesis with a discreet equine position has been said to favour the weight-bearing phase and the

Table 3 Pressure in the regions of the forefoot and the toes

Group	Internal forefoot		Central forefoot		External forefoot		Toes	
	X	SD	X	SD	X	SD	X	SD
Operated on	260.88	117.87	611.17	213.40	290.23	125.35	410.00	146.28
Not operated	352.35	210.49	519.12	246.32	255.88	97.61	524.71	274.75

Figure 2 Three-dimensional plantar pressures of cases. Case 1: a) Right control foot. b) Left foot operated on, with increase in pressure in heel and forefoot. Case 2: c) Right control foot with increased pressure in central and internal areas of the forefoot and the toes. d) Arthrodesed foot with increase in midfoot and central forefoot.

hindfoot in a discreet valgus or in neutral position has been said to avoid weight-bearing on the lateral edge of the foot, diminishing the risk of pain in this area and the formation of calluses. On the other hand, external rotation of the foot allows good mobility of the knee, while preventing it from turning externally, during the weight-bearing phase, which may give rise to laxity in the internal lateral ligament. Moreover, a discrete shortening is also beneficial as it facilitates the take-off of the foot during the oscillating phase of the gait.[15]

For some authors[16,17] the final functional outcome depends on the so-called tibia-foot mobility and not the position of the ankle, although no correlation has been found between mobility and the final outcome.[16,18]

Ankle arthrodesis results in an effective treatment, as it relieves pain and restores the function as reflected in the increased stride length on the side operated on and not operated on compared with prior to surgery. The gait in patients with ankle arthrodesis was studied by Mazur et al.[16] who demonstrated that loss of movement in patients with ankle arthrodesis was compensated for by the movement of the neighbouring small joints and provoking altered mobility in the contralateral leg. Subsequently, Buck et al.[13] used three-dimensional electrogoniometers to show that a valgus arthrodesis is advantageous and provides for a more normal gait cycle. Astion et al.[19] pointed out that arthodeses that include the talus-scaphoid joint limit the movements of the neighbouring joints by about 2°, while Wu et al.[20] saw an increase in movement in the coronal plane of the hindfoot, a reflection of an increase in the foot's eversion during the weight-bearing phase. Mann and Rongstad[21] demonstrated a loss of 74%of the movement in the sagittal plane and, much more significantly, the loss of 70% in the inversion and eversion movements in arthrodesed patients.

Mazur et al.[16] saw that arthrodesis of the ankle diminished stride length and gait velocity. With adequate footwear, all patients returned to their initial occupations and leisure activities, but they showed considerably more limitations barefoot. Waters et al.[22] also saw a drop of 84% in gait velocity with respect to normal whereas Thomas et al.[23] showed a diminished stride length and a shortening in the monopodal weight-bearing phase. Moreover, patients with

ankle arthrodesis significantly diminished the ranges of movement in all spatial planes, in both the hindfoot and forefoot, during the weight-bearing phase and the oscillation phase of the gait cycle.

Our study has been focused on the analysis of the plantar pressures as a whole and the footprint divided into six areas. We have seen that the surface, the vertical force and the weight-bearing pressure are less in the arthrodesed foot than in the control foot although the weight-bearing time is greater in the foot operated on. This indicates a biomechanical alteration in an attempt to bear the weight with less intensity for a longer period of time. Looking at the regions, we have seen that the pressure on the heel, midfoot and forefoot taken together were greater than in the control foot. This may be due to the modification of the structure of the plantar vault after surgery with the functional loss of the so-called second fulcrum.[21] Nonetheless, analyzing the forefoot and the toes divided into four regions we observe that the internal portion of the forefoot and the take-off on the big toe were less in the arthrodesed foot whereas the pressure increased in the central and external portions of the forefoot. In other words, there is a displacement of the load during the foot's take-off from the ground and, instead of pushing on the internal part, taking advantage of the first metatarsal-phalangeal joint, it does so on the head of the three external metatarsals. This is an important change in the biomechanics of the gait and may be triggered by supination of the forefoot or eversion of the sub-talar joint directly caused by the surgery.

We have not found any significant differences due to the variability of the cases and eh sample size. We should also stress that the control foot, albeit referred to as healthy, has to adapt to the function of the foot operated on. Another noteworthy detail is that the patients were analyzed barefoot, which complicates their gait as seven of them need to wear some kind of orthesis together with their footwear to protect them when bearing down on the ground.

The time needed to achieve a well-established function requires an adaptation period of between a year and eighteen months following arthrodesis. After this time has elapsed, despite the opinions expressed by numerous authors,[24-26] the evolution stabilizes without degrading over time. For this reason, it is preferable to carry out arthrodesis early as excessive delay may lead to the operation being effected on a foot with arthrosic joints.[17]

Conflict of interest

The authors declare that they have no conflict of interest.

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