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Study of plantar pressure patterns by means of instrumented insoles in subjects with hallux valgus

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Introduction. The pressures exerted on the forefoot in a condition like hallux valgus have been the subject of much debate, with dissimilar results. This article aims to compare the pressures borne by the forefoot in a group of normal feet with those it bears in a group of feet with mild or moderate hallux valgus.
Materials and methods. A study was performed of 60 subjects (30 with hallux valgus and 30 with normal feet), who were analyzed with the Biofoot/IBV instrumented insole system. The system uses a series of thin insoles (0.7 mm-thick) with 64 piezoelectric sensors. Maximum pressure was analyzed in seven regions, i.e. the five metatarsal heads, the hallux and the lesser rays.
Results. Maximum pressure peaks in the control group were measured significantly in the second and third metatarsal heads (p = 0.001). The hallux valgus group had its pressure peaks at the first metatarsal head and at the hallux (p = 0.001). The presence of pressure peaks at the first ray points to pronation as the factor leading to hallux valgus.
Conclusions. Instrumented insole systems are an excellent tool to analyze normal and pathological pressures. More detailed studies are necessary to come to more definite conclusions. In future, different research ways could be followed such as the study of pressures at pre-established values of cadence and speed of gait and with different kinds of footwear.

Key words: *foot, pressure, hallux valgus, baropodometry, biofoot.*

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Estudio del patrón de presiones plantares en pies con *hallux valgus* mediante un sistema de plantillas instrumentadas

Introducción. Las presiones que soporta el antepié en una patología como el *hallux valgus* ha sido un tema discutido, con resultados dispares. Este artículo pretende comparar las presiones soportadas por el antepié en un grupo de pies normales y en un grupo de pies con *hallux valgus* leves o moderados.
Material y métodos. Se realiza un estudio en 60 sujetos (30 con *hallux valgus* y 30 con pies sanos), que son analizados con el sistema Biofoot/IBV de plantillas instrumentadas. El sistema emplea unas finas plantillas (0,7 mm de grosor) con 64 sensores piezoeléctricos. Se analiza la presión máxima en siete regiones, las cinco cabezas metatarsales, el *hallux* y los dedos menores.
Resultados. Los picos máximos de presión en el grupo control se localizaron significativamente en segunda y tercera cabeza metatarsal (p = 0,001). El grupo de pies con *hallux valgus* registraron picos en la primera cabeza y en el *hallux* (p = 0,001). La localización de los picos de presión en el primer radio sugiere la pronación como factor desencadenante del *hallux valgus*.
Conclusiones. Los sistemas de plantillas instrumentadas son excelentes para analizar las presiones normales y patológicas. Son necesarios estudios más amplios para llegar a conclusiones más precisas. Se abren diferentes vías de investigación, como el estudio de las presiones a cadencias y velocidades determinadas y con diferentes calzados.

Palabras clave: *pie, presión,* hallux valgus*, baropodometría, biofoot.*

The technical development of devices for baropodometric analysis has made it possible for progress to be made with studies of healthy and diseased feet. Electronic baropodometrics make it possible to ascertain the distribution of plantar pressures and to quantify the transmission of weight to the foot. This is a supplementary method to clinical examination, and is very useful to gain further knowledge of diseases of the foot. Baropodometrics has been used to analyze the distribution of pressure in healthy feet, to study the pressure patterns with different footwear, to prevent foot deformities, to design and test orthopedic devices, to prevent and treat alterations in the feet of diabetics, to study plantar pressure patterns in sports medicine and rehabilitation, to design footwear, as well as to assess diverse surgical treatments[1-13].

Analysis and numerical quantification of plantar pressures make it possible to ascertain the behavior of feet and to determine clinical and functional outcomes after treatment: surgical, rehabilitative or orthopedic. The aim of this article is to analyze the measurement of pressure on the forefoot in patients with *hallux valgus* and compare these measurements with those seen in a control group with healthy feet.

MATERIALS AND METHODS

A prospective study was carried out with 60 subjects (n = 60), in whom baropodometric measurements were taken after obtaining their informed consent. The procedures followed are approved by the center's Ethics Committee according to the Helsinki declaration.

There were 60 feet (30 subjects) in the control group. The people included in this group had to be free of morphological alterations, evident deviations between hindfoot and forefoot and pain. There were 60 feet (30 subjects) in the *hallux valgus* group. The people included in this group had to suffer from slight to moderate *hallux valgus,* with no marked deformities and moderate symptoms.

Biofoot (IBV; Valencia, Spain) instrumented insoles were used in this study. Each insole has 64 electrical sensors distributed selectively and a thickness of 0.7 mm (Figure 1). The insoles are connected to 2 amplifiers connected by a cable to a transmission module which is attached to the subject's waist. This module transmits data telemetrically to a computer with a data reception card and software that records and analyzes the data received. This system has a range of 200 m and a battery life of 3 hours, which makes it possible to carry out field tests. This system makes it possible to capture numerical pressure maps with frequencies from 50 to 250 mHz (figure 2). The unit of measurement is the kilopascal (1 kpa = 1/98kg · cm^2).

All the subjects are made to walk down a 40 meter passage in the same direction and under the same conditions of temperature and humidity. The subjects are requested to wear comfortable footwear, with a heel not higher than 4 cm. The subject is connected to the equipment, and the insoles are adapted to the size of the subject's footwear (Figure 3). Subjects have the instrumented insoles in their footwear for a few minutes before any measurement is registered. The system is calibrated according to the manufacturer's instructions. Data is registered while the subject walks and continues during 6 seconds at 100 mHz, a frequency that allows the register of sufficient maps for analysis. This measurement allows the capture of data related to 5 or 6 steps taken by each foot.

The following subject data was collected: age, sex, height and weight. Of the measurements acquired during

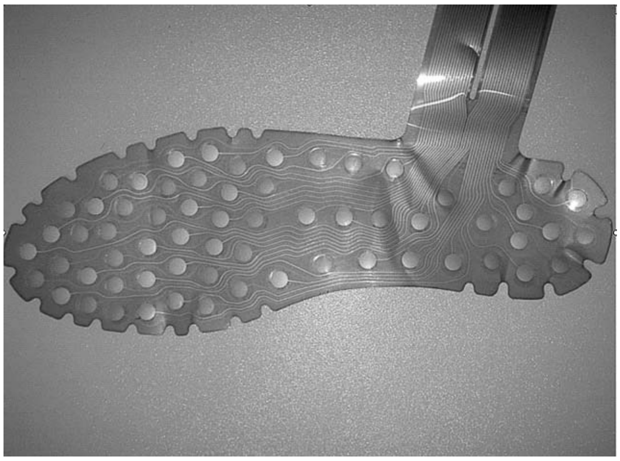

Figure 1. *Insole with 64 electrical pressure sensors.*

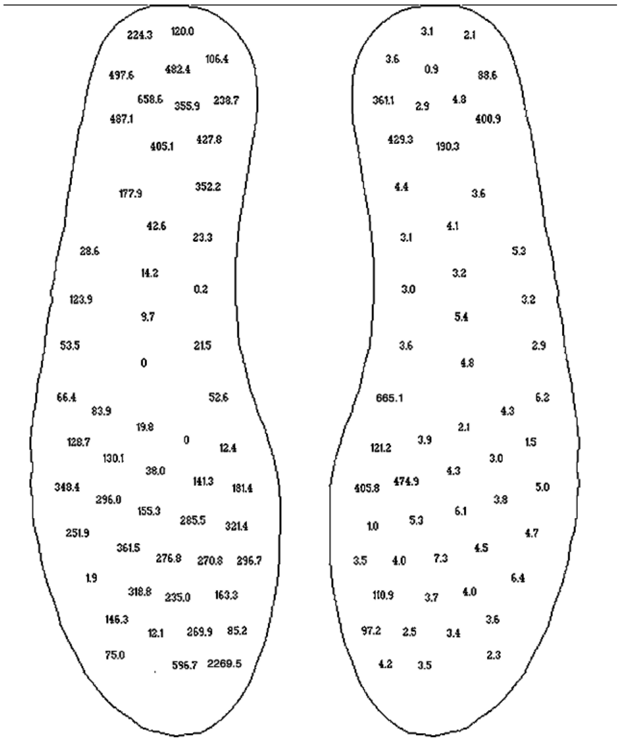

Figure 2. *Numerical graph showing the pressure detected by each sensor.*

Figure3. *System of instrumented insoles adapted to the subjects footwear.*

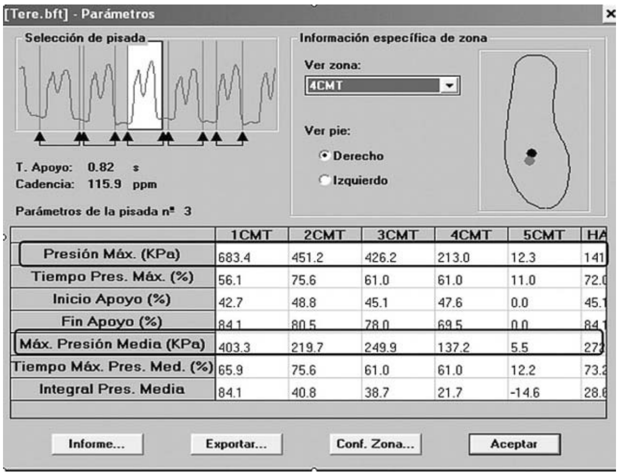

Figure 4. *Parameters used in the study. Maximum pressure peak for each zone selected.*

the test one central step for each foot is selected. The steps with aberrant graphs or evident signs of error or truncation are discarded. The forefoot is divided into 7 zones: first, second, third, fourth and fifth metatarsal head, *hallux* and second to fifth toes. The peak of maximum pressure for each zone is analyzed (Figure 4). The data was processed using SPSS software in 13.0 for Windows.

With the aim of studying independent values at the level of the metatarsal heads, *hallux* and toes, an analysis of variance (ANOVA) is performed. A confidence interval of 95% is established. Therefore, differences are considered statistically significant when the associated p is less than 0.05 ($p < 0.05$).

RESULTS

The mean age of the study population is 29 ± 11 years. The mean pressure value for each zone can be seen in Table 1. The pressures in the control group were greater than in the *hallux valgus* group, since weight in the control group was significantly greater (p = 0.007) than in the *hallux valgus* group.

Pressures in the control group were in this order: third metatarsal head (MTH) (p = 0.001), second MTH (p = 0.001), *hallux*, first MTH, fourth MTH, fifth MTH and toes. Pressure peaks in the *hallux valgus* group were in this order: *hallux* (p = 0.001), first MTH (p = 0.001), third MTH, second MTH, fourth MTH, fifth MTH and toes.

In the control group there were significant differences at the level of the third and second metatarsal heads. There were no significant differences seen at the level of the other metatarsal heads. In the

Hallux valgus group, significant differences were seen at the level of the *hallux* (first toe) and at the level of the first metatarsal head.

DISCUSSION

There are 2 groups of devices for baropodometric assessment: pressure platforms and instrumented insoles. Pressure platforms are fixed surfaces with a certain number of pressure sensors. This surface, that may be a platform or a walkway passage, is connected to a computer that shows the pressure map obtained. This is a clinical system that is useful for static and dynamic measurements. For dynamic measurement, this system is less precise, since the steps must be in the right places on the platform and measurements are taken of barefoot subjects. Instrumented insoles are devices made of flexible material that are placed within footwear. The system has a transmitting module that transmits data telemetrically to a computer. The number of sensors is variable; the greater the number of sensors the more trustworthy the measurements. We consider the insole system of greater interest, since it detects plantar pressures in a more physiological manner, with the patient wearing footwear and walking freely. There are not many studies that assess *hallux valgus* with instrumented insoles. The most frequently used system to assess *hallux valgus* up to now has been the EMED pressure platform.

Different results on weight distribution in *hallux valgus* have been found in the literature. Authors such as Bryant et al[14] and Nyska et al[15] find that in feet with *hallux valgus* there is an increase in pressure in the medial zone of the forefoot. Both studies were carried out using the EMED system.

Yamamoto et al found the first pressure peak in *hallux valgus* at the level of the first metatarsal head and the second peak at the level of the second or third metatarsal head. They saw that the pressure peaks were greater in feet with *hallux valgus* than in normal feet[14]. In this study a pressure sensitive film was used, which is a less trustworthy system

Table 1. Pressure located at each metatarsal head, *hallux* and toes

	Type	N	Mean	Standard deviation	Standard error (mean)
Pressure 1	Normal	60	529.166	272.5844	50.6177
	Hallux valgus	60	651.874	503.4173	90.4164
Pressure 2	Normal	60	617.979	406.7727	75.5358
	Hallux valgus	60	429.055	241.3868	43.3543
Pressure 3	Normal	60	959.528	479.9142	89.1178
	Hallux valgus	60	557.126	401.6190	72.1329
Pressure 4	Normal	60	519.055	388.4641	72.1360
	Hallux valgus	60	414.045	308.2967	55.3717
Pressure 5	Normal	60	459.017	334.3268	62.0829
	Hallux valgus	60	239.832	179.9038	32.3117
Pressure H	Normal	60	653.597	450.4984	83.6554
	Hallux valgus	60	691.068	512.4130	92.0321
Pressure D	Normal	60	244.076	128.4824	23.8586
	Hallux valgus	60	212.458	145.9723	26.2174

Pressure 1. Maximum pressure at the level of the first metatarsal head.
Pressure 2. Maximum pressure at the level of the second metatarsal head.
Pressure 3. Maximum pressure at the level of the third metatarsal head.
Pressure 4. Maximum pressure at the level of the fourth metatarsal head.
Pressure 5. Maximum pressure at the level of the fifth metatarsal head..
Pressure H. Maximum pressure at the level of the *hallux* (first toe).
Pressure D. Maximum pressure in the rest of the toes.

for the quantification of plantar pressures. Planck, with the Musgrave system, located pressure peaks in *hallux valgus* subjects on the third metatarsal head, followed by the second metatarsal head and lastly the first metatarsal head[15]. Bryant et al, in a study carried out with 90 subjects, found that feet with *hallux valgus* had greater pressure on the first, second and third metatarsal head, although this was only significantly greater on the second metatarsal head when compared with healthy feet[16]. Waldecker, in 2002, carried out a study with 100 patients, 50 with symptomatic *hallux valgus* and 50 with asymptomatic *hallux valgus.* In the group of symptomatic patients load patterns on the lateral part of the forefoot were significantly greater than in asymptomatic patients. Subsequently, in another similar study with patients with moderate to severe *hallux valgus* it was seen that loads are transferred from medial to lateral. Pressure increased on the lateral area of the forefoot (29%), and decreased on the first toe (5.6%)[17,18]. Resch et al using the FSCAN system of instrumented insoles found that pressures on the first, second, and third metatarsal head and first toe were 15, 20, 20 and 13% respectively. After surgery, the percentage of pressure on the head of the first metatarsal and first toe decreased, while it increased on the second and third metatarsal head[11]. Nyska et al, in a study carried out with 29 subjects found that in feet with *hallux valgus* there was an increase of the loads on the medial part of the forefoot[19].

In our study, the control group showed greater pressures on the second and third metatarsal heads. These results could be explained by the Doncker and Kovalsky theory. The foot has a central plate (second-third metatarsal) and two lateral plates (first metatarsal and fourth-fifth metatarsal). The central plate is relatively fixed, due to its anatomic structure, since the second and third metatarsal are stuck between wedges[20]. The function of the lateral plates, which possess a greater range of movement than the second and third metatarsals, is to stabilize. The results seen in the control group coincide with those obtained by Bryant et al[16] and Resch et al[11].

Llanos Alcázar et al[21] showed that during normal gait the load supported by the first and second metatarsal is greater than the pressure at other levels. The second metatarsal supports more pressure since it is usually longer and more rigid than the others. On assessing the changes seen after osteotomies of the first metatarsal, determined by podobarography, it has been seen that 50% of patients presented with a decrease in the pressure on the first toe. In the toe off phase, when the foot leaves the ground, during mean metatarsal support, pressure is on the second and third metatarsal heads. These changes seen in the foot after surgery, come close to the normal values seen in this study.

In this study, the subjects in the *hallux valgus* group were seen to have pressure peaks on the first toe and the first metatarsal head. In patients with *hallux valgus* the first metatarsal rotates in *varus* and dorsiflexion. The first toe rotates in *valgus* and plantar flexion. This plantar flexion observed in *hallux valgus* leads to an increase in the pressure in the area. These results, with an increase in the pressure on the internal column of the foot (first toe) suggest that pronation is an important factor in the development of this deformity with multifactorial causes. In this group of patients, plantar pressure does not seem to support the theory of central metatarsal head overloading in cases of *hallux valgus.*

The results seen in feet with *hallux valgus* coincide with the results reported by Kernozek et al[12,13] and Waldecker[17,18]. Waldecker, in a study carried out with symptomatic and asymptomatic *hallux valgus* patients, found that the loading patterns on the lateral part of the forefoot were significantly greater in asymptomatic than in symptomatic patients, and that asymptomatic patients had unchanged pressure patterns on the medial part.

The patients in this study had slight to moderate *hallux valgus*, so, as described by Waldecker, pressures were maintained on the first toe. It is probable that, if our group of patients had had severe *hallux valgus* the load would have been transferred to the central metatarsals.

In conclusion, we can say that, in the control group, maximum plantar pressures were exerted on the third and second metatarsal head, whereas in the *hallux valgus* group they were exerted on the *hallux* (first toe) and the first metatarsal head. In this group of patients, plantar pressure would not explain the theory of overloading of the central metatarsal heads. Baropodometric systems are an excellent method for the analysis of the healthy and diseased foot. Larger-scale studies must be carried out to obtain firmer conclusions.

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Conflict of interests

The authors have declared that they have no conflict of interests.