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ORIGINAL COMMUNICATION

Plantar Pressure Distribution Analysis in Normal Weight Young Women and Men With Normal and Claw Feet: A Cross-Sectional Study

G. GRAVANTE,[1] F. POMARA,[1] G. RUSSO,[1] G. AMATO,[1] F. CAPPELLO,[2] AND C. RIDOLA[2*]

[1]*Sezione di Fisiologia umana, Dipartimento di Medicina Sperimentale, Università di Palermo, Palermo, Italy*
[2]*Sezione di Anatomia umana, Dipartimento di Medicina Sperimentale, Università di Palermo, Palermo, Italy*

We analyzed the plantar support in 72 normal-weight young voluntaries (46 women, 26 men), by a baropodometric platform. We considered subjects with claw foot (CFS) and subjects with normal foot (NFS). We found a significant reduction of total plantar support surface in the CFS ($P < 0.0001$ for women, $P < 0.001$ for men), due to the reduction of the forefoot and rear foot areas of both plantar imprints. Indeed, CFS of both sexes exhibited higher values of both plantar pressure and peak pressure, compared to the NFS. Moreover, the load per units of plantar surface increased in CFS compared to the NFS. In conclusion, the reduction of plantar support surfaces in CFS of both sexes was associated to a major load per units of plantar surface in the forefoot and rear foot areas, and this may be a risk factor to lower extremity overuse injuries. Clin. Anat. 18:245–250, 2005.

Key words: baropodometer; claw foot; plantar pressure distribution

INTRODUCTION

Claw foot is a clinical condition of plantar support with absence or reduction of support on the ground of midfoot (isthmus). Podogram, baropodometer, and X-ray imaging can help in its clinical identification and distinguishing between different levels of claw foot identified in the study of Filipe (1993). Many factors can be responsible for the claw foot. The congenital claw foot can be caused by plantar flexion of the first ray, as shown by Schuster (1939). Spasticity or contraction of the peroneus longus muscle can induce claw foot by a plantar flexion of first ray, like other conditions in the study of Root et al. (1977) including hyposthenia or flaccid paralysis of peroneus brevis or peroneus longus muscles, spasticity of tibialis anterior muscle, contraction of tibialis posterior muscle. In neurologic involvement (spasticity), the peroneus longus muscle action leads to claw foot deformity, commonly evidenced in conditions such as Charcot Marie Tooth Disease.

In children, the claw foot can be temporarily present and disappear or correct itself during adolescence, as shown by ScLuster (1958). Mono- or bi-lateral claw feet can be clinically silent or associated with different diseases and the condition is considered a specific risk factor for different pathologies of bones, joints, and muscles, such as the plantar fasciitis (see Warren et al., 1984, 1987). Using a baropodometer, the present study verifies the influence of bilateral claw foot on the plantar support surfaces and loads in normal weight subjects of both sexes, excluding overweight and obesity, which significantly modify the plantar support (Hills et al., 2001; Gravante et al., 2003).

MATERIALS AND METHODS

We randomly selected 72 normal weight voluntary subjects (29 women and 16 men with normal feet, 17 women and 10 men with bilateral claw foot).

*Correspondence to: Prof. Carlo Ridola, Dipartimento di Medicina Sperimentale, Sezione di Anatomia Umana, Università di Palermo, Via del Vespro 129. CAP 90127, Palermo, Italia.
E-mail: francapp@hotmail.com

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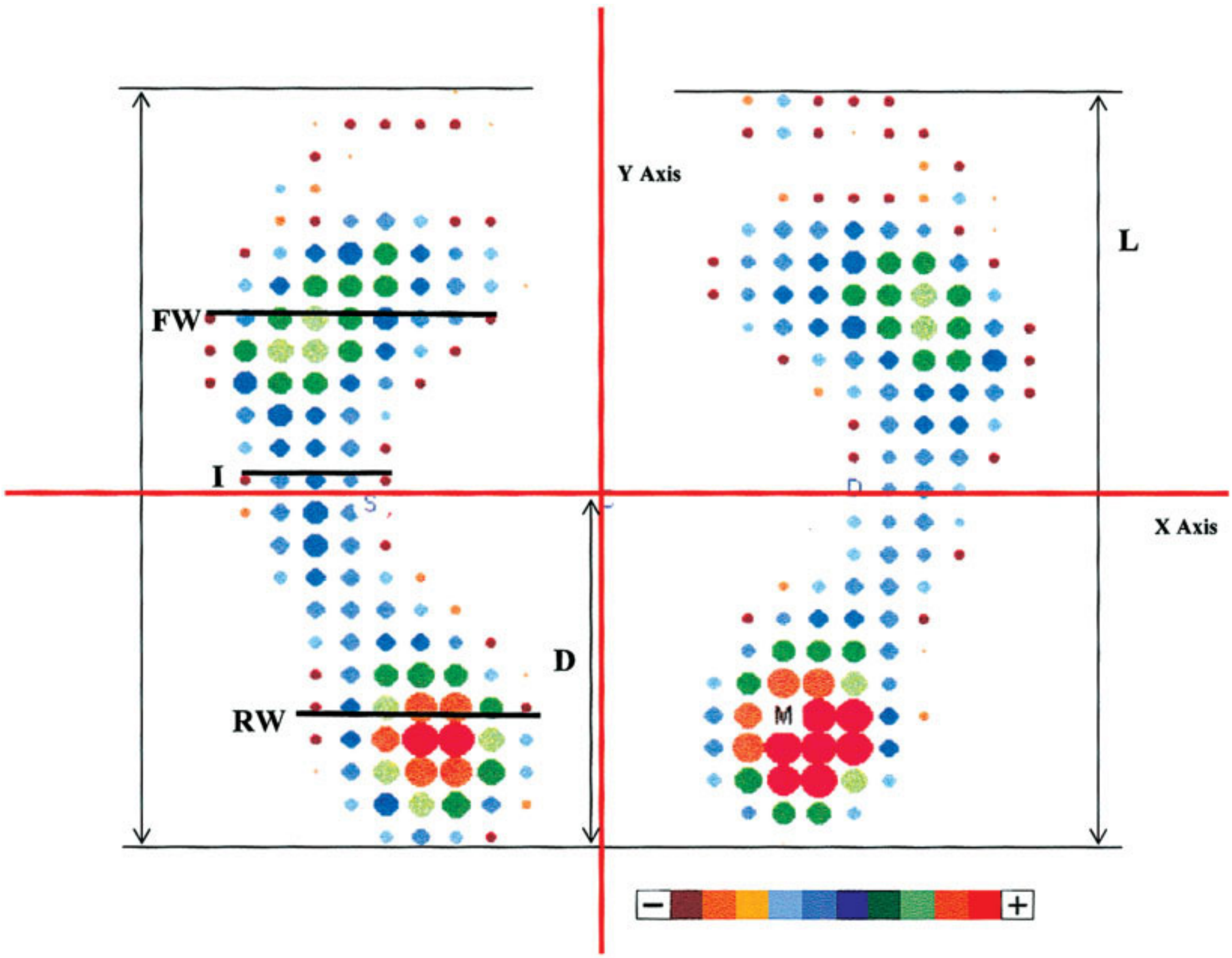

Fig. 1. Geometric measurements on plantar imprints recorded with the force platform: D, the orthogonal distance of the CP from the tangent line to the rear edge; FW, the greatest forefoot width; I, the least midfoot width (isthmus); RW, the greatest rear foot (posterior heel) width; L, maximum length of plantar imprints. Plantar imprint is divided into two regions, forefoot area (FA) and rear foot area (RA), through an axis positioned on the point graphically representing the mean location of the CP during the recording 5-sec time interval. Force vectors are represented as percentages of the peak pressure (M) with different sizes and colors, according to a chromatic scale.

We recorded the body weight to the nearest 100 g using a balance (SECA 709, Hamburg, Germany), and the stature to the nearest 1 mm using a wall-stadiometer (SECA 220, Hamburg, Germany). Considering the indications of the World Health Organisation (1998), the body mass index (BMI = kg/m^2; normal weight subjects = 18.5–24.9) was calculated to exclude preliminarily from the study overweight (25 $<$ BMI $\leq$ 29.9) and obese (BMI $\geq$ 30) subjects. We also excluded the subjects with orthopaedic and nervous pathologies considering their familiar and personal medical history. The same researcher carried out an accurate objective examination of the spine (using scoliosometer Chinesport, Udine, Italy), the limbs, and the sensory organs (using Fukuda and Romberg tests, opened and closed mandible tests, Barrè vertical test). We excluded subjects with spine, limbs, and sensory deficits.

The evaluation of ground midfoot contact for each foot was based on the I:FW ratio between the least midfoot width (or isthmus, I) and the greatest forefoot width (FW), measured to the nearest mm on the paper copy of the plantar imprints recorded with a force platform (Fig. 1); an I:FW ratio = 0 for both foot imprints was indicative of bilateral claw foot and an I:FW ratio comprised between 0.33 and 0.66 for both foot imprints was indicative of bilateral normal foot. We excluded subjects with unilateral claw

TABLE 1. Age and Biometrical Data of the Groups[a]

	Women with normal foot (n = 29)	Women with claw foot (n = 17)	P-value (ANOVA)	Men with normal foot (n = 16)	Men with claw foot (n = 10)	P-value (ANOVA)
Age (years)	22.00 ± 3.15	22.59 ± 4.12	NS	24.25 ± 5.05	25.00 ± 5.94	NS
Stature (cm)	160.32 ± 6.58	159.10 ± 7.25	NS	176.45 ± 7.85	175.45 ± 5.54	NS
Body weight (kg)	55.79 ± 7.09	55.88 ± 8.83	NS	69.84 ± 9.33	68.15 ± 6.56	NS
BMI (kg/m^2)	21.62 ± 1.48	22.07 ± 3.06	NS	22.36 ± 1.88	22.12 ± 1.66	NS

[a]Mean ± SD. NS, no significance.

foot, bilateral incomplete claw foot, and uni- and bilateral flat foot (I:FW ratio > 0.66). On the paper copy, we also measured the maximum length (L) of plantar imprints and the maximum width of rear foot area (RW), equivalent to posterior heel.

For the pressure distribution analysis, we used an electronic modular clinical baropodometer (BPE model 120, Physical Support, Milan, Italy). This instrument has three components: (1) a 40-cm wide modular platform, composed by three elements, the central one being 120 cm long and containing 4,800 rigid sensors; each sensor area is 1 cm^2, for a total surface of 4,800 cm^2 (one sensor per cm^2 resolution); sensors are part of a matrix of active resistance incorporated in an electronic circuit and covered with an ''artificial skin,'' a layer of conductor rubber, of a known thickness, which deforms under the pressure of the feet (the rubber transmits the load applied to the underlying sensors, recording plantar pressures up to 100 kg/cm^2); (2) a computer with a 200 Mhz Pentium processor and a SVGA video card, which records and analyses the sensors input (pressure/current) through a specific program (Physical Gait Software 2.5); and (3) the peripherals (a monitor and a color printer).

In the baropodometric analysis, the subjects were asked to stand bipedally on the force platform with their bare feet side-by-side, and the superior limbs extended along the body, looking at a fixed point in front of them. On the plantar imprints, the software acquires during 5-sec time interval the distribution of mean pressures and location of their centre (Centre of Pressure, CoP). In the plantar imprints were also shown the maximum pressure point (peak), indicated with ''M,'' which was also expressed in g/cm^2 and all the other support points with different sizes and colors, according to a chromatic scale (Fig. 1). Plantar imprints of both feet were divided by software into two regions, forefoot area (FA) and rear foot area (RA), expressed in cm^2 and in % of total foot load, through an axis positioned on the point ''C'' graphically representing the CoP.

Conventional descriptive parameters were used (mean ± standard deviation, minimum and maximum value). Differences between groups were compared by the analysis of variance, using ANOVA test, with a commercial software (Instat, GraphPad Software, San Diego, CA). The P-value was considered to be statistically significant when <0.05.

RESULTS

Age and biometrical data of the subjects of both sexes are shown in Table 1. As expected, no statistically significant difference was evidenced between the groups.

Table 2 shows the plantar surfaces recorded with the baropodometric platform. In both sexes, the group with claw feet (CFS) exhibited a significantly lower total plantar support surface ($P < 0.001$ for women, $P < 0.001$ for men) compared to subjects with normal feet (NFS), due to a reduction in both the plantar imprints of the rear ($P < 0.0001$ for women, $P < 0.0005$ for men) and forefoot ($P < 0.005$ for women, $P < 0.01$ for men) areas.

TABLE 2. Plantar Surfaces Recorded to Baropodometer[a]

	Women with normal foot (n = 29)	Women with claw foot (n = 17)	P-value (ANOVA)	Men with normal foot (n = 16)	Men with claw foot (n = 10)	P-value (ANOVA)
Right plantar surface	130.83 ± 11.57	105.41 ± 15.68	<0.0001	151.44 ± 14.28	121.80 ± 17.26	<0.0001
Left plantar surface	125.31 ± 12.50	111.12 ± 12.67	0.0006	149.06 ± 16.32	128.00 ± 21.94	0.0098
Forefeet surface	141.41 ± 14.42	126.18 ± 16.20	0.0019	167.00 ± 16.92	146.90 ± 19.12	0.0098
Rear feet surface	114.72 ± 8.58	90.35 ± 11.83	<0.0001	133.50 ± 13.16	102.90 ± 21.58	0.0001
Total surface	256.14 ± 21.33	216.53 ± 26.58	<0.0001	300.50 ± 28.73	249.80 ± 38.88	0.0008

[a]Mean ± SD; cm^2.

TABLE 3. Mean and M Peak Pressures (g/cm^2), % Plantar Loads of the Groups[a]

	Women with normal foot ($n = 29$)	Women with claw foot ($n = 17$)	P-value (ANOVA)	Men with normal foot ($n = 16$)	Men with claw foot ($n = 10$)	P-value (ANOVA)
Forefeet mean pressure (g/cm^2)	195.99 ± 29.29	231.49 ± 49.29	0.0036	211.83 ± 29.48	259.78 ± 46.73	0.0036
Rear feet mean pressure (g/cm^2)	247.81 ± 40.55	304.68 ± 67.56	0.0009	261.15 ± 42.39	311.71 ± 79.95	0.0451
Feet mean pressure (g/cm^2)	217.86 ± 34.45	261.41 ± 53.44	0.0016	235.06 ± 34.56	281.90 ± 61.15	0.0194
M peak pressure (g/cm^2)	477.55 ± 94.65	601.53 ± 132.99	0.0006	512.19 ± 85.90	632.50 ± 157.01	0.0182
Right foot load (%)	50.38 ± 4.30	48.12 ± 2.85	NS	49.75 ± 3.07	48.80 ± 1.81	NS
Left foot load (%)	49.62 ± 4.30	51.88 ± 2.85	NS	50.25 ± 3.07	51.20 ± 1.81	NS
Forefeet load (%)	49.34 ± 2.77	51.53 ± 4.57	0.0484	50.44 ± 2.78	55.10 ± 4.28	0.0025
Rear feet load (%)	50.66 ± 2.77	48.47 ± 4.57	0.0485	49.56 ± 2.78	44.90 ± 4.28	0.0025

[a]NS, no significance.

Table 3 shows the plantar loads recorded with the baropodometric platform. Women with claw feet exhibited significantly greater values (g/cm^2) on the forefoot and rear foot areas, M peak, and mean pressure compared to women with normal feet. Similarly, men with claw feet exhibited significantly greater values (g/cm^2) on the forefoot and rear foot areas, M peak, and mean pressure compared to men with normal feet. Relative to % load distribution of all groups, there was no difference between the feet, whereas we found a significant % overload in forefoot areas in CFS ($P < 0.05$ for women, $P < 0.005$ for men) compared to NFS. Consequently, in both sexes, the CFS had a reduction of % load on the rear foot areas. For all groups, the M peak was mainly located in the right posterior heel and resulted greater in subjects with claw feet ($P < 0.001$ for women, $P < 0.05$ for men) compared to subjects with normal feet; the same applied for the plantar mean pressure ($P < 0.005$ for women, $P < 0.05$ for men). Table 3 also shows the load (g) for units of plantar surface recorded by baropodometric platform: women with claw feet exhibited significantly greater values on the forefoot ($P < 0.005$) and rear foot areas ($P < 0.001$), compared to women with normal feet. Similarly, men with claw feet exhibited significantly greater values on the forefoot ($P < 0.005$) and rear foot areas ($P < 0.05$), compared to men with normal feet.

Table 4 shows the linear values of the plantar imprints of all groups. As expected, in both sexes, the groups with bilateral claw feet exhibited a I:FW ratio = 0; moreover, the same groups exhibited a significant reduction of right ($P < 0.01$ for women, $P < 0.05$ for men) and left ($P < 0.05$ for both sexes) width of anterior heel, and a significant reduction of right ($P < 0.05$ for women, $P < 0.0005$ for men) and left ($P < 0.01$ for women, $P < 0.05$ for men) width of posterior heel. In both sexes, the groups with claw feet exhibited a significant reduction of length of right ($P < 0.05$ for both sexes) and left ($P < 0.05$ for both sexes) plantar imprints.

DISCUSSION

In previous studies, Gravante et al. (2000, 2001) analyzed the plantar support of both sexes with the baropodometric platform, standardizing the reference values for plantar areas and loads. Ridola et al. (2000, 2001a, 2001b) and Russo et al. (1999) showed the influence of a regular physical activity and of the body weight on the plantar support, confirming the important diagnostic and clinical value of the baro-

TABLE 4. Plantar Linear Values of the Groups[a]

	Women with normal foot ($n = 29$)	Women with claw foot ($n = 17$)	P-value (ANOVA)	Men with normal foot ($n = 16$)	Men with claw foot ($n = 10$)	P-value (ANOVA)
Right anterior heel	82.86 ± 6.56	76.94 ± 7.64	0.0080	89.38 ± 8.40	81.40 ± 9.44	0.0340
Right isthmus	38.48 ± 6.45	0.00 ± 0.00	<0.0001	40.50 ± 6.73	0.00 ± 0.00	<0.0001
Right posterior heel	61.62 ± 5.82	56.29 ± 7.74	0.0111	68.25 ± 5.53	57.80 ± 7.16	0.0003
Right I:FW ratio	0.47 ± 0.08	0.00 ± 0.00	<0.0001	0.45 ± 0.07	0.00 ± 0.00	<0.0001
Total length right foot	224.93 ± 12.98	213.94 ± 19.28	0.0256	249.63 ± 12.22	235.60 ± 15.50	0.0168
Left anterior heel	81.21 ± 7.80	76.29 ± 7.09	0.0385	88.31 ± 6.63	81.00 ± 9.51	0.0295
Left isthmus	34.90 ± 5.97	0.00 ± 0.00	<0.0001	38.06 ± 6.46	0.00 ± 0.00	<0.0001
Left posterior heel	63.14 ± 5.01	58.29 ± 6.53	0.0070	66.19 ± 6.68	60.10 ± 4.82	0.0198
Left I:FW ratio	0.43 ± 0.07	0.00 ± 0.00	<0.0001	0.43 ± 0.07	0.00 ± 0.00	<0.0001
Total length left foot	222.90 ± 15.24	211.88 ± 17.23	0.0291	250.25 ± 11.77	237.20 ± 14.47	0.0188

[a]Mean ± SD; mm.

podometric platform, as shown by Pomara et al. (2002). We wanted to progressively analyze the different patterns of plantar support in both sexes, such as claw foot, to identify peculiar pressure patterns predisposing to musculoskeletal pathologies.

The study of Cole (1983) indicated several forms of claw foot, with specific anatomical features and different outcomes. This deformity is often associated with scoliosis and it may be secondary to altered balance or to disorders of the central nervous system, as shown by Carpintero et al. (1994). In a multidisciplinary study of Tynan et al. (1992), it was found that in the majority of cases of claw foot, the peroneal compartment was enlarged in relation to the anterior compartment when compared to the normal controls. Recent studies have shown that claw foot is one of the risk factors, including also flat foot, restricted ankle dorsiflexion, increased hind foot inversion, to predispose people toward lower extremity overuse injuries, as indicated by the studies of Kaufman et al. (1999) and Keegan et al. (2002).

To the best of our knowledge, this is the first research in which a baropodometric platform was used to study the bilateral claw feet in young normal weight subjects of both sexes, comparing them to controls. In the study of Sneyers et al. (1995), it was shown that the relative load of the forefoot in athletes with claw foot was higher compared to controls.

CONCLUSION

Our study indicates that claw foot is associated with a significant reduction of the plantar support surface in young normal weight sedentary subjects of both sexes; these data were expected because probably associated with a peculiar redistribution of body weight on the plantar support, being a different % load between forefoot and rear foot. In the smaller forefoot and rear foot areas, the subjects with claw feet exhibited an increased load, particularly on the forefoot areas, according to Sneyers's study (1995). In conclusion, the reduction of plantar support surfaces in CFS of both sexes was associated to a major load per units of plantar surface in the forefoot and rear foot areas, and this may be a risk factor to lower extremity overuse injuries. In fact, Dawson et al. (2002), Sosenko (2002), Olson et al. (2003), and Kernozek et al. (2003) already evidenced that claw foot, with other foot deformities, is a risk factor for pathologies of inferior limbs. Further studies would be necessary to confirm whether claw foot is associated with modifications of the posture or gait.

REFERENCES

Carpintero P, Entrenas R, Gonzalez I, Garcia E, Mesa M. 1994. The relationship between pes cavus and idiopathic scoliosis. Spine 19:1260–1263.

Cole WH. 1983. The classic. The treatment of claw-foot. By Wallace H. Cole, 1940. Clin Orthop 181:3–6.

Dawson J, Thorogood M, Marks SA, Juszczak E, Dodd C, Lavis G, Fitzpatrick R. 2002. The prevalence of foot problems in older women: a cause for concern. J Public Health Med 24:77–84.

Filipe G. 1993. Pes cavus in children. Ann Pediatr 40:217–222.

Gravante G, Russo G, Pomara F, Ridola C. 2003. Comparison of ground reaction forces between obese and control young adults during quiet standing on a baropodometric platform. Clin Biomech 18:780–782.

Gravante G, Pomara F, Russo G, Genduso D, Cortimiglia R, Amato G. 2000. Analisi delle impronte plantari e della proiezione al suolo del baricentro corporeo rilevate alla pedana baropodometrica elettronica (BPE). Chir del Piede 24:187–195.

Gravante G, Russo G, Pomara F, Amato G, Bucchieri F, Ridola G, Ridola C. 2001. The influence of body weight on the orthostatic footprint on the computerized baropodometer. [Abstract] It J Anat Embryol 106(Suppl):135.

Hills AP, Hennig EM, McDonald M, Bar-Or O. 2001. Plantar pressure differences between obese and non-obese adults: a biomechanical analysis. Int J Obes Relat Metab Disord 25:1674–1679.

Kaufman KR, Brodine SK, Shaffer RA, Johnson W, Cullison TR. 1999. The effect of foot structure and range of motion on musculoskeletal overuse injuries. Am J Sports Med 27:585–593.

Keegan TH, Kelsey JL, Sidney S, Quesenberry CP Jr. 2002. Foot problems as risk factors of fractures. Am J Epidemiol 155:926–931.

Kernozek TW, Elfessi A, Sterriker S. 2003. Clinical and biomechanical risk factors of patients diagnosed with hallux valgus. J Am Podiatr Med Assoc 93:97–103.

Olson SL, Ledoux WR, Ching RP, Sangeorzan BJ. 2003. Muscular imbalances resulting in a clawed hallux. Foot Ankle Int 24:477–485.

Pomara F, Gravante G, Russo G, Riolo M, Amato C, Amato G. 2002. Ground reaction force analysis in athlete with plantar fasciitis: a case report. Chir del Piede 26: 105–108.

Ridola C, Russo G, Gravante G, Pomara F, Truglio G, Gugliuzza M. 2000. Morphological evaluation of orthostatic footprint at computerized baropodometry and of digital formula of healthy adult feet. [Abstract] Ital J Anat Embryol 105(Suppl):196.

Ridola C, Palma A. 2001a. Functional anatomy and imaging of the foot. Ital J Anat Embryol 106:85–98.

Ridola C, Palma A, Cappello F, Gravante G, Russo G, Truglio G, Pomara F, Amato G. 2001b. Symmetry of healthy adult feet: role of orthostatic footprint at computerized baropodometry and of digital formula. Ital Anat Embryol 106:99–112.

Root ML, Orien WP, Weed JH. 1977. Normal and abnormal function of the foot. Clinical biomechanics, Vol. 2, Los Angeles: Clinical Biomechanics Corp.

Russo G, Truglio G, Pomara F, Gravante G, Almasio PL, Gugliuzza M, Ridola C. 1999. Preliminary observation of orthostatic footprint in young adults by computerized baropodometry. [Abstract] Ital J Anat Embryol 104(Suppl): 88.

Schuster ON. 1939. Foot orthopaedics. Albany: JB Lyon Co.

ScLuster RO. 1976. Flexible flatfoot in childhood and adolescence. In: Smith SD, Di Giovanni JD, editors. Decision making in foot surgery. New York: Stratton Intercontinental Medical Book Corp.

Sneyers CJ, Lysens R, Feys H, Andries R. 1995. Influence of malalignment of feet on the plantar pressure pattern in running. Foot Ankle Int 16:624–632.

Sosenko J. 2002. The epidemiology of neuropathic foot ulcers in individuals with diabetes. Curr Diab Rep 2:477–481.

Tynan MC, Klenerman L, Helliwell TR, Edwards RH, Hayward M. 1992. Investigation of muscle imbalance in the leg in symptomatic forefoot pes cavus: a multidisciplinary study. Foot Ankle Int 13:489–501.

Warren BL. 1984. Anatomical factors associated with predicting plantar fasciitis in long-distance runners. Med Sci Sports Exerc 16:60–63.

Warren BL, Jones CJ. 1987. Predicting plantar fasciitis in runners. Med Sci Sports Exerc 19:71–73.

World Health Organization. 1998. Obesity: preventing and managing the global epidemic, report of a WHO consultation on obesity. Geneva: WHO.