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Morphofunctional changes in distribution of pressure center in multiple sclerosis

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Abstract

Introduction: Gait evaluation and assessment of motor performance are of utmost importance in the clinical management of multiple sclerosis (MS). A new approach to the analysis of static and dynamic balance of MS patients is the use of complex biomechanical analysis that includes an analysis of the distribution of the center of pressure (DCP) and loading, measured by using the pressure and force platforms. *Patients and Methods*: The study was conducted on a total of 18 patients with MS, with the mean age of 41.2 years old, divided into two groups, according to the presence of clinically detectable gait disturbances. The biomechanical analysis that included the assessment of the loading and DPC was performed using the platform of force distribution. DPC represented the center of all the forces applied and its value could appreciate the mediolateral stability, hence the pronation or, respectively, the supination. Group 1, consisting of 12 patients with MS with clinically detectable gait disorders, including six men and six women, and group 2, of six MS patients without clinically detectable gait disorders, including two men and four women. *Results*: For group 1, the center of pressure had a left–right asymmetric distribution, and also an anterior–posterior one. There was a predominant distribution at the medial heel, at metatarsals 1–3 and at the hallux. For group 2, the analysis of the plantograms recorded in our study indicated a tendency of the distribution of the pressure center in the metatarsals 2, 3 and less in the heel. *Conclusions*: The analysis of the loading and distribution of the pressure center was important not only to appreciate the static equilibrium disorders but also to appreciate how these disorders affected the gait initiation, since the patients suffered from anterior–posterior and mediolateral disorders, which produced spatial and temporal distortion preventing gait initiation. In the study of pressure and force, we noticed a predominant distribution on the lateral region of the heel, explained by an attempt of the body to compensate the disorders of balance and orientation of the reaction force of the ground to normalize the gait.

Keywords: multiple sclerosis, gait, biomechanically, center of pressure, balance.

Introduction

Multiple sclerosis (MS) appears to be a sum of heterogeneous syndromes rather than a clear disease and seems to involve multiple and diverse pathogenic mechanisms [1, 2]. In Europe, epidemiological studies indicate a prevalence of 30–80/100 000 inhabitants, the incidence of MS being about 50% higher in women than in men [3–5].

Gait evaluation and assessment of motor performance are of utmost importance in the clinical management of MS. The most commonly used tests are those which assess the maximum walking speed on short distances and the tests evaluating a 10-minute walk and a 6-minute walk. Although these tests are easy and predictable for the development of the disease, they do not provide a comprehensive assessment of the specific characteristics of the gait [6], nor an objective image of the impact of gait dysfunction on the patients' daily activities and on their life quality [7–10].

A new approach to the analysis of static and dynamic balance [11] of MS patients is the use of complex biomechanical analysis that includes an analysis of the distribution of the center of pressure (DCP) and loading, measured by using the pressure and force platforms.

The distribution of pressure in the plantar region provides the clinician data about the projection of the mass center of the body, hence the information of the morphofunctional changes of the neuromyoarthrokinetic system, and also the reaction of this system in terms of postural recovery [6, 12].

The model of tissue lesions of MS seems to be completely unpredictable; both acute and chronic cases of MS present new and old lesions, which show the dynamic aspect of the disease. Despite this variability, the "silent" chronic lesion (without an active inflammation) represents a constant and pathognomonic characteristic of MS [13]. From the anatomopathological point of view, there is a lesional diversity that includes the existence of demyelinization plaques, some active, others old on large areas, mainly located in the optic nerves, brain stem, posterior chords of the cervical bone marrow. The functional implications of these lesions reflect in symptoms

of muscular fatigue (70% of cases), motor disorders characterized by the diminishing of the muscular force to the onset of paresis, coordination disorders, gait disorders.

The aim of the present study is to make an analysis of the morphofunctional aspects that install pathognomonically in patients with MS, which can be evaluated biomechanically in the analysis of the distribution center at the plantar level. The morphofunctional aspects specific to MS are aspects that generate static and dynamic balance disorders [14], which are to be evaluated in order to initiate a comprehensive, definite rehabilitation program.

Patients and Methods

The study was conducted on a total of 18 patients from the urban area, with MS, with the mean age of 41.2 years old (between 22–62 years old). Inclusion criteria: patients with the residence in Dolj County (Romania) and the established diagnosis of MS according to the clinical and paraclinical criteria, presenting a capacity of preserved movement, members of the *National Association of Multiple Sclerosis*. Thus, according to the diagnosis and staging criteria for MS [15], there were selected the patients included in the certain clinical MS group, namely two bursts and a clinical presentation for two separate lesions or a clinical presentation for one lesion and another subclinical lesion (highlighted by neurophysiological or neuroimagistic investigations). Exclusion criteria: patients whose data were inaccessible, incomplete or they were against their inclusion in the study. The duration of the disease was between one year and 31 years.

The patients were divided into two groups, according to the presence of clinically detectable gait disturbances. Therefore, there were two groups of patients: group 1, consisting of 12 patients with MS with clinically detectable gait disorders, including six men and six women (P1–P12), and group 2 of six MS patients without clinically detectable gait disorders, including two men and four women (P13–P18). The subjects had the following progressive forms of MS: relapsing-remitting multiple sclerosis (RRMS), progressive multiple sclerosis flare-ups (PMSF), secondary progressive multiple sclerosis (SPMS), chronic primary progressive multiple sclerosis (CPPMS) (Table 1, Figure 1).

The clinical evaluation consisted in performing the physical examination and the neurological examination that triggered the presence of motor, sensitivity symptoms and signs, sphincter and genital disorders, brain signs, signs caused by the damage of the brain stem, symptoms at face level, changes of accurate sight and hearing, mental changes. Also, there was performed a magnetic resonance imaging (MRI). The functional evaluation was performed using the following scales and scores: Hamilton score, activities of daily living (ADL) scale, Kurtzke scale [16, 17].

Gait disorders were detected by the neurological clinical examination, which observed the balance and stability during walking, the damage of the support area when walking started, the use of assistant means during walking.

Table 1 – ***Distribution of the patients according to MS evolution stages***

Evolution stage	Group 1	Group 2
RRMS	7	4
PMSF	3	2
SPMS	1	0
CPPMS	1	0

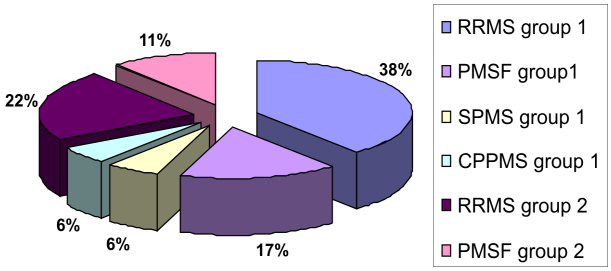

Figure 1 – ***Percentage distribution of the evolution stages of MS patients. MS: Multiple sclerosis; RRMS: Relapsing-remitting multiple sclerosis; PMSF: Progressive multiple sclerosis flare-ups; SPMS: Secondary progressive multiple sclerosis; CPPMS: Chronic primary progressive multiple sclerosis.***

The research was carried out in compliance with the principles of ethics, the Declaration of Helsinki and the Law No. 206/2004. All patients signed an informed consent on their inclusion in the study.

The study objective consisted in comparing the morphofunctional parameters in the two groups of subjects with MS. We did not take into consideration a reference group (subjects of the same age, without MS), as in this moment there is no staging of these parameters on age or gender groups.

The biomechanical analysis that included the assessment of the DPC was performed using the platform of force distribution and plantar pressure Footscan Scientific Version, RSscan International, Olen, Belgium, able to perform measurements with a frequency of 500 Hz in two-dimensional (2D) mode and to record the complete intervention of both plants. Applying the plant on the platform, we measured the local pressure [18] during the full contact with the ground at a high frequency, the operating substrate being represented by the measurement of the total impact force applied at the level of a sensor matrix on a known area.

The recording was performed on a complete gait cycle, which included a balance phase (contact), representing 60% of the total duration of the cycle and an oscillation phase (40%). The Footscan system measured only the contact phase, with a duration of 0.6–0.8 s, in normal gait. It is important that the current measurement be executed in a manner as close to the physiological activity evaluated (the gait) as possible. There were also made dynamic measurements, the patient being instructed to walk normally, at a comfortable speed rate, taking into account the pathological changes experienced by most patients. Aided gait was not allowed.

Three phases out of the eight of a complete gait cycle were analyzed: the attack phase (the initial contact of the heel), the semi-aid phase and the propulsion phase. The values recorded corresponded to the appropriate

anthropometric parameters of the patients and were provided by the equipment database. The pressure distribution during the gait was one of the parameters analyzed during the gait [19] and its expression was graphic and colorimetric. Colorimetrically, the highest pressures were represented by red, followed by orange, yellow, green, blue, violet. Each contact surface area (cm^2) was determined automatically and could be found on the right side of the image (Figure 2).

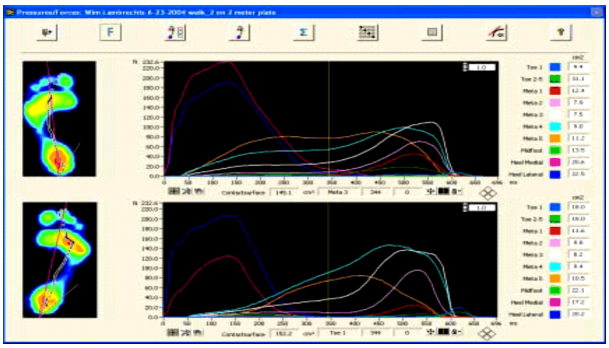

Figure 2 – ***Pressure and force values recorded at the level of plantar zones analyzed in relation to the contact surface.***

DPC represented the center of all the forces applied and its value could appreciate the mediolateral stability, hence the pronation or respectively, the supination. If the point was medially, we had a pronation movement, and if it was laterally, the movement was of supination. If we measured at a frequency of 350 Hz and 800 ms, we would get 200 frames. By calculating the center of pressure for each of them and placing successive points, we got the posture line (gait line).

Loading is a biomechanical, kinematic parameter, which assesses the way the stimulation of proprioceptors to force, generated by the appropriate weight, is realized in the studied region. This parameter was also measured in the four regions of the plant: medial heel, lateral heel, middle foot, toes 2–5, corresponding to the above-mentioned three main moments of the gait.

Results

The Hamilton mean score was 10 for group 1 and 6 for group 2, respectively. The ADL score recorded mean values for the group of MS patients with clinically detectable gait disorders and for the patients without these disorders were 6 and 8, respectively. Framing in Kurtzke scale was 3 for group 1 and 2 for group 2.

The results of the DCP recording in the four plantar regions are presented in individual plantograms P1–P12 for group 1 (Figures 3–14) and P13–P18 for group 2 (Figures 15–20).

We performed the study by analyzing the DCP distribution at plantar region (medial heel, lateral heel, middle foot, toes 2–5). Therefore, we observe that is a DCP at left heel and metatarsal left side for most of the patients like those we present as follows: distribution on the left heel and on the right metatarsals 2–5, with anterior–posterior imbalance and loading on the right forefoot (P1); predominant distribution on the left heel and metatarsal 3 (P2); DPC on metatarsals 1–3, left toes 1–3, with loading on the right heel, which meant a disturbance in the balance in the sagittal plane (P3); DPC on the left heel, on the right metatarsals 3–5, with disturbance in the balance in the sagittal plane and antero-lateral right deviation (P4); DPC on the left metatarsal 1 and on the left heel, toe 1, on the right metatarsal 1, with a tendency to approach to the longitudinal axis of the body in anterior plane (P5); DPC on the right heel and on the right metatarsals 2–4, with loading on the left metatarsal 5 and supination tendency of the left lower limb (P6); DPC on metatarsals 4–5, medial left heel and loading on the right heel (P7); DPC complete distribution on the left heel (P8); DPC on the left medial heel, the right metatarsal 5, right medial heel – a kind of imbalance right–left and anterior–posterior (P9); DPC on the medial heel, on the left metatarsals 2, 3, with 3–5 distribution and hallux at the right lower limb, which showed an important loading takeover with dynamic balance deviation in the front plane to the left (P10); DPC on the left lower limb, lateral heel and hallux, respectively the heel and metatarsals 1, 2 in the right lower limb, which meant an important loading in the right limb in anterior and lateral side (P11); DPC on the left metatarsals 2, 3, with hallux loading in the right limb, which showed an anterolateral deviation on the left side (P12).

In conclusion, for group 1, the center of pressure had a left–right asymmetric distribution, and also an anterior–posterior one. There was a predominant distribution at the medial heel, at metatarsals 1–3 and at the hallux. This distribution could be left–right symmetric, but most of the patients showed an asymmetry in the distribution of the center pressure on the medial heel, to one foot, associated with the distribution of the pressure center on the metatarsals to the other foot.

For group 2, the analysis of the plantograms recorded in our study indicated a tendency of the distribution of the pressure center in the metatarsals 2, 3 and less in the heel and the results for the six patients from the group are the following: maximum distribution on the mean metatarsal zone of the right lower limb (P13); average metatarsal distribution on the left medial heel and on the right heel (P14); distribution on the left heel – metatarsals 2, 3, metatarsal 4 of the right limb, predominant supination in the right limb and pronation in the left limb (P15); distribution on the left metatarsal 1, with predominant pronation without loading in the right limb (P16); distribution on the metatarsals 2, 3, medial left heel – in the right limb, there was the same distribution, but more significant (P17); distribution on the right heel, metatarsals 1, 2, with distribution on the metatarsal 1 in the left limb, which explained a deviation in the dynamic balance in frontal plane, on the right side (P18).

For both groups, the distribution is represented in the Figures 3–20.

Concerning the loading in the lateral heel, the mean values were 10.55 N/cm^2 for group 1 and 2.53 N/cm^2 for group 2, for the right foot, and 8.95 N/cm^2 for group 1 and 3.86 N/cm^2 for group 2, for the left foot (Table 2, Figure 21).

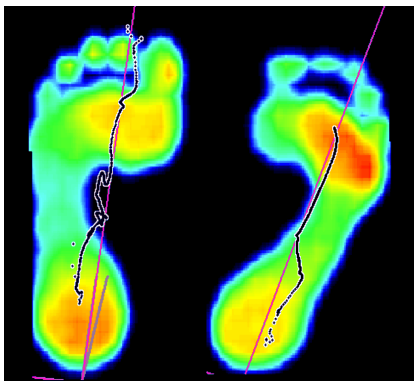

Figure 3 – ***Plantogram of patient No. 1 (P1).***

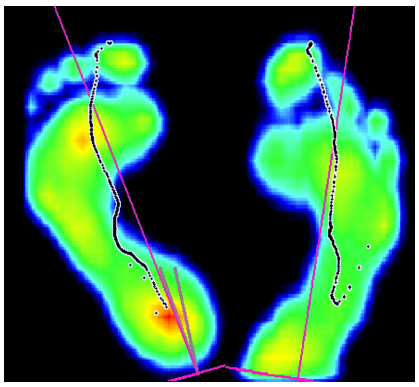

Figure 4 – ***Plantogram of patient No. 2 (P2).***

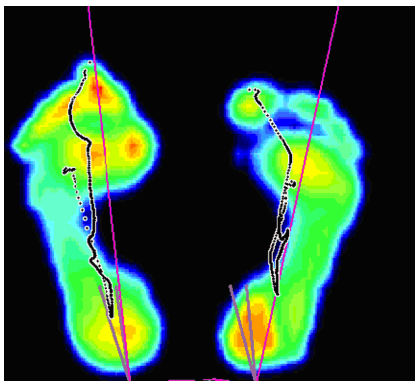

Figure 5 – ***Plantogram of patient No. 3 (P3).***

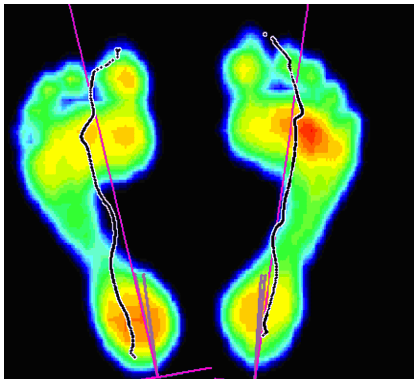

Figure 6 – ***Plantogram of patient No. 4 (P4).***

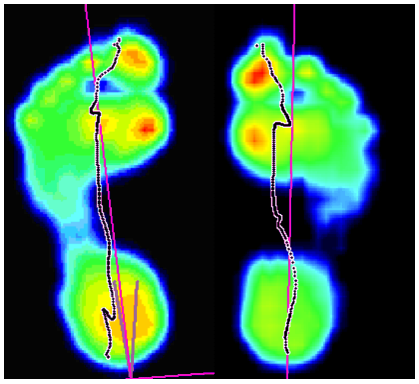

Figure 7 – ***Plantogram of patient No. 5 (P5).***

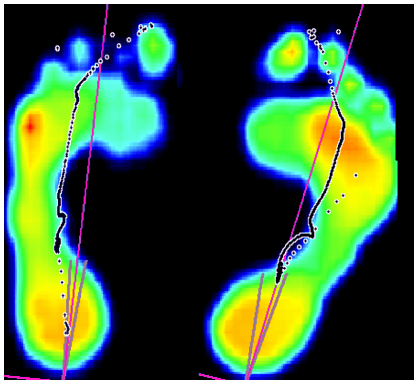

Figure 8 – ***Plantogram of patient No. 6 (P6).***

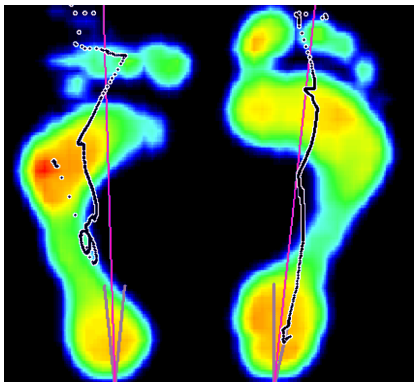

Figure 9 – ***Plantogram of patient No. 7 (P7).***

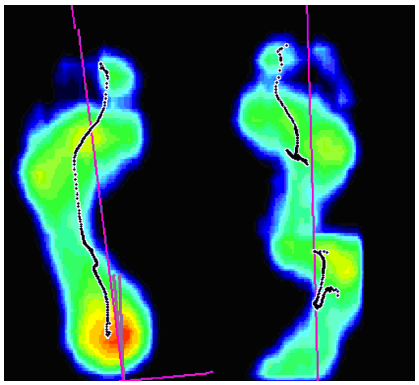

Figure 10 – ***Plantogram of patient No. 8 (P8).***

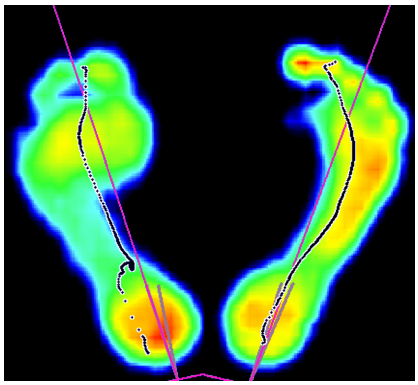

Figure 11 – ***Plantogram of patient No. 9 (P9).***

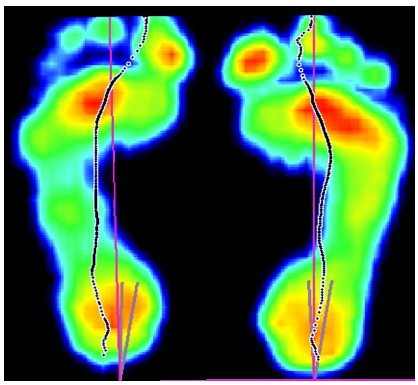

Figure 12 – ***Plantogram of patient No. 10 (P10).***

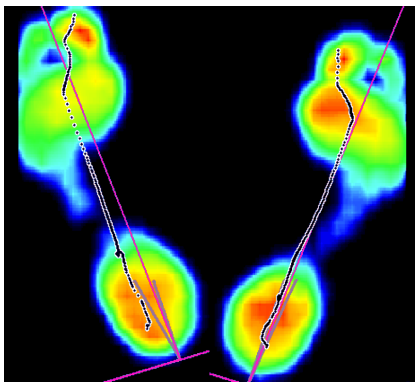

Figure 13 – ***Plantogram of patient No. 11 (P11).***

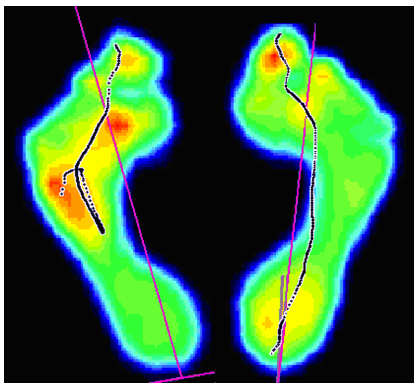

Figure 14 – ***Plantogram of patient No. 12 (P12).***

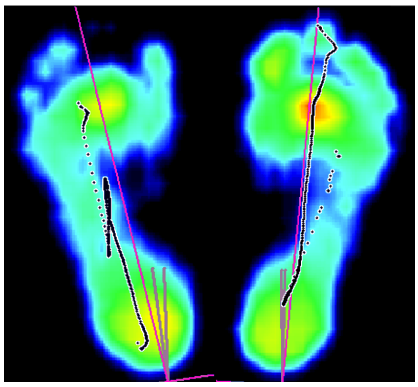

Figure 15 – ***Plantogram of patient No. 13 (P13).***

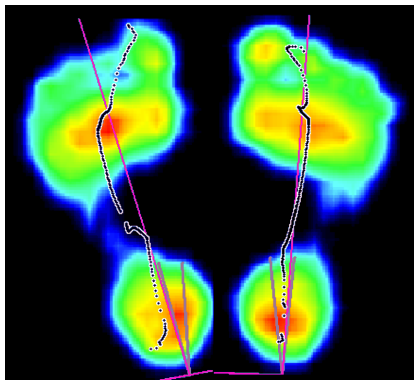

Figure 16 – ***Plantogram of patient No. 14 (P14).***

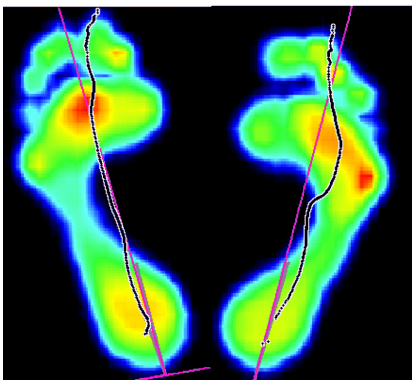

Figure 17 – ***Plantogram of patient No. 15 (P15).***

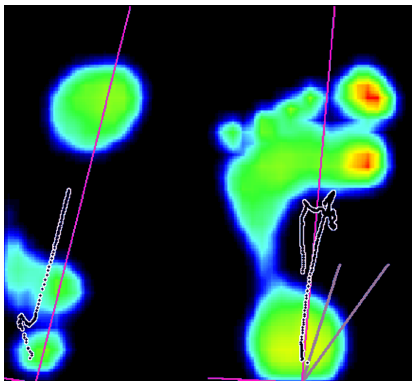

Figure 18 – ***Plantogram of patient No. 16 (P16).***

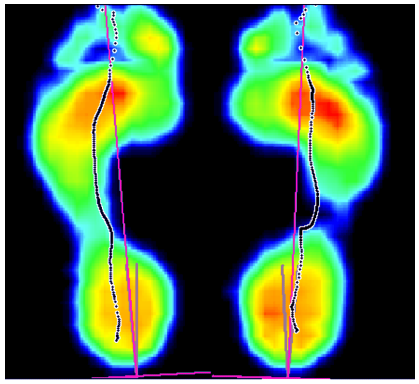

Figure 19 – ***Plantogram of patient No. 17 (P17).***

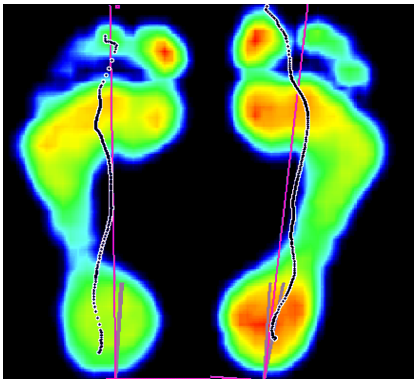

Figure 20 – ***Plantogram of patient No. 18 (P18).***

Table 2 – ***The mean values of loading relative to pressure and force***

Gait moment	Studied group	Parameter	Loading/Pressure		Loading/Force	
			Left	*Right*	*Left*	*Right*
Lateral heel	MS with gait disorders (Subgroup A)	Mean	0.591538	0.552308	8.958462	10.55231
		Standard deviation	1.608705	0.843081	27.94906	17.14469
		Min.	0.01	0.02	0.19	0.14
		Max.	5.91	2.74	101.95	58.25
		No. of values	13	13	13	13
	MS without gait disorders (Subgroup B)	Mean	0.268571	0.147143	3.861429	2.538571
		Standard deviation	0.367534	0.107968	5.321486	2.545862
		Min.	0.01	0.04	0.05	0.43
		Max.	1.08	0.36	15.56	7.87
		No. of values	7	7	7	7
Medial heel	MS with gait disorders (Subgroup A)	Mean	0.305	0.085833	4.909167	1.7425
		Standard deviation	0.600553	0.073788	12.05704	1.488575
		Min.	0.01	0.01	0.07	0.1
		Max.	2.05	0.21	43.1	3.95
		No. of values	12	12	12	12
	MS without gait disorders (Subgroup B)	Mean	0.218571	0.15	3.294286	2.802857
		Standard deviation	0.231043	0.102632	3.192652	2.096519
		Min.	0.02	0.01	0.18	0.09
		Max.	0.7	0.3	9.64	5.51
		No. of values	7	7	7	7
Medial foot	MS with gait disorders (Subgroup A)	Mean	0.023636	0.021	0.924615	0.617692
		Standard deviation	0.015667	0.013703	0.812072	0.582954
		Min.	0.01	0.01	0.1	0.1
		Max.	0.05	0.05	2.53	1.85
		No. of values	11	10	13	13

Gait moment	Studied group	Parameter	Loading/Pressure		Loading/Force	
			Left	*Right*	*Left*	*Right*
Medial foot	MS without gait disorders (Subgroup B)	Mean	0.034286	0.035714	1.17	1.075714
		Standard deviation	0.032071	0.019881	1.166462	0.668378
		Min.	0.01	0.01	0.39	0.25
		Max.	0.1	0.06	3.57	1.9
		No. of values	7	7	7	7
Toes 2–5	MS with gait disorders (Subgroup A)	Mean	0.024444	0.022222	0.191	0.232727
		Standard deviation	0.016667	0.014814	0.150292	0.170827
		Min.	0.01	0.01	0.01	0.03
		Max.	0.05	0.05	0.43	0.5
		No. of values	9	9	10	11
	MS without gait disorders (Subgroup B)	Mean	0.02	0.016667	0.118571	0.171429
		Standard deviation	0.014142	0.012111	0.112905	0.068173
		Min.	0.01	0.01	0.05	0.07
		Max.	0.05	0.04	0.37	0.27
		No. of values	7	6	7	7

MS: Multiple sclerosis.

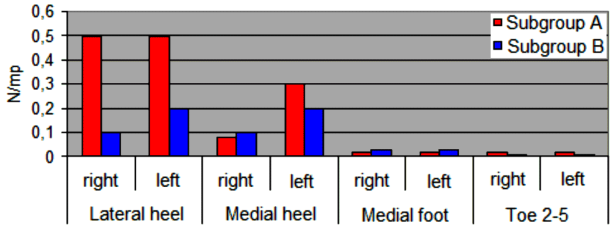

Figure 21 – *The mean values of loading relative to pressure in both lower limbs.*

In the region of the medial heel, the mean recorded values were 1.74 N/cm^2 for group 1 and 2.8 N/cm^2 for group 2, for the right foot, and 4.9 N/cm^2 for group 1 and 3.29 N/cm^2 for group 2, for the left foot (Table 2).

In the middle foot region, the values recorded were 0.61 N/cm^2 for group 1 and 1.07 N/cm^2 for group 2, for the lower right limb, and 0.92 N/cm^2 for group 1 and 1.17 N/cm^2 for group 2, for the left lower limb, and 2.58 N/cm^2 for the right foot (Table 2).

In the region of toes 2–5, the loading values were 0.23 N/cm^2 for group 1 and 0.17 N/cm^2 for group 2, for the right lower limb, and 0.19 N/cm^2 for group 1 and 0.11 N/cm^2 for group 2, for the left lower limb (Table 2).

We observed that for the patients for group 1, there is a predominant of the evolutive form of MS with a progressive character or in burst, correlated with DCP in the region of the foreleg (medial foot, toes 2–5). Also, there may be observed a high asymmetry of the plantar arch, with a predominant wearing of the metatarsal region corresponding to metatarsals 2, 3.

In the patients of group 2, there prevails the recurrent form, characterized by a complete remission or a persistence of certain minimal signs and clinically defined only in the circumstances of neurological dysfunctions. In this context, in the subjects of group 2 we observe the existence of an anteroposterior major disbalance regarding the calcaneous and metatarsal loading, aspects that may represent prediction elements for the onset of gait disorders within the context of developing morphological changes at plantar level.

Discussions

The recording of the maximum pressure values in the lateral heel indicated higher values for group 1, in the left limb, while for group 2 the pressure was greater in the right lower limb. Regarding the left lower limb, we noticed that the values recorded for group 1 were higher than for group 2; the situation was reversed in the right lower limb. These values showed that the significant changes occurred in the lateral heel, in the tendency to increase the support [20, 21]. This observation is also confirmed by the studies performed by Remelius *et al.* [22] and Miff *et al.* [23], which showed a minimal displacing towards the posterior of the DCP during the support stage. These results suggest that the neurological disorders are much more evolved than the neuromotor disability, clinically highlighted. We noticed that the values recorded in the right limb were close to the normal ones, both in the lateral and medial heel.

Analyzing the data recorded in the medial lower limb for the same parameter, we noticed a significant drop in pressure in MS subjects, more significant in the right limb in the patients belonging to group 1, while at the level of toes 2–5, we recorded no values that could guide us significantly to determine any morphological and functional changes specific to MS during the gait.

The overall analysis of the recorded values indicated that there was a tendency to develop a higher pressure in the heel region, because, reflexively, as noted above, it was an increase in the aid base. We did not notice a similar aspect in the medial region of the limb, where the pressure was much lower [24].

Loading was a kinematic parameter related to the muscle strength and momentum, a parameter that could guide us to understand the way the stimulation of the receptors and, thus the motor control was produced [25].

Analyzing the data mentioned above, we noticed that there was a large range of minimum and maximum values in the lateral heel region in the patients for group 1 (0.19 / 101.95–0.14 / 58.25) comparing with group 2, whose maximum values were around 15.5 and the

minimum values around 0.2. This showed that the patients with MS and gait disturbance recorded a higher loading, and also a more significant left right asymmetry, which could be explained by the balance disorders developed [26].

In addition, the analysis of the distribution of the pressure center was important not only for the estimation the static balance disorders [27] but also for the estimation of how these disorders affected the gait initiation, since the patients suffered from anterior–posterior and medio-lateral deterioration, which produced spatial and temporal distortion preventing gait initiation [22, 28].

Analyzing the results recorded during loading, we noticed that in the region of the medial heel, the mean values recorded for groups 1 and 2 were low, the minimum values being around 0.2 N/cm^2 for group 2, while for group 1 the value was 0.07 N/cm^2. Also, in the case of maximum values, they were high for group 1, for the lower left limb and low for the left limb, underlying the existence of a right–left asymmetry in loading.

The same parameter analyzed at the mid-foot region showed that the values recorded for groups 1 and 2 were low in both limbs. We noted that there was some left–right symmetry in this region for the two studied subgroups, which meant that biomechanically there was no distribution of force in the middle region of the foot, the loading being predominant in the region of the heel, so that the subject kept the center of gravity within the support base. The minimum and maximum loading values in the mid-foot region were lower for group 1, explained by the gait disorders and dynamic balance disorders.

At the level of toes 2–5 region, we found higher values for group 1 than for group 2, probably due to the low loading values in the other regions of the foot during the other gait moments and to the need to adapt to the balance disorders, in the sense of anteroposterior recovery. We also noticed that the minimum values were around the same average value of 0.2 N/cm^2 in the two subgroups.

Therefore, we could appreciate that loading in MS subjects was predominantly in the heel region, right–left asymmetrically, which was consistent with the evolution of force and pressure values.

Analyzing objectively the two biomechanical parameters, we noticed that despite the fact that the patients were clinically divided into the two subgroups (with and without gait disorders) the subclinical disorders were detected only by kinetic analysis tests.

Regarding the distribution of the pressure center, we found out that the lack of a physiological plantar control, the lack of a suitable motor control of the lower limb and the balance disorders caused abnormal distribution of the pressure center.

The existence of two groups allows the performance of clinical predictions on the neuromotor progress, an aspect supported by Cameron & Lord [29], who speak about the onset of posture disbalances and of a delayed gait in relation to the developing of balance and walking disorders. Also, the research of Lukens *et al.* supports the idea that symptoms of MS, such as neuromotor disorders, balance disorders, begin at the same time with the onset of autoimmune phenomena, even if they become clinically highlighted much later [30].

Conclusions

DCP in the medial plantar and antefoot areas for group 1 is explained by the action of mechanisms that resolve the static and dynamic posture as a compensatory mechanism. The discrepancy between the morphofunctional changes reflected in DCP, loading and the MS time of progress for group 2 allows the prediction of a subsequent progression. The right–left asymmetry is explained by decreasing the drive force during walking. The distributions of the loading and the pressure center in the lateral heel are explained by the development of some compensatory mechanisms.

Conflict of interests

The authors declare that they have no conflict of interests.

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