

A different brace model to retrain hemiparetic gait with *genu recurvatum*: effects on plantar pressure distribution

Um modelo diferente de brace para a reeducação da marcha hemiparética com genu recurvatum: efeitos sobre a distribuição das pressões plantares

Un modelo distinto de rodillera en la rehabilitación de la marcha hemiparética con genu recurvatum: efectos sobre la distribución de las presiones plantares

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ABSTRACT | The model of brace developed consists of a neoprene kneepad that has an inflatable cuff positioned over the popliteal region of the knee. It provides stimuli on joint structures as well as a better biomechanical alignment during the stance phase of the gait. The aim of this study was to quantify the changes and adaptations induced by gait training with the use of orthotic device in hemiparetic patients. A quasi-experimental before-after study was held with twelve adult patients with hemiparesis due to cerebrovascular accident. The peaks of plantar pressure were the markers used to compare the three moments of the study: the baseline, when they were using the brace, and post-gait training. After the sessions of gait retraining with the orthosis, the redistribution of plantar pressures showed increased symmetry during the stance phase, mainly by reducing the pressure on the paretic forefoot ($p=0.024$) and by the increase in the rearfoot in the paretic side ($p=0.010$). In addition, these changes were associated with a decrease in pressure on all regions of the foot not affected, especially in the rearfoot after training. The results of the study suggest a change in the gait pattern of participants after using the brace. There has been greater symmetry of the values of the plantar pressure peaks when the affected side was compared with the nonaffected side. Training with the brace helps in the rehabilitation process, since it provides baropodometric

values approaching the normal pattern of plantar distribution.

Keywords | Stroke; Gait; Orthotic Devices.

RESUMO | O modelo de *brace* desenvolvido consiste em uma joelheira de neoprene que apresenta um balonete inflável posicionado sobre a região poplíteia do joelho. Ele proporciona estímulos sobre estruturas articulares, bem como um melhor alinhamento biomecânico durante a fase de apoio da marcha. O objetivo do estudo foi quantificar as alterações e adaptações induzidas pelo treinamento da marcha com a utilização do dispositivo ortótico em pacientes hemiparéticos. Realizou-se um estudo quase-experimental do tipo antes e depois com doze pacientes adultos com hemiparesia decorrente de acidente vascular encefálico. Os picos de pressão plantares foram os marcadores utilizados para comparar os três momentos do estudo: na linha de base, quando estivessem utilizando o *brace* e após o treinamento da marcha. Após as sessões de reeducação da marcha com auxílio da órtese, a redistribuição das pressões plantares evidenciou aumento na simetria durante a fase de apoio, principalmente pela diminuição da pressão sobre o antepé parético ($p = 0,024$) e pelo aumento no retropé no lado parético ($p = 0,010$). Além disso, estas alterações foram associadas a uma diminuição da pressão sobre todas as regiões do pé não afetado, especialmente no retropé no

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momento de pós-treinamento. Os resultados do estudo sugerem uma mudança no padrão de marcha dos participantes após a utilização do *brace*. Houve maior simetria dos valores dos picos de pressão plantares quando se comparou o lado afetado com o não afetado. O treino com o *brace* contribui no processo de reabilitação, uma vez que forneceu valores baropodométricos que se aproximaram ao padrão normal de distribuição plantar.

Descritores | Acidente Vascular Cerebral; Marcha; Aparatos Ortopédicos.

RESUMEN | En una rodillera de neoprene se desarrolló un tipo de rodillera ortopédica, que lleva un manguito inflable, puesto en la región poplíteica de la rodilla, y que les proporciona estímulos a las estructuras articulares, así como mejora la alienación biomecánica durante la fase de apoyo de la marcha. El propósito del estudio es cuantificar las alteraciones y adaptaciones producidas por el entrenamiento con este dispositivo ortopédico en pacientes hemiparéticos. Se trata de un estudio casi experimental de tipo antes y después, del cual participaron doce adultos hemiparéticos debido al accidente cerebrovascular. Se utilizaron

como marcadores los picos de presión plantar para comparar tres momentos del estudio: el inicio del estudio; el momento en que utilizaban la rodillera y tras entrenar la marcha. Después de las sesiones de rehabilitación de la marcha con ayuda de la rodillera, en la redistribución de las presiones plantares ocurrió un aumento en la simetría durante la fase de apoyo, principalmente disminución de la presión sobre el antepié parético ($p=0,024$) y aumento en el retropié en el lado parético ($p=0,010$). Además, estas alteraciones se las asociaron a la disminución de la presión sobre todas las regiones del pie no alterado, especialmente en el retropié en el momento posterior al tratamiento. Los resultados del estudio muestran un cambio en el patrón de marcha de los participantes después de utilizar este tipo de rodillera. Hubo una mayor simetría de los valores de los picos de presión plantar cuando se comparó el lado alterado con el no alterado. El entrenamiento con este tipo de rodillera ayudó en el proceso de rehabilitación, puesto que presentó valores baropodométricos cerca del patrón preestablecido de distribución plantar.

Palabras clave | Accidente Cerebrovascular; Marcha; Aparatos Ortopédicos.

INTRODUCTION

Retraining the gait after a stroke represents one of the greatest challenges of the rehabilitation process, once the locomotion allows greater autonomy and has direct impact on the levels of functionality¹. About half of the stroke survivors exhibit motor deficiencies, such as muscle weakness, abnormal muscle tone, and sensory disabilities, often combined with spasticity or contractures of muscles of the paretic lower limbs². The hemiparetic gait is characterized by changes in the kinematic and spatial-temporal parameters. During the stance phase, the hyperextension of the knee often occurs, which is known as *genu recurvatum*².

From the biomechanical point of view, the *genu recurvatum* is characterized by a ground reaction force vector that passes exactly in front of the knee. In patients with quadriceps weakness, this phenomenon raises a knee extensor moment, avoiding the fall in flexion during the midstance, as a strategy for greater stability in the lower limb. Besides being a walking aesthetic problem, it can cause pain and therefore limit the autonomy of the patient in daily life activities³. It can be caused due to various phenomena, such as weakness or spasticity of the quadriceps muscle, spasticity and/

or contracture of the plantarflexors, and proprioceptive deficits². The profile of plantar pressure distribution of patients with stroke proves to be very different from what it is observed in healthy individuals⁴. In this sense, the measurement of plantar pressures quantifies the degree of commitment of the hemiparetic patient and assesses objectively the effectiveness of the intervention with an orthotic device in the rehabilitation process².

The traditional approach of locomotor training involves walking on the ground or on the treadmill. Thus, a better control over the knee joint affected can be obtained through orthotic resources that seek to facilitate a motor response desirable and inhibit the abnormal primitive motor activities⁵. The orthosis used in this study was developed to retrain the gait and minimize the *genu recurvatum* after considering the neurophysiological and biochemical aspects¹. Accordingly, we considered that the application of moderate pressure on structures of the musculoskeletal system could change the strategies of muscle recruitment, to promote better alignment of the knee, as well as to contribute to the functional recovery of the gait without blocking or limiting the joint motion completely. Consequently, the plantar pressures could also be changed and measured by baropodometry. Thus,

the aim of this study was to assess the distribution of plantar pressures during the walking of patients with hemiparesis after using a different brace to train the gait of hemiparetic people with *genu recurvatum*.

METHODOLOGY

Quasi-experimental before-after study. Twelve (12) adult patients who have had a stroke participated, they received physical therapy follow-up in a clinic. Inclusion criteria were the presence of hemiparesis after stroke with evolution between six and 24 months, ability to walk without auxiliary devices, and presence of *genu recurvatum* during the gait midstance phase. Exclusion criteria were the conditions that obstructed the assessment and training with the orthosis, as well as the presence of fixed deformities or contractures in lower limbs and moderate-to-severe compromises of cognitive, perceptual, of attention or language nature. This first screening was performed by one of the physical therapists responsible for the study through physical and functional assessment and by data from patient records.

The researchers developed the orthotic device used. It has four neoprene strips fixed with hook and loop tape above and below the patella, gathered in the posterior region through neoprene and leather fabrics (Figure 1A). It also has, on the popliteal fossa, a rubber inflatable cuff wrapped with neoprene, which must be positioned in a way that ensures more pressure on that local (Figure 1B).

The pressure of the cuff was established at 0.35 kg/cm^2 with a calibration sensor so that it could offer a moderate degree of pressure on the popliteal region. The hook and loop tapes on the anterior surface of the thigh and leg were adjusted according to the patient's response, they should be comfortable and securely fixed.

After receiving explanations about the study and signing an informed consent form, the first gait assessment was held. The flowchart of assessments and training was divided into three moments. At first, we held an assessment of plantar pressure measurement. The records of plantar pressures were collected through dynamic baropodometry. To obtain the baropodometry data, we used a digital baropodometer of the pressure platform type of the brand Novel, Emed-X model (690mmx403mmx190mm) resolution of 4 sensor/cm², maximum sampling rate of 100Hz.

The platform was positioned in the center of a runway of Ethylene-vinyl acetate (EVA) of approximately 7 meters in length. We asked the patient to walk naturally and barefoot in self-selected speed on the runway. The patient started the gait with parallel feet from the mark previously delineated, allowing the implementation of the third step on the platform, according to the three-step protocol⁶. Each individual walked five times the path to become familiar with the procedures and, after this period, the software was enabled to carry out the acquisitions. The Peak Plantar Pressure in kilopascals (kPa) –maximum pressure recorded in specific plantar areas – of four regions of the foot (rearfoot, midfoot, forefoot, and toes) was established through the Novel Scientific 12.3.30 software.



Figure 1: Orthosis for gait rehabilitation. (A) lateral view of the neoprene strips above and below the patella; (B) greater detail of the position of the inflatable cuff on the popliteal region (arrow)

Three records were acquired from the affected foot and from the nonaffected foot on the platform. At moment 1, the orthosis was not used, this first assessment served as a baseline, that is, the standard baseline of the participants' gait. After an interval of 30 minutes for rest, at moment 2, this same procedure of baropodometric assessment was also carried out with the patient wearing the orthosis.

The day after that assessment, patients began four weeks of gait training with the orthosis under the supervision and observation of a physical therapist who belongs to the group of authors of this study. Twice a week, for five weeks, before the sessions in the physical therapy clinic, the patients who participated in the study were asked to walk with self-selected speed on level ground, a hall with 50 meters in length, wearing the orthosis to retrain the gait in the affected side during fifteen minutes. The amount of interventions was based on a study that showed significant and lasting effects on the control of *recurvatum* in the gait after 10 electrogoniometric biofeedback sessions⁷. On the first day following the tenth session of training, we held the moment 3 to assess the plantar pressures without the orthosis.

Data processing and analysis

For the statistical analysis, we calculated the average and the standard deviation of both feet of the variables of Peak Plantar Pressure (maximum pressure recorded in the plantar specific areas: rearfoot, midfoot, forefoot, and toes). Thus, eight independent analyses were performed, aiming to compare the situations without brace, with brace, and post-training, one for each limb and regions of the foot. The values of peak pressure in these areas of both feet were compared with the affected and nonaffected sides in different moments of the gait assessment. These comparisons were made using parametric tests (ANOVA for repeated measures) or non-parametric tests (Friedman), according to the presence or absence of normal distribution of the data. Shapiro-Wilk test was used to verify the normality of the data. The version 17 of the program SPSS® (Statistical Package for the Social Sciences, Inc., Chicago, USA) was used to analyze the data. The significance level adopted was $p \leq 0.05$.

RESULTS

From a total of twelve hemiparetic patients, the average age was 61.5 ± 10.7 years, 7 of them were male. The average time post-stroke was 12.9 ± 5.6 months. The graphical representations of the variables of peak pressure in the four regions of the feet on the sides affected (AF) and nonaffected (N-AF) with and

without the orthosis in the paretic knee are exposed in Figures 2, 3, and 4.

Moment 1 (baseline)

In the rearfoot, the plantar pressure behavior showed significantly different average values on the affected side compared with the nonaffected side with 209.65 (SD 51.38) and 349.16 (SD 120.68), respectively, ($p=0.003$). As well as on the region of the toes, the average values were 229.51 (SD 107.87) and 335.32 (SD 180.69), ($p=0.004$), with the largest distributed pressures on the nonaffected side.

Moment 2 (wearing the brace)

Comparing the affected side with the nonaffected side, the orthosis did not show changes in the pattern identified in the baseline. Differences in the pressures of the rearfoot remained with 215.55 (SD 50.52) and 322.62 (SD 109.16), ($p=0.005$), as well as in the toes with 260.44 (SD 118.15) and 327.92 (SD 133.06), ($p=0.004$) being the biggest pressures presented on the healthy side.

When comparing the AF wearing the orthosis with its baseline values, we identified increase in peak plantar pressure in the region of the toes, going from 229.51 (SD 107.87) to 260.44 (SD 118.15), ($p=0.007$) and a decreasing trend in the pressure on the forefoot on the paretic side, going from 287.53 kPa to 265.41 kPa. The healthy side showed decreased values in all regions, in particular on the rearfoot, 349.16 (SD 120.68) to 322.62 (SD 109.16), ($p=0.041$).

Moment 3 (gait training)

The pressure peaks, comparing the AF with the N-AF side, maintained the differences similar to those observed at baseline. In comparison with the baseline data obtained after the training, the region of the paretic forefoot showed significant reduction of peak pressure, going from 287.53 (SD 150.18) to 243.76 (SD 128.62), ($p=0.024$), while the region of the rearfoot presented a tendency to increase. Also, all the regions of the N-AF foot, rearfoot, midfoot, forefoot, and toes have demonstrated reductions in plantar pressures, however only the rearfoot has significant value going from 349.16 (SD 120.68) to 307.83 (SD 104.82), ($p=0.010$).

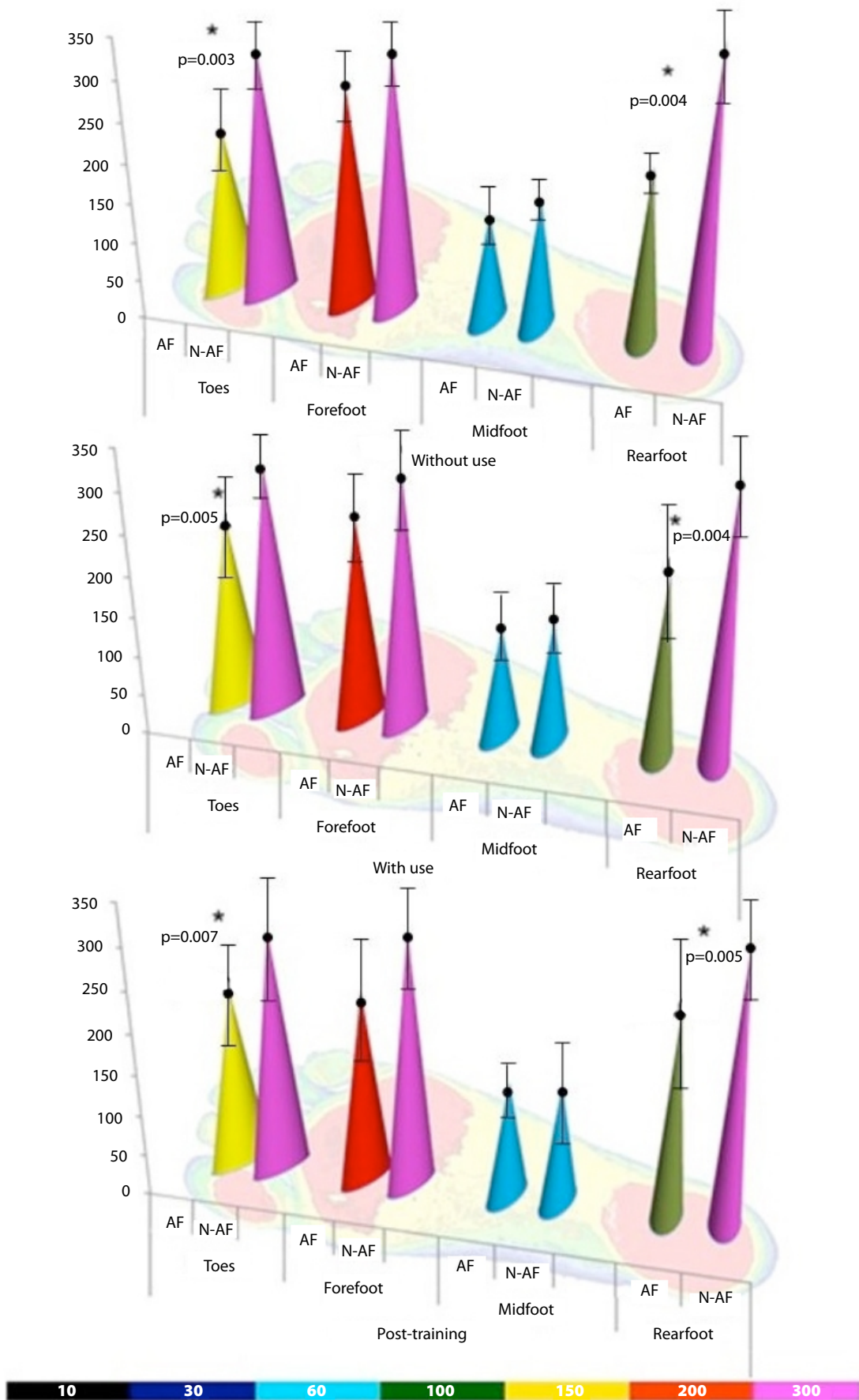


Figure 2: Graphical representations of the peak pressure variables compared between the affected side with the unaffected side without orthosis, with orthosis, and after training in the different areas of the foot

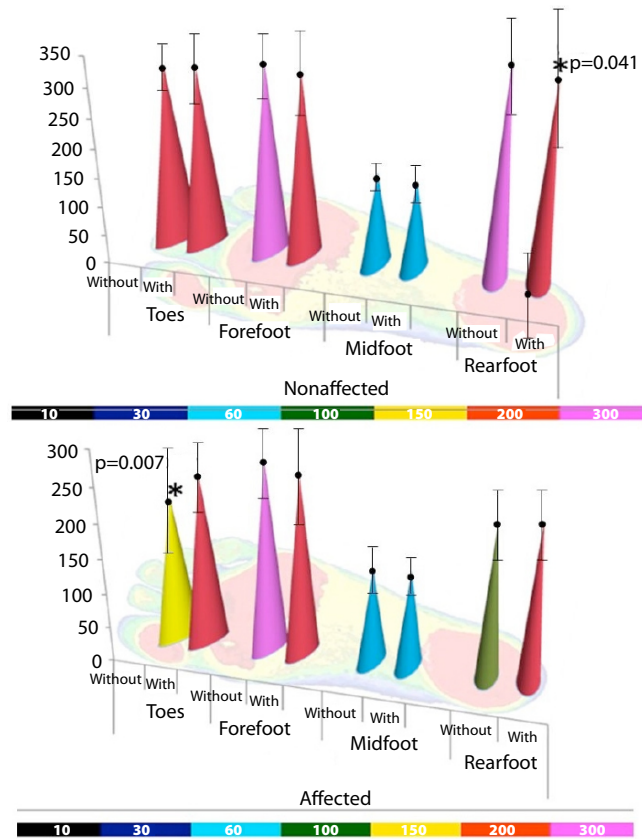


Figure 3: Graphical representations of the variables of peak pressure compared without and with the use of orthosis on the side affected and nonaffected in different regions of the foot at moments 1 and 2

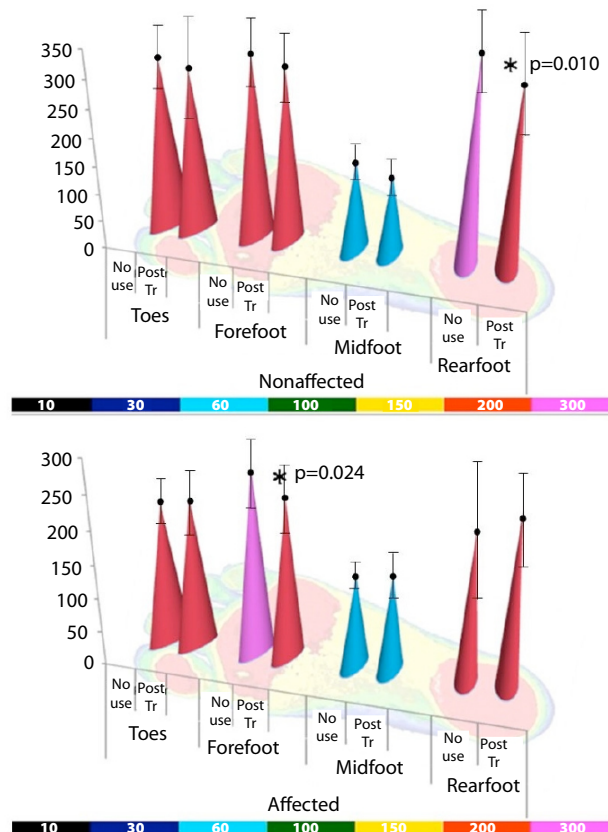


Figure 4: Graphical representations of the variables of peak pressure comparing the baseline (no use) with the data after training (post Tr) on the nonaffected and affected side in different areas of the foot

DISCUSSION

The pattern of contact with the ground of the patients assessed in our study showed a predominance of higher peak pressure on the forefoot paretic region. This aspect can be noted when comparing the pressure areas in three-dimensional format of the initial contact of a hemiparetic patient with those of a healthy individual. Figure 5 shows an example of comparison between a paretic foot with that of a healthy individual. Insufficient dorsiflexion and spasticity of plantiflexors can explain this form of “heel strike” in hemiparetic patients^{4,8}.

When comparing the values of pressure peaks between the affected and the nonaffected side, smaller values were observed on the region of the rearfoot and toes on the affected side without the orthosis, constituting the basal pattern of the patients. The distribution of the peak plantar pressure, during the gait without the orthosis for gait rehabilitation, showed patterns similar to other studies involving baropodometry in hemiparetic people^{8,9-12}. The dynamic plantar pressure of hemiplegic patients shows, on the affected side, a change of initial contact, from the rearfoot to the forefoot area, an increase in the lateral plantar stance, a limited bearing, and a reduced or absent heel-off movement in terminal stance¹⁴.

On the affected side, the pressures are mainly displaced on the forefoot, on the basis of spasticity of triceps surae, on the N-AF side, however, there is a greater transfer of stance on the foot not affected in patients with severe motor impairment¹⁵. The peak of reduced pressure at the base of the third metatarsal, according to studies, denotes a higher transverse arch of the forefoot: that would be connected to the greater spasticity of the intrinsic foot muscles¹². The comparison of peak pressure between the nonaffected and affected side of nine hemiparetic patients showed that the nonaffected side had the highest peaks of pressure, while on the affected side, the forefoot and the lateral plantar arch showed greater values⁸. This can occur due to equinism and spasticity, which commonly occur in hemiparetic patients, as well as due to coordination disturbance, sensory alteration, and insufficient transfer of weight on the paretic side¹¹. The analysis of distribution in peak plantar pressure of 25 hemiparetic patients and of 31 healthy patients showed reduction of peak pressure on the sides affected, mainly in the medial metatarsal area of hemiparetic patients¹³. Other studies have also observed that the distribution of plantar pressures of hemiparetic patients showed low-pressure peak around the foot of the affected side¹².

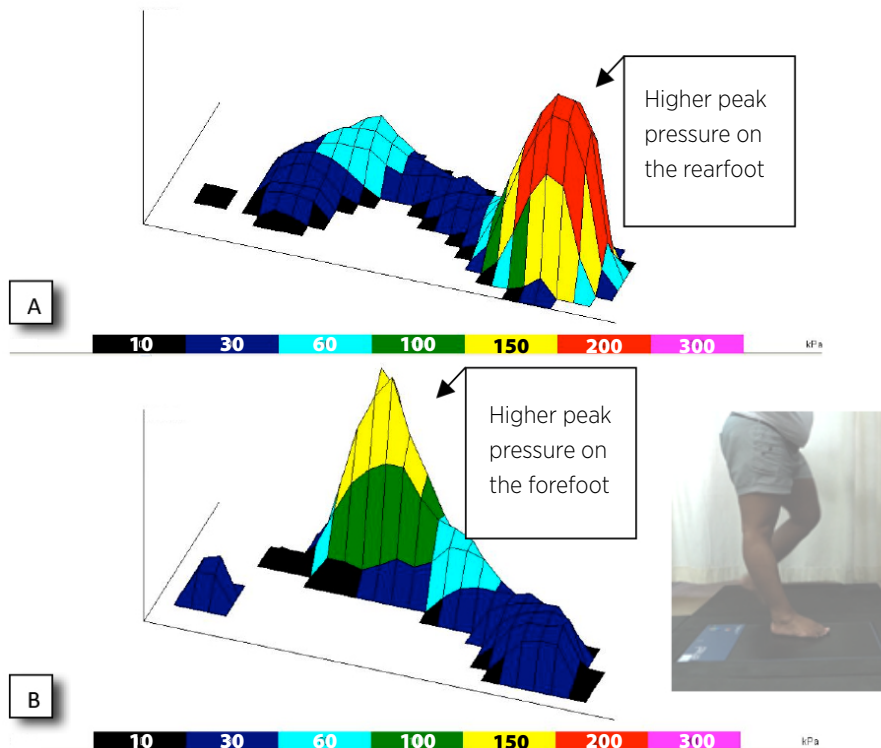


Figure 5: Forms of visualization of pressure distribution in three-dimensional pattern of peaks of plantar pressures during the initial contact of the heel. (A) characterizes the gait pattern in normal individual¹⁹. (B) presents example of a hemiparetic patient with *genu recurvatum*

In the second part of the study, the asymmetries found in the baseline remained, from a comparison of the affected side with the orthosis versus the nonaffected side. Comparing the peaks of baseline pressure with the ones of paretic knee use, some changes were observed: on the affected side, the region of the toes showed more pressure against the ground, a tendency to decrease the pressure on the forefoot and increase on the rearfoot. All nonaffected regions of the foot showed decreased peak pressure, mainly in the region of the rearfoot. Studies with analysis of normal patterns of plant distribution consider that an ordered sequence of events occurs, during the stance, starting by the heel, heel and forefoot strike, only the forefoot and, finally, forefoot and toes. In this final moment of contact with the ground, the weight is being transferred to the other foot with heel strike¹⁴. The reduction of the pressure on the rearfoot of the N-AF side after the training can be attributed to a better motor control, conferred by a better angle of the calcaneus entry and subsequent softening in the heel strike, observed in better distribution of plantar pressures in the stance phase on the AF side.

The verification of the effects of the orthosis on the gait, at moment 3, showed positive functional results. In the forefoot region of the affected side, where usually the highest peak pressures occur in the hemiparetic foot¹², there was a significant reduction of the values after the training. On the nonaffected side, the peak plantar pressure decreases in all regions, in particular in the rearfoot. The reduction of the pressures on the foot on that side, both when using the orthosis, and post-training, suggest that the body weight is being distributed more to the paretic side. Hemiparetic individuals transfer approximately 70% of the total weight on the nonaffected lower limb¹⁶. The postural alignment and symmetry in transfers of weight, in patients with stroke, and its relationship with functional skills, of balance and gait are essential for a successful rehabilitation¹⁷.

Irregularities and asymmetries in the distribution patterns of plantar pressures between the limbs reflect a disturbance in the articular movement^{9,10,18}. Possibly the decreased dorsal flexion by spasticity of the triceps surae contributes with the highest peaks of pressure on the forefoot on the affected side. The difficulties in the transfer of weight from the rearfoot to the forefoot can be due to *genu recurvatum*, tilted uterus and insufficient hip extension on the paretic side¹⁸.

The results of the study revealed that the orthosis developed must necessarily be accompanied by a period

of adjustment and gait training to obtain better results at the level of the forefoot. We found that only the use itself does not cause significant changes in the pattern of plantar pressures. After ten sessions, there was more adequate distribution of plantar pressure to the rearfoot on the affected side and greater symmetry in relation to the N-AF side. On the nonaffected side, the pressure, which was greater in the rearfoot, showed a decreasing trend in the pressure peaks in this region after the training. We can therefore infer that training with the orthosis contributes to the rehabilitation process, since it provides favorable biomechanical alignment in the joint, and thus a best performance of knee flexors that are weaker in the *genu recurvatum*. In addition, it can provide proprioceptive input, giving the patient a feedback about the knee hyperextension, informing the patient of the need to correct this unwanted movement.

Among the limitations of the study, in addition to the reduced sample, we highlight the lack of a control group to document normal developments with the conventional physical therapy. In an upcoming assessment, in addition to the incorporation of placebo group, it would be important to obtain baropodometry data associated with electromyography and/or kinematic analysis to quantify the degree of *genu recurvatum* at different speeds, correlating the muscular behavior with changes in plantar pressure and in kinematic parameters.

When considering the mechanical characteristics of the brace, we understand that it proves to be a differentiated management of the gait with *genu recurvatum*, compared with the other existing resources. This device does not restrict the movement of the knee in a fixed angle, but “reports” to the patient by means of tactile and proprioceptive stimuli the occurrence of hyperextension during the midstance. This study suggests a better gait pattern in the participants by presenting greater symmetry in plantar pressure peak values, i.e., a contact of the foot with the ground closer to normal. We can thus infer that the training with the orthosis can help hemiparetic individuals to obtain better motor control and biomechanical alignment of the knee during the gait.

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