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Baropodometric technology used to analyze types of weight-bearing during hemiparetic upright position

Tecnologia baropodométrica utilizada para analisar tipos de suporte de peso durante postura ortostática hemiparética

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Abstract

Introduction: Although baropodometric analysis has been published since the 1990s, only now it is found a considerable number of studies showing different uses in the rehabilitation. **Objective**: To amplify the use of this technology, this research aimed to analyze baropodometric records during upright position of subjects with hemiparesis, describing a way to define weight-bearing profiles in this population. **Method**:

20 healthy subjects were matched by gender and age with 12 subjects with chronic spastic hemiparesis. This control group was formed to establish the limits of symmetry during weight-bearing distribution in the hemiparesis group. Next, hemiparesis group was submitted to procedures to measure baropodometric records used to provide variables related to the weight-bearing distribution, the arch index and the displacements in the center of pressure (CoP). Data were used to compare differences among kinds of weight-bearing distribution (symmetric, asymmetric toward non-paretic or paretic foot) and coordination system for CoP displacements. **Results**: Hemiparesis group was compounded by eight symmetrics, eight asymmetrics toward non-paretic foot and four asymmetric toward paretic foot. Significant differences in the weight-bearing distributions between non-predominantly and predominantly used foot did not promote differences in the other baropodometric records (peak and mean of pressure, and support area). Mainly in the asymmetry toward non-paretic foot it was observed significant modifications of the baropodometric records. **Conclusion**: Baropodometric technology can be used to analyze weight-bearing distribution during upright position of subjects with hemiparesis, detecting different kinds of weight-bearing profiles useful to therapeutic programs and researches involving subjects with this disability.

Keywords: Baropodometry. Posture. Balance. Stroke. Hemiplegy.

Resumo

***Introdução**: Embora análises baropodométricas sejam encontradas desde a década de 1990, somente agora é observado número considerável de estudos mostrando usos na reabilitação. **Objetivos**: Para ampliar o uso dessa tecnologia, objetivou-se analisar registros baropodométricos durante a posição ortostática de sujeitos com hemiparesia, descrevendo o suporte de peso nessa população. **Métodos**: 20 sujeitos saudáveis foram pareados por gênero e idade com 12 sujeitos com hemiparesia espástica crônica. Controles foram formados para estabelecer limites de simetria na distribuição do suporte de peso no grupo hemiparesia. Em seguida, o grupo hemiparesia foi submetido a procedimentos usados para fornecer variáveis como: distribuição no suporte de peso, índice de arqueamento e deslocamentos no centro de pressão (CoP). Os dados diferenciaram tipos de distribuição do suporte de peso (simétrico, assimétrico em direção ao pé não parético ou parético) e estabeleceram sistemas de coordenadas para deslocamentos do CoP. **Resultados**: O grupo hemiparesia apresentou oito simétricos, oito assimétricos em direção ao pé não parético e quatro em direção ao pé parético. Distribuição assimétrica do suporte entre os pés não predominantemente ou predominantemente usados não promoveram diferenças em registros baropodométricos (pico e média de pressão e área de suporte). Principalmente para a assimetria em direção ao pé não parético, observou-se modificações significativas nos registros baropodométricos. **Conclusão**: Tecnologia baropodométrica pode ser usada para analisar a distribuição no suporte de peso durante a posição ortostática de sujeitos com hemiparesia, detectando diferentes tipos de suporte de peso, úteis para serem usados em programas terapêuticos e em pesquisas envolvendo sujeitos com essa incapacidade.*

***Palavras-chave**: Baropodometria. Postura. Equilíbrio. Acidente vascular encefálico. Hemiplegia.*

Introduction

Few studies have investigated the influence of hemiparetic upright position on the structural and functional characteristics of the feet and its probable implications for functioning of stroke survivals (1-2). Although computerized baropodometric analysis represents an available technology to investigate feet characteristics described in scientific studies since the 1990s (3-5), just in this last decade a considerable number of studies has shown different uses of this technology (1-2, 6-19).

Computerized baropodometric analysis allows to record plantar imprints and ground reaction forces in the support area during quiet standing (upright position), divided by feet (right and left) and subdivided in three regions named “forefoot”, “midfoot” and “backfoot” for each foot. This support area is expressed in square centimeters (cm^2) and in percentage of the total body weight (2, 7, 18-19).

The weight-bearing distributed by feet during upright position allows to determine the percentage of total body supported by each foot and to calculate the ratio between them, giving us a symmetry ratio, important coefficient to guide therapeutic decisions during rehabilitation programs for stroke survivals with hemiparetic posture (6, 20-22). Moreover, for each foot it can also be calculated an arch index defined by percentage of total foot load on the midfoot imprint, informing kinds of feet (9).

Besides the mentioned records, this technology provides stabilometric parameter derived by spatial and temporal behavior of the center of pressure (CoP), with great usefulness to assess stability and functioning in this population (10, 23).

In this study, computerized baropodometric analysis was performed to find the limits of symmetry to the weight-bearing distribution observed in healthy subjects, that established the criteria to classify weight-bearing symmetrically or asymmetrically distributed during 20 seconds in the hemiparetic upright position. The aim was to compare baropodometric records among different kinds of support during upright position in stroke survivals with hemiparesis, contributing to amplify the use of this technology for rehabilitation programs. Our hypothesis is that the baropodometric technology can be used to help professionals to understand the compensatory strategies used to maintain the posture and balance in hemiparetic individuals.

Methods

Subjects

Subjects with hemiparesis were recruited among the patients that composed the database of participants in previous researches occurred in the Laboratory of Therapeutic Skills in the Faculty of Ceilandia, University of Brasília, Brasília, Federal District, Brazil. Inclusion criteria were: (1) to have a post-stroke period of over 6 months; (2) to have spastic hemiparesis defined as scores ≥ 1 on the modified Ashworth scale (24); and (3) to be able to maintain themselves in the orthostatic position during a period of time long enough to register the weight-bearing in this posture. Participants presenting other types of major orthopedic or neurologic diagnoses (e.g. amputation, fracture of any extremity within the past year, Parkinson's diseases and repeated strokes) in addition to the stroke that resulted in hemiparesis were excluded. Control group subjects were matched by gender and age with each hemiparetic subject and they were recruited among local community. On the basis of these criteria, 20 subjects with and 20 without hemiparesis formed the total sample (n = 40), divided in hemiparesis and control group, respectively. All subjects gave written informed consent. The protocol was approved by the local Ethics Committee of the University of Brasília, Brazil.

Study design and clinical examination

An observational study with screening purpose in a cross-sectional prospective design was used, and the measurements were performed in a single session. Firstly, participants were assessed to record temporal and anthropometric variables (age, chronicity, height and weight), as well as personal and clinical characteristics including leg dominance (25), mental functions and spasticity.

Height and total weight was used to calculate the body mass index (BMI). The mini mental state examination was included to determine a score of the mental health condition, and individuals with score < 13 were excluded (26) and Ashworth scale was used to measure the level of spasticity in the NPUH (24).

Leg dominance was identified by **Waterloo Footedness Questionnaire – Revised** (25) and it was used to identify the predominantly used lower limb that defines the non-predominantly-used (NPUH) and predominantly-used hemibodies (PUH). Despite hand and leg dominance do not always match in hemiparesis and control group, the correspondence of non-affected side in hemiparesis was done with dominant leg in the controls, considering to be these lower limbs the predominantly used during upright position for each group. Then**,** affected and non-dominant sides were considered as NPUH for hemiparesis and control group respectively.

Symmetry analysis and baropodometric measures

The measurements of the weight supported under each lower limb of the body were obtained during baropodometric records using a Barapodometer of the Biomech Studio – Logan Engenharia SrL, version: 1.1.3891.31030, with the Arkipelago platform – Capacitive Sensory, 2010, with EPS-C system. The equipment has 400 mm per 400 mm of active surface, the dimensions of the platform are 575 x 450 x 25 mm, the thickness is of 4 mm / 5 mm, with rubber. It is coated by polycarbonate and its weight is 3 kg. Concerning the electronic characteristics, the platform has 2704 capacitive sensors and frequency of 150 Hz.

The subjects were placed barefoot, with their feet free and aligned on the platform, each foot about 20 cm away from the other, without any type of additional support. All subjects were oriented to maintain an upright position as comfortable as possible, always looking to a fixed point on the wall in front of your face in a distance of around 3 m.

The values obtained for each limb in percentage of the total body were registered as weight-bearing values for the NPUH (affected/non-dominant) and PUH (non-affected/dominant).

Symmetry ratios (SR) were calculated as described by Martins and collaborators (22), however, to calculate this coefficient, the integer values in kilograms recorded for each foot, as published by the authors, were replaced by percentage of the total body for each foot.

The 95% confidence interval (95% CI) of the SR mean obtained in control group was used to establish limits of symmetry (i.e. symmetry was defined as values within 95% CI). Values of SR higher than maximum limit of the 95% CI would represent weight-bearing asymmetries towards the NPUH and values of SR lower than minimum limit of the 95% CI would indicate asymmetries towards the PUH.

Besides percentage of the whole body, the barometry provides information on the peak of pressure, the mean of pressure, the area of support, the Arch index, and the CoP.

Statistical analysis

Descriptive statistics and tests for normality were carried out for all outcome variables, informing average and standard error of the mean (SEM) used to describe the variables.

All variables assessed in this study were processed by Kolmogorov-Smirnov test to verify that they showed a Gaussian distribution. The variables meet the criteria of normal distribution, so parametric tests were used in the analyses.

Student paired t-test were used to compare the means observed in hemiparesis versus control groups. Two-way ANOVA with Bonferroni post-tests was used to compare the means observed in NPUH versus PUH for each kind of weight-bearing distribution (symmetric or asymmetric toward NPUH or PUH). One-way ANOVA was used to compare the means observed among kinds of weight-bearing distribution. The significance level for all analyses was established at $\alpha = 0.05$.

Cartesian coordinate systems were used to show the means of the CoP position during 20 seconds record for each subject and for the hemiparesis group.

Results

Twenty hemiparetic subjects (12 men and 8 female) with a mean age of 59.40 ± 3.04 years (ranging from 29 to 81), a mean time of chronicity of 41.45 ± 12.45 months (ranging from 6 to 252), and twenty healthy subjects with mean age of 58.55 ± 3.11 (ranging from 27 to 82) completed all tests. Their demographic, anthropometric and clinical characteristics are given in Table 1, which demonstrates the similar characteristics between control and hemiparesis group.

The Table 2 shows that baropodometric technology provides information to define three different postural behaviors in stroke survivals, defined as symmetric ($1.253 > SR > 1.059$), asymmetric with overload toward non-paretic foot ($SR < 1.059$) and asymmetric with overload toward paretic foot ($SR > 1.253$). Possibly, the individuals with stroke adapt in different ways, generating different postural behaviors that may be related to other factors than neurologic injury.

The percentage of the total body between bilateral weight-bearing distribution (NPUH versus PUH) presented significant differences for each postural behavior (symmetric, asymmetric toward non-paretic and paretic foot), including subjects with symmetric postural behavior (Figure 1A). Although the behavior to overload paretic side has been similar between subjects with symmetric and asymmetric toward paretic foot, the magnitude of the overload toward paretic side in the symmetric subjects was not enough to provide SR value outside symmetry limits defined by 95% CI recorded for controls (Table 2).

Table 1 - Personal and clinical characteristics by control (n = 20) and hemiparesis (n = 20) group

Personal and clinical characteristics	Control	Hemiparesis
Age (years)	58.55 ± 3.11	59.4 ± 3.04
Chronicity (months)	Not applied	41.45 ± 12.45
BMI (kg/m^2)	28.03 ± 0.92	27.37 ± 1.21
Mini-mental score (points)	28.20 ± 0.31	26.10 ± 0,95
Ashworth score in the NPUH (points)	Not applied	1.30 ± 0.20
Symmetry ratio (SR)	1.15 ± 0.04	1.082 ± 0.10
PUH, n (%)		
Right	17 (85)	14 (70)
Left	3 (15)	6 (30)
Gender, n (%)		
Male	12 (60)	12 (60)
Female	8 (40)	8 (40)

Source: Research data.

Legend: Values are presented as a mean ± SEM (standard error of the mean) for quantitative variables and by absolute (n) and relative (%) frequency for qualitative variables. Groups were matched by age and gender. It was not found significant differences between means. BMI – Body Mass Index; NPUH – Non-predominantly Used Hemibody; SR – Symmetry Ratio; and PUH – Predominantly Used Hemibody.

Table 2 - Classification of the subjects with hemiparesis by weight-bearing distribution

Weight-bearing classification	n (%)
Symmetric	8 (40)
1.253 > SR > 1.059	
Asymmetric with overload toward non-paretic foot	8 (40)
SR < 1.059	
Asymmetric with overload toward paretic foot	4 (20)
SR > 1.253	

Source: Research data.

Legend: Values are presented by absolute (n) and relative (%) frequency for types of weight-bearing distribution, determined by upper and lower limits of the 95% confidence interval for Symmetry Ratio (SR) obtained in the control group.

Differing from the other two kinds of weight-bearing distribution, asymmetrical subjects with overload toward non-paretic side overloaded predominantly used hemibody, and the percentage of total body recorded under each foot, were significantly different from subjects with symmetric postural behavior (Figure 1A).

Despite differences has been found for weight-bearing distribution observed by percentage of total body, when observed by peak of pressure (Figure 1B), the difference between bilateral weight-bearing distributions was just detected for subjects with asymmetry toward non-paretic side (PUH), differing significantly from peak of pressure recorded in the subjects with asymmetry toward paretic side (NPUH). Moreover, when the same conditions were analyzed by mean of pressure (Figure 1C) and support of area (Figure 1D) records, no significant differences were detected.

The Arch Index is represented by the percentage of the weight-bearing supported by each foot (total foot) in the midfoot region. Figure 2A demonstrates Arch Index values, comparing NPUH versus PUH for each postural behavior (symmetry, asymmetry toward non-paretic and paretic foot) identified in the hemiparesis group. Significant difference was not observed between NPUH and PUH for any condition. Nevertheless, for subjects with asymmetry toward non-paretic side the Arch Index value recorded under PUH (non-paretic side) was significantly increased when compared with the same record in the subjects with symmetry.

Samples of individual records can illustrate the differences in the postural behaviors (Figures 2B, 2C and 2D). In Figure 2B, it can be observed that although the subject had a PUH, weight-bearing for each foot was equally distributed, providing SR with values within symmetry limits defined by de 95% IC of the control. In Figure 2C, it is observed an overload toward the PUH. Differing from subjects with asymmetry toward non-paretic side, in the Figure 2C, it is observed a subject overloading the NPUH.

The postural behavior characterized by NPUH overloaded was observed either in subjects with symmetry or asymmetry toward paretic side. However, in the subjects with asymmetry toward paretic side this behavior was followed by enhanced decrease of the peak of pressure when compared with the peak observed in the subjects with asymmetry toward non-paretic side (Figure 1B).

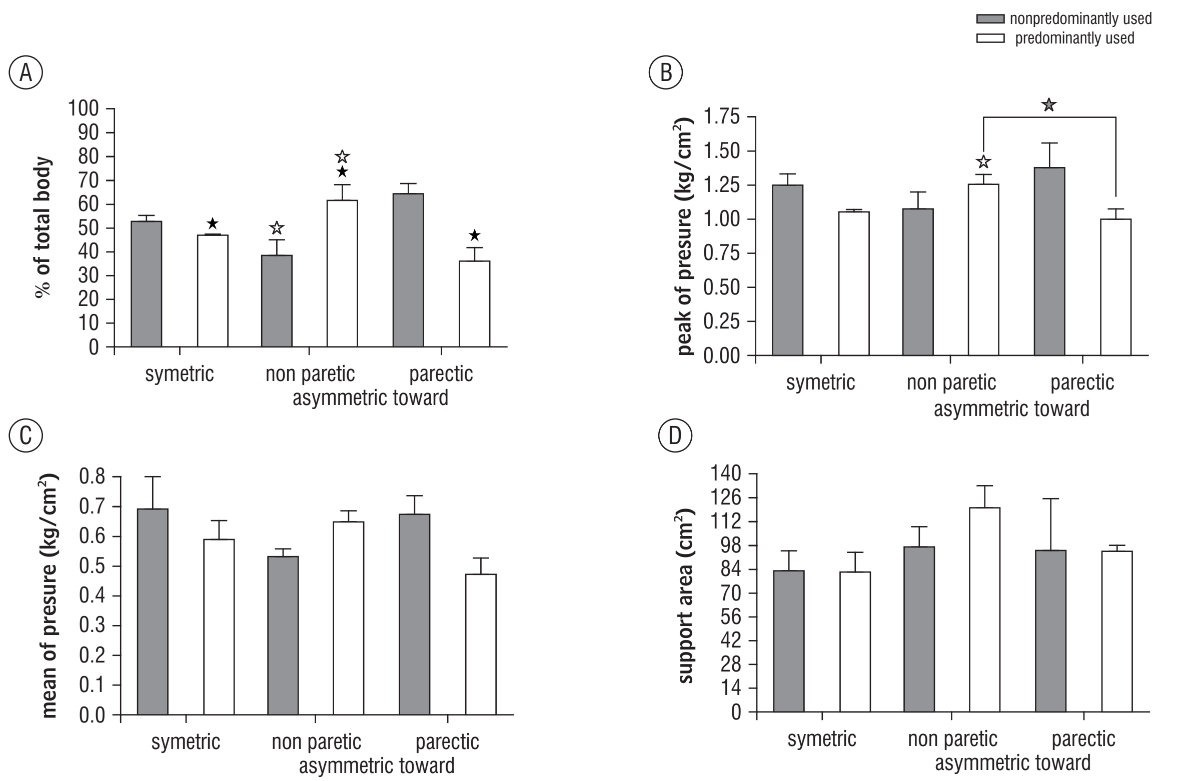

Figure 1 - Bars graphs showing baropodometric parameters (mean ± SEM) under non-predominantly (gray bars) and predominantly (white bars) foot used for hemiparesis group classified by weight-bearing distribution type (symmetric, asymmetric toward non-paretic side and asymmetric toward paretic side). Baropodometric parameters are indicated by weight-bearing in percentage of the total body (A), peak of pressure in kg/cm^2 (B), mean of pressure under the foot in kg/cm^2 (C), and support area under the foot in cm2. Significant differences between non-predominantly and predominantly foot were indicated by black stars. Differences between types of weight--bearing distributions when compared with symmetric were indicated by white stars, and when compared with asymmetric types were indicated by gray stars.

Source: Research data.

Other set of variables available by computerized baropodometric technology is that derived from Center of Pressure (CoP). Named as "stabilometric parameters", variables as displacement, distance and velocity of CoP can be investigated during upright position. Three Cartesian coordinate systems were indicated in the Figure 3 to illustrate individual (asterisks) and group (gray stars) behavior of the CoP recorded during 20 seconds in upright position for subjects with symmetry (A), asymmetry toward non-paretic (B) and paretic (C) side.

The system represented in the Figure 3A (symmetry) shows a majority of CoP position that was resulted from displacement swinging backward and toward the NPUH with the average of these individual CoP (group behavior) also placed in this area. However, the systems for asymmetries (3B and 3C) showed a large variation of individual CoP.

In the Figure 3B, although a large variation has been observed for individual records, the group behavior of the subjects with asymmetry toward non-paretic side was represented by a CoP placed in the NPUH.

In the Figure 3C, despite the large variation, the majority of the individual records of subjects with asymmetry toward paretic side swing backward and toward the PUH. The group behavior of these individual records showed a CoP placed in the backward toward PUH areas.

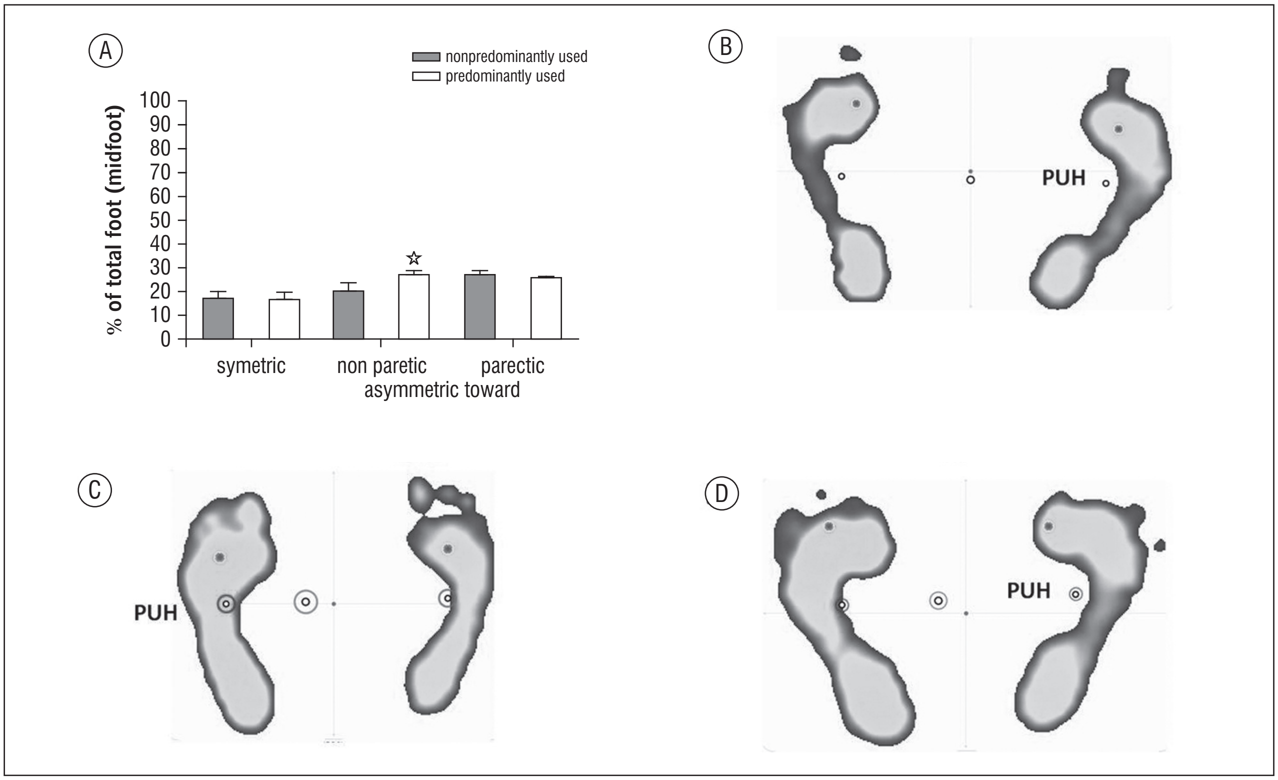

Figure 2 - Bars graph showing Arch Index (mean ± SEM) under non-predominantly (gray bars) and predominantly (white bars) foot used for hemiparesis group classified by weight-bearing distribution type (symmetric, asymmetric toward non-paretic side and asymmetric toward paretic side). Arch Index is indicated by weight-bearing in percentage of the total foot presented under midfoot (A). Significant difference between Arch Index when compared with symmetric type was pointed by the white star. Images B, C and D are baropodometric representations of the weight-bearing distribution showing, respectively, samples of subjects with symmetry (B), asymmetry toward predominantly used hemibody (PUH – non-paretic side – C), and asymmetry toward non--predominantly used hemibody (NPUH – paretic side – D). Subjects with hemiparesis represented in the images B, C and D had, respectively, left, right and left hemiparesis.

Source: Research data.

The averages of the distance covered by CoP for each postural behavior (symmetry, asymmetry toward non-paretic or paretic sides) do not differ among them. The same was observed in the averages of the CoP's velocity.

Discussion

As it was used in previous papers published by our group (20-22), in this work SR was utilized to define types of weight-bearing during upright position. However, in this study the variable used to calculate SR was the percentage of total body supported by each foot and recorded by computerized baropodometry. It was also obtained data from a control group matched by age and gender that was used to establish a 95% CI to define limits of symmetry (22).

As it was previously observed for us (20-22), in this new study using baropodometric technology, we confirm to be incorrect to always consider weight-bearing asymmetrically distributed in individuals with hemiparesis, because it was found eight subjects (40%) with hemiparesis presenting SR within symmetry limits obtained in control group. Again, now using computerized baropodometry, a majority of the subjects with hemiparesis and asymmetry during weight-bearing distribution (40%) showed postural behavior classified as asymmetry toward non-paretic side (PUH) and a minority of these subjects with hemiparesis (20%) showing

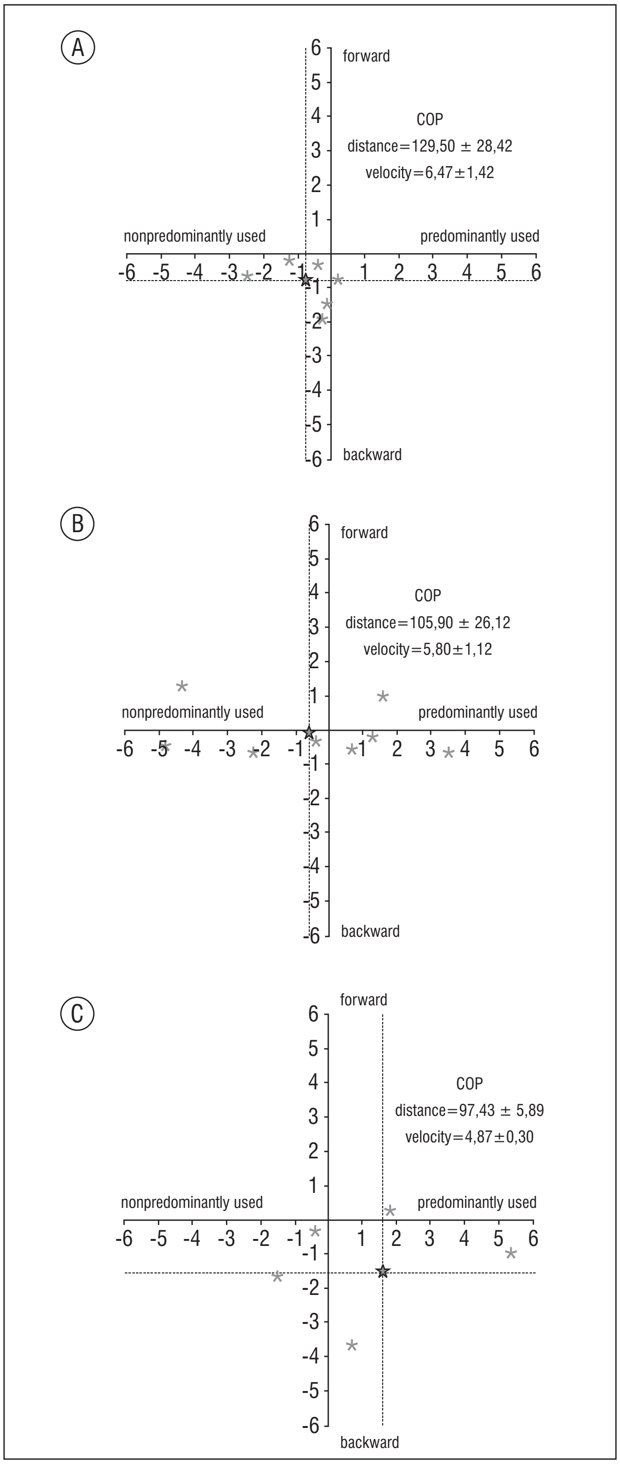

Figure 3 - Cartesian coordination systems showing individual (asterisk) and group behavior (gray stars) of the Center of Pressure (CoP) displacements for hemiparesis group classified by weight-bearing distribution type: symmetric (A), asymmetric toward non-paretic side (B) and asymmetric toward paretic side (C). The mean distance and velocity were described in right upper quadrant

Source: Research data.

postural behavior classified as asymmetry toward paretic side (NPUH) was observed. These subjects with asymmetry toward paretic side probably must be individuals with Pusher Syndrome and/or some type of neglect disorder (27-28). To review this results, see Table 2.

These results demonstrate that baropodometric technology, as well as digital scales used in the previous studies (20-22), provides variables that can be used to investigate the different wearing-bearing distribution in hemiparetic individuals.

Although baropodometry had already been used in other studies to assessment individuals with several different conditions (9, 29-30), the present study introduces a novelty, because it is the first research to use this technology to calculate SR in subjects with hemiparesis showing all analysis that can be applied in this population with therapeutics and research aims.

In therapeutic terms, different types of weight-bearing distribution could represent different compensatory strategies to maintain posture and balance necessary to acquire motor function.

According to Genthon and collaborators (31), the weight-bearing asymmetrically distributed during upright position of the stroke survival subjects is not the primary cause of their postural imbalance, they mainly affirm that balance is the consequence of impaired control of postural stabilization involving both limbs.

Motor weakness, asymmetrical muscular tone, deficits in the somatosensory system and alterations in spatial cognition with reference to the postural body scheme may participate in this postural instability (32-33). These authors suggest that the weight-bearing asymmetrically distributed may not be the principle target during rehabilitation programs aiming to restore standing balance after stroke, and other factors could contribute to a compensatory strategy in posture control. This compensatory strategy would not be precisely symmetric (20-22).

The postural behavior analyzed by parameters provided during a computerized baropodometric records showed interesting results that must be better studied. For this twelve subjects presenting symmetry or different types of asymmetry in the weight-bearing distribution during upright position, the analysis from ground reaction forces occurring in the contact surface of the feet, the characteristics of contact in the midfoot region (Arch Index) and the variation of the CoP (stabilometric parameters) showed a lot of information.

A clear result is observed: complete symmetry during upright position and represented by SR with value equal 1 was almost not found in the hemiparesis and control group (i.e. all subjects, including controls, will always presents some level of overload toward one side). This observation is supported by evidences that showed a natural postural sway (34-37). However, as observed in by 95% CI of the SR record from control group, this overload varied in a range of 0.194 with upper limit of 1.253 and lower limit of 1.059, characterizing that subjects with SR closer than the complete symmetry (Table 2). Then, to be classified as asymmetry, the SR must overpass upper or lower limits.

Separated by types of weight-bearing distribution, subjects with hemiparesis presented differences in the postural behavior analyzed by this technology. By observing the percentage of weight-bearing bilaterally distributed, it was confirmed an overload toward one side (Figure 1). Subjects with symmetric behavior significantly overloaded NPUH, however inside limits of symmetry (Figure 1A). This postural behavior is quite similar the postural behavior observed in subjects without hemiparesis (21-22). As expected, significant overloads toward one side and now outside the symmetry limits were also observed in subjects with asymmetry behavior, presenting two different types (Figure 1A) toward PUH in the subjects that overloaded non-paretic side and toward NPUH in the subjects that overloaded paretic side.

The overloads detected by percentage of total body (Figure 1A) were not followed by changes in the peak of pressure (Figure 1B), mean of the pressure (Figure 1C) and support area (Figure 1D). The non-matching of the differences detected from percentage of total body with the other variables recorded can suggest an effect of the normalization. Variables normalized by support area can be better used than percentage of total body to show difference between weight-bearing distributions in each hemibody, avoiding small differences related with natural postural sway (38-39).

Only in the subjects with hemiparesis and asymmetry toward non-paretic side it was observed an increase in the Arch Index (Figure 2A), reflecting consequences of the foot overloaded and with a higher peak of pressure. The increase in the Arch Index could suggest changes in the medial longitudinal arch of the foot, which could impair the absorption of the reaction shock forces during gait (40-41).

The three types of weight-bearing distribution identified in the hemiparesis showed particular postural behavior that must be better studied. In the Cartesian coordination systems for each condition (Figure 3), an interesting feature was observed: in the symmetry, the mean of CoP displacement during 20 second in upright position was placed in the overloaded side, differing from asymmetries where it was observed that the mean of CoP displacement was placed in the opposite from the overloaded side. Despite this feature could represent something important, the few subjects for demonstrate aspects of each type of weight-bearing condition represented a limitation of this study, hindering a good discussion about associations of CoP displacement and postural behavior.

The results here presented allowed to explore the potentialities of this technology for rehabilitation and future researches aiming to acquire benefits to the subjects with hemiparesis condition.

Conclusion

Baropodometric technology can be used to analyze weight-bearing distribution during upright position of subjects with hemiparesis detecting different types of postural behavior, considering the different profiles of weight-bearing distribution, and this knowledge is useful to be applied in therapeutic programs and researches involving subjects with hemiparesis.

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