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# Quantitative parameters of gait imbalance in multiple sclerosis patients

ZOFIA DZIĘCIOŁ-ANIKIEJ[1], PAULINA MALINOWSKA[1], KRISTINA DAUNORAVICIENE[2], JOLANTA PAUK[3]*, ALINA KUŁAKOWSKA[1], AGNIESZKA DARDZIŃSKA-GŁĘBOCKA[3], ANETTA SULEWSKA[1]

[1] Medical University of Bialystok, Białystok, Poland.
[2] Vilnius Gediminas Technical University, Department of Biomechanical Engineering, Vilnius, Lithuania.
[3] Bialystok University of Technology, Białystok, Poland.

*Purpose*: The purpose is to identify objective quantitative parameters for a more accurate evaluation of gait imbalance and relate it to Body Mass Index and age. *Methods*: 25 multiple sclerosis (MS) and 30 healthy people (CG) aged between 22 and 66 years old (50.4 ± 9.5) were examined in static and dynamic tasks. The demographic data were as follows: body mass (72.4 ± 18.4 kg in CG vs. 66.8 ± 11.5 kg in MS); body height (1.78 ± 0.15 m in CG vs. 1.70 ± 0.11 m in MS); BMI (24.7 ± 4.5 kg/m$^2$ in CG vs. 23.5 ± 3.0 kg/m$^2$ in MS). First, all individuals remained static for baropodometric, pulse and saturation evaluation. Later on, a 6-minute walk and timed up and go tests were performed and additionally included quantitative measurements by barometry and pulse oximeter. *Results*: The dynamic condition revealed meaningful differences in the foot surface and hindfoot loading, in addition to foot max. loading between study groups. TUG disclosed significantly different results between groups in time and the number of steps. For MS in statics, the moderate positive correlations between BMI and the right forefoot and right hindfoot, and in MS statics, the correlation of the age vs. maximal left foot loading, forefoot loading and hindfoot loading was observed. In the dynamic, the age and plantar angle of the foot had weak relation. *Conclusions*: Quantitative parameters defining balance deviations of MS are related to BMI and age in statics and dynamics, therefore should be taken into account during MS imbalance assessment.

*Key words*: *gait, baropadometry, multiple sclerosis, plantar pressure, BMI, Timed Up and Go*

## 1. Introduction

Multiple sclerosis (MS) is a chronic disease of the nervous system. It was firstly described in the 19th century, and now it is one of the most common neurological diseases in young people between the ages of 20–40 years old [8]. It affects over 2 300 000 people worldwide. The highest prevalence has been reported in the north of Europe. In Poland, there are about 40 000 sick people and women get sick more often than men [33]. This could be associated with changes in women's lifestyle (smoking, obesity, stressful occupation or a later first delivery) [2]. The etiology of the disease is not fully understood and its pathogenesis is complex and multifactorial. However, disseminated process, inflammatory, degenerative changes that affect the nerve tissues of the brain and spinal cord are observed [33]. One of the most common symptoms is spastic paresis (about 80% of MS patients), reflecting on the gait of people with MS and causing many problems in everyday functioning. Patients also complain of excessive fatigue, sensory disturbances, irregularities in the work of the urinary system, as well as cerebellar disorders (intentional tremor, chanted speech, problems with balance). Moreover, cerebellar symptoms occur in 75% of MS patients, including scanned speech, an increased risk of falls and clumsiness or balance disturbances [27]. Sometimes a paroxysmal or chronic pain is a result of nervous system damage.

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* Corresponding author: Jolanta Pauk, Bialystok University of Technology, Biomedical Engineering Institute, ul. Wiejska 45C, 15-351 Białystok, Poland. Phone: 510 034 086, e-mail: j.pauk@pb.edu.pl
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The spastic pain primarily affects limbs, tonic muscle spasms, headaches and back. Fatigue is a significant problem of MS patients; more than half of people suffer from this commonly [14]. Although the problem is known, patients are not adequately diagnosed and treated.

Gait-related dysfunctions affect many patients with multiple sclerosis and significantly affect the quality of life [31]–[34]. Patients are manifested by walking difficulties, such as reduced walking speed, stride length, cadence [13], the extension of the double support phase and a shorter swing phase compared to healthy people [8], reduced strength muscle or malfunction of the cerebellum [31]. Many tests are used to assess balance and gait in MS patients, including the Timed Up and Go test (TUG), the 12-item Multiple Sclerosis Walking Scale (MSWS-12), and a 6-minute walk test [3], [16]. Baropodometric analysis are increasingly used, thanks to which it is easier to detect changes in gait parameters [4], [6], [7], [12]. The MSWS-12 questionnaire (Multiple Sclerosis Walking Scale) consists of twelve elements that show the effect of the disease on the ability to move. It focuses only on the last two weeks before the survey [30]. In turn, the TUG requires patients to get up from the chair, walk 3 meters, turn around and sit on the chair [1]. Often, the Tinetti balance and gait scale is used to examine the patient. The test is divided into two stages: the first focuses on balance in three positions: standing, turning and sitting, while the second – on walking. The sum of the points in the test is 28. The test requires a lot of activity from the patient, but his advantage is using orthopedic equipment [24]. Another test called BBS (Berg Balance Scale) contains 14 commands for the patient (including standing on one leg, reaching for objects, rotating around own axis and climbing the step). The time needed to complete those tasks takes about 20 minutes. It characterizes sensitivity and specificity when it comes to assessing the risk of falls. Berg scale is called the gold standard for the assessment of functional balance [4], [23]. Few studies [9], [11], [16], [20], [21], [28], [32] focus on the gait analysis of people with MS static disorders, however to best our knowledge the relation between baropodometric and BMI and age in those groups of patients have not been recognised. Determining which gait parameters and walk tests are sensitive enough to characterize BMI and age-dependent differences in gait patterns of MS patients may be sufficient for routine clinical use. Our study focused on the problem of imbalance in MS. We sought to highlight quantitative parameters that best identify imbalance. Herein, the following issues related to imbalance of MS patients in static and dynamic state are discussed: 1. the percentage distribution of the pressure between forefoot and hindfoot in statics and dynamics; 2. the impact of fatigue, HR and SPO during the 6-min walk distance (6MWD) test; 3. the relationship between defined imbalance quantitative parameters and BMI in addition with an age.

# 2. Materials and methods

## 2.1. Subjects

The cross-sectional study was carried out at the hospital assisted by the team of physicians and technical professionals. The total of 55 subjects enrolled in the study. The study included 25 MS patients (15 women and 10 men) with relapsing-remitting MS (RRMS) aged between 22 and 66 years old (50.4 ± 9.5). The control group consisted of 30 healthy people aged between 31 and 61 years old (46.9 ± 8.9). The demographic data were measured using Jawon Medical X-Contact 357S as follows: body mass (72.4 ± 18.4 kg in CG vs. 66.8 ± 11.5 kg in MS); body height (1.78 ± 0.15 m in CG vs. 1.70 ± 0.11 m in MS); BMI (24.7 ± 4.5 kg/$m^2$ in CG vs. 23.5 ± 3.0 kg/$m^2$ in MS). The inclusion criteria for MS patients were ability to walk at least 30 meters without the orthopedic supplies or assisting person and maintaining a stable and upright posture for one minute. People who recently had surgery or steroid therapy were excluded from this study. All the participants in the study provided their informed consent and the research was carried out in the Rehabilitation and the Neurology Clinic of the Medical University of Bialystok. The Bioethics Committee approved this study (No. R-I-002/392/2019).

## 2.2. Measurement protocol

First, the fatigue before and after the examination was assessed using shortened Berg scale [15], [21], [30]. Tasks included both static and dynamic balance tasks. The activities were ranked from the least to the most difficult to perform, and scoring was given based on the ability to perform the items independently and to meet a certain time or distance requirements. Patients were tested twice by the same rater and at the same time of day with five days gap between tests for test-retest reliability. During baropodometric measurements, patients walked barefoot at the same time (2 p.m.). The evaluation was performed in a static and dynamic state on both feet separately (right foot, left foot). Later on, a 6-minute walk (6MWD) and timed up and go (TUG) tests were performed over a 3-meter distance along with time capture and steps counting [19], [22], [29]. Each measurement was repeated three times per foot (right foot – RF; left foot – LF). The average of three measurements was calculated for data analysis. Additionally, heart rate was measured three times after a 5-minute rest in the supine position. Patients were asked to remain motionless while the device was in operation. Moreover, the oxygen saturation (SPO) was evaluated (2nd, 4th, and 6th minute). The sensor was attached to the patient's left middle finger. For quantitative assessment the baropodometer FreeMed Posture (Koordynacja, Poland), pulsoximeter (Yonker, Republic of China) and timer were used. The following parameters were determined: foot surface [$cm^2$], forefoot and hindfoot loading [%], maximum loading of foot [$gr/cm^2$], plantar angle of foot [°], number of steps executing TUG, performance time [min], distance [m], fatigue scores, pulse (HR) and oxygen saturation (SPO). All data collected were compared between the MS and CG.

## 2.3. Statistical analysis

The normality of the distribution of data was checked using the Shapiro–Wilk test. The Mann–Whitney *U*-test was performed when normal distribution was not achieved. The relationship between the variables was investigated using Pearson correlation coefficient. The statistical significance level was set at $p < 0.05$. Absolute value of coefficient means: weak correlation $0.3 \leq R \leq 0.5$ moderate correlation $0.5 \leq R < 0.7$, high correlation $0.7 \leq R < 0.9$, very high correlation $R \geq 0.9$. Statistica 12.5 (StatSoft, Poland) software was used for computations.

# 3. Results

## 3.1. Subjects

There were no statistically significant differences in descriptive statistics between the groups in terms of age, body weight and height or BMI (Table 1).

## 3.2. Plantar pressure distribution

Based on the Mann–Whitney *U*-tests, significant differences were found between CG and MS groups in the balance and gait parameters in static and dynamic tasks (Tables 2 and 3).

In static condition, the differences between all parameters in patients with multiple sclerosis compared to healthy are not statistically significant ($p > 0.05$).

In the dynamic condition, the differences in the foot surface, foot and hindfoot loading, plus max. loading of the foot have been demonstrated in MS under both feet compared to CG ($p < 0.05$). The mean values of the angles were higher in MS patients compared to CG, but the difference was not statistically significant ($p > 0.05$). The average distance of MS patients was almost 200 meters shorter than the CG during the 6-minute walk test ($p < 0.05$). The difference in pulse (HR) and oxygen saturation (SPO) between groups were not statistically significant ($p > 0.05$). Based on the shortened Berg scale, the test was more demanding for patients with MS ($p > 0.05$). Our study disclosed these significantly different results of TUG test in groups: time (on average 5.9 s in healthy vs. 13.6 s in MS patients) and the number of steps (in average 9.3 in healthy vs. 15.9 in MS patients), Table 4.

For the CG, the moderate and high correlations between BMI and accordingly the maximal right foot loading during static ($R = 0.62$) and dynamic ($R = 0.73$) examination were found. The time for TUG and BMI demonstrated moderate relation ($R = 0.52$), $p < 0.05$. The age and the left forefoot loading ($R = 0.59$) and hindfoot loading ($R = 0.63$), $p < 0.05$ in static condition have moderate correlation (Table 5). In dynamic condition, the correlation between age and the surface, maximal loading, forefoot and hindfoot for the left foot was observed as follows: 0.58, 0.71, 0.70, 0.68, 0.29, separately.

In turn, for MS the correlations between BMI and the right forefoot ($R = 0.64$); right hindfoot ($R = 0.67$) considered as moderate; and BMI vs. the right plantar angle ($R = 0.41$) – weak, $p < 0.05$ in statics. Furthermore, the correlation between age and maximal left foot loading ($R = 0.69$), left forefoot loading ($R = 0.65$) and left hindfoot loading ($R = 0.67$) was observed as moderate in static. It means that BMI could be recognized as a factor which determines functional capacity of the feet. In the dynamic, the age and plantar angle of the foot ($R = 0.36$) had weak relation. BMI and age was negatively correlated with SPO-2 and was $R = -0.26$ and $R = -0.24$, respectively. It suggests that increased BMI could impair the ability to breath.

Table 1. Demographic data of CG and MS patients

| Parameter | CG | | MS | |
|---|---|---|---|---|
| | Mean (SD) | Max–Min | Mean (SD) | Max–Min |
| Age [years] | 46.9 ± 8.9 | 61.0–31.0 | 50.4 ± 9.5 | 66.0–22.0 |
| Body mass [kg] | 72.4 ± 18.4 | 114.0–49.0 | 66.8 ± 11.5 | 90.0–50.0 |
| Height [m] | 1.78 ± 0.15 | 1.68–1.95 | 1.70 ± 0.11 | 1.63–1.82 |
| BMI [kg/m$^2$] | 24.7 ± 4.5 | 34.4–18.4 | 23.5 ± 3.0 | 30.1–19.3 |

Table 2. The balance and gait parameters of CG and MS patients in static

| Parameter | CG | | MS | |
|---|---|---|---|---|
| | Mean (SD) | Max–Min | Mean (SD) | Max–Min |
| Left foot Surface [cm$^2$] | 64.8 ± 21.7 | 121.0–30.0 | 58.5 ± 13.7 | 92.0–33.0 |
| Right foot Surface [cm$^2$] | 67.7 ± 24.2 | 129.0–35.0 | 70.3 ± 20.0 | 114.0–36.0 |
| Left foot loading [%] | 49.0 ± 5.6 | 63.0–36.0 | 42.7 ± 8.8 | 67.0–27.0 |
| Right foot loading [%] | 51.0 ± 5.6 | 57.0–37.0 | 57.3 ± 8.8 | 73.0–33.0 |
| Left forefoot loading [%] | 31.4 ± 17.7 | 63.0–1.0 | 35.5 ± 15.9 | 78.0–12.0 |
| Right forefoot loading [%] | 32.9 ± 16.2 | 67.0–4.0 | 39.9 ± 15.5 | 78.0–39.0 |
| Left hindfoot loading [%] | 68.6 ± 17.7 | 99.0–37.0 | 64.5 ± 15.9 | 88.0–22.0 |
| Right hindfoot loading [%] | 67.1 ± 16.2 | 96.0–33.0 | 60.1 ± 15.5 | 83.0–22.0 |
| Max. loading of left foot [gr/cm$^2$] | 1357.2 ± 282.4 | 1983.0–991.0 | 1237.8 ± 282.3 | 1867.0–678.0 |
| Max. loading of right foot [gr/cm$^2$] | 1353.8 ± 289.3 | 1983.0–761.0 | 1349.4 ± 342.1 | 2132.0–781.0 |
| Plantar angle of left foot [°] | 8.7 ± 6.4 | 23.0–1.0 | 8.2 ± 5.6 | 21.0–0.0 |
| Plantar angle of right foot [°] | 9.4 ± 7.2 | 34.0–0.0 | 9.0 ± 6.3 | 21.0–0.0 |

* $p < 0.05$.

Table. 3. The balance and gait parameters of CG and MS patients during the 6-minutes test

| Parameter | CG | | MS | |
|---|---|---|---|---|
| | Mean (SD) | Max–Min | Mean (SD) | Max–Min |
| Distance [m] | 677.7 ± 111.5 | 895.0–375.0 | 482.5 ± 147.3* | 815.0–150.0 |
| Left foot Surface [cm$^2$] | 70.9 ± 19.0 | 114.0–37.0 | 97.1 ± 20.5* | 222.0–59.0 |
| Right foot Surface [cm$^2$] | 69.4 ± 17.7 | 114.0–33.0 | 99.1 ± 21.8* | 203.0–37.0 |
| Left foot loading [%] | 31.4 ± 17.8 | 63.0–1.0 | 55.1 ± 14.0* | 73.0–22.0 |
| Right foot loading [%] | 32.9 ± 16.2 | 67.0–4.0 | 56.0 ± 11.5* | 80.0–38.0 |
| Left hindfoot loading [%] | 68.6 ± 17.8 | 99.0–37.0 | 44.9 ± 14.0* | 78.0–27.0 |
| Right hindfoot loading [%] | 67.1 ± 16.2 | 96.0–33.0 | 44.0 ± 11.5* | 62.0–20.0 |
| Plantar angle of left foot [°] | 8.7 ± 6.5 | 23.0–1.0 | 9.7 ± 5.6 | 20.0–0.0 |
| Plantar angle of right foot [°] | 9.4 ± 7.2 | 34.0–0.0 | 12.6 ± 5.4 | 23.0–2.0 |
| Max. loading of left foot [gr/cm$^2$] | 1420.0 ± 408.9 | 3004.0–991.0 | 2967.2 ± 717.6* | 4120.0–1326.0 |
| Max. loading of right foot [gr/cm$^2$] | 1413.6 ± 402.3 | 2912.0–761.0 | 2933.7 ± 858.4* | 4640.0–1158.0 |
| HR before test | 85.2 ± 14.4 | 122.0–53.0 | 83.4 ± 11.7 | 102.0–60.0 |
| HR-2 min. test | 94.6 ± 20.0 | 140.0–58.0 | 97.0 ± 11.9 | 124.0–77.0 |
| HR-4 min. test | 100.6 ± 23.8 | 168.0–59.0 | 98.3 ± 11.9 | 120.0–80.0 |
| HR-6 min. test | 107.0 ± 29.6 | 179.0–59.0 | 98.0 ± 15.7 | 126.0–72.0 |
| SPO before test | 97.6 ± 1.7 | 99.0–91.0 | 98.0 ± 1.0 | 99.0–96.0 |
| SPO-2 min. test | 95.3 ± 2.6 | 99.0–91.0 | 97.2 ± 1.2 | 99.0–95.0 |
| SPO-4 min. test | 95.3 ± 2.2 | 99.0–91.0 | 96.8 ± 1.2 | 99.0–94.0 |
| SPO-6 min. test | 95.8 ± 1.9 | 99.0–92.0 | 96.8 ± 1.2 | 99.0–93.0 |
| BERG before test | 0.0 ± 0.0 | 0.0–0.0 | 1.0 ± 0.0 | 5.0–0.0 |
| BERG after test | 1.1 ± 1.1 | 4.0–0.0 | 3.0 ± 2.4 | 8.0–0.0 |

* $p < 0.05$.

Table. 4. TUG results of CG and MS patients

| Parameter | CG | | MS | |
|---|---|---|---|---|
| | Mean (SD) | Max–Min | Mean (SD) | Max–Min |
| Time [s] | 5.9 ± 0.0 | 7.0–4.0 | 13.6 ± 12.6* | 55.0–6.0 |
| Number of steps | 9.3 ± 1.4 | 12.0–6.0 | 15.9 ± 6.1* | 36.0–10.0 |
| Number of steps during rotation | 2.1 ± 0.9 | 4.0–1.0 | 3.7 ± 1.4* | 8.0–2.0 |

* $p < 0.05$.

Table. 5. Significant relationships between the in CG and MS patients

| Parameter | Type of research | Parameter | *R* | *P*-value |
|---|---|---|---|---|
| CG | | | | |
| BMI | Static | Max. loading RF | 0.62 | 0.033 |
| | Dynamic | Max. loading RF | 0.73 | 0.010 |
| | TUG | Time | 0.52 | 0.049 |
| Age | Static | Forefoot loading LF | 0.59 | 0.002 |
| | | Hindfoot loading LF | 0.63 | 0.002 |
| | Dynamic | Surface LF | 0.58 | 0.042 |
| | | Max. loading LF | 0.71 | 0.026 |
| | | Forefoot loading LF | 0.70 | 0.001 |
| | | Hindfoot loading LF | 0.68 | 0.001 |
| | TUG | Number of steps during rotation | 0.29 | 0.028 |
| MS | | | | |
| BMI | Static | Forefoot loading RF | 0.64 | 0.047 |
| | | Hindfoot loading RF | 0.67 | 0.047 |
| | | Plantar angle RF | 0.41 | 0.039 |
| | Dynamic | SPO-2 | –0.26 | 0.030 |
| Age | Static | Max. loading LF | 0.69 | 0.019 |
| | | Forefoot loading LF | 0.65 | 0.044 |
| | | Forefoot loading RF | 0.67 | 0.030 |
| | Dynamic | Plantar angle LF | 0.36 | 0.006 |
| | | SPO-2 | –0.24 | 0.038 |

# 4. Discussion

The symptoms of multiple sclerosis are usually variable. They depend on the location of the affected areas. Balance problems, muscle spasticity and strength, visual abnormalities and urinary system disorders observed in patients [8]. Our study focused on the problem of imbalance in MS. We sought to highlight quantitative parameters that best identify imbalance using routine clinical assessment tools and pedobargraphy. Many scientists observed how the disease affects the stability of body posture [4]–[7], [12], [26], [35]. For example, Brincks et al. [6] assessed the gait and balance parameters using stabilometric, TUG and T25FW tests; however, no correlation was found between balance and gait efficiency. We examined MS and healthy patients in static and dynamic activity as well. Our results revealed that the forces distributed over the feet in MS are lesser than in CG during the static. In addition, MS exhibit higher plantar pressure distribution and increased foot contact area under the right foot. The differences between the forefoot and hindfoot loadings were not significant ($p > 0.05$). However, higher loads on the hindfoot were found in CG than in the MS during the static. In turn, during a dynamic study, MS patients had two times increased lower limb loading than healthy people. Moreover, the bodyweight of MS moved to the forefoot (in more than 50%); in the CG, the values were around 30%. In both groups, the mean values of the plantar foot angles were higher in the right foot (in static and dynamic tasks). However, in the static examination, higher angular values were reported in the CG.

MS gait is extensively studied to establish relationships between objective parameters. Gait patterns are analyzed for different forms of MS. However, gait variability is observed [9], [13], [28], [32] which is influenced by many factors that are not limited to MS. Dujmovic et al. [10] showed that the gait of patients with MS differs significantly from the gait pattern in healthy people. They found a shorter stride length, a longer cycle time and a slower walking speed. Yildiz [34] demonstrated the impact of slower walking speed on activities of daily living in patients with multiple sclerosis. The results are in line with our research. In our study, the TUG test results in MS patients differ significantly from CG (5.9 s in healthy vs. 13.6 s in MS patients). The average distance length in MS patients was almost by 200 meters shorter than the CG during the 6-minute walk test. However, it is necessary to look deeper and relate the changes in gait pattern, in concern with decrease in gait speed, the shortening of the distance to the fatigue experienced by MS patients. Kalron [17] used the Modified Fatigue Impact Scale in order to link perceived fatigue to walking speed in MS individuals. In addition, this relation was confirmed by study results, nevertheless, a contribution of walking speed to level of fatigue was found as limited. Assessing fatigue using the shortened Berg scale showed that the test was more demanding for patients with MS than it was expected. Although, before the test, many of them reported a weakness, one person out of 25 respondents was unable to do a 6-minute walk test and be very tired.

One of the goals of this study was to correlate the obtained study parameters with BMI and age. What we saw in the comparative analysis of CG and MS correlation was of great interest to us. In the CG group and in statics and dynamics, we found more strong and moderate relationships, $p < 0.05$ with BMI and age than in the MS group (Table 2). All significant relations are positive, which means that their values grow together and influence the stability work in tandem. One more thing we noted was that, generally, all significant relationships are different in CG and MS, for example, in the case when CG demonstrated strong correlation between BMI and max. loading RF in dynamics, MS even don't have the same relation (Table 5). In MS, more significant relationships were found in statics than in dynamics and values of correlation coefficient were near to strong. In MS statics, we found moderate relation between BMI and the right forefoot ($R = 0.64$); right hindfoot ($R = 0.67$), weak correlation with the right plantar angle ($R = 0.41$). Furthermore, age in MS statics displayed positive moderate relationship with: maximal left foot loading ($R = 0.69$), left forefoot loading ($R = 0.65$) and left hindfoot loading ($R = 0.67$). In MS dynamics: the age and plantar angle of the foot ($R = 0.36$) had weak relation; BMI and age was negatively correlated with SPO-2 and was $R = –0.26$ and $R = –0.24$, respectively. Based on the preliminary results obtained in this study, we would like to emphasize the need to assess the influence of BMI and age on the MS balance. Many authors confirmed that obesity is a growing problem among various age and professional groups, contributing to functional disorders [18], [25]. However, we understand that more detailed cross-sectional studies are needed to define the magnitude of the effect of BMI and age on equilibrium parameters.

We recognized the limitation of our study. We did not analyse actual levels of physical activity which might affect some aspects of mobility, especially in patients before 70 years old.

# 5. Conclusions

Imbalance in MS patients is best characterized and defined in terms of dynamics rather than statics. However, quantitative parameters that define balance state are related to BMI and age in statics and dynamics, therefore, should be taken into account when assessing the MS balance. These results may be helpful in walking limitations assessment and treatment or disease-progression monitoring as well can be used in development of a deficit-specific and patient-tailored exercise programs.

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