Anticipatory postural adjustment during gait initiation in multiple sclerosis patients: A systematic review

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Background: Multiple sclerosis (MS) causes balance and walking disorders. Gait initiation is the complex transition between standing and walking and is characterized by two distinct phases: the anticipatory postural adjustment (APA) phase followed by the execution of the first step phase.

Research aim: To determine alterations in the APA during gait initiation in patients with MS.

Methods: A systematic search was conducted in May 2018. The search was carried out by the use of the following databases: PubMed, Web of Science and the Cochrane Library. The following keywords were used: MS, gait initiation, step initiation, and postural adjustment(s). Outcomes of interest were the variables generally used to assess APA, including electromyography, force-plate data, or video-based data, duration of APA, and length of first step. The Ottawa scale was used to assess the quality of the studies.

Results: Eight case-control studies were included; one was a transverse study. A total of 215 MS patients and 116 healthy subjects were included with ages ranging from 22 to 76 years old. In MS patients, Expanded Disability Status Scale (EDSS) scores ranged from 0 to 7. APA CoP displacements were smaller in the anteroposterior axis. Four studies evaluated muscle activation during APA. The latencies of all muscles were delayed, and smaller magnitudes of muscle activity during APA were found, even in the early stage of disease. The first step was shorter in MS patients than in healthy patients. No previous study has reported joint movement or trunk in-clination during gait initiation.

Significance: This review illustrates the gap in knowledge of APA alterations in MS patients. APA assessment in the early stage of MS could be an interesting measure to characterize balance, dynamic control and risk of fall for such patients.

1. Introduction

Multiple sclerosis (MS) is an autoimmune inflammatory chronic disease of the central nervous system that affects young and middle-aged adults. The pathological and clinical presentations of MS are heterogeneous and include muscle weakness, somatosensory loss, ataxia, visual disturbance that impairs coordination, postural control and gait. Balance disturbance is often described as one of the initial consequence of these symptoms of the disease [1]. This balance disorder increases the risk of falling, contributes to a fear of falling, and reduces activity and social participation in MS patients [2,3]. A recent meta-analysis reported that the fall risk peak may be at the expanded disability status scale (EDSS) score of 4.0 [3]. At this EDSS, patients had also a reduction in walking distance. However, MS patients present postural instability and gait impairments before this stage of the disease [4,5]. Clinical measures of postural instability to determine the predictive value or validity in identifying risk of fall are poor [4,6]. In addition, quantification of orthostatic balance through posturography does not allow to highlight balance disorders at such early stage of the disease [7]. However, the exploration of the mechanisms of postural instability in MS at early stage of the disease with objective measures is necessary to contribute to prevent fall and to improve rehabilitation of such patients.

Standing on unstable surfaces [8] or under induced somatosensory deficits [9] are means to assess the risk of falling. However, gait initiation is more challenging because of the dynamic postural control necessary to achieve the first step from quiet standing [10]. Gait initiation is characterized by two distinct phases: the anticipation phase

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1
followed by the execution phase to achieve the first step from a quiet standing posture, presented in Fig. 1 [11,12]. The anticipation phase corresponds to Anticipatory Postural Adjustments (APA) that establish the dynamic conditions to move the body forward by specific motor activations. This necessary and daily repetitive destabilizing task requires the integration of multiple sensory systems (visual, vestibular and somatosensory systems) to develop a specific motor command [13]. Because falling is more common during transition movements [14], gait initiation is often used as an objective measure to evaluate postural instability and risk of fall. Gait initiation, especially APA is commonly used to assess postural instability in other populations such as older people or people with neurologic disorders, as Parkinson’s disease (PD). Hence, evaluation of APA can be an objective measure to assess the postural instability of MS patients [15,16]. Currently, APA are still poorly investigated in the MS population, although MS is also a degenerative central nervous system disease characterized by balance and gait troubles. In the present study, the results described in Parkinson’s patients will be compared with those found in MS patients.

APA are characterized by muscular patterns and spatiotemporal characteristics that are well identified. During quiet standing, the centre of mass (CoM) vertical projection and the CoP trajectories move together and are phased [17]. Gait initiation programmes induce dissociation of these trajectories through specific motor patterns, creating a disequilibrium torque in the sagittal plane. APA are characterized by a basic motor pattern that induces dissociation between the CoM and CoP trajectories. The motor pattern begins with a bilateral inhibition of the soleus followed by the activation of the tibialis anterior, which generates the posterior CoP displacement towards the initial swing heel [11,12], whereas the CoM moves towards the stance leg. This shift is associated with activation of the swing lower limb hip abductors. During the APA, the flexion of the stance knee is favoured by bilateral inhibition of the soleus and greater ipilateral tibialis anterior activity, whereas hip flexion is associated with activation of the stance rectus femoris. Finally, from its posterior position, the CoP shifts laterally towards the stance leg. Functional roles are allocated to the displacements of the CoP during APA: displacement along the anteroposterior axis is predictive of motor performance, whereas displacements along the mediolateral axis are linked to postural stability of gait initiation [11,13,18,19].

The literature review of specific impairments in displacements of the CoP during APA in MS patients could allow us to understand and assess balance control in the early stage of the disease. Several studies have assessed APA in MS patients, but to date, no review about APA in this population has been published. The aim of this systematic review is to assess APA during gait initiation of MS patients.

2. Methods

2.1. Search strategy

This review was performed in accordance with PRISMA Guidelines PRISMA (http://www.prisma-statement.org/) Table 1. A systematic search was conducted in May 2018. The search was carried out using the following databases: PubMed, Web of Science, and the Cochrane Library. The following keywords and medical subject headings were used: multiple sclerosis AND gait initiation OR step initiation OR postural adjustment(s). Only articles published in the English language were considered. There was no limit to the year of publication. Articles were excluded if the article was a case report or if the article was not peer reviewed.

2.2. Study identification

The population of interest was MS patients with a definitive diagnosis of MS or clinically isolated syndrome (CIS). Outcomes of interest were the variables of APA including electromyography, CoP and CoM spatiotemporal parameters, kinematics, duration of APA, and ground reaction force. Additionally, the step length of gait initiation was reported to supplement previous data and illustrate the overall gait initiation process.

2.3. Data extraction

An eligibility assessment was performed by screening the title and reading the abstract (Fig. 2). Due to methodological study heterogeneity (differences in procedures to induce gait initiation), there was a lack of comparative data and the meta-analysis could not be performed; therefore, data are presented descriptively. The following data were extracted from selected studies: study design (case-control study, cohort study), population characteristics (gender, age, EDSS, MS form), instrumentation used, devices and procedures for gait initiation assessment (electromyography (EMG), force platform, instruction for gait initiation), reported outcome parameters, study results (CoP and CoM spatiotemporal parameters including displacements, velocity, and acceleration), kinematics, duration of APA, EMG results, and ground reaction force and step length.
After a systematic search of the databases, we retrieved 180 articles (Fig. 2). Nine articles were included in this review: 8 case-control studies and one transversal study \[16,20–26\]. A total of 215 MS patients (132 women, 49 men, sex was not specified for 34 patients) and 116 healthy subjects (76 women, 25 men, sex was not specified for 15 subjects) were included. The sex ratio for controls was similar to that for MS patients. For the 2 studies by Krishnan, the sample of MS patients and healthy subjects was the same; therefore, patients and healthy subjects were counted only once \[21,22\]. For all the studies, ages ranged from 22 to 76 years old. In MS patients, EDSS scores ranged from 1 to 7. Thirty-seven patients had relapsing-remitting multiple sclerosis (RRMS), 2 patients had secondary progressive multiple sclerosis (SPMS) and 1 patient had primary progressive multiple sclerosis (PPMS), 20 patients presented a Clinical Isolated Syndrome (CIS). The form of MS was not described for 155 patients (72%). In one study, MS patients were divided into 2 groups: fallers (patients with a history of at least one fall during the previous 6 months), and non-fallers \[15\].
Population, procedures, outcomes and results are presented in Table 2.

3.1. CoP displacement, velocity and acceleration during APA

All included studies reported CoP displacements in the anteroposterior direction, and only 3 studies assessed mediolateral direction [20,23,24]. For MS patients, CoP displacements during APA were smaller, especially in the anteroposterior axis. No modification of the CoP displacement in the mediolateral direction was reported. Peak CoP displacements were larger [21,22] and velocity was decreased during APA.

3.2. CoM displacements and velocity during APA

CoM displacements were shorter and velocity was reduced in MS patients [20]. The maximal lateral displacement of the CoM was not significantly larger in MS patients compared to that in healthy controls [20].

Kinematics during APA: no one of the evaluated studies reported data about kinematics during the APA.

3.3. APA duration and APA phase

The duration of gait initiation was assessed in 4 studies [20,23–25]. APA were longer in MS patients. In the dual-task condition, the duration of gait initiation was longer than in the single-task condition [23]. The foot lift-off phase was delayed in the dual-task condition. APA were divided into different phases only in 2 studies, as presented in Fig. 1 [16,20]. The duration of APA2 (i.e. lateral translation of the CoP towards the stance limb), especially APA2b (i.e second part of CoP translation during APA2), was increased [20] in the Galli et al. study [16]. The velocities of APA1 (i.e posterior displacement of the CoP), APA2b and LOC (i.e anterior CoP displacement during swing phase) were decreased [16], and the double phase support was longer [20].

3.4. EMG during APA

EMG was reported in 4 studies [15,21,22,26]. The latencies of all studied muscles were delayed, and the magnitudes of muscle activity during APA were smaller. In the Krishnan study [21], subjects were required to perform rapid bilateral shoulder flexion and extension movements while standing on a force platform. MS patients did not present specific patterns of activation of muscles during flexion extension movement for the rectus femoris, soleus and tibialis anterior muscles when compared to healthy subjects (Table 2). In the Tajali study [15], MS fallers presented delayed activities in several muscles (rectus abdominis, erector spinae, biceps femoris and medial gastrocnemius) compared to MS non-fallers and healthy subjects.

3.5. Step length

The first step length was shorter for MS patients [20,23,24]. The effect of the dual-task condition on step length was different between 2 studies [23,24]: Jacobs et al. reported a smaller step length in the dual-task condition, whereas Brecl Jakob et al. did not find an effect of dual-task on step length. Remelius et al. noticed that the first step was wider for MS patients than for healthy subjects [20].

3.6. Testing procedures

Testing procedures were different for all the studies that evaluated APA in MS patients. Procedures included visual and auditory cues, external perturbation or dual tasks (cognitive task or motor task). Three studies analysed APA with a concurrent cognitive tasks [23–25], such as the auditory Stroop task, Brook’s spatial memory task, the 2-back verbal working memory task or reciting alternating letters of the alphabet.

3.7. Quality assessment of studies

According to the Ottawa scale checklist, all the studies were of moderate quality. A detailed overview of the quality of the studies is
Regarding differences between groups, MS patients exhibited significantly longer APA durations and significantly later foot lift onset times than the healthy subjects. Sensitivity of APA depended on the method of recording them. APA measure may be more sensitive than the clinical assessment in MS patients with low disability.
20 healthy subjects (13 women, 7 men), mean age 33.3 ± 8.5 SD

MS patients with low disability presented a reduced step length. This change could be a compensation strategy to avoid the approach of stability boundaries. The reduction of step length in MS patients was shorter. There were no significant differences between single and dual tasking performance in MS patients were observed. Correlations between APA CoP and ML and AP CoP displacement were found in MS patients. Step length in MS patients was shorter. There were no significant differences between single and dual tasking performance in MS patients were observed. Correlations between APA CoP and ML and AP CoP displacement were found in MS patients. Step length in MS patients was shorter.

Neuropsychological tests: TAP battery, SDMT, RFFT, the Stroop colour-word interference test

 APA alone and with dual tasks maximal amplitudes of mediolateral (ML) and anteroposterior (AP) displacement of CoP, the length of the APA, duration, step length MFIS, ABC

Neuropsychological tests were performed for all the patients. Tests were conducted on a treadmill with force-plates. Gait initiation was instructed when the bright light turned ON. APA were recorded alone and while dual tasking (Brook’s spatial and 2-back verbal working memory).

Neuropsychological tests: TAP battery, SDMT, RFFT, the Stroop colour-word interference test APA alone and with dual tasks maximal amplitudes of mediolateral (ML) and anteroposterior (AP) displacement of CoP, the length of the APA, duration, step length MFIS, ABC

47.3% of MS patients performed within normal range on all cognitive measures. Regarding mental tasks, 2b task and 8 task significant difference between single vs dual tasking performance in MS patients were observed. Correlations between APA CoP and ML and AP CoP displacement were found in MS patients. Step length in MS patients was shorter. There were no effects of dual tasks on step length.

Significant difference were found: CoP displacements were reduced in the anteroposterior axis, velocity of APA1, APA 2a and LOC were reduced, and durations of APA2b and LOC were increased in MS patients. Significant positive correlations were observed between EDSS score and the anteroposterior coordinate of point B, the anteroposterior component of APA1 velocity, APA2b duration and LOC duration. Significant negative correlations were found with Y component of APA2b velocity and anteroposterior component of LOC velocity.

MS patients with mild to moderate disability presented slower gait initiation, and cognitive distraction was correlated to falls and risk of fall. These results suggested that cognitive challenge represent a future target for falls prevention protocols.
Muscle activities were delayed in MS patients. MS fallers initiated significantly later muscle activities than MS non-fallers and controls. The inability to produce efficient APA could explain the reduced initial forward progression of the swing leg. The inability to produce APA might have been due to decreased anterior ankle moment and reduced posterior displacement of the CoP. Moreover, reduced ankle movement could be compensated for by an increased anterior ankle moment to move the CoP behind the ankles and create the disequilibrium required for gait initiation [11]. One can assume that in MS patients, the reduced and delayed muscle activities lead to a lesser ankle moment to move the CoP in the posterior direction. These alterations could explain the reduced initial forward propulsive force and step length in MS patients [20,25]. In 4 studies, the authors attributed these observations to a compensatory strategy to maintain the CoP trajectory away from the posterior stability boundary [16,20,21,24]. Moreover, no study has discussed spasticity, muscle weakness and somatosensory disorders, which are current phenomena in MS [30]. This perturbation could also be due to alterations in joint movements in the lower limb. Lesser and delayed activity of the tibialis anterior muscle or a delayed inhibition of the soleus in MS patients could decrease ankle moment and reduce posterior displacement of the CoP. Moreover, reduced ankle movement could be compensated for by an increase in the duration of APA to generate a sufficient movement to propel the swing leg [31].

Furthermore, trunk inclination is not reported in these studies. Trunk inclination changes the muscle activities in the soleus and tibialis anterior muscles [32]. At an early stage of MS disease, the activity of the rectus abdominis, internal obliques, and lateral flexor of muscles trunk was reduced [33]. Moreover, trunk flexion in MS patients is correlated with gait speed and gait activity [34,35]. Atypical inclination of the trunk induced by motor deficit of trunk muscles could also change APA and anteroposterior displacement of the CoP.

Mediolateral displacement was reported in only 3 studies, and no alteration was found in MS patients. However, these studies included patients at an early stage of disease. Mediolateral displacement predicts the stability of gait initiation and the risk of lateral fall [18,19]. This objective parameter could predict fall risk in MS patients. These reduced and delayed muscle activities in MS patients observed during APA could change the mediolateral displacement of the CoP and the movement of the hip, knee and ankle joints. Indeed, muscle synergy is observed during APA. This synergy generates the disequilibrium torque in the frontal plane. CoP displacement towards the swing foot is due to tibialis anterior activity, which is greater in the stance leg, knee flexion and hip abduction. Alteration of the mediolateral CoP could cause an increased velocity during a medial fall from a single stance due to a larger distance between the CoP and CoM during step execution. The risk of fall could be increased in MS patients if mediolateral CoP...
displacements are altered.

Similar changes in kinematic, kinetic and electromyographic parameters during APA have been found in the PD population. Reduced CoP displacements (in both anteroposterior and mediolateral axes), delayed muscle activities (especially for the tibialis anterior), longer duration of APA and shorter step length have also been reported [36,37]. These alterations can occur early in the evolution of PD [38] and are considered to be a major pathophysiological mechanism underlying impaired gait initiation. Given these similarities between PD and MS populations, one can reasonably assume that APA alterations significantly contribute to step impairments in MS. This literature review suggests a postural reeducation program, aimed at improving a forward body posture while moving the CoP backward.

In the PD population [36], it has been shown that gait initiation can be influenced by several factors. For example, Rogers et al. (2011) and Nieuwboer et al. (2008) showed that external sensory cues (visual or auditory) improve and facilitate gait initiation in PD patients [39,40]. Moreover, positive or negative emotions modulate gait initiation [41]. The reaction time of gait initiation was longer and step size was shorter in PD patients when they took a step forward in response to an unpleasant image. To the best of our knowledge, external cues or emotions were not evaluated in the gait initiation of MS patients. However, APA tend to be impaired in MS patients when dual-task paradigms are performed during gait initiation, such as in elderly fallers [42], whereas this was not observed in PD [43]. This difference between MS and PD for dual-task paradigms is explained by the cognitive decline of the MS patients, especially in terms of cognitive processing speed, even in the early stage [44], which suggests cognitive-motor interference in MS patients. Cognitive processing speed evaluation during gait initiation would be interesting to include in the assessment of APA at an early stage, but there is no cognitive test recommended for this analysis currently. Regarding these observations, rehabilitation programmes should nevertheless include cognitive-motor tasks, especially at the early stage of MS.

The present review revealed that all the included studies used different protocols to assess APA. This methodological heterogeneity made the results incomparable. Indeed, MS patients had an EDSS score range from 1 to 7, and no information on the form MS was recorded for half of the patients. The Newcastle-Ottawa Scale was used to assess the quality of the included studies. In addition, information about the recruitment of the healthy subjects was not described in all the studies. Consequently, a meta-analysis was not possible due to the different protocols used to assess the APA and the small number of studies with similar outcomes.

5. Conclusion

Alterations of APA are present in MS patients even at an early stage of the disease, principally characterized by a decrease in the posterior displacement of APA and reduced muscle activity of the lower limbs. APA evaluation at an early stage of MS seems to be an interesting measure to assess balance control and risk of fall in these patients. Nevertheless, this literature review highlights some potential improvements to better understand the underlying mechanisms of gait initiation in MS patients at the early stage of the disease. It would also be relevant to better correlate the gait initiation impairments with the risk of falling in MS patients to prevent falls and to adapt rehabilitation programmes at the early stage of the disease.

Declaration of Competing Interest

All authors declare that they have no conflicts of interest.

References


