Review Article

The Clinical Relevance of Force Platform Measures in Multiple Sclerosis: A Review

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Balance impairment and falls are frequent in patients with multiple sclerosis (PwMS), and they may occur even at the earliest stage of the disease and in minimally impaired patients. The introduction of computer-based force platform measures (i.e., static and dynamic posturography) has provided an objective and sensitive tool to document both deficits and improvements in balance. By using more challenging test conditions, force platform measures can also reveal subtle balance disorders undetectable by common clinical scales. Furthermore, posturographic techniques may also allow to reliably identify PwMS who are at risk of accidental falls. Although force platform measures offer several theoretical advantages, only few studies extensively investigated their role in better managing PwMS. Standardised procedures, as well as clinical relevance of changes detected by static or dynamic posturography, are still lacking. In this review, we summarized studies which investigated balance deficit by means of force platform measures, focusing on their ability in detecting patients at high risk of falls and in estimating rehabilitation-induced changes, highlighting the pros and the cons with respect to clinical scales.

1. Introduction

Balance can be defined as the ability to maintain the body’s centre of gravity (COG) within the base of support with minimal sway [1]. The control of human balance is a complex task which is assured by an uninterrupted flow of afferent signals reaching the central nervous system (CNS) from the muscle, tendon and joint proprioceptors, skin exteroceptors, and vestibular and visual inputs [2]. The deficient integration of these pathways, due to the widespread and variable distribution of CNS damage in patients with multiple sclerosis (PwMS), can affect postural response and the ability to maintain adequate balance [3–5]. Balance impairment is frequently observed in PwMS, and it is among the most disabling symptoms [6]. A wide-base gait with worsening balance when changing direction has been often described in PwMS [7]. Fatigue, muscle weakness, and spasticity further contribute to compromise adequate balance and predispose them to accidental falls [8–11]. Fall tendency may occur early in the course of the disease, even before walking and balance impairment becomes clinically evident [12].

The incidence of accidental falls (i.e., an unexpected contact of any part of the body with the ground) in PwMS has been reported from 30% to 63% in a period variable from 1 to 12 months, according to different studies [13–27]. Recently, a large survey on about 195,000 veterans found a 2-fold increased risk of injurious falls in PwMS compared with sex/age-matched veterans without MS [28].

Studies investigating demographic and clinical characteristics related to a high risk of accidental falls in PwMS are quite heterogeneous in terms of sample size, setting, and design, and for reporting (retrospectively) or collecting (prospectively) the occurrence of falls [29]. Studies relying on retrospectively collected patient report of falls at the inclusion are prone to recall bias [16, 30], although a good correlation ($r = 0.82$) between prospectively and retrospectively collected falls has been demonstrated [16]. In addition, even if prospectively collected, falls resulting in injury are more likely
to be reported, and cognitive or memory impairment may further decrease the accuracy of their recall [16, 18].

From a clinical point of view, reliably discriminating fallers between nonfallers is crucial for the development of a program aimed at fall prevention. Potentially, force platform measures may provide an objective, reliable, and accurate tool for this purpose. Moreover, they may be useful for documenting not only deficits but also improvements of balance skills after specific intervention.

In this review, we aimed to summarize studies investigating the role of force platform measures in MS setting, focusing on (i) differences between PwMS and general population; (ii) ability in detecting PwMS at high risk of falls, highlighting also the differences with clinical scales; (iii) evaluation of rehabilitation-induced changes.

1.1. Clinical Scales to Assess Balance. Clinical tests usually rate balance performance on a set of motor tasks. Scoring is based on the sum of ordinal item scores or stopwatch measurements. Ideally, an evaluation of postural balance should include clinical scales that are practical, sensitive, selective, reliable, and valid. Although some clinical scales are easy and relatively quick to use, they are hampered by their variable execution and by the room left for evaluator judgment in the scoring system [31, 32]. Table 1 summarizes the most commonly used clinical scales to assess balance in PwMS and their main psychometric properties [33–41].

So far, few studies provided data on diagnostic accuracy of clinical scales in detecting PwMS prone to accidental falls. These studies showed conflicting results, probably due to different cutoffs established (see also Table 1). Cattaneo and colleagues [14] showed that clinical balance scales exhibit good specificity (i.e., performance in detecting nonfallers), but low sensitivity (i.e., performance in detecting fallers). Although other authors found differences between fallers and nonfallers in clinical scale scores of balance and even mobility [20, 22, 23, 25], they did not provide data on sensitivity and specificity. Nilsag˚ard and colleagues [16] suggested a combination of patient variables and selected clinical scales to predict the risk of falls but failed to identify the “best candidate” to apply in the daily setting. More recently, it has been suggested that the BESTest was 92% accurate in identifying fallers and nonfallers among PwMS [35]. Despite this high accuracy, the BESTest is time consuming and requires a lot of tools. The use of a short version (mini-BESTest), having only a 10-minute administration time, could be more useful in clinical practice, but it needs to be validated in PwMS [42]. Lastly, an association between cognitive processing speed and fall frequency has been recently described in PwMS [43]. D’Orio and colleagues [23] also suggested that cognitive impairment, especially impaired verbal memory, predicted an increased risk of recurrent falls.

1.2. Force Platform Measures: Basic Principles. Force platforms are instruments that measure ground reaction forces generated by a body standing on or moving across them, to quantify biomechanical parameters of human balance control. Force platforms are also used for gait analysis.

Posturography is the general term encompassing all the techniques used to quantify postural control in upright stance, in either static or dynamic conditions, by means of a force platform [44]. The term static posturography refers to the characterization of postural sway of the centre of pressure (COP) (i.e., the point of application of the resultant from the vertical force’s action) during quiet standing on a fixed support surface (i.e., a relatively unperturbed state). In quiet stance, the COP is estimated as compatible with the centre of gravity at about 97%; this compatibility diminishes in dynamic condition [45]. Variations in the instant positions of the COP during a 30- or 60-second test are used to calculate time-domain measures, including the velocity of the COP on the anteroposterior or mediolateral axes (mm/s), the sum of the displacements (path) of COP (mm), and the 95% confidence ellipse area of COP (mm²). From biomechanical standpoint, the displacement of the COP represents a marker of energy expenditure to maintain balance [46]. Usually, a posturographic assessment consists in two test conditions (eyes opened and closed) and, sometimes, in dual-task condition [47]. This paradigm allows an evaluation of cognitive processing required to maintain standing balance, simply by applying a concurrent cognitive task (e.g., aloud or silent backward counting, Stroop test, and paced auditory serial addition test).

Static posturography provides linear, objective, and reliable measurements of static balance [44]. In spite of its reliability and accuracy in PwMS [24, 48], the main limitation of static posturography is a lack of standardisation that precludes the possibility to generalize its application for multicentre purposes. This is due to the fact that different force platform equipment and different test procedures are used in clinical practice. Parameters that should be considered are not well defined (e.g., velocity, path, area, etc.), as well as feet position and test duration [49]. Additionally, static posturography evaluates balance control only in the most simplistic condition, thus not reflecting situations occurring in daily-life activities.

Dynamic posturography involves the use of experimentally induced (external or self-generated) balance perturbation, such as shifting the support surface, using an unstable support surface, moving the visual surround, applying stimuli to upper body parts, and performing voluntary weight shift [50]. By manipulating one or more specific inputs (visual, vestibular, or proprioceptive) for postural control, a dynamic posturography assessment may provide important data on the motor and sensory contribution to balance control [51]. Thereby, impairments in sensory reweighting and integrating afferent inputs can be easily detected. Moreover, these data can be combined into composite scores, such as the equilibrium score or the postural stability index [52]. The main advantage of dynamic posturography is the possibility to obtain information on balance control in a variety of conditions simulating situations encountered in daily-life activities [32]. Unfortunately, it requires a long time of administration and an expensive and bulky equipment. Moreover, subjects cannot maintain balance under the more difficult conditions, especially when they are forced to rely only on vestibular input. A fall frequency as high as 22% has been reported
Table 1: Commonly used clinical scales to assess balance in patients with multiple sclerosis.

<table>
<thead>
<tr>
<th>Tool</th>
<th>Authors/ Journal</th>
<th>Brief description</th>
<th>Time of administration</th>
<th>Overall score</th>
<th>Test-retest reliability in PwMS</th>
<th>Accuracy in predicting fall status in PwMS</th>
</tr>
</thead>
</table>
| Activities-specific balance confidence (ABC) | Powell and Myers [33]
J. Gerontol. A. Biol. Sci. Med. Sci. 1995 | 16-item self-administered questionnaire rating the perceived level of confidence in performing daily living activities | 15 minutes             | 0 to 100      | 92% SE: 65%, SP: 77%              | (cutoff: 40) [14]                        |
| Balance evaluation system test (BESTest)  | Horak et al. [34]
Phys. Ther. 2009                        | 36-item physician-rated scale evaluating 6 systems (biomechanical constraints, stability limits/verticality, anticipatory postural adjustments, postural responses, sensory orientation, and stability in gait) | 30 minutes             | 0 to 108      | 88%–91% SE: 86%, SP: 95%         |                                            |
| Berg balance scale (BBS)                  | Berg et al. [36]
Can. J. Public Health. 1992             | 14-item physician-rated scale exploring the ability to sit, stand, lean, and turn and postural transition. | 15 minutes             | 0 to 56       | 96% SE: 40%, SP: 90%              | SE: 40%, SP: 90% (cutoff: 44) [14]        |
| Dizziness handicap inventory (DHI)        | Jacobson and Newman [37]
Arch. Otolaryngol Head Neck Surg 1990   | Multidimensional 25-item self-administered questionnaire quantifying the level of disability in three domains: physical, emotional, and functional | 15 minutes             | 0 to 100⁰     | 90% SE: 50%, SP: 74%              | SE: 50%, SP: 74% (cutoff: 59) [14]        |
| Dynamic gait index (DGI)                  | Whitney et al. [38]
J. Vest. Res. 2000                      | 8-item physician-rated scale exploring mobility function and dynamic balance      | 10 minutes             | 0 to 24       | 85% SE: 45%, SP: 80%              | SE: 45%, SP: 80% (cutoff: 12) [14]        |
| Four-square step test (FSST)              | Dite and Temple [39]
Arch. Phys. Med. Rehabil 2002          | Stop-watch measurement of the duration of rapidly step over low obstacles in clockwise and counterclockwise direction | 3 minutes or less      | N/A           | 93%–98% SE: 60%, SP: 75%         | SE: 60%, SP: 75% (cutoff: 16.9 s) [16]    |
| Functional reach test (FRT)               | Duncan et al. [40]
J. Gerontol. 1990                       | Measurement of the maximum distance reached forward while standing in a fixed position. | N/A                    | N/A           | 85%–95% SE: 73%, SP: 54%         | SE: 73%, SP: 54% (cutoff: 13.6 s) [16]    |
| Timed-up-and-go test (TUG)                | Podsadlo and Richardson [41]
J. Am. Geriatr. Soc. 1991                | Stop-watch measurement of the duration of standup from a chair, walking 3 meters, turning around, walking back and sitting down. | 3 minutes or less      | N/A           | 98% SE: 73%, SP: 54%              | SE: 73%, SP: 54% (cutoff: 13.6 s) [16]    |

PwMS: patients with multiple sclerosis; SE: sensitivity; SP: specificity; *the only scale in which the lower the score, lower the level of disability; †as estimated in populations other than MS; ‡cognitive TUG was used in this study.

while PwMS performed the more challenging conditions of dynamic posturography (i.e., surface moving, eyes opened; surface moving, eyes closed; surface and surround moving, eyes opened) [48].

2. Methods

2.1. Data Sources. PubMed was searched for abstracts using the following medical subject heading (MeSH) terms: “multiple sclerosis” AND “posturography” OR “multiple sclerosis” AND “force platform” OR “multiple sclerosis” AND “postural balance.” No limitations or time period restrictions were applied and the latest search was undertaken on January 10th 2013, Both prospective and retrospective studies were encompassed. Published conference abstracts, case reports, meta-analyses and reviews, articles not available in English, and studies including also patients affected by neurological conditions other than MS were excluded. Finally, studies where postural sway was measured by means of tools (e.g., accelerometers or gyroscopes) other than force platforms were also excluded. Abstracts of resulting articles were then hand searched in order to select studies which met eligibility criteria. Attempts to identify further articles were done by searching for the references of the studies.

3. Results

The search initially yielded a total of 178 articles; out of these, 58 studies conducted on PwMS were selected for this narrative review. After removing duplicates, 35 met the inclusion criteria. In 21 studies, force platform measures were used to detect impairments in balance in PwMS with
Mean ± st. dev = 219 ± 62 mm
Median [interval] = 218 [119–380] mm

Mean ± st. dev = 352 ± 136 mm
Median [interval] = 319 [197–805] mm

Mean ± st. dev = 585 ± 357 mm
Median [interval] = 490 [298–1,389] mm

Mean ± st. dev = 1,379 ± 625 mm
Median [interval] = 693 [337–1,392] mm

Mean ± st. dev = 325 ± 121 mm
Median [interval] = 293 [141–588] mm

COP path (EO); 𝑛=1 7
COP path (EO); 𝑛=1 4
COP path (EO); 𝑛=3 1

COP path (EC); 𝑛=1 7
COP path (EC); 𝑛=1 4
COP path (EC); 𝑛=3 1

Controls
Nonfallers
Fallers
Controls
Nonfallers
Fallers

Figure 1: Superimposed displacements of centre of pressure (COP path) on x-y-axes with both eyes opened (EO) and closed (EC) (upper and lower rows, resp.) of healthy volunteers (controls, 𝑛=31), patients without a history of falls (nonfallers, 𝑛=17), and those reporting one or more falls in the past 6 months (fallers, 𝑛=14) (modified from [19]).
discriminate patients reporting at least one fall over the past 12 months from those reporting more frequent falls. Impaired forward limit of stability, gait asymmetries, and leg flexor-extensor muscle weakness also contributed to detecting recurrent fallers.

Only one recent study supports the notion that the adjunction of posturographic evaluation did not improve the ability to detect PwMS prone to fall [21]. However, as also recognized by authors, there are some limitations to their study: (i) a small sample size (n = 37); (ii) the incidence of falls was lower compared to other published papers, probably due to the short observational time-frame considered (2 months); (iii) they did not use traditional force platform measures as outcome, but the derivative virtual time to contact (i.e., the change on a measurement instrument required to overcome the measurement error). Therefore, future research efforts are warranted to establish MIC and SRC for force platform measures.

3.3. Evaluating Rehabilitation-Induced Changes. Force platform measures ensure an objective, reliable, and linear assessment of balance, avoiding the risk of ceiling effect [32]. Force platform measures demonstrated a high sensitivity in detecting rehabilitation-induced changes and sometimes provided more rewarding results than clinical scales [74–77, 79–81]. Concurrent improvements in postural sway measures, clinical, and/or patient-reported outcomes were always described [74–77, 79–81]. Only two studies did not show any improvement of postural sway measures of PwMS after home-based resistance exercises [73] and balance-based torso weighting [78].

One recent study aimed at investigating the effectiveness of a 12-week home-based balance training using a commercial videogame platform showed also a slight increase in the proportion of nonfallers when compared with the 3-month period prior to study enrolment [81]. However, this latter study was not designed (and not powered to perform a post hoc analysis) to estimate a relationship between force platform measure changes and clinically relevant outcomes.

Unfortunately, there are still no data on the clinimetric property [82] of responsiveness of force platform measures, assessed by minimally important change (MIC) over time (i.e., the change that is relevant for the patient) and smallest real change (SRC) (i.e., the change on a measurement instrument required to overcome the measurement error). Therefore, future research efforts are warranted to establish MIC and SRC for force platform measures.

4. Conclusions

Balance impairment and falls are frequent in PwMS, and they may occur even at the earliest stage of the disease. Reliably identifying subjects who are at risk of accidental falls is a clinical challenge. Asking about the presence of prior falls is unreliable because patients often neglect their falls. Clinical balance scales are hampered by their variable execution and subjective scoring system, thus providing conflicting results about their ability to detect patients prone to falls.

By contrast, within few minutes, computer-based force platform measures of standing and dynamic balance can provide useful information regarding the risk of future falls, as well as intervention-induced changes. Moreover, computerised postural sway measures have been reported as correlated with disability and functional scales [24, 35, 65, 83]. Table 2 summarizes pros and cons of force platform measures, contrasted with those of clinical measures.

Although relevant, the differences in postural control between PwMS and healthy subjects cannot definitively elucidate the neuropathological mechanisms leading to balance...
impairments in MS. Given the widespread and variable distribution of CNS damage, it is generally thought that postural control impairment in PwMS has multifactorial causes that differ from one person to the next [4, 17]. Studies investigating the structure-function relationship by means of force platform measures do not provide comparable results. Jackson and colleagues [55] suggested that postural balance deficit in PwMS resulted from impaired central integration of visual, vestibular, and somatosensory input. Slowed afferent proprioceptive conduction along demyelinated dorsal columns of spinal cord has been proposed as an important cause of impaired postural control [84, 85]. Another hypothesis proposes the damage of cerebellar connections (i.e., cerebellar peduncles) as the primary contributor to the balance impairment [19] or, more extensively, the focal and diffuse involvement of the cerebellum, its connections, and other associative regions [5].

4.1. Future Recommendations. Posturographic systems have become more affordable and potentially useful for both clinical practice and research purposes. Nevertheless, they still represent a significant cost (especially dynamic posturography equipment) need a dedicated space and trained staff to run the tests. This is not always feasible in a clinical practice setting. A possible solution to overcome the main drawbacks of laboratory-grade force platforms could be the implementation of software to interface a commercial Nintendo balance board with a common personal computer [86]. Similarly to laboratory-grade force platform, the balance board contains force sensors which detect subject’s COP and weight shifts. This commercial device—that has been recently included in the neurorehabilitation process of PwMS [79–81]—is low expensive, portable, and user friendly. In conclusions, further efforts are warranted to establish (i) which parameters of balance (velocity, path, area, etc.) should be evaluated; (ii) normative values for the force platform measures; (iii) how to standardize the posturographic assessment for multicentre study purposes; (iv) the ecological validity of this tool.

Table 2: Summary of pros and cons of force platform measures and clinical scales.

<table>
<thead>
<tr>
<th></th>
<th>Force platform measures</th>
<th>Clinical scales</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Equipment</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expensive</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Cumbersome</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Training of staff</td>
<td>Y</td>
<td>Y/N</td>
</tr>
<tr>
<td><strong>Data collection</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Easy and fast to admin</td>
<td>Y/N</td>
<td>Y/N</td>
</tr>
<tr>
<td>Affected by emotional</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>external factors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Invasive for patients</td>
<td>N</td>
<td>Y/N</td>
</tr>
<tr>
<td><strong>Statistical consideration</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linear values</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Objective measurements</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Ceiling effect</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Reliability</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td><strong>Clinical utility</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detection of subclinical impairment</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Identification of underlying causes of imbalance</td>
<td>Y/N</td>
<td>Y/N</td>
</tr>
<tr>
<td>Prediction of falls</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Ability in detecting improvements</td>
<td>Y</td>
<td>Y</td>
</tr>
</tbody>
</table>

*Self-administered questionnaire did not require any specific training; 
*bESTest and dynamic posturography may be time consuming; 
*dynamic posturography may be poor tolerated; 
"bESTest and dynamic posturography can identify the system that mainly affect balance.

References


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