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Evaluation of Clinical Gait Analysis parameters in patients affected by Multiple Sclerosis: Analysis of kinematics

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A R T I C L E I N F O

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A B S T R A C T

Background: Clinical Gait Analysis is commonly used to evaluate specific gait characteristics of patients affected by Multiple Sclerosis. The aim of this report is to present a retrospective cross-sectional analysis of the changes in Clinical Gait Analysis parameters in patients affected by Multiple Sclerosis.
Methods: In this study a sample of 51 patients with different levels of disability (Expanded Disability Status Scale 2–6.5) was analyzed. We extracted a set of 52 parameters from the Clinical Gait Analysis of each patient and used statistical analysis and linear regression to assess differences among several groups of subjects stratified according to the Expanded Disability Status Scale and 6-Minutes Walking Test. The impact of assistive devices (e.g. canes and crutches) on the kinematics was also assessed in a subsample of patients.
Findings: Subjects showed decreased range of motion at hip, knee and ankle that translated in increased pelvic tilt and hiking. Comparison between the two stratifications showed that gait speed during 6-Minutes Walking Test is better at discriminating patients' kinematics with respect to Expanded Disability Status Scale. Assistive devices were shown not to significantly impact gait kinematics and the Clinical Gait Analysis parameters analyzed.
Interpretation: We were able to characterize disability-related trends in gait kinematics. The results presented in this report provide a small atlas of the changes in gait characteristics associated with different disability levels in the Multiple Sclerosis population. This information could be used to effectively track the progression of MS and the effect of different therapies.

1. Introduction

Patients suffering from Multiple Sclerosis (MS) commonly show marked impairments in the lower extremities, leading to several disabilities and gait abnormalities. In the clinical setting such abnormalities are usually assessed using functional tests such as the Timed 25-Foot (Polman and Rudick, 2010), the 6 Minutes Walking Test (6MWT), the 10 Meters Walking Test (Feys et al., 2014) and using self-reporting tools.

Clinical Gait Analysis (CGA) exams are often used to add information on the specific kinematic and kinetic patterns associated with neurological and orthopedic impairments. CGA is an instrumental examination of the ambulatory characteristics of the patients by means of movement analysis techniques. CGA allows for estimation of time/distance, kinematic and kinetic gait parameters of the patients. Several different parameters can be extracted from joint kinematics and kinetics using CGA. These parameters have been shown to correlate with different aspects of human walking and have potential for application in the clinical environment (Benedetti et al., 1998).

Few works in literature have made extensive use of CGA-based parameters for investigating gait characteristics in MS patients. Some of these works only limited their analysis to the sagittal plane or to time/distance parameters and range of motions of the different joints (Gehlsen et al., 1986; Holden et al., 1986; Kempen et al., 2016; Lizrova Preiningerova et al., 2015), while a few more comprehensive studies analyzed patients at the early stage of the disease or with minimal level of disability (Benedetti et al., 1999; Martin et al., 2006; Nogueira et al., 2013). MS patients walk more slowly, with a decreased cadence and step length (Morris et al., 2002) and present a longer stance phase during the gait cycle with respect to controls (Givon et al., 2009; Sosnoff et al., 2012). Further investigations have reported a direct correlation between the decrease in walking speed that is

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common in MS patients and the level of disability assessed using the Expanded Disability Status Scale (EDSS) (Kurtzke, 1983).

Similar results have been observed in treadmill-based testing protocols (Faude et al., 2012; Kalron et al., 2013). A study by Kelleher and colleagues showed significant differences in CGA-based parameters between controls and MS patients, but not between groups of MS patients with different levels of disability (Kelleher et al., 2010). Benedetti and colleagues reported significant variations in CGA-based parameters in a small sample of minimally impaired MS patients (Benedetti et al., 1999). Finally, Pau and colleagues were able to find a moderate correlation between the levels of disability estimated using the EDSS and specific gait scores obtained from a limited subset of CGA-based parameters (Pau et al., 2014).

The aim of this retrospective cross-sectional study was to investigate the correlation between a set of 52 different CGA-based parameters, extracted following the approach showed by Benedetti (Benedetti et al., 1998), with the different levels of disability estimated using EDSS and 6MWT speed in a broad sample of MS patients. In this work we examined parameters related to the time/distance and kinematic characteristics of gait of MS patients in order to understand which of these parameters better correlate with gait speed and disability level in the general MS population. We expect that this analysis will give us a better insight in which particular kinematic and time/distance gait features are captured by the EDSS and 6MWT.

2. Methods

Fifty-five patients with a diagnosis of MS that had undergone a CGA at the Rehabilitation Unit of the Ferrara University Hospital between 2004 and 2015 were considered for the analysis. After initial screening of the data, 4 subjects were excluded from the study due to data quality or missing trials. Fifty-one MS subjects (30 Females, 21 Males, age mean 51 (SD 9.6) years) were selected for the final analysis. Additionally, a sample of 10 control subjects (CS, 2 Females, 8 Males, age mean 36.7 (SD 18.9) years) was also recorded for reference. All participants gave their written consent for participation in the study. All data collections took place at the Motion Capture Laboratory of the Rehabilitation Unit of the Ferrara University Hospital. The study was approved by the ethics committee of Ferrara University Hospital (approval #150284).

Among the MS subjects, 18 were diagnosed as Primary Progressive (PP), 26 as Secondary Progressive (SP), 6 as Relapsing-remitting (RR) and 1 as Relapsing-progressive (RP), following Poser's criteria (Poser et al., 1983). The 6MWT and the EDSS were used to assess the level of disability at the time of the CGA. Among the subjects, 21 used an assistive device (AD, unilateral or bilateral canes or crutches) during the gait analysis. For this reason we decided to limit the analysis to kinematics and time/distance parameters, excluding aspects of CGA related to kinetics, as these parameters cannot be precisely estimated when using assistive devices.

A stereophotogrammetric system (Vicon Motion Systems Ltd., Oxford, UK), was used for the acquisition of the lower limb kinematics. Kinematic data were acquired at a sampling rate of 100 Hz. Reflective markers montage and estimation of the joint angles was based on the Plug-In-Gait model. Each subject performed a series of walking trials at a self-selected velocity. During each trial, subjects were asked to walk in the Motion Capture Laboratory. Each subject performed 3 to 5 walking trials in a 15 m walkway. Subjects were instructed to walk at their normal self-selected gait speed during each trial.

In total, 153 trials (3 per subject) were used in the final analysis. For each trial of each subject we isolated a single gait cycle in the middle of the trial and for that cycle we extracted a series of parameters relative to general and specific features of the kinematics observed during the trial. The parameters extracted represent an adapted subset of those analyzed by Benedetti and colleagues (Benedetti et al., 1998) and an expanded set with respect of those that the same authors used to evaluate gait abnormalities in MS patients (Benedetti et al., 1999).

Table 1
List of CGA-parameters extracted in the analysis.

	Time/distance parameters	Unit
T/D1	Stance duration	% gait cycle
T/D2	Swing duration	% gait cycle
T/D3	Stride length	cm
T/D4	Gait cycle duration	ms
T/D5	Cadence	strides/min
T/D6	Velocity	cm/s
T/D7	Normalized stride length	% height
T/D8	Normalized velocity	% height

	Kinematic parameters		Temporal parameters	
		Unit		Unit
H1	Hip angle at heel-strike	Degrees		
H2	Max hip flexion at loading response	Degrees	TH2	% stride H2
H3	Max hip extension in stance	Degrees	TH3	% stride H3
H4	Hip flexion at toe-off	Degrees		
H5	Max hip flexion at swing	Degrees	TH5	% stride H5
H6	Hip sagittal ROM	Degrees		
H7	Hip coronal ROM	Degrees		
H8	Max hip adduction in stance	Degrees	TH8	% stride H8
H9	Max hip abduction in swing	Degrees	TH9	% stride H9
K1	Knee angle at heel-strike	Degrees		
K2	Max knee flexion at loading response	Degrees	TK2	% stride K2
K3	Max knee extension in stance	Degrees	TK3	% stride K3
K4	Knee angle at toe-off	Degrees		
K5	Max knee flexion at swing	Degrees	TK5	% stride K5
K6	Knee sagittal ROM	Degrees		
K7	Knee coronal ROM	Degrees		
K8	Max knee adduction in stance	Degrees	TK8	% stride K8
K9	Max knee adduction in swing	Degrees	TK9	% stride K9
A1	Ankle angle at heel-strike	Degrees		
A2	Max plantarflexion at loading response	Degrees	TA2	% stride A2
A3	Max dorsiflexion in stance	Degrees	TA3	% stride A3
A4	Ankle angle at toe-off	Degrees		
A5	Max dorsiflexion in swing	Degrees	TA5	% stride A5
A6	Ankle Sagittal ROM	Degrees		
Pel1	Pelvic tilt range	Degrees		
Pel2	Max pelvic obliquity	Degrees	TPel2	% stride Pel2
Pel3	Min pelvic obliquity	Degrees	TPel3	% stride Pel3
Pel4	Max pelvic rotation	Degrees	TPel4	% stride Pel4

The parameters (see Table 1) evaluated included: 1) Time/Distance parameters; 2) Kinematic parameters (see Fig. 1), that were extracted from the joint angles in the sagittal and coronal plane and for all three planes of the pelvis; 3) Temporal parameters, that correspond to the temporal occurrences, expressed as % of the gait cycle, of the kinematic parameters (excluding ranges). A total of 52 parameters were extracted from the most affected limb for each trial of each patient.

Parameters were then averaged across the three trials of each patient. The same parameters were also extracted from both the dominant and non-dominant sides of the 10 control subjects. Two different criteria were used for stratifying the MS group for descriptive and statistical analysis. The first criteria were based on the walking speed of the patients recorded as the average speed during the 6MWT. This metric has been chosen as indicative of the walking speed of each subject under normal conditions. For the walking speed, two thresholds were set to identify different groups of subjects. Specifically, subjects with a walking speed below 0.4 m/s were classified as high-disability (HD-6M, N = 11, 10 used ADs), subjects with walking speed between 0.4 and 0.8 m/s were classified as mild-disability (MD-6M, N = 23, 11 used ADs) and subjects with gait speed above 0.8 m/s were classified as low-disability (LD-6M, N = 17, no ADs). These thresholds were selected in accordance with the work by Schmid and colleagues (Schmid et al., 2007). The second criteria were based on the EDSS,