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Original Article

Knee muscle strength in multiple sclerosis: relationship with gait characteristics

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Abstract. [Purpose] To investigate the relationship between isokinetic knee muscle strength and kinematic, kinetic and spatiotemporal gait parameters of patients with multiple sclerosis (MS). [Subjects and Methods] Twenty-nine MS patients (mean age 31.5±6.5) were investigated in this study. The isokinetic knee muscle strength and gait parameters of MS patients with moderate and severe disability, as determined by the expanded disability status scale (EDSS): EDSS=1–4.5 (n=22, moderate disability) and EDSS>4.5 (n=7, severe disability) were measured. [Results] Isokinetic knee muscle strength, kinematic, kinetic and spatiotemporal gait parameters differed between moderate (EDSS=1–4.5, n=22) and severe disability (EDSS>4.5, n=7). The correlation between each of gait speed, stride length, total range of knee joint movement and the four strength parameters (minimum and maximum quadriceps and hamstring muscle strengths) were significant for the MS group as a whole. Within subgroups, the correlation between minimum hamstring strength and total range of knee movement was significant only in group EDSS>4.5; minimum hamstring correlated with peak knee extensor moment in group EDSS=1–4.5, but at a reduced level of significance. [Conclusion] The present study revealed significant correlations between gait characteristics and isokinetic strength parameters of the quadriceps and hamstring muscles. Our study suggests that rehabilitation protocols for MS patients should include a critical strength training programme particularly for the hamstring and quadriceps muscles.

Key words: Multiple sclerosis, Gait analysis, Muscle strength

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INTRODUCTION

Multiple sclerosis (MS) is a chronic inflammatory disease of the central nervous system, characterised by destruction of axons and neurons. MS is the most common progressive neurological disease in young adults, with a prevalence of 30–110 per 100,000 adults. MS is characterised by neurological deficits such as motor weakness, spasticity, ataxia and sensory disturbance, and may lead to significant impairment of gait[1–3]. Initial motor symptoms include muscle weakness, hypertonia and coordination problems, which are most frequent in the lower limbs[4].

Muscle weakness causes loss of mobility and upper limb function, alters posture and places abnormal stress on many of the structures essential for ambulation. As a result, patients employ various compensatory techniques to enable them to continue walking[5, 6]; indeed, 85% of patients report gait disturbance as their main complaint[7]. Walking impairment has been documented using tests of walking endurance and speed, as well as spatiotemporal markers of gait[8, 9].

Compared with normal subjects, patients with MS typically walk slowly, with a shorter stride length and prolonged double support phase[9–17], at a decreased cadence[8, 9] and with reduced joint motion[11, 13, 18], all of which result in reduced mobility[19]. Muscle strength is an important determinant of walking ability. In their study of a representative sample of 100 patients with MS, Thoumie et al. reported that walking ability was reduced[8]. They observed differences in both the hamstring and quadriceps muscles strength between patients who normally walked with a cane compared with those who walked unaided. In particular, the isokinetic (60°/s) strength of the knee flexor muscles was most strongly related to gait velocity.

Broekmans et al. indicated that resistance training protocols, aiming to enhance the walking ability those with moderate ambulatory dysfunction, should increase the endurance of knee extensors and the isometric strength of knee flexors[20].

Many studies indicate that resistance training increases maximal muscle strength in MS; moreover, some have

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reported that resistance training has a positive impact on walking, as revealed by other functional capacity tests. This observation may relate to the intensity and duration of training as well as the level of disability experienced by the patient[6, 20–22].

The purpose of this study was to evaluate the muscle strength and deficits in gait ability of patients with MS, and to determine the nature of the relationship, if any, between them. The results of this study will be used to enhance our knowledge of gait impairment in MS in terms of correlation between knee muscle strength and spatiotemporal, kinematic and kinetic parameters of gait. The findings will also help us to make recommendations for rehabilitation programmes tailored to different clinical and functional situations and disability levels.

SUBJECTS AND METHODS

Twenty-nine patients consulting at the outpatient rehabilitation clinic at Hacettepe University Hospital were recruited. Patients included those with relapsing-remitting MS, those who had not experienced a relapse within the past 6 months and those with an expanded disability status scale (EDSS) score of between 1 and 6. All participating patients were competent to give informed consent, which they provided in accordance with procedures approved by the University's Medical Center Institutional Review Board. The patients ages ranged between 19 and 60 years.

Exclusion criteria for patients with MS included cognitive disorders, severely impaired visual function, severe psychiatric disorder, severe arthritis of the knee or hips, pregnancy, other neurological or vestibular disorders, or high-level spasticity of the lower limbs. The EDSS scale is used worldwide to evaluate MS[23]. The score ranges from 0 to 10: a score of 0 corresponds to a normal neurological examination, whereas a score of 6 or more corresponds to limited walking ability and the need to use a technical aid for walking. Subjects were subdivided into two groups according to their ambulatory dysfunction by EDSS: in group 1, EDSS=1–4.5, and in group 2, EDSS>4.5. This EDSS score of 4.5 is a suitable cut-off score, as it describes patients who are able to walk without aid or rest for around 300 m. It has previously been used to discriminate between patients with moderate and severe ambulatory dysfunction[19]. Spasticity scores for the quadriceps and hamstring muscles were below 3 on the modified Ashworth scale, enabling the isokinetic evaluation of these knee muscles[24].

Three-dimensional gait analyses were carried out at the Motion Analysis Laboratory of the Department of Physical and Rehabilitation Medicine at the Hacettepe University Medical School, using a Vicon motion analysis system (Vicon 612 System, Oxford Metrics, Oxford, UK) and a sampling rate of with six infrared cameras 50 Hz. The standard plug-in gait marker set (15 markers: one on the sacrum and one each bilaterally on the anterior superior iliac spine, mid-lateral thigh, lateral knee joint, lateral shank, lateral malleolus, on the shoe over the second metatarsal head, and over the posterior calcaneus) was used. Ground reaction forces were measured by two Bertec force plates (Bertec Co, Columbus, OH, USA), which were placed at the middle of a 10-m walkway. Before data collection, the camera and force plate were calibrated. Patients were asked to walk at their natural, comfortable speed. Data were collected after several practice trials. For all trials, subjects wore flat shoes with soft soles. Data from five trials were collected and averaged. All data collection was carried out by the same physiotherapist, experienced in analysing gait.

Isokinetic muscle strength measurements were made using the Biodex System 3 (Biodex Medical Systems, Inc., New York, USA), a dynamometer with knee attachments. Orientation of the dynamometer was kept at 0° for both tilt and seat orientation. Patients were seated and secured to the apparatus with chest and thigh straps. The attachments of the dynamometer were adjusted so that the centre of motion of the lever arm was aligned as accurately as possible with the slightly changing flexion-extension axis of the joints. The range of motion was kept within 0–90° for the knee joint. Bilateral isokinetic (concentric/concentric) flexion and extension of the knee at 60°/s was performed five times. Patients had periods of rest between the sessions and verbal encouragement was standardised. The results were expressed as the peak torque values of both the most affected (minimum hamstring and minimum quadriceps) and the least affected (maximum hamstring and maximum quadriceps) sides. Gait analysis was performed first, followed by strength evaluation, with a break of at least 15 min between the measurements.

Descriptive statistical analysis was performed using SPSS version 16.0. Correlations between strength (minimum and maximum quadriceps and hamstring peak torques) and gait parameters were assessed using Pearson and Spearman coefficients. Comparisons between and within subgroups were made using the Mann-Whitney and Kruskal-Wallis tests.

RESULTS

In total, 29 MS patients (mean age 31.5±6.5 years) were investigated in this study. The gait and strength characteristics of MS patients within the two EDSS subgroups (EDSS=1–4.5, n=22; EDSS>4.5, n=7) are shown in Table 1. Spatiotemporal, kinematic and kinetic gait parameters were compared between groups EDSS=1–4.5 and EDSS>4.5: stride length and gait speed were significantly lower in EDSS>4.5 than in EDSS=1–4.5. Range of movement of the knee joint was less in group EDSS>4.5 than in EDSS=1–4.5, with the difference in flexion being the most marked ($p<0.001$, Table 2).

Minimum and maximum hamstring and quadriceps strength differed significantly between the subgroups. Muscle strength was greater in group EDSS=1–4.5 than in group EDSS>4.5.

Gait speed, stride length, and total range of movement of the knee joint all correlated significantly with the four strength parameters of MS patients overall ($p<0.01$). Within the subgroups, the correlation between minimum hamstring strength and total range of movement of the knee was significant only in the group EDSS>4.5; minimum hamstring strength correlated with peak knee extensor moment in group EDSS=1–4.5, but at a reduced level of significance ($p<0.05$, Table 3).

Table 1. Gait and strength characteristics in MS patients within EDSS subgroups

Variable	MS patients (n=29)	EDSS=1–4.5 (n=22)	EDSS>4.5 (n=7)
Age (years)	31.5±6.5	29.7±5.2	37.5±7.2
Height (cm)	164.6±10.2	165.1±9.1	163±14.1
Weight (kg)	68.9±13.2	68.1±12.4	71.8±15.8
Gait parameters			
Cadence (step/min)	102.11±10.75	104.32±7.67	94.85±16.2
Stride length (cm)	0.98 ±0.17	1.05±0.08	0.76±0.19
Walking speed (m/min)	0.84± 0.18	0.91±0.11	0.59±0.16
Kinematics parameters			
Knee total exurcison (degree)	48.2±9.66	52.2±5.8	35.03±7.98
Kinetics parameters			
Peak knee extensor moment	135.96±325.45	215.34±256.96	−124.87±407.8
Peak knee flexor moment	−189.88± 241.096	−274.69±196.5	88.79±145.58
Muscle strength			
Max quadriceps (N/m)	144.03±51.15	163.56±38.89	79.87±28.88
Min quadriceps (N/m)	118.15±48.6	139.11±32.84	49.27±15.56
Max hamstring (N/m)	80.48 ±28.31	91.74±21.01	43.5±13.17
Min hamstring (N/m)	74.16±23.19	84.25±14.75	41.01±11.42

Mean and SD values

Table 2. Gait Parameters and mean peak torque for the quadriceps and hamstring muscles at 60° s^{-1} in EDSS groups

	EDSS=1–4.5 (n=22) Mean± SD	EDSS>4.5 (n=7) Mean± SD
Gait parameters		
Cadence (step/min)	104.32±7.67	94.85±16.2
Stride length (cm)	1.05±0.08*	0.76±0.19
Walking speed (m/min)	0.91±0.11*	0.59±0.16
Kinematics parameters		
Knee total exurcison (degree)	52.2±5.8*	35.03±7.98
Kinetics parameters		
Peak knee extensor moment	215.34±256.96*	−124.87±407.8
Peak knee flexor moment	−274.69±196.5*	88.79±145.58
Muscle strength		
Max quadriceps (N/m)	163.56±38.89*	79.87±28.88
Min quadriceps (N/m)	139.11±32.84*	49.27±15.56
Max hamstring (N/m)	91.74±21.01*	43.5±13.17
Min hamstring (N/m)	84.25±14.75*	41.01±11.42

*p<0.05

DISCUSSION

The present study revealed significant correlations between gait parameters and peak torque generated by quadriceps and hamstring muscles. These results have applications in both research and the evaluation of new therapeutic strategies.

The reported correlation between upper limb muscle strength and parameters of gait, such as speed, stride length, and kinematics, suggest that a specific rehabilitation programme based on strength training may lead to functional improvement in the walking ability of MS patients through gains in knee stability, motor ability and posture[25, 26].

Cantalloube et al. reported significant correlations between peak torque values of the quadriceps and hamstring muscles and gait speed in a study of 21 MS patients[27]. Similarly, our results show a high correlation between the peak torque values of the quadriceps and hamstrings and gait speed, stride length, knee range of motion, as well as peak knee extensor and flexor moments. Mevellec et al. reported a observed correlation between motor impairment and gait speed in 27 MS patients, which was strongest for the hamstring muscle[28]. Our results indicate there are significant correlations between minimum hamstring torque and peak knee extension and flexion moment. Olney et al. studied the correlation between speed and flexor moments of the hips, knees and ankles, but found no correlation with extensor moment in patients with hemiplegia[29]. Yahia et al. reported a significant correlation between both balance and gait disorders and quadriceps and hamstring muscle weakness in MS patients[30].

Impairment of quadriceps and hamstring muscles may vary with the level of disability in MS. Factors contributing to reduced walking velocity in group EDSS>4.5 included impaired hip extension in both mid and terminal stance and reduced knee extension in late swing and heel contact, both of which reduce stride length, and thus the speed of walking. Our study showed a significant correlation between minimum hamstring strength and total range of knee movement in EDSS>4.5 group. Rodgers et al. studied the range of motion of each joint in a group of MS patients and found that patients had a reduced range of movement at slow walking speeds[17].

Table 3. Correlations matrix table between gait kinematic and kinetic parameters and muscle parameters in the whole MS group and two deficiency level subgroups

	Total Sample (n=29)				EDSS=1–4.5 (n=22)				EDSS>4.5 (n=7)			
	Max Quadriceps	Min Quadriceps	Max Hamstring	Min Hamstring	Max Quadriceps	Min Quadriceps	Max Hamstring	Min Hamstring	Max Quadriceps	Min Quadriceps	Max Hamstring	Min Hamstring
Cadence (step/min)	0.184	0.309	0.170	0.249	−0.185	−0.101	−0.314	−0.227	−0.36	0.450	0.129	0.149
Stride Length (cm)	0.649**	0.641**	0.529**	0.609**	0.180	0.301	−0.127	−0.054	0.600	−0.247	0.229	0.277
Walking speed (m/min)	0.599**	0.642**	0.473**	0.585**	0.047	0.142	−0.259	−0.152	0.539	0.069	0.159	0.333
Knee total exurcison (degree)	0.648**	0.661**	0.598**	0.675**	0.155	0.091	−0.12	−0.18	0.580	0.449	0.530	0.794*
Peak knee extensor moment	0.432*	0.416*	0.482*	0.590**	0.235	0.108	0.394	0.521*	0.057	0.175	−0.186	0.243
Peak knee flexor moment	−0.526**	−0.590**	−0.384*	−0.465**	−0.056	−0.140	0.227	0.253	−0.613	−0.388	−0.214	−0.719

Pearson correlation values are reported. *p<0.05, **p<0.01

Thoumie et al. reviewed their rehabilitation results for 100 ambulatory MS patients[8]. They proposed that achieving consistent strength of the hamstring muscles should be the primary goal for maintaining gait. This view is supported by our results, which show that hamstring strength tends to correlate with kinematic and kinetic gait parameters in MS patients, and notably that minimum hamstring strength correlated highly with the peak knee extensor moment in group EDSS=1–4.5.

Relatively few studies have investigated the relationship between strength and kinetic and kinematic gait parameters in MS patients. Broekmans et al. demonstrated that both the isokinetic and isometric strength of the knee extensor muscles were significantly related to performance in short and longer walking tests in groups of MS patients not stratified by level of disability[31]. An EDSS cut-off score of 4.5 distinguishes between subgroups with mild and moderate ambulatory dysfunction, identifying significant differences in walking capacity. In healthy individuals, knee flexor muscles act concentrically at the point of mid-swing to increase knee flexion for limb advancement, and then eccentrically at the terminal point of swing and initial heel contact, to decelerate the lower limb and avoid hyperextension. A major role of the knee flexor muscles in the maintenance of gait is to increase step length and prepare the leg for initial contact of the foot with the ground[32]. The association between walking capacity and both isokinetic knee flexor strength and knee extensor strength has been reported in stroke and MS[4, 8, 33].

In the present study, we demonstrated that MS patients in group EDSS>4.5 had poor knee flexion during the swing phase, as isokinetic muscle strength correlated significantly with the knee's range of movement, resulting in a shorter swing phase, decreased stride length and slower gait speed. In a rehabilitation programme study, Robineau et al. reported that eccentric, isokinetic strengthening of the hamstring led to an improvement in gait parameters in 28 MS patients[25]. Aubry et al. confirmed the efficacy of a strength training programme (eccentric, isokinetic) after 12 training sessions to increase hamstring muscle strength, improve knee control during gait in a clinical examination, and increase maximum attainable walking distance[34]. Yahia et al. found a positive correlation between muscle strength and balance parameters, especially for the hamstring muscle when patients had their eyes closed, indicating that hamstring muscle impairment appears to be related to gait and balance parameters, whereas quadriceps impairment may be more related to functional status[30]. These results suggest that both motor and proprioceptive components affect balance.

Future investigations of the relationship between muscle strength, and kinetic and kinematic gait parameters should include strength measurements of hip and ankle muscles, as this will help elucidate whether distal rather than proximal muscle weakness negatively impacts gait phase and spatio-temporal parameters. Our results suggest that rehabilitation protocols for MS patients should include a critical strength training programme, and that hamstring and quadriceps muscles strength training may enhance the efficacy of the treatment.

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