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Changes in electromyographic activity after botulinum toxin injection of the rectus femoris in patients with hemiparesis walking with a stiff-knee gait

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ABSTRACT

Purpose: This study was designed to evaluate the effects of botulinum toxin type-A (BoNTA) injection of the rectus femoris (RF) muscle on the electromyographic activity of the knee flexor and extensor and on knee and hip kinematics during gait in patients with hemiparesis exhibiting a stiff-knee gait.
Method: Two gait analyses were performed on fourteen patients: before and four weeks after BoNTA injection. Spatiotemporal, kinematic and electromyographic parameters were quantified for the paretic limb.
Results: BoNTA treatment improved gait velocity, stride length and cadence with an increase of knee angular velocity at toe-off and maximal knee flexion in the swing phase. Amplitude and activation time of the RF and co-activation duration between the RF and biceps femoris were significantly decreased. The instantaneous mean frequency of RF was predominantly lower in the pre-swing phase.
Conclusions: The results clearly show that BoNTA modified the EMG amplitude and frequency of the injected muscle (RF) but not of the synergist and antagonist muscles. The reduction in RF activation frequency could be related to increased activity of slow fibers. The frequency analysis of EMG signals during gait appears to be a relevant method for the evaluation of the effects of BoNTA in the injected muscle.

1. Introduction

Reduced peak knee flexion in the swing phase of gait, known as stiff-knee-gait (SKG), is a common abnormality in patients with hemiparesis. Inappropriate activity of the rectus femoris muscle (RF), due to spasticity, has been widely reported as a cause of SKG. Botulinum toxin type-A (BoNTA) is a common treatment for spasticity in adults (Pittock et al., 2003). BoNTA has been shown to be effective and safe in patients with hemiparesis with lower limb spasticity in several placebo-controlled trials (Tok et al., 2012; Dunne et al., 2012). Reduced use of walking aids (Pittock et al., 2003), reduced energy cost (Caty et al., 2008), increased gait velocity (Pradon et al., 2011) and improved ankle (Novak et al., 2009) and knee (Robertson et al., 2009; Stoquart et al., 2008) joint kinematics have been demonstrated. More specifically, in patients with hemiparesis exhibiting a SKG, BoNTA injection of the RF increased knee flexion during the swing phase of gait (Tok et al., 2012; Robertson et al., 2009; Stoquart et al., 2008), increased knee angular velocity at toe-off (Robertson et al., 2009; Stoquart et al., 2008), and tended to increase hip flexion during swing without changes in hip, knee or ankle kinetics (Robertson et al., 2009).

Electromyography (EMG) is a useful tool for the evaluation of abnormal patterns of muscle activation in patients with neurological disorders, helping in clinical decision making. Recently, Phadke et al. (2012) highlighted the problems related with EMG amplitude normalization for the evaluation of the effects of BoNTA in patients with neurological lesions. The main cause being that patients with neurological lesions may demonstrate varying levels of strength. Since BoNTA blocks neuromuscular junctions of the injected muscle, this may also decrease strength. Several other EMG techniques may be used to evaluate the effects of BoNTA. For example, the evaluation of changes in patterns of muscle co-activation after BoNTA injections does not require amplitude normalization (Manganotti et al., 2010). Another method which does not require amplitude normalization is frequency analysis of the EMG signal. This technique aims to decompose EMG signal into its individual frequencies. The pattern of muscle fiber activation is provided by the frequency of the EMG signal. This informs on the shapes and conduction velocities of the action potentials of the motor unit (Hermens et al., 1992). Continuous wavelet transform (CWT) has been used to evaluate muscle activation in the gait of patients with neurological diseases (Lauer et al., 2005).

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Studies which have used EMG to evaluate the effects of BoNTA on muscle activation during gait have shown contradictory results. For example, Van der Houwen et al. (2011) showed that BoNTA (multilevel injections) has no effect on muscle activation patterns, based on a root mean square difference analysis in children with cerebral palsy. Another study in a similar population found an improvement in the EMG patterns (Manganotti et al., 2007), whereas Desloovere et al. (2001) observed a decrease in EMG activity of the gastrocnemius and the hamstring muscles after injection in the hamstring muscles. In patients with hemiparesis, Hesse et al. (1996) found a reduction in the activity of the calf muscles in terminal swing and early stance following BoNTA treatment. To our knowledge, only one study has evaluated the effects of BoNTA on the EMG in patients with hemiparesis exhibiting a SKG. Stoquart et al. (2008) showed that BoNTA injection of the RF modified the activation of the knee extensor and flexor muscles during gait, particularly during the pre-swing and swing phases of the gait cycle. However, the EMG analyses and normalization techniques used in these studies may not be appropriate (Phadke et al., 2012). Because BoNTA decreases muscle strength and co-activation of antagonistic muscles (Bhakta et al., 2008) and is widely used to manage focal limb spasticity, it is very important to improve understanding of its effects on muscle activation during gait. However, the effects of BoNTA on muscle activation frequency and co-activation during gait have never been studied.

The aim of this study was to evaluate changes in the EMG signal (amplitude and frequency) of the knee extensor and flexor muscles as well as changes in knee and hip kinematics after BoNTA injections of the RF in patients with hemiparesis walking with a SKG. Based on findings in the literature, we hypothesized that RF activity would decrease both in amplitude and frequency after BoNTA injection, during the pre-swing and swing phases of the gait cycle. Our second hypothesis was that this reduction in RF activity would decrease co-activation between the knee extensor and flexor muscles.

2. Methods

2.1. Participants

14 subjects with chronic hemiparesis following stroke and SKG were enrolled in the study (Table 1). The average age of participants was 53.5 ± 11.7 years (range from 40 to 75 years). The inclusion criteria were: over 18 years old, more than 6 months post stroke, a score ⩾1 on the Modified Ashworth Scale (MAS) (Bohannon and Smith, 1987) for the quadriceps muscle with the hip in extension, ability to walk 10 m without walking aids, RF EMG activity in the mid swing phase before BoNTA injection gait analysis (considered as inappropriate), no BoNTA injections in the last 4 months, no other anti-spastic treatment or neurosurgery within the last 6 months. This study was approved by the local ethics committee and all subjects provided written informed consent prior to participation.

2.2. Gait assessment

Each patient carried out one gait analysis session on 2 separate days: before BoNTA injections into the spastic RF (PRE) and four weeks after (POST). Gait parameters were recorded using 8 optoelectronic cameras (Motion Analysis Corporation, CA, USA) which measured the 3D coordinates of 30 reflective markers. Markers were positioned according to the Helen Hays protocol (Kadaba et al., 1990). This protocol includes a static trial in order to define the centers and axes of rotation of the hip and knee. Each gait trial was carried out in a 10 m gait corridor (6 gait trials). This corridor allowed at least eight successive gait cycles to be recorded. Patients walked at their self-selected walking velocity. Data were filtered using a fourth-order zero-lag Butterworth low-pass-filter with a cutoff frequency of 6 Hz. Gait velocity, cadence, step length, step width and stride were computed for the paretic limb. Because knee flexion angle during the swing phase and knee angular velocity at toe-off of the paretic limb are two important parameters regarding the mechanisms of SKG, they were included in this study (Piazza and Delp, 1996). Since the RF is a biarticular muscle, maximal hip flexion angle during swing and hip angular velocity at toe-off were also included (Robertson et al., 2009).

Spasticity of the RF was evaluated in the PRE and POST conditions using the Duncan–Ely test. The test is considered positive if during the passive knee flexion, the patient simultaneously flexes the ipsilateral hip or resistance is felt by the examiner. The angle of knee flexion at which the hip flexed was noted. This test has been shown to have a good positive predictive value for RF dysfunction during gait, more specifically for decreased dynamic range of motion and delayed timing of peak knee flexion in swing (Marks et al., 2003).

2.3. Electromyographic assessment

Electromyographic activity of the RF, vastus lateralis (VL) and biceps femoris (BF) muscles of the paretic limb was recorded during the gait trials. The VL and BF muscles were chosen (along with the RF), because of their role in controlling the knee during the pre-

Table 1
Subject demographics.

Description of the population	Gender	Paretic limb	Age (years)	Mass (kg)	Height (cm)	Time since hemiplegia (months)
1	M	R	75	59	159	120
2	M	R	68	73	174	72
3	F	R	42	59	167	144
4	M	R	52	78	178	85
5	M	R	46	80	180	56
6	M	R	55	83	177	156
7	M	R	72	91	171	72
8	M	R	44	75	184	84
9	M	R	62	76	185	24
10	M	L	43	105	172	72
11	M	R	42	70	172	54
12	F	R	56	63	162	72
13	M	R	52	80	174	56
14	F	L	40	57	160	132
Mean (SD)			54 (12)	75 (13)	173 (8)	86 (38)

M = male, F = female, R = right, L = left.