Clinical Biomechanics 43 (2017) 15–22

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Improvement of upper trunk posture during walking in hemiplegic patients after injections of botulinum toxin into the arm☆

Harald Hefter *, Dietmar Rosenthal

Department of Neurology, University of Düsseldorf, Moorenstrasse 5, D-40225 Düsseldorf, Germany

ARTICLE INFO

Article history:
Received 5 November 2015
Accepted 24 January 2017

Keywords:
Stroke
Botulinum neurotoxin
Hemiplegic gait
Upper trunk posture
Trunk muscles

ABSTRACT

Background: It has been hypothesized that altered trunk movements during gait in post-stroke patients or children with cerebral palsy are compensatory to lower limb impairment. Improvement of trunk movements and posture after injections of botulinum toxin into the affected arm would be at variance with this hypothesis and hint towards a multifactorial trunk control deficit.
Patients and Methods: Clinical gait analysis was performed in 11 consecutively recruited hemiplegic patients immediately before and 4 weeks after a botulinum toxin type A-injection into the affected arm. Kinematic data were collected using an 8 camera optical motion-capturing system and reflective skin-markers were attached according to a standard plug-in-gait model. Deviation of the trunk in lateral and forward direction and the trajectory of the C7-marker in a sacrum-fixed horizontal plane were analyzed in addition to classical gait parameters. The Wilson-signed-rank test was used for pre/post-botulinum toxin comparisons.
Findings: After botulinum toxin injections a significant improvement of forearm flexion scores from 2.57 to 2.0 ($p < 0.014$), and a reduced lateral deviation of the upper trunk from 3.5 degrees to 2.5 degrees ($p < 0.014$) were observed. Free-walkers tended to walk faster ($p < 0.046$, 1-sided), with reduced pre-swing duration of both legs and an increased step length of the non-affected leg. The C7-marker trajectory was shifted towards the midline.
Interpretation: Injections of botulinum toxin into the affected arm of hemiplegic patients improve abnormal trunk lateral flexion. This shift of the center of mass of the upper body towards the midline improves various gait parameters including gait speed.

1. Introduction

Stroke is a major cause of death and affects 150 to 200 out of every 100.000 people (Bakhai, 2004). If survived, a variety of disabling symptoms develop among which cognitive impairment and motor deficits are the most common type (Rathore et al., 2002). Between 19 and 43% of stroke survivors will develop spasticity (Leathley et al., 2004; Sommerfeld et al., 2004; Urban et al., 2010; Watkins et al., 2002) as "plus" symptom of the upper motor neuron syndrome with increased muscle tone, enhanced tendon reflexes, flexor and/or extensor spasms as well as complex associate reactions (Hefter et al., 2012; Sheean, 2002).

Intramuscular injections of botulinum toxin (BoNT) have turned out to be highly effective to reduce muscle tone not only in dystonic but also in spastic muscles (for a survey see (Moore and Naumann, 2003)). Following evidence-based evaluations of published data the Therapeutics and Technology Assessment Committee of the American Academy of Neurology and the Royal College of Physicians recommended botulinum toxin type A (BoNT/A) as effective treatment of spasticity in adults (Royal College of Physicians, British Society of Rehabilitation Medicine, Chartered Society of Physiotherapy, 2009; Simpson et al., 2008).

Significant improvement of muscle tone after BoNT treatment in upper and lower limbs in adults and children has been demonstrated in many studies. Treatment of severe hip adductor spasticity (Snow et al., 1990) as well as of closed fist and flexed forearms (Nam et al., 2015) significantly reduces caregiver burden. "However, in spite of significant reduction of muscle tone, functional benefit has less consistently been demonstrated" (Pittock et al., 2003; Schweizer et al., 2014; Sheean, 2001).

Patient's spontaneous walking speed has frequently been used as functional outcome measure. But even in the well-designed study by Caty et al. (Caty et al., 2008) demonstrating increased knee flexion during swing phase and decreased energy costs and for the first time a functional improvement in walking after injections of 200 MU onaBoNT/A (Botox®) into several proximal and distal leg muscles in 20 patients with a stiff knee gait, walking speed remained unchanged. In a much

☆ This work was co-funded by the German federal state North Rhine Westphalia (NRW) and the European Union (European Regional Development Fund: Investing in Your Future). Grant number: Z1104me31c//005-1111-0056.
* Corresponding author.
E-mail address: harald.hefter@online.de (H. Hefter).

http://dx.doi.org/10.1016/j.clinbiomech.2017.01.018
0268-0033/

larger study ($n = 234$) with four different treatment groups (500 MU, 1000 MU, 1500 MU aboBoNT/A (Dysport®) and placebo), no significant difference between the 3 abo-BoNT/A-subgroups and the placebo-subgroup was found (Pittock et al., 2003). In a meta-analysis including 8 papers and 228 patients a small increase of walking speed around 0.044 m/s was described as significant, and it was concluded that "the use of BoNT/A for lower limb post-stroke equinovarus because of spasticity was associated with a small, but statistically significant increase of gait velocity" (Foley et al., 2010). Obviously, it is difficult to improve gait speed in patients with hemiplegia by injections of BoNT/A into the leg.

This seems to be different when BoNT/A is injected into the arm. In a recent study on 15 post-stroke patients a significant increase of walking speed of 0.07 m/s was observed after injections of 120–200 MU ona-BoNT/A into the forearm flexors (Esquenazi et al., 2008). In another study a reduction in stride time was found in all patients ($n = 13$) analyzed after abo-BoNT/A-injections into the arm (Hirsch et al., 2005). Previously, Backeit and Sawyer (Backheit and Sawyer, 2002) had analyzed knee flexion in mid-swing phase of the gait cycle after BoNT-injections into the ipsilateral arm. Two of 9 patients had improved knee flexion, two of 9 became worse and five did not change. Eight of 9 patients reported "moderate or significant improvement of walking ability". No improvement of gait velocity or other gait parameters was mentioned (Backheit and Sawyer, 2002). Smith et al. (Smith et al., 2000) had also observed an improved gait in 6 of 11 patients after injections into the arm.

So far this consistently described improvement of patient's gait after BoNT-injections into the arm is barely understood. The spectrum of possible explanations ranges from a placebo effect (Smith et al., 2000) to modulation of feedback loops and modulation of CNS-plasticity (Backheit and Sawyer, 2002; Esquenazi et al., 2008; Hirsch et al., 2005; Smith et al., 2000).

In the present study a more concrete, biomechanical explanation is offered. Our hypothesis is that BoNT-injection into the arm reduces the rotational moment of the upper body in the transversal plane and therewith trunk lateral flexion to the affected side. This has positive implications on patient's gait. Furthermore, this is the first study analyzing the influence of BoNT-injections on trunk position and trunk control in adult post-stroke spasticity. It contributes to the discussion whether abnormal trunk position reflects impairment of lower legs or an a priori trunk control deficit (Perry and Burnfield, 2010). Therefore the present study has influence on clinical practice of BoNT-application on the one hand and on the understanding of trunk control in patients with spasticity on the other.

2. Methods

2.1. Participants

Inclusion criteria for the present study were: (i) age ≥ 18 yrs.; (ii) medical history of only one stroke and time since stroke >6 months; (iii) no orthopedic or neurological deficit interfering with walking other than the stroke; (iv) MRI-scan available not older than 3 months without additional brainstem, midbrain, cerebellar or contralateral hemispheric lesion; (v) ability to walk a distance of 12 m at least 12 times with intermittent pauses; (vi) no BoNT-injection during the last 3 months.

Fifteen patients who were treated on a regular basis every three months in the botulinum toxin clinic of the University of Düsseldorf were screened. Patients who gave informed consent underwent clinical investigation. Four patients were excluded because of a recent MRI-scan showing multiple lesions with temporal and/or spatial dissociation. Demographical as well as treatment related data of the included eleven patients are presented in Table 1. The entire group of patients was subdivided into a free-walker subgroup (FW-group, $n = 7$) and a subgroup of patients using a walking aid (3 cane user and one wheel walker user; WA-group).

To demonstrate the difference of patients' data to normal trunk movements, data of a healthy male from the lab data base are presented, whose age (54 yrs) was closest to the mean age of our patients before stroke (54.9 yrs). Due to the design of the study (pre/post botulinum toxin comparison) no control data were necessary for data analysis.

2.2. BoNT/A-injection into the affected arm

All 11 participants received injections of 500 to 1000 MU abo-BoNT/A (Dysport®) exclusively into the affected arm. Forearm flexors (brachialis, biceps, brachioradialis muscle) were injected with 250 to 500 MU, the rest of the total dose was distributed to hand- and/or finger flexors (Table 1). Shoulder muscles were not injected. Oral medication, and frequency and intensity of physical therapy (differing from patient to patient) had to be kept constant during the four weeks between the performance of the two clinical gait analyses (CGAs). The technician who performed the gait analysis was blind for dose of BoNT/A and injection scheme.

2.3. Assessment of the effect of BoNT/A-injections

Muscle tone at the elbow joint was scored by means of the Modified Ashworth scale (MAS). Arm position (APS) was scored by means of the item "arm" of the "ReHabX-score" (Ferreira et al., 2015) (0 = arm swings normally; 1 = arm is slightly flexed (0–45 degrees) with mildly reduced arm swing; 2 = arm is moderately flexed (45–90 degrees) with clearly reduced arm swing; 3 = arm is flexed at least 90 degrees without arm swing). MAS and APS (see Table 2) were performed during the baseline clinical investigation and 4 weeks later before CGA, at the time of the peak effect of the BoNT/A-injections.

For each patient arm and hand position (ArmP resp. HandP, see Table 2) were determined from pairs of videos being recorded during CGAs from an anterior/posterior (a/p) and a lateral position of the cameras. Eleven pairs of videos resulted from the pre- and 11 from the post-

Table 1
Demographic and clinical data of the patients and dose of abo-BoNT/A used for injection of the upper arm and forearm flexors.

Subject no.	Age (yr)	Sex f/m	Time since stroke (months)	Paresis (R/L)	Comments	Walking aid	Abo-BoNT/A upper arm muscles (MU)	Abo-BoNT/A forearm muscles (MU)
1	76	m	121	R	Barefoot		500	500
2	72	m	79	R	Barefoot	Wheel walker	250	250
3	70	f	200	R	Barefoot		400	350
4	69	m	304	R	Barefoot		250	250
5	65	m	81	R	Barefoot	Cane	250	250
6	59	f	91	R	Shoes		400	400
7	78	m	68	L	Shoes	AF-orthosis	350	150
8	69	f	88	L	Barefoot	Cane	250	250
9	67	m	82	L	Barefoot		350	150
10	52	f	71	L	Shoes	AF-orthosis	500	500
11	47	f	76	L	Barefoot	Cane	500	500

yr = years; f = female; m = male; R = right, L = left; AF = ankle-foot-orthosis; dose of abo-BoNT/A (Dysport®) in mouse units (MU).