Journal of Electromyography and Kinesiology 24 (2014) 11–17

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

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

Electromyographic analysis of upper limb muscles during standardized isotonic and isokinetic robotic exercise of spastic elbow in patients with stroke

Minki Sin [a,1], Won-Seok Kim [b,1], Daegeun Park [a], Yu-Sun Min [b], Woo Jin Kim [c], Kyujin Cho [a,*], Nam-Jong Paik [b]

[a] School of Mechanical and Aerospace Engineering, Seoul National University/IAMD, Seoul, Republic of Korea
[b] Department of Rehabilitation Medicine, Seoul National University College of Medicine and Seoul National University Bundang Hospital, Seongnam, Republic of Korea
[c] Department of Physical Medicine and Rehabilitation, Haeundae Paik Hospital, Inje University of Medicine, Busan, Republic of Korea

ARTICLE INFO

Article history:
Received 12 April 2013
Received in revised form 3 September 2013
Accepted 4 October 2013

Keywords:
Stroke
Muscle spasticity
Isotonic contraction
Isokinetic contraction
Co-contraction
Surface electromyography
Rehabilitation robotics

ABSTRACT

Although it has been reported that strengthening exercise in stroke patients is beneficial for their motor recovery, there is little evidence about which exercise method is the better option. The purpose of this study was to compare isotonic and isokinetic exercise by surface electromyography (EMG) analysis using standardized methods.

Nine stroke patients performed three sets of isotonic elbow extensions at 30% of their maximal voluntary isometric torque followed by three sets of maximal isokinetic elbow extensions with standardization of mean angular velocity and the total amount of work for each matched set in two strengthening modes. All exercises were done by using 1-DoF planner robot to regulate exact resistive torque and speed. Surface electromyographic activity of eight muscles in the hemiplegic shoulder and elbow was recorded. Normalized root mean square (RMS) values and co-contraction index (CCI) were used for the analysis.

The isokinetic mode was shown to activate the agonists of elbow extension more efficiently than the isotonic mode (normalized RMS for pooled triceps: 96.0 ± 17.0 (2nd), 87.8 ± 14.4 (3rd) in isokinetic, 80.9 ± 11.0 (2nd), 81.6 ± 12.4 (3rd) in isotonic contraction, $F[1,8] = 11.168$; $P = 0.010$) without increasing the co-contraction of muscle pairs, implicating spasticity or synergy.

1. Introduction

Upper limb muscle weakness is a common impairment (Go et al., 2013) after stroke and has been known to be associated with functional ability (Harris and Eng, 2007). Strength training has been suggested as one of the therapies to restore strength in the paretic arm of stroke patients in several clinical trials (Hammami et al., 2012; Harris and Eng, 2010). For this purpose, many strength training strategies have been suggested to reduce the disability after stroke (Pinter and Brainin, 2012), and some of them use robotic device for their rehabilitation study (Jezernik et al., 2003; MinKi et al., 2011).

For strength training, variable contraction type of exercises can be applied; isotonic and isokinetic modes are the most commonly used in clinical settings. Some studies investigated the effect of isotonic strength training (Gelber et al., 1995; Logigian et al., 1983) and other studies used the isokinetic mode as an intervention (Chang et al., 2007), which proved beneficial effects on upper limb strength and function in stroke patients. However, there have been no studies to compare the differential effect between the two modes in stroke patients.

Although studies using surface electromyography (EMG) reported some differences in EMG parameters between the isotonic and isokinetic modes in healthy individuals (Purkayastha et al., 2006; Remaud et al., 2009), these results cannot be extrapolated to patients with stroke directly because this group of individuals may display spasticity and abnormal synergy during the strength training. It has been considered that strength training of the hemiplegic arm can aggravate the tone, abnormal synergies and pain in the view of classical rehabilitation (Bobath, 2000). Although some previous studies reported that strength training did not increase the tone in stroke patients, a definite conclusion for patients with spasticity is difficult because most studies include stroke patients with only a low level of tone (Harris and Eng, 2010). EMG complementary analysis in spasticity and synergisms of stroke patients is suitable for the isotonic and isokinetic contraction exercises.

In addition, to compare the isotonic and the isokinetic exercises, it has been suggested that standardization method is needed. How-

* Corresponding author. Tel.: +82 2 880 1703.
E-mail address: kjcho@snu.ac.kr (K. Cho).

[1] These authors contributed equally to this work.

1050-6411/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jelekin.2013.10.002

ever, standardized comparison of the two modes was only performed in the lower extremities of healthy people (Remaud et al., 2009). Furthermore, the isotonic exercise in the previous study cannot simulate the real isotonic exercise in usual clinical settings, because it was designed to increase the velocity directly proportional to the force measured by the dynamometer, while the real isotonic mode should give constant load throughout overall range of motion (ROM) (Kovaleski et al., 1995; Remaud et al., 2009). Therefore, in this study, 1 degree of freedom (DoF) planner robot was used to provide actual isotonic and isokinetic exercises for our experiments.

Accurate measurement and accurate motion generation of the robotic device allows regulation of exact desired force or motion, designation of certain amount of exercise load and intention driven exercise, which facilitates advanced rehabilitation protocols.

The purpose of this study was to compare the efficiency of isotonic and isokinetic exercises in stroke patients. Surface EMG was analyzed while the patients performed standardized exercise. In addition to agonist and antagonist activities, co-contraction index (CCI) for selected muscle pairs in the shoulder and elbow was included for EMG analysis to compare the spasticity and synergy between the two modes.

2. Methods

2.1. Subjects

Inclusion criteria were as follows: (1) unilateral hemiparesis in the upper extremity caused by unilateral first-ever stroke, (2) 20 years or older, (3) elbow joint spasticity in the range of one plus to three in the modified Ashworth scale in the hemiparetic arm, (4) voluntary elbow extension strength of three or above in the hemiparetic arm as measured by the manual muscle test proposed by Medical Research Council, (5) no previous disease affecting the function of the hemiparetic arm, except for stroke itself (6) free of cognitive, language, visuospatial or attention deficits that would prevent subjects from following the experimental procedures, and (7) free of medical conditions which would cause hemodynamic instability. Patients were recruited from June 2012 to September 2012. The subjects were inpatients or outpatients with stroke in one Department of Rehabilitation Medicine of a tertiary hospital. One physiatrist is affiliated with the Department of Rehabilitation Medicine screened the patients, and total of nine patients who met the above-mentioned criteria and provided their written consent were enrolled in this study. This research was approved by the local institutional review board and was conducted in accordance with the regulatory standards of Good Clinical Practice and the Declaration of Helsinki (World Medical Association Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects, 2008).

2.2. System and devices

For the experiment, the customized experimental platform has been built. The platform consists of 5 parts: exoskeleton part, control unit, measurement unit, base frame and chair. The detailed composition of the platform is in a Supplementary file.

2.3. Experimental design

The experiment was designed to compare isotonic exercise and isokinetic exercise during elbow extension. The target motion, planar elbow extension at shoulder height, was decided to remove the effect of gravity and minimize the effect of action of shoulder external rotator and abductor (Hu et al., 2007). The experimental protocol suggested by Remaud was used with modifications to compare the isotonic and the isokinetic exercise with standardization of mean angular velocity and total amount of work (Remaud et al., 2009). The experiment was divided into three sessions: setup, familiarization and actual test.

In the setup session, Brunnstrom and Fugl-Meyer Assessment (FMA) scale in the affected arm were checked. After that, surface electrodes (1.8 × 1.2 mm Ag–AgCl, Bioprotech Inc., Wonju, Korea) were attached on the following muscles in the patient's hemiplegic upper extremity based on the "Surface EMG for Non-Invasive Assessment of Muscles (SENIAM)" (Hermens et al., 2000): anterior, middle and posterior deltoid, biceps short and long head, triceps long and lateral head and brachioradialis. One ground electrode was attached at the backside of the neck (C7). The EMG data were corrected for DC bias removal, band-pass filtered from 10 to 450 Hz and sampled at 1024 Hz.

After EMG electrodes were attached, the maximum voluntary isometric contraction (MVIC) of each muscle was performed to measure maximum EMG value. First, MVIC of shoulder and forearm muscles (anterior, middle and posterior deltoid and brachioradialis) was performed (Hurst et al., 2012). In the anatomical position of the hemiparetic upper extremity, three 5-s MVIC were performed while an experienced physiatrist blocked the shoulder from moving. In detail, the physiatrist stabilized the shoulder with one hand and the upper arm with the other hand while the patient was asked to exert maximum voluntary force in three directions; flexion, extension and abduction. 30-s rest period between trial and 2-min rest period between each action were given. EMG activities were measured during MVIC of each muscle.

Before MVIC of upper arm muscles (biceps short and long head, triceps long and lateral head), subjects were set to experimental posture. Trunk of subject was restricted by shoulder and abdominal straps that attached to the chair and the height of the chair was adjusted to let the patient's shoulder and the robot lie in the same horizontal plane. The shoulder of the subject was abducted 90°, forearm was in the neutral position and elbow was positioned at 90° in the horizontal plane. The rotation axis of the robot was aligned to the anatomical axis of the elbow as shown in Fig. 1. Forearm was fastened to the manipulandum using straps. Elbow angle of 90° (with 180° for full extension) was selected because it is known that the maximum torques of the elbow can be obtained around this angle (Koo et al., 2003).

Following the posture setting, MVIC of the upper arm muscles was assessed (Hu et al., 2007). Three sets of 5-s elbow extension and flexion were performed with the same rest periods as the shoulder and forearm MVIC assessment. In addition to EMG activities, torques were measured during MVIC of the upper arm muscle (see Fig. 2).

In the familiarization session, subjects were asked to try both isotonic and isokinetic exercise. Resistive torque during isotonic elbow extension was set at 30% of the maximal elbow extension torque of each subjects from the setup session. Several elbow isotonic extensions from 60° to 110° were tried. In cases the subjects cannot extend the elbow from 60° to 110° during the isotonic mode, the range was adjusted (Table 1). After deciding the angle, several isotonic elbow extensions were performed. Next, several isokinetic elbow extensions with the same range and mean velocity of the previous isotonic session were performed.

Before actual test session, the subjects took a 10-min rest period. Resistive torque and range of exercise were set using the same parameters determined in the familiarization session. Firstly, in the actual test session, the subjects performed three sets of six isotonic elbow extensions with a 2-min rest period between the sets. During the isotonic elbow extension, angle, angular velocity and external torque were measured by the robot and mean angular velocity and total work done by the subjects were calculated for each exercise sets using external torque and angular velocity. After 10 min of rest period, the subjects performed standardized three sets of