Clinical Neurophysiology 125 (2014) 988–994

Contents lists available at ScienceDirect

Clinical Neurophysiology

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

Power spectral analysis of surface electromyography (EMG) at matched contraction levels of the first dorsal interosseous muscle in stroke survivors

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ARTICLE INFO

Article history:
Accepted 30 September 2013
Available online 21 November 2013

Keywords:
Surface electromyography (EMG)
Stroke
Spectral analysis
First dorsal interosseous (FDI) muscle

HIGHLIGHTS

- Spectral analysis of surface EMG post stroke was performed in FDI muscles.
- Subjects showed reduced mean frequency in paretic side at matched forces.
- Spectral difference between two sides was not correlated to clinical scales.

ABSTRACT

Objective: The objective of this study was to help assess complex neural and muscular changes induced by stroke using power spectral analysis of surface electromyogram (EMG) signals.
Methods: Fourteen stroke subjects participated in the study. They were instructed to perform isometric voluntary contractions by abducting the index finger. Surface EMG signals were collected from the paretic and contralateral first dorsal interosseous (FDI) muscles with forces ranging from 30% to 70% maximum voluntary contraction (MVC) of the paretic muscle. Power spectral analysis was performed to characterize features of the surface EMG in paretic and contralateral muscles at matched forces. A Linear Mixed Model was applied to identify the spectral changes in the hemiparetic muscle and to examine the relation between spectral parameters and contraction levels. Regression analysis was performed to examine the correlations between spectral characteristics and clinical features.
Results: Differences in power spectrum distribution patterns were observed in paretic muscles when compared with their contralateral pairs. Nine subjects showed increased mean power frequency (MPF) in the contralateral side (>15 Hz). No evident spectrum difference was observed in 3 subjects. Only 2 subjects had higher MPF in the paretic muscle than the contralateral muscle. Pooling all subjects' data, there was a significant reduction of MPF in the paretic muscle compared with the contralateral muscle (paretic: 168.7 ± 7.6 Hz, contralateral: 186.1 ± 8.7 Hz, mean ± standard error, $F = 36.56$, $p < 0.001$). Examination of force factor on the surface EMG power spectrum did not confirm a significant correlation between the MPF and contraction force in either hand ($F = 0.7$, $p > 0.5$). There was no correlation between spectrum difference and Fugl–Meyer or Chedoke scores, or ratio of paretic and contralateral MVC ($p > 0.2$).
Conclusions: There appears to be complex muscular and neural processes at work post stroke that may impact the surface EMG power spectrum. The majority of the tested stroke subjects had lower MPF in the paretic muscle than in the contralateral muscle at matched isometric contraction force. The reduced MPF of paretic muscles can be attributed to different factors such as increased motor unit synchronization, impairments in motor unit control properties, loss of large motor units, and atrophy of muscle fibers.
Significance: Surface EMG power spectral analysis can serve as a useful tool to indicate complex neural and muscular changes after stroke.

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http://dx.doi.org/10.1016/j.clinph.2013.09.044

1. Introduction

Spectral analysis of electromyogram (EMG) signals has been used for decades to reveal pathophysiology of neuromuscular impairment (Dimitrov et al., 2008; Farina et al., 2004; Kaplanis et al., 2009; Lindstrom and Magnusson, 1977; Muro et al., 1982). Changes in spectral frequency of surface EMG are associated with peripheral factors, such as muscle fiber conduction velocity, muscle fiber length and orientation, motor unit location, intracellular action potential shape and its negative after-potentials (Dimitrov et al., 2008; Farina et al., 2004; Lindstrom et al., 1970; Lowery et al., 2000; Zaman et al., 2011). Modifications of the spectral characteristics are also related to synchronization of multiple motor units (mainly associated with central nervous system) or motor unit recruitment and firing rate changes (associated with both central nerve system and motor unit properties) (Gabriel and Kamen, 2009; Lago and Jones, 1977; Solomonow et al., 1990; Wakeling, 2009; Yao et al., 2000). Other non-physiological factors such as temperature, thickness of the subcutaneous layers, electrode position and configuration, etc. may also influence the EMG spectral distribution (Moritani and Muro, 1987; Petrofsky and Lind, 1980; Zipp, 1978).

Subsequent to a cerebral lesion, progressive peripheral changes in hemiparetic muscles have been reported during the course of the disease involving loss of muscle fibers, changes of motor unit type composition, loss of functioning motor units, or structural reorganization of survival motor units (Brown and Snow, 1990; Charcot, 1893; Dattola et al., 1993; Hara et al., 2004; Spaans and Wilts, 1982). Meanwhile, disorganization of motor unit control properties have been observed in the hemiparetic muscles described as compressed motor unit recruitment range, abnormally low motor unit discharge rate (Gemperline et al., 1995; Rosenfalck and Andreassen, 1980), as well as increased intensity of motor unit synchronization (Farmer et al., 1993). Presently, there are few studies documenting the impact of post stroke neuromuscular modifications on the spectral characteristics of the surface EMG. In one study an increase of power density in the lower spectral frequency section was observed in one subject's paretic biceps brachii muscle whereas no significant spectrum difference was found between paretic and contralateral muscles in the remaining five subjects (Gemperline et al., 1995). The spectral analysis was also used to characterize individual motor unit action potentials (MUAPs) which demonstrated lower mean power frequency in the paretic side compared with the contralateral side (Kallenberg and Hermens, 2009). However, there was no significant difference of the mean power frequency in the global surface EMG analysis between two sides in the same group of subjects.

Another question that has not been intensively explored in stroke is the relation between the EMG power spectrum and the contraction force. Previous investigations of such relation in healthy subjects have provided contradictory observations (Farina et al., 2002; Kaplanis et al., 2009; Rainoldi et al., 1999; Seki et al., 1991). For example, it was reported that the mean power frequency (MPF) or median frequency (MF) values of surface EMG continuously increase with isometric force up to 80% maximal voluntary contraction (MVC) (Kaplanis et al., 2009; Moritani and Muro, 1987). Conversely, decreased spectrum frequency was also observed with the increment of contraction levels (Gabriel and Kamen, 2009; Rainoldi et al., 1999). In stoke there was only one study investigating the relation of surface EMG spectrum and force, which reported a reduction of median frequency in the hemiparetic muscles and a slight increase of median frequency in the contralateral side along force (Kallenberg and Hermens, 2009).

In light of the few and inconsistent observations on post stroke power spectral changes of surface EMG, the objective of the current study was to evaluate the spectral characteristics of the surface EMG in stroke survivors. Particularly, we compared power spectrum patterns of surface EMG between paretic and contralateral muscles during sustained voluntary contractions. We further examined the association between surface EMG spectral characteristics and isometric muscle contraction levels.

2. Methods

2.1. Subjects

Fourteen chronic stroke survivors (6 females and 8 males, aged 45–70 years old) with mild to severe weakness in the contralesional side participated in the study. All subjects were screened by a physician based on clinical history and physical examination. Subjects with concurrent neurological disorders or other symptoms (such as neuropathy, radiculopathy, cervical spondylosis, and hyperglycemia, etc.) were excluded. No subjects reported any arm pain, numbness or paresthesia. The disease duration since the onset of the stroke ranged from 1 year 6 months to 24 years. All subjects submitted written consent approved by the Institutional Review Board of Northwestern University (Chicago, IL, USA) before experiments. Their motor function was evaluated based on the Fugl-Meyer test and the Chedoke-McMaster test. Maximal voluntary contraction (MVC) force was additionally measured from the first dorsal interosseous muscles of the paretic and contralateral hands, respectively. The MVC ratio between paretic MVC and contralateral MVC was used as an index of relative weakness (Gemperline et al., 1995). A summary of subjects' information is presented in Table 1.

2.2. Experiments

Subjects were seated comfortably in a mobile Biodex chair. Their forearm and wrist were casted and positioned on a plastic platform, where the wrist was fastened inside a ring-mount interface. This setup kept the wrist in a pronated position and minimized its movement (Fig. 1a). The index finger was immobilized in a fiberglass cast and placed inside a small ring interface that was attached to a six degree-of-freedom load cell (ATI, Apex, NC). The position of the index finger was aligned with the center of the load cell.

Surface EMG signals were recorded from a four-channel sensor array (Delsys, Boston, MA) dwelling on top of the first dorsal interosseous (FDI) muscle. The configuration of the sensor is illustrated in Fig. 1b, as five pin electrodes in a square, one in each corner and the fifth in the center. The inter-electrode distance between two neighboring corner electrodes is 5 mm. Each pin electrode is 0.5 mm in diameter. Details of the sensor can be found in (De Luca and Hostage, 2010). Since it was difficult to align all the four bipolar recording pairs of pins (i.e. the center pin with respect to each of the four corner pins) with the muscle fiber orientation, placement of the sensory array was arranged in a way that three electrode-pins (two diagonal pins and the center pin) were in parallel with the orientation of the muscle fibers. This assures the same alignment of the electrode with respect to the FDI muscle. The output differential signals were filtered with a bandpass filter of 20–2000 Hz. Voluntary contraction force exerted by the index finger was measured in abduction (Fx), flexion (Fy), and the anterior–posterior direction (Fz) in the sagittal plane. All forces and surface EMG signals were sampled at 20,000 Hz using EMG-Works® (Delsys, Boston, MA).