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Surface electromyography based method for computing muscle strength and fatigue of biceps brachii muscle and its clinical implementation

Chetan D. Kuthe[a,*], Rashmi V. Uddanwadiker[b], Alankar A. Ramteke[c]

[a] Maharashtra Institute of Technology, Aurangabad, India
[b] VNIT, Nagpur, India
[c] Joint Reconstruction & Replacement Surgeon, Nagpur, India

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ABSTRACT

Introduction: The main objective of the present study is to compute muscle strength in terms of muscle force and fatigue for biceps brachii, using trained and untrained subjects in static contraction (isometric contraction).
Methods: There are two groups of 14 subjects each as trained subjects and untrained subjects. An isometric contraction is performed by two groups at three submaximal contraction levels L1 (50% MVC), L2 (75% MVC) and L3 (100% MVC) for 60 s each or until task failure, whichever comes first. The study compared the strength of the two groups based on maximal isometric muscle force and state of muscle fatigue using the slope of median frequency (MDF).
Results: It was found that there was an 18.39% increase in the biceps brachii muscle strength for trained subjects as compared with untrained ($P < 0.05$), and the difference in the value of MDF between trained and untrained subjects was 1.36% at L1, 3.48% at L2 and 6.17% at L3. The untrained group showed a more negative slope (-0.2470) as compared to the trained group (-0.2155).
Clinical implementation: The proposed method is clinically validated on total knee replaced patients with their consent.
Conclusions: The method is used to monitor the muscle strength and for prognosis of muscle fatigue in isometric contraction.

1. Introduction

Current physiological monitoring with wireless transmission system can be applied to many bio-medical applications [1], such as healthcare monitoring using portable medical devices [2]. Surface EMG (S-EMG) is an important non-invasive measurement for monitoring muscle fatigue among the physiological measurement systems. Yu et al. developed a wireless medical sensor measurement system, inclusive of electromyography (EMG), motion detection, and muscle strength, to detect fatigue in multiple sclerosis patients [3]. There are many applications based upon S-EMG, such as exercise analysis, fitness monitoring [4,5], and upper limb prosthesis control [6]. Therefore, there are several applications of EMG-driven muscle models for determining muscle forces in the ankle, knee, back, and upper limb, for normal and pathological conditions [7,8]. Detection of muscle fatigue is one of the important issues among the applications of EMG. There are several studies discussing muscle fatigue detection by surface EMG (S-EMG) amplitude and frequency [9,10]. Insufficient blood oxygen and nutrition gives rise to a complicated phenomenon of muscle fatigue in the human body. There are three types of fatigue: (1) central fatigue, (2) fatigue of the neuromuscular junction, and (3) peripheral muscle fatigue [11]. Peripheral muscle fatigue is of interest in human-computer interaction (HCI), ergonomics, occupational therapy and sport science. There are three types of controlled muscle contractions, pp. (1) isometric (constant position or no change in muscle length) (2) isotonic (constant force or shortening/lengthening of muscles) and (3) isokinetic (constant velocity of contraction). Isometric contraction is a contraction in which there is no change in muscle length (e.g. the subject is asked to hold a dumbbell in a static position). Time dependent muscle fatigue can be continuously monitored by S-EMG, using parameters such as muscle force and work done by the muscle during its isometric and isotonic contraction. S-EMG can be used as a kinesiological tool to examine muscle function during specific tasks. It is used to assess muscle strength, muscle fatigue, and type of muscle contraction [12]. To analyze fatigue conditions, various methods are in practice, such as isometric strength tests, exercise endurance tests, muscle biopsy, and muscle imaging. Analysis of surface electromyography (sEMG) signals is another widely used technique to assess and characterize muscle

* Corresponding author.
E-mail address: 786chetankuthe@gmail.com (C.D. Kuthe).

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fatigue [13].

The analysis of EMG signals can be generally divided into three main issues, i.e., muscle force, muscle geometry, and muscle fatigue [14]. The mean absolute value, root mean square, and zero crossing per second are commonly used time domain based features of the surface EMG [14]. Time-domain features are frequently used as a muscle force detection tool, whereas detection of muscle fatigue using these features was ineffective [14]. Whereas, frequency based EMG feature analysis for the muscle fatigue detection was found to be effective [14]. Several spectral S-EMG analysis methods can be used to reveal changes in electrophysiological characteristics of muscle and, therefore, its validity to assess muscle fatigue [15]. Two mostly used features of power spectrum analysis of the EMG are the median frequency (MDF) and mean frequency (MNF). However, a usage of MDF and MNF in determining muscle force illustrates contradictory findings [14]. Existing studies [14,16,17] have shown a continuous increase of MDF and MNF as levels of muscle force increase. In contrast, MDF and MNF decrease with increasing force levels in a number of studies [14]. Moreover, the values of MDF and MNF are unaffected by change in muscle force (independent of the contraction levels) [14].

Myoelectric manifestations of muscle fatigue can be considered as investigational tools, at least in isometric fatiguing contractions, and are of considerable interest in Occupational Medicine [18]. EMG power spectral analysis during sustained quadriceps muscle isometric contraction is an important technique [19]. With regard to the relevance of the parameters of the EMG power spectral analysis, previous studies have suggested that the MF slope during fatigue reflects the changes in action potential propagation of individual muscle fibers, which is the result of the associated accumulation of metabolic byproducts (lactate and extracellular $K+$) [19]. Very few time–frequency based features, namely, instantaneous mean frequency, instantaneous median frequency, and instantaneous spectral moment, have been reported to track the instantaneous changes of spectral components of SEMG signals [20].

Gonzalez identified several EMG power spectral parameters during dynamic muscle contractions [21]. When muscle fatigue occurs during muscle contraction, the MNF and MDF usually shift to lower frequencies; which indicates that muscle fatigue begins at that stage of contraction. Thus the muscle fatigue estimation is one of the important applications of S-EMG measurement, along with the need for exercise and rehabilitation programs. Moreover, it is still unclear which parameter of the power spectrum could depict fatigue more effectively [22]. Thus, the present study aimed to find the most suitable parameter to depict muscle fatigue more effectively.

The main problem with wireless S-EMG systems is that a high transmission rate required. In general, the required sample frequency for measuring S-EMG is above 1 kHz [15,21,23]. If MDF is used to evaluate muscle fatigue, the sampling frequency must be 1 kHz. In this study, muscle performance is recorded using a wireless S-EMG recording system with a 1 kHz sample rate for fatigue estimation.

The strength enhancement that comes from lengthening a contracting muscle prior to using it to produce motion is visible in countless activities, particularly in sports [24,25]. A valid clinical assessment of strength requires that the joint position at which strength is assessed be maintained for each subsequent test [26]. The clinician must consider the effects of joint position on muscle output when measuring strength, and also when designing intervention strategies to improve muscle movement. There are various subjective tests to assess muscle strength (e.g. manual muscle testing, isometric break test). Since these are subjective tests, they can show inter-tester variability. Estimation of individual muscle force remains one of the main challenges in biomechanics [27]. There is very little research that has been carried out on the implementation of detecting/predicting fatigue using an autonomous system [28].

Thus, the present study aimed to quantify muscle strength on the basis of force generated by the muscle during isometric contraction and the muscle fatigue. Also, the study aimed to validate the methodology presented based upon clinical trials.

2. Method

2.1. Subjects

Twenty eight men (18–25yr, 18.5–22.5 kg/m^2) volunteered to participate in the study after having been informed of the experimental procedures and possible risks, and signed an informed consent form. All subjects were physically active and had no history of upper limb injuries. They (control subjects) were divided into two groups as trained subjects and untrained with 14 subjects in each group. The trained subject group was inclusive of those men who were involved in a daily structured training programme. The untrained subject group was a group of active men who were not involved in any training programme. The study protocol was approved by the Central India Medical Research Ethics Committee of India.

2.2. Experimental protocol

All subjects were familiarized with the experimental set up used for measurement of MVC and type of muscle contractions prior to conducting the test. The strength and fatigue protocol for this study consisted of submaximal contractions such as 50% MVC (L1), 75% MVC (L2) and 100% MVC (L3) for 60-s or failure of task, whichever is early. Muscle contractions of biceps brachii are based on each subject's MVC. Each subject completed a warm-up of 8–10 full range elbow movements using the experimental set-up shown in Fig. 1, followed by a 10 min rest before starting the protocol.

2.3. MVC test

This test comprised the subjects performing three MVC's, each 3–4 s in duration, separated by 10-min rest intervals. The mean of the two highest values was taken as 100% force generation during MVC (no more than 5% variation between the two highest MVC's was tolerated). This value was used to compute the subject specific L1, L2 and L3.

2.4. Strength and fatiguing task

The strength and fatigue of the subjects were tested at 50% MVC, 75% MVC and 100% MVC specific to subject. Subjects were given a 10 min rest period before engaging in the fatigue and strength protocol.

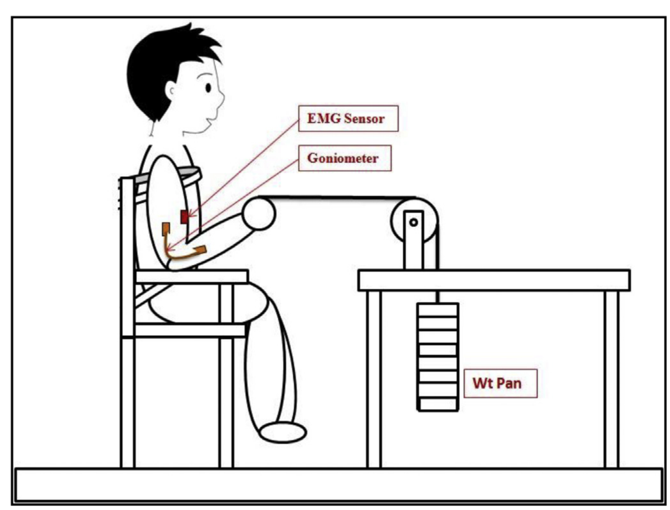

Fig. 1. Experimental set up for the measurement of isometric contraction from biceps brachii muscle.