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A simulation model of the surface EMG signal for analysis of muscle activity during the gait cycle

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Abstract

This work describes a model able to synthetize the surface EMG (electromyography) signal acquired from tibialis anterior and gastrocnemious medialis muscles during walking of asymptomatic adult subjects. The model assumes a muscle structure where the volume conductor is represented by multiple layers of anisotropic media. This model originates from analysis of the single fiber action potential characterized by the conduction velocity. The surface EMG of voluntary contraction is calculated by gathering motor unit action potentials estimated by the summation of all activities of muscle fibers assumed to have a uniformly parallel distribution. The parameters related to the gait cycle, such as onset and cessation timings of muscle activation, amplitude of muscle contraction, periods and sequences of motor units' recruitment, are included in the model presented. In addition, the relative positions of the electrodes during gait can also be specified in order to adapt the simulation to the different acquisition settings.

Keywords: Simulation model; Surface EMG; Motor unit action potential; Motor unit recruitment; Gait cycle

1. Introduction

The surface EMG (electromyography) signal represents the characteristics of muscle function and provides information about muscle activities. The analysis of this signal provides diagnostic information and can be used as an aid for choosing the most appropriate methods of treatment for muscle dysfunction.

New methods or algorithms for the analysis of muscle activity need to be assessed by comparing actual and known values of parameters with the values obtained using the new methods. Therefore, a simulation

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model of surface EMG during the gait cycle is a valuable aid in order to assess novel techniques. This is the problem addressed in this work.

A wide range of models has been presented over recent decades by many research groups [1–13]. Some of the models aimed to simulate the single fiber action potential [1], or voluntary and elicited muscle contractions [2–4]. The characteristics of the surface EMG signal detected by the electrodes depend on anatomical, physiological and experimental system parameters. Other simulation models [5–7] are used to test the influence of various parameters on the surface EMG signals, such as the effect of an anisotropic homogeneous medium, the interpretation of the influence of internal bone [8], and illustration of the effect of the detection system [9] such as the influence of the electrode shape and size [10,11].

Despite the large number of publications on the subject of surface EMG simulation, only few researchers have attempted to explore the relationship between the surface EMG and the phases of the gait cycle, and to model the surface EMG signal based upon those different phases. In this paper, we describe a novel method to produce a model of the surface EMG signal during the gait cycle, which covers the characteristics of the surface EMG, such as the fiber distribution, motor unit type, location and recruitment, tissue anisotropy, electrode configuration and phases of the gait cycle.

2. Simulation model

2.1. Physiological basis of the model

The muscles are composed of many muscle fibers, which are united into functional units called motor units. The motor unit is the basic level of nervous system of the muscle. The motor unit has many branches and innervates a great deal of muscle fibers. Various lengths and diameters of the branching nerve fibers that spread to each muscle fiber cause the time that the nerve action potentials arrive at the endplate to vary. As a result, the activations of muscle fibers within a given motor unit are asynchronous. Gathering the different temporal muscle fiber action potentials comes into being motor unit action potential. Motor unit recruitment territories are imagined as small, overlapping circles on a cross-section of muscle. When a muscle is activated, motor unit recruitment abides by the size principle. The smaller motor units are recruited at the beginning of the muscle contraction occurrence, and subsequently, the larger motor units are activated, which play an important role in increasing the surface EMG signals. In general, the range of firing rate of human muscle fibers is between 8 and 50 Hz [14]. Accompanying the increase of muscle contraction, the firing rate of motor units changes from the lower to the higher value. Both the additional motor unit recruitment and the increase in firing rate result in stronger surface EMG signals.

The gait cycle is a main parameter of this simulation model. When the body attempts to move forward, one limb performs the support function while the other one moves itself to the new support site. Then, the two limbs exchange their roles. Walking is composed of a repetitious sequence of limb functions both moving the body forward and maintaining body stability. A single sequence of these functions accomplished by one limb is defined as the gait cycle [15]. There is no specific onset or cessation point in a gait cycle. In our model, the initial floor contact with heel is selected as the onset of the gait cycle because the moment of initial contact is easier to identify than other events. In other words, a complete gait cycle begins when the heel of one foot contacts the ground and ends when it contacts the ground again. Each gait cycle is made up of two periods, stance phase and swing phase. Stance phase describes the period during which the foot is on the ground. Correspondingly, the swing phase presents the period