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Intra- and interday reliability of voluntary and electrically stimulated isometric contractions of the quadriceps femoris

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ABSTRACT

The reliability of voluntary and electrically stimulated isometric contractions of *m. quadriceps femoris* of male participants ($n = 10$; age 30 ± 8 years; height 1.79 ± 0.05 m; body mass 79.4 ± 8.3 kg) was investigated using ratio limits of agreement (LoA) on a time scale common to examine recovery from muscle damaging exercise. No systematic changes in reliability occurred over time (baseline versus 2, 24, 48, and 72 h). Maximal voluntary contraction (MVC) and interpolated twitch technique (ITT) showed no mean bias ($P > 0.05$) with 95% LoA of ±12.7 and ±5.4, respectively. Resting twitch and potentiated doublet peak force showed no mean bias ($P > 0.05$). However, 95% LoA were smaller for the doublet (±13.9) than the twitch (±32.0). Twitch and doublet rates showed similar trends. Ratio of low (20 Hz) to high (50 Hz) frequency forces showed no mean bias ($P > 0.05$) and 95% LoA of (±9.2). However, there was significant mean bias ($P < 0.05$) and wider 95% LoA for peak force, contraction and relaxation parameters of the low and high frequency forces. In conclusion, MVC, ITT, potentiated doublet and the ratio of low to high frequency forces are recommended to most reliably examine functional muscle recovery between 2 and 72 h after damaging exercise.

1. Introduction

Prolonged or strenuous exercise results in functional impairments of skeletal muscle due to fatigue and/or damage (Appell et al., 1992; Millet and Lepers, 2004). Functional impairments are preferred evidence to quantify muscle damage rather than soreness or blood myofibril proteins (Warren et al., 1999). In addition, the immediate neuromuscular (Byrne et al., 2004) and metabolic (Tee et al., 2007) consequences of muscle fatigue/damage can have such a prolonged effect on physical performance (Warren et al., 2002), that it is common to measure the recovery of muscle force in the following hours or days (Bentley et al., 2000; Martin et al., 2004; Skof and Strojnik, 2006). It is therefore essential that the reliability of the measurements taken during the recovery period is known.

The *m. quadriceps femoris* experiences high levels of neuromuscular impairment following prolonged exercise and the properties of voluntary and involuntary contractions have been extensively studied (e.g. Bentley et al., 2000; Millet and Lepers, 2004; Skof and Strojnik, 2006). Understanding the reliability of these measurements is important in informing the most appropriate methods to quantify the recovery of muscle function following exercise. Mmaximal voluntary isometric contractions of the *m. quadriceps femoris* have been used to provide information on the muscles maximal force producing capability (Millet and Lepers, 2004). Furthermore, contractile muscle properties and contribution of peripheral and central mechanisms to decrements in performance can be measured through electrical muscle stimulation (Allen, 2001; Merton, 1954), by skin surface electrodes or direct nerve stimulation (Paillard et al., 2005). The most common electrical stimulation procedure is a single twitch applied to the resting muscle (Edwards et al., 1977). This allows calculation of contractile properties of the muscle such as peak force, contraction time, average rate of force development, half relaxation time, maximal rate of force development and maximal rate of force decrease (Millet et al., 2003b; Place et al., 2004). Such parameters provide information on the excitation–contraction coupling process, independent of central factors. It is essential to obtain reliable measurements of these parameters as the excitation–contraction coupling process can account for 75% of strength loss following muscle damaging exercise (Warren et al., 2002). Muscle damage is also associated with low frequency fatigue (LFF) (Jones, 1996); the observation of large force losses at low (e.g. 20 Hz) compared to high (e.g. 50 Hz) stimulation frequencies (which is normally expressed as a ratio e.g. 20/50 Hz) indicates a reduction in release of Ca^{2+} from the sarcoplasmic reticulum (Chin et al., 1997), an effect that can last for days after an initial exercise bout (Edwards et al., 1977; Westerblad et al., 1993). Another

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common measurement used in the literature is the interpolated twitch technique (ITT) to examine the central or peripheral origin of fatigue (Merton, 1954). However, more recently, Oskouei et al. (2003) recommended the use of an interpolated doublet as it was effected less by posttetanic potentiation than a single twitch.

A previously published study has examined the inter-day reliability (3–5 days between test sessions) of twitches and doublets at rest and after exhaustive isometric contraction of the *m. quadriceps femoris* (Place et al., 2007). However, changes in muscle function following damaging exercise can last for several days (Warren et al., 1999). Morton et al. (2005) studied the reliability of the force produced during isometric maximal voluntary contractions, twitches and the ITT of the *m. quadriceps femoris* over a time frame normally used to measure recovery from muscle damaging exercise. However, the reliability of other twitch characteristics and multiple stimulations which have been widely used in other previously published studies were not investigated. Morton et al. (2005) also "strongly recommended that each individual laboratory conduct a similar temporal and statistical evaluation of reliability estimates that is specific to the particular population under consideration". A study on the reliability of a large battery of functional tests including resting twitch, interpolated and potentiated doublet, low and high frequency force has not been examined for a timescale that is common after damaging exercise.

Therefore, the aim of this study was to examine the intra and inter day reliability of voluntary and electrically stimulated isometric contractions of the *m. quadriceps femoris*. An analysis of the intra and interday reliability of voluntary and electrically stimulated isometric contractions will inform the choice of functional parameters to examine recovery over days, as is common following damaging exercise.

2. Methods

2.1. Participants

Ten healthy male participants (mean ± SD, age 30 ± 8 years; height 1.79 ± 0.05 m; body mass 79.4 ± 8.3 kg) volunteered to participate in this study. Ethical approval was provided by the institutional ethics committee and written informed consent was obtained prior to commencing the study. Participants abstained from vigorous and unaccustomed physical activity 24 h before the start and during the study. Before baseline testing, participants were questioned to ensure they were adequately rested and free from muscle injury and completed a muscle soreness questionnaire. The questionnaire divided the body into 12 segments (Corlett and Bishop, 1976) with the perception of muscle soreness in each segment rated on a visual analogue scale from 0 (no soreness) to 10 (unbelievable soreness). All participants reported a rating of 0 (no soreness) for all segments before each testing session. All of the testing was conducted by the same experimenter.

2.2. Familiarisation

At least five days prior to beginning the experimental protocol, participants completed three MVCs and experienced all electrical stimulation procedures (described in detail below). The current to produce a maximal twitch (i.e. increases in current that caused no further increase in force of the twitch) (group mean ± SD; 830 ± 54 mA) and sub-maximal twitch (5% MVC force) (group mean ± SD; 433 ± 65 mA) were recorded and maintained constant in all test sessions.

2.3. Experimental protocol

Participants completed the muscle testing protocol described below at 0 (baseline), 2, 24, 48 and 72 h. Test order was the same on each occasion (Fig. 1). For all tests, participants were secured in a custom built chair for testing the *m. quadriceps femoris* with hip and knee at 90°. Velcro straps were placed around the chest and waist to restrict movement of the upper body and hips. A cuff was attached to the ankle (proximal to the fibular notch and medial malleolus) and an s-beam load cell (RS 250 kg, Tedea Huntleigh, Cardiff, UK) via a steel chain at the base of the chair. The force produced from the *m. quadriceps femoris* was recorded at 1000 Hz (Chart 4 V4.1.2, AD Instruments, Oxford, UK). Two custom made saline soaked electrodes (9 × 18 cm) were placed just above the patella and over the muscle belly of the *m. quadriceps femoris* in the proximal part of the thigh of the non-dominant leg. The electrodes position was marked to ensure the same placement on subsequent tests. Electrically evoked stimulations were provided through an electrical muscle stimulator (Model DS7A, Digitimer Limited, Welwyn Garden City, UK) and multiple pulses were controlled by a NeuroLog pulse generator (Digitimer Limited, Welwyn Garden City, UK). Participants conducted three 5 s sub-maximal contractions (~200 N) to become accustomed to the experimental setup before completing the test battery described below (Fig. 1).

2.4. Maximal voluntary contraction (MVC)

Participants produced a 3–5 s MVC with strong verbal encouragement. If the experimenter or participant deemed that the effort was not maximal the procedure was repeated following 2 min rest (90% of performed MVCs were maximal on the first attempt). The single absolute highest force and the highest mean force over 0.25 and 0.50 s divisions were recorded. A typical example of the force during a MVC is illustrated in Fig. 2A.

2.5. Electrically evoked twitch

Participants were instructed to exert a small amount of tension (⩽3 N) on the connecting chain. A single 50 µs pulse of 100 mA, limited to a maximum of 400 V was applied to the *m. quadriceps femoris*. Current was then increased to the pre-determined maximal twitch current. The following parameters were measured: (a) peak force (N); (b) contraction time (s), time between the first derivation from baseline and peak force; (c) average rate of force development (N s^{-1}), peak force/contraction time; (d) half relaxation time (s), time taken to fall from peak force to half of the value during the relaxation phase; (e) maximal rate of force development (N s^{-1}), highest value of the first derivative of the force signal; and (f) maximal rate of force decrease (N s^{-1}), lowest value of the first derivative of the force signal. A resting twitch was used as the peak force is more reliable than a potentiated twitch over a similar

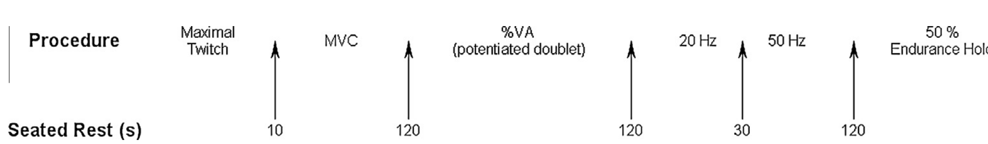

Fig. 1. Test order of isometric contractions of the *m. quadriceps femoris* by voluntary activation and electrical stimulation. Tests were conducted in a custom-built chair (hip and knee angle 90°), in the same order at baseline, 2, 24, 48 and 72 h.