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Determining minimal stimulus intensity for mechanomyographic analysis

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ABSTRACT

Introduction: Mechanomyography (MMG) has recently shown promise in monitoring recovery of injured muscles. However, delivering a maximal percutaneous neuromuscular stimulus (PNS) could potentially be painful on severely damaged muscles. The aim of this paper was to determine whether delivering a sub-maximal PNS could still obtain accurate MMG recordings of muscle contraction time (Tc). The effect of muscle architecture on determining the minimal level of current was also investigated. *Methods:* Six muscles were investigated; 5 lower limb and the 1st dorsal interosseous. A 'current ramp' procedure was performed to determine minimal stimulus intensity required for accurate Tc recordings. A current ramp entails beginning at a low current (30 mA) and increasing in increments of 10 mA until a maximal muscle contraction is observed. *Results:* For lower limb muscles, 130 mA was the largest current required to obtain accurate Tc recordings in at least 95% of the population. This was up to a 50% reduction in the amount of current delivered for some muscles. Fibre type distribution showed the greatest relationship with mean minimum current. *Discussion:* Future studies investigating injured or uninjured muscles via MMG, could use these submaximal currents to obtain accurate MMG recordings, whilst improving patient comfort and reducing experiment duration.

1. Introduction

Serious muscle injuries occur frequently throughout life, particularly in sporting and workplace environments, leading to often extended periods of time away from normal daily activity. Treatment of muscle strains typically involves a two stage process; firstly the RICE protocol: Rest, Ice, Compression and Elevation, and secondly interventions to improve range of motion and muscle strength through stretching and strength improving exercises (Järvinen et al., 2007). It has been reported that a full range of motion and a cut-off of around 80% of total muscle strength of the contralateral side is recommended for a return to normal training/activity; however there are no specific criteria for resuming normal training/activity with zero risk for recurrence of injury (Orchard et al., 2005).

Mechanomyography (MMG) is the recording of the mechanical signals, such as a muscle's contraction time (Tc), produced by muscles in response to either voluntary or electrically stimulated muscle contractions (Orizio, 1993; Dahmane et al., 2001, 2005). MMG has been utilised in a variety of applications, including determining muscle fibre type populations (Dahmane et al., 2001, 2005), prosthesis control (Barry et al., 1986), identifying muscle atrophy (Pisot et al., 2008), as well as aiding in the diagnosis of neuromuscular disorders (Ng et al., 2006).

More recently, MMG has been investigated to determine whether it can be reliably utilised in monitoring the recovery of injured muscles (McAndrew et al., 2005). In a study by Hunter et al. (2012), the authors employed an eccentric fatiguing protocol on the forearm flexor muscles, in a group of volunteers, in order to induce a delayed onset of muscle soreness (DOMS). Inducing muscle contractions through the delivery of percutaneous neuromuscular stimulations (PNS) to monitor contraction dynamics daily, the authors showed changes in contraction dynamics between non-injured and injured muscle states and between the onset of injury to complete recovery. From these results it was concluded that the MMG technique could be utilised to non-invasively quantifying muscle injury through analysing the contractile properties of recovering muscles.

Abbreviations: AM, adductor magnus; ASIS, anterior superior iliac spine; BF, biceps femoris; DI, 1st dorsal interosseous; Dmax, maximal muscle displacement; MMG, Mechanomyography; PNS, percutaneous neuromuscular stimulation; RF, rectus femoris; S, sartorius; Tc, contraction time; Tc_{final}, final contraction time; Tc_{min}, contraction time at minimum current; VM, vastus medialis.

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However due to the more severe nature of muscle strains and tears, delivering a maximal PNS in order to non-invasively record the injured muscle's mechanical properties, may be clinically contraindicated as it could elicit considerable pain or further injury. Normally, the maximal PNS is determined through a procedure called a 'current ramp'. A current ramp entails delivering a series of PNS impulses of increasing amperage (mA) whilst keeping a constant voltage and stimulus duration until a maximal muscle contraction is observed – as determined by detecting the maximal lateral displacement of the muscle's belly (Dmax). The contractile properties (Tc, Dmax, etc.) of a muscle are determined from the MMG waveforms, which may be recorded from these artificially induced maximal PNS impulses (Fig. 1).

However, exposing a patient to a maximal PNS stimulation maybe painful and lead to the possibility of further injury and thus, if the MMG technique is to have widespread clinical application, a sub-maximal PNS impulse needs to be employed. This study determines whether sub-maximal PNS impulses can provide an accurate indication of a muscle's contractile properties. If successful, not only would the outcome be more comfortable for the participants, but also less time consuming for the Clinician as a lengthy current ramp would not be required.

2. Materials and methods

2.1. Subjects

Ethical clearance for this study was obtained from the University of Queensland Medical Research Ethics Committee, and informed consent was obtained from each participant. MMG was recorded in both males and females, aged 18–25 years with no previous history of muscle strains or neuromuscular disorders. Six muscles were selected for analysis; the rectus femoris (RF, $N = 15$), biceps femoris (BF, $N = 40$), vastus medialis (VM, $N = 20$), adductor magnus (AM, $N = 19$), sartorius (S, $N = 19$) and the 1st dorsal interosseous (FDI, $N = 13$). Of particular interest were the RF and BF due to their substantially higher reported rates of injury (Garett et al., 1984; Ekstrand et al., 2011).

2.2. Mechanomyographic analysis

To ensure a consistent skin resistance across electrode sites and between participants, a standardised skin preparation procedure was performed. Following hair removal from the electrode site, the skin was abraded with sandpaper cleansed with alcohol wipes. Skin resistance was set at <7 k ohms as measured using an impedance meter (Digitimer D175). Following PNS electrode placement (see Fig. 3) upper and lower limbs were secured in place with large Velcro straps (Fig. 2).

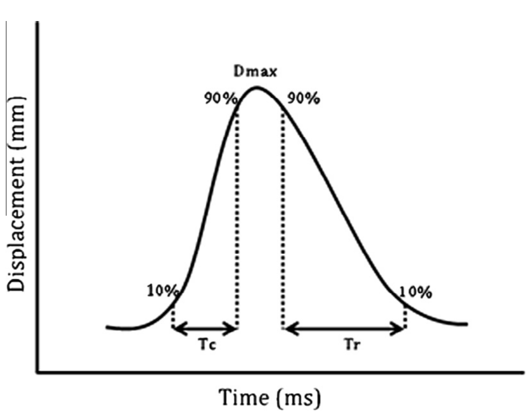

Fig. 1. MMG waveform showing contraction dynamics; Tc = contraction time, Tr = relaxation time, Dmax = maximal muscle belly displacement. Tc &Tr measured from 10% to 90% of Dmax.

The MMG laser distance sensor (Banner®, LG10A65PU) was placed 10 cm away from the skin overlaying the muscle belly, perpendicular to the direction of skin displacement following PNS. A current ramp was then performed to obtain a maximal muscle contraction for each muscle. MMG waveforms were recorded in Labchart® (AD Instruments) software and were analysed using the Peak Analysis module. A Low Pass Digital Filter (9 Hz) was applied for recording of waveforms.

2.3. PNS electrode placement

To assist in locating ideal electrode placement sites, reference was made to the 'Anatomical Guide for the Electromyographer' (Perotto, 2011):- BF: Subjects were placed face down on a padded plinth with their knees flexed at 120° (angle between lateral malleolus of fibula and greater trochanter of femur). For electrode placement, a straight line was drawn from the ischial tuberosity to the head of the fibula, with electrodes placed 5 cm either side of the mid-point on this line.

RF, S, VM: Subjects were placed sitting up on a padded plinth with knee joints in anatomical position and hips flexed at 110° (angle between head of fibula and head of humerus). For electrode placement on RF, a line was drawn from the superior border of the patella to the anterior superior iliac spine (ASIS), with one electrode placed at the midpoint on the line, and the other 10 cm further distally. For S, a straight line was drawn from the ASIS to the medial condyle of the tibia, and electrodes were placed 5 cm either side of a point on the line placed 23% distal to the ASIS. For electrode placement on VM, the same line was used as for S, however electrodes were placed 5 cm either side of a point placed at 25% proximal to the medial condyle of the tibia.

AM: Subjects were laid down on their right side and flexing their left knee so as to expose the adductor compartment of the right thigh. For electrode placement, a line was drawn from the pubic tubercle to the medial epicondyle of the femur, with one electrode placed at the mid-point on the line and the second 10 cm proximally along the line.

FDI: Subjects had their hands tightly strapped with the 1st digit abducted to create an 80° angle between the 1st and 2nd digits. For electrode position, a line was drawn perpendicular to the long axis of the hand at the level of the 1st metacarpal joint and a second line was drawn intersecting the prior just radial to the second metacarpal. Along this line, electrodes were placed 2 cm either side of the intersection.

2.4. Statistical analysis

Upon determining the current required for a maximal muscle contraction, each preceding stimulus (and level of current) throughout the current ramp procedure was analysed individually in descending order. For any level of current to be accepted as statistically accurate, their corresponding Tc value must have been within 5% of the final Tc (Tc_{final}; determined at the Dmax). The "minimum current" for a muscle was therefore determined once the Tc from a current level (as descending through the current ramp) fell out of a ±5% range of Tc_{final}. Tc values at this minimum current level termed Tc_{min}.

3. Results

The mean minimum current for each of the muscles was determined to be as follows: S = 83.5 mA, VM = 71 mA, AM = 67.37 mA,