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Phonomyography as a non-invasive continuous monitoring technique for muscle ischemia in an experimental model of acute compartment syndrome

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ABSTRACT

Background: In acute compartment syndrome (ACS), clinicians have difficulty diagnosing muscle ischemia provoked by increased intra-compartmental pressure in a timely and non-invasive manner. Phonomyography records the acoustic signal produced by muscle contraction. We hypothesize that alterations in muscle contraction caused by muscle ischemia can be detected with phonomyography, serving as a potential non-invasive technique in the detection of ACS.
Methods: The left hind limb of 15 Sprague-Dawley rats was submitted to a reversible ischemic model of limb injury for 30 min and 1, 2, 4, 6 h (3 rats in each group). The right limb served as control. Phonomyography microphones were placed over the posterior calf of both limbs and the sciatic nerve was stimulated percutaneously at 10-min intervals to evaluate muscle contraction. Histopathological analysis of muscles and nerves biopsies was performed and correlation was made between duration of injury, phonomyography output and degree of muscle and nerve necrosis.
Results: There was a statistically significant decrease in the phonomyography signal output in the ischemic limb that correlated with the duration of ischemia and histological findings of muscle and nerve necrosis. The phonomyography signal decrease and histological findings were respectively: 55.5% ($n = 15$; $p = 0.005$) with rare muscle and nerve necrosis at 30 min, 65.6% ($n = 12$; $p = 0.005$) with 5–10% muscle necrosis at 1 h, 68.4% ($n = 9$; $p = 0.015$) with 100% muscle necrosis and little nerve damage at 2 h, 72.4% ($n = 6$; $p = 0.028$) with 100% muscle necrosis and severe nerve damage at 4 h, and 92.8% ($n = 3$; $p = 0.109$) with 100% muscle necrosis and severe nerve degeneration at 6 h.
Conclusion: Changes in phonomyography signal are observed in early ischemic injury prior to the onset of nerve or muscle necrosis. Therefore, phonomyography could serve as a non-invasive technique to detect early ischemic muscle changes in acute compartment syndrome.
Clinical relevance: The detection of abnormal muscle contraction in a timely fashion and non-invasive manner is of interest in clinical settings where the presence of ischemia is not easy to diagnose.

Introduction

Acute compartment syndrome (ACS) of an extremity is an orthopedic emergency. It is a condition characterized by increased pressure in a muscle compartment, causing ischemic changes of muscles and nerves. The annual incidence of ACS is 7.3/100 000 for men and 0.7/100 000 for women [1,2]. Severe functional deficits may result from missed or undiagnosed ACS due to muscle necrosis, contracture and irreversible muscular and neuronal

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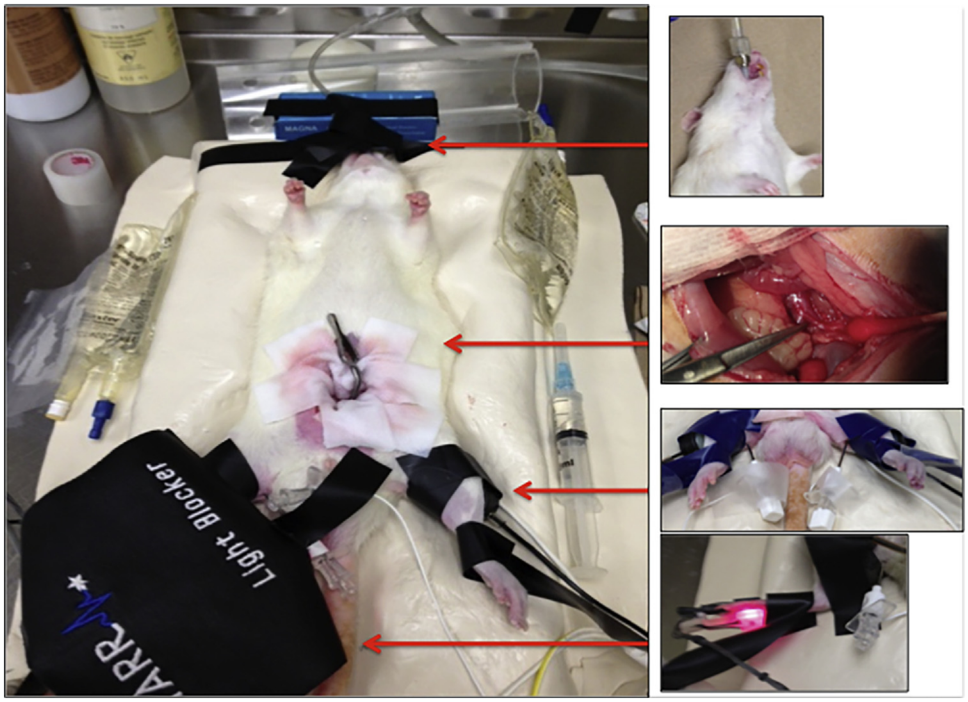

Fig. 1. Procedure Ischemic Model. Picture of anaesthetized, intubated rat, in supine position. A laparotomy provides access to the left common iliac artery for reversible clamping. A saturation probe confirms absence of perfusion in the left foot upon clamping and is then transferred to right foot to provide intraoperative cardiac monitoring. A percutaneous nerve stimulator is positioned next to the sciatic nerve in both thighs. A phonomyography microphone is taped to the calf on both sides to monitor acoustic output upon contraction.

damage, loss of limb function, or rhabdomyolysis [3–6]. Once identified, immediate surgical intervention is required to relieve the pressure by means of fasciotomy. Delayed treatment exposes to superinfection of necrotic tissue by bacterial pathogens, which can result in septicemia and amputation [7]. Missed ACS and delayed fasciotomy can result in severe morbidity and has severe medico-legal implications [8].

The American Department of Defense has adopted liberal indications for prophylactic fasciotomy in injured soldiers considered at risk, especially those requiring prolonged transportation to a level four medical facility where military patients can receive definitive treatment of their injuries [9–12]. It has been reported that 71% of military blast injuries cause severe extremity trauma, and 86% of these require fasciotomy [13,14]. However, the drive to reduce the incidence of ACS with prophylactic fasciotomy must be weighed against associated complications and subsequent limitation of surgical approach options for later definitive procedures; in addition, increased cost to health care systems and increased morbidity should be considered [9,15,16].

It would be highly desirable to develop a continuous, non-invasive method for reliable detection of ACS [17]. Acoustic myography, also known as phonomyography; was initially described by Francesco Grimaldi in 1665 [18]. It has been shown to be useful for monitoring of neuromuscular blockade in the operating room [19,20]. This method uses special microphones to detect the low-frequency sounds emitted by muscle contraction [21]. Since acute ischemia is known to rapidly impair muscle contraction and since phonomyography can be used to measure muscle contraction, it is hypothesized that phonomyography may be a reliable, non-invasive tool to continuously measure the degree of muscle ischemia in an animal model.

Materials and methods

All protocols and experiments were conducted in agreement with the McGill Animal Care Committee, following the highest standards of the Canadian Council on Animal Care.

Animals

Fifteen eight-week old male Sprague-Dawley rats (Charles River Laboratories, Sherbrooke, QC) weighting 350–400 g (at the beginning of the study) were permitted 2 weeks of acclimation prior to the experiments, with food and water ad libitum. The rats were housed in an animal room under controlled conditions (temperature 22–24 °C, humidity 55–60%, 12-h light/12-h dark cycle). All experiments were performed in accordance with our institutional guidelines for animal care and use. The rats were

Table 1
Histopathology grading of muscle and nerve ischemia.

Muscle ischemia	Nerve ischemia
The percentage of muscle damage is based on the presence of segmental degeneration, necrosis and regeneration	The grade is based on the presence of ischemic changes such as: distension and fragmentation of myelin sheaths multifocal, axonal swelling and/degeneration
N: normal (No ischemic changes present)	N: normal (<2%)
1–100%	Grade 1: modest/rare (3–25%)
	Grade 2: mild/infrequent (26–50%)
	Grade 3: moderate/frequent (51–75%)
	Grade 4: severe/extensive (>75%)