The effects of limb elevation and increased intramuscular pressure on nerve and muscle function in the human leg

Abstract In this study we investigated the effects of increased intramuscular pressure (IMP) on nerve and muscle function in the leg and foot. In study A, muscle pressure was increased by inducing venous stasis in both legs, placed in plaster casts, of eight healthy subjects having a mean age of 29 years. The results from elevated and non-elevated limbs were compared. In study B, two different models for increasing IMP were studied in nine healthy subjects having a mean age of 32 years. The results of increased IMP and decreased blood perfusion pressure on local (= leg) and distal (= foot) function of muscle and nerve induced by venous stasis of a leg in a plaster cast and by external compression of the contralateral leg were compared. Contraction pressure of the tibialis anterior muscle in the leg was recorded. A biphasic compound muscle action potential was measured from the extensor hallucis brevis and the extensor digitorum muscles as an indication of foot muscle function. Muscle contraction pressure was 87 (SD 38) mmHg in the vein-obstructed leg and 133 (SD 42) mmHg in the externally compressed leg ($P < 0.05$). In both studies the skin sensibility of the feet was significantly lower in the vein-obstructed elevated leg after 30 min ($P < 0.05$). Vein stasis in an elevated humen leg in a plaster cast defines a model for simulating imminent acute compartment syndrome with reversible neuromuscular dysfunction.

Key words Intramuscular pressure · Perfusion pressure · Simulated imminent acute compartment syndrome · Muscle contraction pressure

Introduction

In the literature, it has been recommended that fasciotomy should be performed at intramuscular pressures (IMP) varying between 30 mmHg and 60 mmHg (Ashton 1975; Matsen 1975; Whitesides et al. 1975; Heppenstall et al. 1988; Hargens et al. 1989). Few authors have included components other than IMP and clinical symptoms in influencing the decision to perform a fasciotomy. The theory presented by Ashton (1975) and Heppenstall et al. (1988) suggested that the calculation of the perfusion pressure (MAP–IMP, where MAP is mean arterial pressure), is more important than these for the evaluation of an impending acute compartment syndrome. This theory is supported in our model. The results indicated neuromuscular dysfunction if the perfusion pressure is below 35–40 mmHg.

Methods to produce models of abnormally increased IMP in humans have included external compression of all leg compartments by a cylindrical air splint (Ashton 1966; Matsen et al. 1977; Styf 1990) or external compression of one selected compartment using a plexiglas plate (Hargens et al. 1993).

Vein stasis of a leg in a plaster cast combined with limb elevation has been used by Wiger and Styf (1998) to simulate imminent acute compartment syndrome in humans. Using this model, they increased IMP and decreased local perfusion pressure. The effects of the experimental model on local (= leg) and distal (= foot) nerve and muscle function have not been studied.

The aim of this study was twofold:

1. To study the effects of limb elevation, increased IMP and decreased perfusion pressure on neuromuscular function in the leg and the foot at rest and during maximal contraction.

2. To study how neuromuscular function in the leg and foot was affected by vein stasis of a leg in a plaster cast and by external compression.
Methods

After informed consent eight healthy subjects (six men, two women) with a mean age of 29 (range 21–48) years participated in study A and nine healthy subjects (five men, four women) with a mean age of 32 (range 23–36) years participated in study B. All the subjects were active in sports and had no symptoms of any illness. The study was approved by the Research Ethics Committee of the University of Göteborg, Sweden. The ethics permission was for a tourniquet to be applied for a maximum of 30 min.

Experiment setup

In both studies the subject lay supine with no external compression on the legs from the bed. Two specially constructed leg holders were used to elevate the legs. The feet were kept in neutral position at an angle of 90° relative to the tibia. This arrangement allowed the subject to dorsiflex his/her ankle joints and the toes. The skin of the feet was available to test sensibility. The experiment included 30 min of abnormally increased IMP in both legs. All recordings were made simultaneously in both legs, before and during the experiments.

In study A, a segmental padded plaster cast was applied to both legs and a tourniquet on both thighs. The test leg was elevated and the contralateral leg was kept at heart level as has been described elsewhere (Wiger and Styf 1998). In study B, a segmental padded plaster cast was applied to one leg and a tourniquet on the ipsilateral thigh. A segmental circumferential air splint was applied to the contralateral leg. When the leg holder was elevated, the knee and hip joints were flexed to 90°, and both the catheter tip and the transducer were located between 35 and 40 cm above heart level.

Intramuscular pressure

The IMP was measured using the intermittent microcapillary infusion technique. A Myopress catheter (Myopress, Atos Medical, Hörby, Sweden) for IMP recordings was introduced bilaterally via a 1.7 mm diameter sheathed Venflon needle as has been described elsewhere (Styf and Körner 1986). The skin was anaesthetized 2 cm lateral to the tibial tuberosity using 2 ml of 1% lidocaine without adrenaline. An introducer was then inserted into the anterior tibial muscle fascia in a distal direction at an angle of 30° while the subject kept the ankle joint dorsiflexed. The tip of the needle was kept retracted within the plastic sheath of the introducer, and the set was bluntly advanced parallel to the fibres of the relaxed muscle. The needle was then withdrawn, and the Myopress catheter was inserted 4.5 cm into the plastic sheath and was located at a depth of 2.5 cm in the central part of muscle (Styf and Körner 1986). The plastic sheath of the introducer was then removed. The catheter had four side holes at its tip to increase the area of contact with the tissue. The infusion rate was set at 1 ml·h⁻¹ at a pressure of 100 mmHg above that of the microcapillary pressure. The function of the catheters was checked by the response to external compression and to active muscle contraction. The transducer was connected to a SC 9000 recorder (Siemens-Elema, Malmöldal, Sweden) for simultaneous continuous measurements. The pressure recording system was calibrated before and after each experiment.

Contraction pressure in the anterior tibial muscle during ankle joint dorsiflexion was recorded bilaterally before, during, and after the experiment.

Blood pressure

Blood pressure was measured using a 10 cm cuff on the left arm and a NAIIS manometer (Matsushita, Electronic Works, Ltd., Japan). The MAP was obtained by adding the diastolic blood pressure to one-third of the pulse pressure (pulse pressure = systolic minus diastolic pressure). The MAP was measured from the left arm (MAP_left) in both studies. Blood perfusion pressure was estimated in the anterior compartment to be MAP_left minus IMP minus the height of limb elevation in centimetres above heart level divided by 1.3 (Ashton 1966; Matsen et al. 1979; Heppenstall et al. 1988). The value of 1.3 represents the conversion factor for the height of the blood column in centimetres to millimetres of mercury.

Plaster of Paris

A four-layer plaster cast, which was 20 cm wide and applied over two layers of cotton padding, extended from 10 cm above the malleoli to the proximal part of the leg. To avoid external compression on the anterior compartment, the anterior part of the cast rested on the tibial tuberosity. The posterior part of the cast was adjusted to allow for 90° of knee flexion.

Segmental air splint

A segmental cylindrical air splint was applied to compress the contralateral leg. The air bag covered 20 cm of the leg, which was the same distance as the plaster cast. The pressure in the air bag was continuously adjusted so that IMP in the anterior compartment was the same in both legs.

Vein stasis

An 18-cm-wide pneumatic thigh tourniquet, which was inflated to 60 mmHg, was applied to obstruct venous return from the limb for 30 min. Recordings were taken when IMP changed less than 1 mmHg·min⁻¹ during stasis.

Neuromuscular function

A 10 cm long visual analogue scale was applied to estimate sensory function in the subject’s feet every 10 min during the experiment. The ends of the scale were “normal sensibility” (10 cm) and “no sensibility” (0 cm). The subject’s motor function was evaluated with standard surface electrodes, using a neurograph (Keypoint, Dantec Medical A/S, Denmark). The peroneal nerve was stimulated over the fibular head, using 0.1 ms electrical pulses of intensity sufficient to elicit maximal amplitude of the muscle action potential. The active surface electrode was positioned over the motor point of the extensor digitorum and extensor hallucis brevis muscles. The reference electrode was located on the fifth metatarsophalangeal joint and the earth electrode positioned on the calf. A biphasic compound muscle action potential was recorded being the summered electrical activity arising from the synchronous depolarisation of the muscle fibres innervated by the peroneal nerve. Stimulation exceeded a maximal level by 25% or at least 5 mA.

Statistical analyses

The Wilcoxon signed rank test was used. Significance was set at \( P < 0.05 \).

Results

Intramuscular pressure

In study A, IMP at rest was 5.8 (SD 1.0) mmHg in the leg at heart level and 5.5 (SD 0.5) mmHg in the elevated leg before the experiment started. When the plaster cast and vein stasis had been applied for 30 min, IMP was 39.0 (SD 2.5) mmHg in the leg tested during limb elevation and 40.1 (SD 2.8) mmHg in the contralateral