INSTITUTE OF PHYSICS PUBLISHING PHYSIOLOGICAL MEASUREMENT

Physiol. Meas. **26** (2005) 951–963 doi:10.1088/0967-3334/26/6/006

Can mechanical myotonometry or electromyography be used for the prediction of intramuscular pressure?

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Received 8 December 2004, accepted for publication 31 August 2005
Published 17 October 2005
Online at stacks.iop.org/PM/26/951

Abstract

The aim of the study was to characterize the electromechanical properties of skeletal muscle during isometric loading as well as to assess the potential of estimating intramuscular pressure by electrical and mechanical methods. Simultaneous electromyography (EMG), mechanical myotonometry (MYO, frequency and decrement of decay) and intramuscular pressure (IMP) measurements were conducted at rest and during short-term and long-term isometric contractions in patients with chronic pain in the anterior leg or dorsal forearm. The EMG amplitude and $\mathrm{MYO_{freq}}$ accounted significantly (24–73%, $p < 0.0001$) for the variations in the IMP under short-term isometric loading. The IMP, EMG and $\mathrm{MYO_{freq}}$ increased linearly with the relative muscle load ($r = 0.868$–0.993, $p < 0.05$). Mean values of EMG amplitudes at the contraction levels of 75% and 100% maximum voluntary contraction (MVC) and $\mathrm{MYO_{freq}}$ values at all contraction levels (0–100% MVC) were higher for subjects with pathological values of IMP than for those with IMP values in the normal range. Total changes in IMP and EMG amplitude during 1 min isometric contraction were linearly interrelated ($r = 0.747$, $p < 0.0001$). We conclude that both surface electromyography and myotonometry parameters are indicative of intramuscular pressure, but neither of these methods can be used alone to diagnose non-invasively chronic compartment syndrome with acceptable accuracy.

Keywords: intramuscular pressure, biomechanics, myotonometry, electromyography, isometric contraction

Introduction

Intramuscular pressure (IMP) of healthy skeletal muscle is linearly related to isometric muscle load (Järvholm *et al* 1989, 1991, Parker *et al* 1984, Sejersted and Hargens 1995). Mechanical loading of the muscle increases IMP, which may subsequently decrease muscle perfusion (Järvholm *et al* 1988, Sadamoto *et al* 1983, Styf *et al* 1987). At a critical level of loading, the muscle membrane may not be able to stretch to allow the increase in the muscle volume, and as a result capillary flow can decrease significantly. At this point, muscle fatigue impairs the normal functioning of the tissue. When associated with pain, fatigue and disability, this exercise-induced state is called the chronic compartment syndrome (CCS) (Renemann 1975, Styf *et al* 1987). IMP also depends on other factors such as muscle geometry (Bourne and Rorabeck 1989, Järvholm *et al* 1989, Sejersted and Hargens 1995). At present, CCS is clinically diagnosed by invasive IMP measurements.

Electromyography (EMG) is a physiological measure of muscle activity and fatigue. EMG can exhibit a linear (Aratow *et al* 1993, Perry and Bekey 1981) or nonlinear (Lawrence and De Luca 1983, Solomonow *et al* 1986) relationship with isometric muscle force. It has been suggested that EMG amplitude (Krogh-Lund and Jorgensen 1991, 1992), as well as IMP (Crenshaw *et al* 1997), increase during sustained submaximal isometric contraction to fatigue. Possibly, the changes in EMG are due to metabolic alterations in the muscle, especially if the contraction level is greater than 45% of the maximal voluntary contraction (MVC) (Brody *et al* 1991, Crenshaw *et al* 1997). At levels below 30% of the MVC, the changes in EMG are mainly attributable to neural changes (Crenshaw *et al* 1997, Krogh-Lund and Jorgensen 1991, 1992). Even though the relationships between IMP and EMG have been widely studied, it is still poorly understood whether EMG variations are consistent with those of IMP when investigating subjects with pathological values of IMP.

After electric activation of the skeletal muscle, its functional state is reflected by the muscle tone, an indicator of the mechanical stiffness of muscle (Vain 1993, 1995, 1999). Muscle tone increases as a function of contraction force. Myotonometry (MYO) represents a noninvasive way to characterize the viscoelastic properties, i.e. frequency ($\mathrm{MYO}_{\mathrm{freq}}$) and decrement of decay ($\mathrm{MYO}_{\mathrm{dec}}$), of skeletal muscle *in vivo* (Vain *et al* 1992, Veldi *et al* 2000). The interrelationships between the viscoelastic properties of muscle and IMP are not clarified but should be assessed to improve the understanding of their mechanical interactions.

In the present study, simultaneous IMP, EMG and MYO measurements were conducted at rest as well as during short-term and long-term isometric loading for subjects with pain in the dorsal forearm or anterior leg (possibly due to chronic CS). The objective of this study was to establish if there is a relationship between IMP, EMG and MYO, and whether EMG or MYO could be used to estimate IMP non-invasively in the diagnosis of chronic CS. Differences in the measured parameters during two maximal voluntary contractions, and the capabilities of EMG and MYO to estimate IMP under short-term loading were evaluated. The potential of EMG and MYO to differentiate subjects with pathological values of IMP from those with normal values was investigated under short-term isometric loading. Finally, EMG and IMP changes during long-term loading were interrelated. We hypothesized that EMG and MYO could be useful in predicting clinically significantly increased IMP. Possibly, with the aid of these non-invasive methods, some of the current invasive tests for patients with normal IMP may be eliminated.

Table 1. Description of the study subjects (mean ± SD).

						Blood pressure (kPa)	
Sex	n	Age (years)	Height (cm)	Weight (kg)	BMI[a] (kg m^{-2})	Systolic	Diastolic
Men	15	45.8 ± 10.0	177.8 ± 5.2	86.0 ± 7.6	27.2 ± 2.9	18.0 ± 0.9	9.9 ± 1.1
Women	22	40.3 ± 11.5	163.8 ± 4.2	64.5 ± 10.3	24.9 ± 4.0	18.4 ± 2.4	10.1 ± 1.5

[a] Body mass index.

Materials and methods

Measurements were carried out in 37 subjects (37 IMP, 30 EMG and 26 MYO subjects, table 1) who had pain in the dorsal forearm (extensor compartment) or anterior leg (anterior compartment). First, the interrelationships between IMP, EMG and MYO were studied. Second, the subjects were divided into two groups: (1) high values of IMP indicative of chronic CS and (2) low values of IMP suggesting no chronic CS, based on clinically used criteria in the Kuopio University Hospital (Jurvelin and Mussalo 2003): (a) >1.3 kPa or >2 kPa IMP in the dorsal forearm and anterior leg, respectively, at rest, (b) >0.2 kPa/% intramuscular pressure during contraction of 0–100% MVC, (c) >3.3 kPa IMP 1 min after loading or >2.7 kPa IMP 5 min after loading, and (d) pain associated with decrease of muscle force during contraction. Subsequently, the diagnostic performances of EMG and MYO to differentiate these groups were determined.

Before the measurements, the IMP catheter and EMG electrodes were positioned in the muscle compartment and on the skin surface above the muscle, respectively (figure 1). For the measurements, the subjects were lying in a supine position and the limb under investigation was loaded with a loadmeter (Digitest force, Digitest OY, Finland) using a standardized protocol for short-term (5 s, 0%, 100%, 75%, 50%, 25% and 100% MVC) and long-term (60 s, 40% and 20% MVC) isometric loading of the muscle (Jurvelin and Mussalo 2003).[6] The foot or arm was lying on the bed in a natural position without any extra stretch. Loading of the dorsiflexed wrist or ankle was used (figure 2). Since the loading force can be influenced by the angle of the hand or foot and by the position of the strap relative to the joint center, the hand and foot were always held at the angles of $\sim 20°$ and $\sim 0°$, respectively. Displacements a and b in figure 2 were ∼8 cm and ∼15 cm, respectively. The reason for the differences in the angle and displacement was purely anatomical. Furthermore, due to the differences in the measurement geometries, the analyses were made separately for hand and foot. During loading IMP, EMG and load signals were continuously recorded for 4 min, while myotonometric measurements were conducted at rest and during isometric loading periods (figure 3).

Intramuscular pressure

IMP was measured using a slit catheter method (Stryker, Intra-Compartmental Pressure Monitor System, Indwelling Slit Catheter Set, USA) (Bourne and Rorabeck 1989). First, the patient's skin was cleaned carefully and the saline-filled catheter of 1.6 mm in outer diameter was inserted in the proximal direction into the muscle compartment through a needle. Since IMP is influenced by the depth of the catheter in the muscle (Sejersted *et al* 1984), care was taken to position the catheter tip at the same depth in all patients. The depth varied between

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[6] IMP measurements were conducted according to the clinical protocol in use in the Kuopio University Hospital.

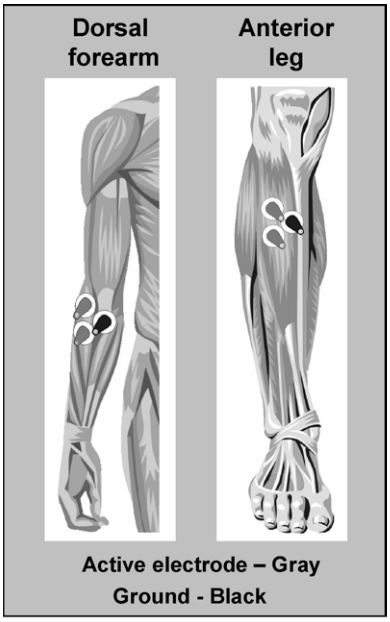

Figure 1. Electrode placements in the electromyography (EMG) measurements. In the intramuscular pressure (IMP) measurements, the catheter tip was positioned in the muscle compartment of interest, 2–4 cm under the active EMG electrodes. Test location for the measurements using myotonometry (MYO) was on the muscle surface between the active electrodes.

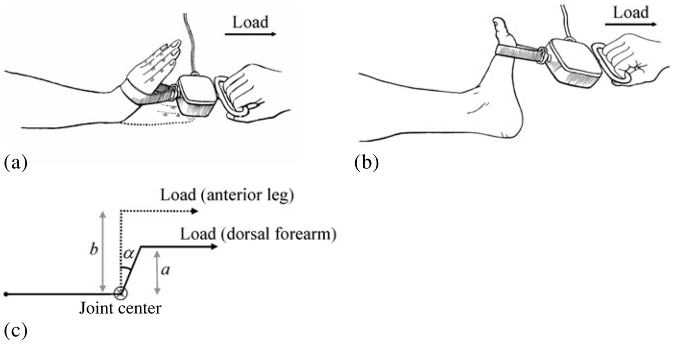

Figure 2. A schematic representation for the isometric loading of dorsal forearm (a) and anterior leg (b) muscle compartments with description of the measurement geometries (c). The wrist and ankle joints were dorsiflexed. The hand and the foot was always held at an angle of $\alpha \approx 20^\circ$ and $\alpha \approx 0^\circ$, respectively. Displacements a and b were $\sim$8 cm and $\sim$15 cm, respectively.

2 and 4 cm, depending on the amount of subcutaneous fat and the muscle compartment. The needle was pulled out and the catheter was attached to an external pressure transducer[7] (AE-840, Sensonor, Horten, Norway) connected to a pressure amplifier (Mingograph 4, Siemens-Elema, Solna, Sweden). After amplification, the pressure and loadmeter signals were relayed to a PC through a 12-bit AD-converter board. To avoid the artificial effect

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[7] Transducer specifications—resonant frequency: 300 Hz, sensitivity: 50 μV V^{-1} cmHg^{-1}, pressure range: $-20\cdots+300$ mmHg, nonlinearity and hysteresis: max 0.5% of full scale.

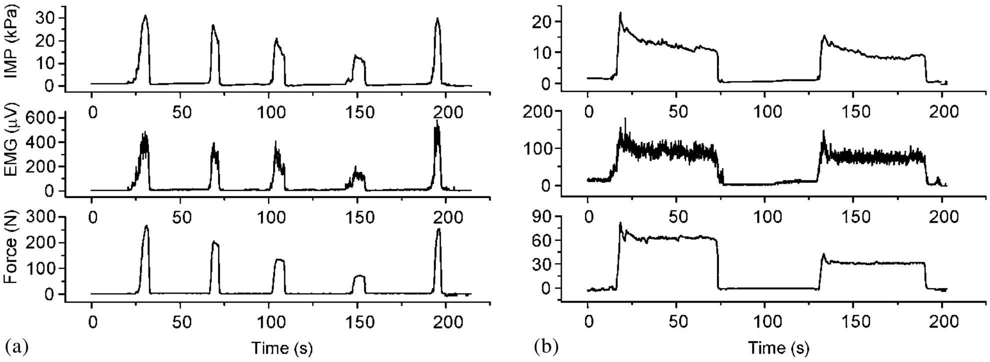

Figure 3. Intramuscular pressure (IMP) and electromyography (EMG) at rest and during short ((a): 100%, 75%, 50%, 25% and 100% MVC) and long ((b): 40% and 20% MVC) term isometric contractions.

of gravity, the pressure transducer was kept at the same height as the catheter tip. The pressure transducer was calibrated against a mercury sphygmomanometer (Erkameter, Erka, Bad Toelz, Germany). The IMP analysis was performed using custom-made software. In addition to pressure-time data, the IMP values, corresponding to each short-term load, were systematically quantitated from the measurements.

Quantitative surface EMG

Simultaneously with IMP measurements, EMG of the muscle was recorded using bipolar Ag/AgCl electrodes, attached to the skin surface above the muscle of interest (figure 1). The skin contact size of the electrodes was 48 mm in diameter. The EMG signal was preamplified and sent to a ME3000P Muscle Tester unit with a 2 MB SRAM-card (Mega Electronics Ltd, Kuopio, Finland). The signal was amplified and filtered in the ME3000P unit. The frequency band for the measurement was 15–500 Hz with a sampling frequency of 1000 Hz. Simultaneous IMP and load signals were also relayed to the ME3000P unit through a ME3000 ISO isolation unit. After registration of EMG, IMP and load signals, the data from the SRAM-card were downloaded to a PC with an appropriate software (Multi Signal System ME3000P V2.05 software, Mega Electronics Ltd, Kuopio, Finland). The raw EMG signal was subsequently rectified and averaged by the software using an averaging time of 10 ms (figure 3). EMG amplitudes were quantitated during each (0–100% MVC) short-term muscle load. To describe the time-dependent behavior of the EMG (and IMP) during long-term loading (figure 3(b)) curve-fitting was performed using $y = A_0 + A\exp(-kt)$, where A_0 is the amplitude of EMG (μV) or IMP (Pa) at equilibrium, A is the change of the amplitude, k (s^{-1}) is the time constant and t (s) is time. This exponential best-fit could describe accurately the time-dependent behavior of both EMG and IMP.

Myotonometry

Simultaneously with IMP and EMG measurements, the mechanical characteristics of the muscle were determined at rest and during isometric contractions using myotonometry (Vain *et al* 1992, 1996, Vain 1999, Veldi *et al* 2000). In this method, the viscoelastic response of the muscle due to the constant mechanical impact (duration ~10 ms) on the skin surface above the muscle is recorded as a damped harmonic oscillation (figure 4). Each myotonometry

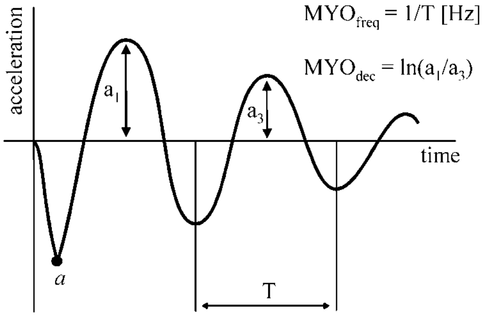

Figure 4. Typical damped oscillation curve, as measured with myotonometry. During the measurement, the test probe of the instrument is positioned against the muscle of interest and after a short mechanical impact released at the point *a*. Frequency and decrement of decay are calculated from the curve to estimate the elastic and viscous properties of tissue.

measurement took ~250 ms including five oscillations. From these data, the oscillation frequency (MYO$_{freq}$ (Hz)) and logarithmic decrement of decay (MYO$_{dec}$) can be calculated to quantify the functional state of the muscle (Bader *et al* 1992, Vain *et al* 1992, Veldi *et al* 2000, Fung 1993). MYO$_{freq}$ characterizes the elastic properties of the muscle and reflects the tissue ability to resist the force that changes its shape. MYO$_{dec}$ characterizes the viscous properties of the muscle and reflects the ability of the tissue to restore its initial shape. Three measurements were performed at rest and during each short-term loading period, and the mean values of MYO$_{freq}$ and MYO$_{dec}$ were calculated from these measurements.

Statistical analyses

The mean values and standard deviations (±SD) were calculated for the IMP, EMG and MYO values. Linear regression analysis and Bland and Altman analysis (Bland and Altman 1986) were utilized to describe the relationships between recorded parameters and best-fit equations, correlation coefficients (r) and p-values were determined using Origin V5.0 software (Microcal Software, Inc, Northampton, MA, USA). The Wilcoxon signed ranks and Mann–Whitney U-tests were used for statistical comparisons.

Results

The mean values of the recorded parameters in the dorsal forearm and anterior leg for the subjects with high (group 1) and low IMP (group 2) values at rest and at maximum load are shown in table 2. The IMP values of group 1 were statistically higher ($p < 0.05$, Mann–Whitney U-test) than those of group 2 at 100% MVC both in the arm and the leg. EMG values of group 1 in the arm at rest and at 100% MVC, as well as MYO$_{dec}$ values of group 1 in the leg at 100% MVC, were significantly different ($p < 0.05$, Mann–Whitney U-test) than those of group 2. All parameter values were statistically ($p < 0.05$, Wilcoxon signed ranks test) higher (except MYO$_{dec}$) at the maximum load than at rest. At the 100% MVC, the loading force correlated significantly with IMP, EMG and MYO$_{freq}$ in the anterior leg ($r = 0.628$, $r = 0.617$, $r = 0.680$, respectively, $p < 0.05$), whereas in the dorsal forearm only IMP correlated significantly with force ($r = 0.654$, $p < 0.05$).

A Bland and Altman plot shows agreement between the values of registered parameters during the first and last 100% MVC (figure 5). The measured parameters, except MYO$_{dec}$ ($r = 0.273$, $p = 0.178$, data not shown), during the first and last 100% MVC correlated

Table 2. Mean (±SD) values of the intramuscular pressure (IMP) elecromyography (EMG) and myotonometry (MYO) parameters (MYO_{freq} and MYO_{dec}) in the dorsal forearm and anterior leg for subjects with high IMP (possible chronic CS, group 1) and subjects with low IMP (no chronic CS, group 2) at rest and at 100% maximal voluntary contraction.

	Dorsal forearm						Anterior leg					
	Group 1			Group 2			Group 1			Group 2		
	Rest	Max	*n*	Rest	Max	*n*	Rest	Max	*n*	Rest	Max	*n*
IMP (kPa)	*0.92 ± 0.41	#17.2 ± 8.1	12	*0.74 ± 0.57	3.09 ± 1.88	8	*2.48 ± 0.95	#17.2 ± 7.7	11	*1.78 ± 1.72	4.23 ± 1.48	6
EMG (μV)	*#3.25 ± 1.27	#318 ± 119	9	*7.05 ± 1.26	183 ± 84	5	*3.79 ± 1.97	335 ± 252	11	*4.60 ± 3.91	317 ± 193	5
MYO_{freq} (Hz)	*15.7 ± 2.0	25.5 ± 2.5	7	*15.7 ± 1.2	26.7 ± 4.5	6	*23.4 ± 2.8	33.8 ± 7.5	9	21.8 ± 4.3	27.0 ± 6.1	4
MYO_{dec}	1.14 ± 0.27	1.02 ± 0.13	7	1.01 ± 0.34	1.09 ± 0.34	6	0.94 ± 0.32	#0.80 ± 0.14	9	1.12 ±.23	1.00 ± 0.11	4

[*] $p < 0.05$, as compared with the value at 100% maximal voluntary contraction (Wilcoxon signed ranks test).

[#] $p < 0.05$, as compared with the value of group 2 (Mann–Whitney *U*-test).

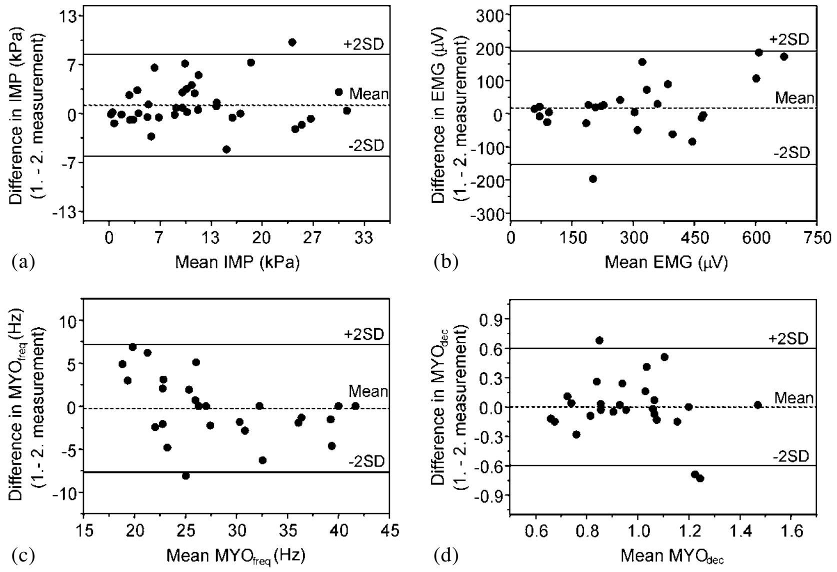

Figure 5. Differences in intramuscular pressure (IMP) (a), electromyography (EMG) (b) and myotonometry parameters ($\mathrm{MYO_{freq}}$ = frequency (c), $\mathrm{MYO_{dec}}$ = decrement of decay (d)) between the first and last 100% MVC (see figure 3((a)) as a function of the mean values of the corresponding pairs by using a Bland and Altman plot (Bland and Altman 1986). Number of subjects in IMP, EMG and MYO groups were 37, 25 and 26, respectively.

Table 3. Linear correlation coefficients of the electromyography (EMG) and myotonometry (MYO) parameters (frequency ($\mathrm{MYO_{freq}}$) and decrement of decay ($\mathrm{MYO_{dec}}$)) with the intramuscular pressure (IMP) in the dorsal forearm and anterior leg. For the correlation analysis parameter values at different levels (0, 25, 50, 75, 100% MVC) of isometric loading were normalized with that at 25% MVC.

	IMP			
	Dorsal forearm	*n*	Anterior leg	*n*
EMG	0.515*	70	0.855*	80
$\mathrm{MYO_{freq}}$	0.487*	65	0.773*	65
$\mathrm{MYO_{dec}}$	0.178	65	−0.109	65

* $p < 0.0001$, n is the number of data points (e.g. $n = 70$ refers to 14 subjects).

significantly ($r = 0.887$–0.918, $p < 0.0001$, data not shown). Only the IMP values during the last 100% MVC were statistically lower than those during the first 100% MVC ($p < 0.05$, Wilcoxon signed ranks test).

EMG and $\mathrm{MYO_{freq}}$ correlated positively and significantly ($r = 0.487$–0.855, $p < 0.0001$, table 3) with IMP at rest and during loading periods in the dorsal forearm and the anterior leg. Mean values of IMP, EMG and $\mathrm{MYO_{freq}}$ correlated significantly ($r = 0.868$–0.993, $p = 0.0007$–0.06) with the relative (%MVC) muscle load both in group 1 and 2 (figure 6). Mean values of EMG (75% and 100% MVC) and $\mathrm{MYO_{freq}}$ (0–100% MVC) were higher for patients with high values of IMP (group 1).

When all subjects were pooled, the IMP and EMG amplitude (A) changes during 1 min 20% and 40% MVC were highly correlated ($r = 0.747$, $p < 0.0001$, figure 7). In 25 out of 38

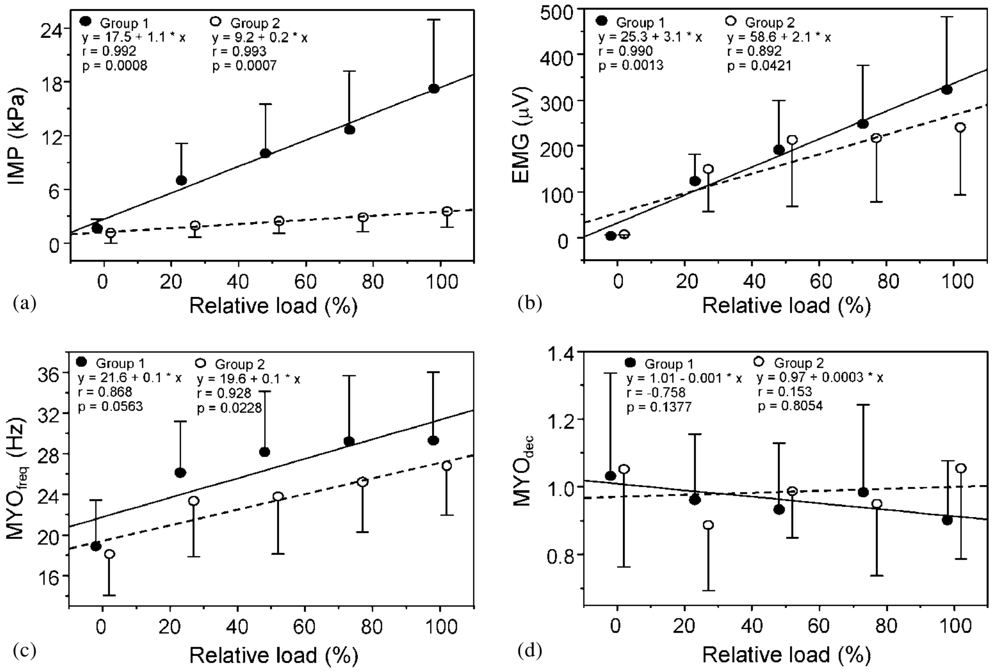

Figure 6. Intramuscular pressure (IMP) (a), electromyography (EMG) (b) and myotonometry parameters (MYO_{freq} = frequency (c), MYO_{dec} = decrement of decay (d)) (mean ± SD) as a function of relative, isometric muscle load (0%, 25%, 50%, 75%, 100% MVC) for subjects with high (group 1) and low (group 2) values of IMP. Number of subjects in each group can be seen from table 2.

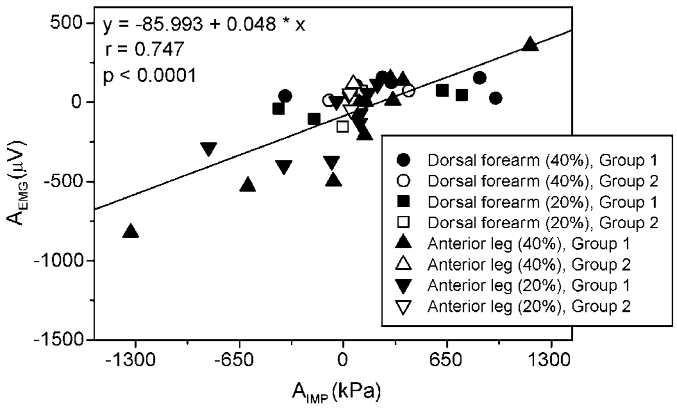

Figure 7. Linear correlation between the total change in intramuscular pressure (IMP) and electromyography (EMG) amplitudes during 1 min isometric contractions (20% or 40% MVC). An exponential fit, $y = A_0 + A\exp(-kt)$, was made to each IMP and EMG measurement (figure 3(b)), and the amplitudes (A) were correlated. Group 1 refers to the subjects with high IMP values (suggesting chronic CS) and group 2 are the subjects with IMP values in the normal range. Number of successful measurements was 38, which does not indicate the number of subjects as the measurements for one subject were conducted during 20% and 40% MVC (figure 3(b)).

(66%) measurements, the EMG amplitude decreased and in 26 out of 38 (68%) measurements, the IMP amplitude decreased.

Discussion

In the present study, simultaneous IMP, EMG and MYO measurements were conducted during short-term and long-term isometric loading in subjects with pain in the anterior leg or dorsal forearm. EMG and MYO parameters correlated positively and significantly with the IMP values and could typically explain 24–73% (r^2) of the variation found in IMP at the same time. The mean values of EMG amplitudes at the contraction levels of 75% and 100% MVC and $\mathrm{MYO_{freq}}$ values at all contractions levels (0–100% MVC) were higher for subjects with pathological values of IMP compared to those with IMP values in the normal range. During 1 min isometric loading, IMP and EMG amplitudes exhibited similar time-dependent changes.

The similar time- and load-dependent behaviors of the IMP and EMG revealed the interplay between the mechanical and electrical characteristics of skeletal muscle, and suggest that major changes in the EMG signal may be indicative of chronic compartment syndrome. There are earlier studies focusing on the IMP and EMG during sustained contraction (Crenshaw *et al* 1997, Körner *et al* 1984, Sadamoto *et al* 1983, Sjogaard *et al* 1986, 2004) which have detected mainly an increase in IMP and EMG amplitudes during loading, but the measurements were conducted on healthy subjects, whereas in the present study the subjects suffered from pain in the leg or arm. Some of the patients had high (pathological) values of IMP, suggesting possible chronic CS. IMP is influenced by the muscle water content, compartmental volume as well as the properties of the surrounding muscle fascia (Bourne and Rorabeck 1989). Isometric loading probably increases transfer of fluid into the compartment leading to the IMP elevation. However, in most subjects in this study, both the IMP and EMG amplitudes decreased during 1 min of isometric loading. Possibly, the constant load was not maintained in the muscle compartment of interest during the loading period but the test geometry allowed the subject to transfer the load to other muscles of the arm or leg during recording. Unfortunately, we were not able to conduct simultaneous EMG measurements on other muscles which would possibly have revealed if load transfer had taken place. On the other hand, the time-dependent behavior of the IMP might reflect the dynamic balance of interstitial muscle fluid and mechanical properties of the muscle and fascia. After the initiation of loading there is an immediate increase in the interstitial muscle pressure. In response to this increased pressure, the fascia becomes tensed and extended at a rate controlled by the viscoelastic properties of the tissue. These changes increase the compartment volume and may reduce IMP. Finally, a static mechanical equilibrium is achieved between the existing forces from the fluid flow induced muscle swelling and the tension of the muscle-fascia, after which no further change in IMP takes place.

MYO reflects the functional state of skeletal muscle. In particular, MYO reflects the tension of the muscle fascia and fibers (Vain 1993, 1995, 1999, Vain *et al* 1992, Veldi *et al* 2000). In principle, during isometric contraction, the muscle length does not change, although increased IMP may subject the muscle fascia into tension in a load-dependent manner. Also, as shown in figure 2, after the measurements at rest, the wrist was set to dorsiflexion and measurements during 25–100% MVC were taken in this position. Obviously, this change in the measurement position could cause nonlinearity in the MYO values at 0–25% MVC.

EMG and MYO measurements predicted IMP with similar accuracy. The thickness of the subcutaneous fat above the muscle varies from patient to patient which may cause some uncertainty in the MYO measurements, though this is more significant if the fat is greater than 4.0 mm thick (Boiko 1997). Bipolar quantitative surface EMG measurements can also be influenced by many factors such as the placement of the electrodes. These kinds of disturbances were minimized by normalizing all the recorded parameters to 25% MVC. With all relative load levels, $\mathrm{MYO}_{\mathrm{freq}}$ was systematically higher in subjects with pathological values of IMP as compared to subjects with low IMP values. This finding indicates that high muscle tonus might be indicative of chronic CS. Myotonometry can therefore be a helpful tool in the diagnosis of muscle pathology. At high (75–100%) levels of isometric load, there was a trend to increased EMG amplitudes in subjects with pathological IMP values, as compared to those with low IMP values.

The positioning of the strap and the angle of the hand or foot can affect the total force which the subject is able to resist. Therefore, these parameters were standardized during the measurements as well as possible, even though small patient-to-patient variations may have slightly influenced the results. In spite of standardization due to the anatomical differences, the analyses were made separately for the dorsal forearm and the anterior leg. The significant linear correlations detected between the maximum force and IMP, EMG and $\mathrm{MYO}_{\mathrm{freq}}$ suggested that the measurement geometries were relatively constant from one subject to the next. Furthermore, as the main aim was to characterize the relationships between EMG, IMP and MYO, the measurement geometry for all the parameters during one measurement session was invariably the same.

For technical reasons we were not able to successfully conduct all EMG and MYO measurements but had to neglect some from the final analyses. The IMP-based diagnosis of chronic compartment syndrome follows the standard clinical protocol established in the Kuopio University Hospital (Jurvelin and Mussalo 2003). As some of the measurements were technically unsuccessful, and could not be repeated due to time limits, there are a different number of patients in the IMP, EMG and MYO groups, and a different number of EMG measurements during the second 100% MVC (figure 5) and during the long-term measurements (figure 7). The different number of subjects may slightly affect the mean values of the measured parameters, but not the correlation analyses. Due to practical limitations, the consistency of the relationships between the EMG, MYO and IMP could not be determined. However, the mean differences in the recorded parameters during the first and last 100% MVC were close to zero indicating no systematic differences between the repeated measurements. Using the present loading configuration and protocol, it may not be relevant to expect identical IMP, EMG or MYO values between the measurements. The relatively large magnitude of the 95% confidence intervals, i.e. ±2SDs, in Bland and Altman plots may set some limitations for the effective diagnostics and monitoring of the patients with small pathological impairments. We emphasize that more studies are warranted to reveal the true precision of the employed techniques.

We conclude that both the surface EMG and MYO are indicative of IMP and could be used as guiding tools in the diagnosis of chronic CS. However, due to the significant patient-to-patient variations, we believe that neither of these methods can be used alone to diagnose CCS.

Acknowledgments

Financial support from The National Technology Agency (TEKES), Finland; The Academy of Finland (No. 107846); The Kuopio University Hospital (EVO), Kuopio, Finland; The Sigrid Jusélius Foundation, Helsinki, Finland; The Invalid Foundation, Helsinki, Finland; and The Alberta Heritage Foundation for Medical Research, Alberta, Canada is acknowledged. The authors want to thank Mikko S Laasanen, PhD, University of Kuopio, Finland for technical support.

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