Ljubljana, Dec 4, 2006
Slovenian-Italian Workshop on Quantitative Needle and High Resolution Surface EMG

SURFACE EMG IN EXERCISE PHYSIOLOGY AND CLINICAL MEDICINE

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SURFACE EMG IN EXERCISE PHYSIOLOGY
Muscle Activation Intervals

Basic Assumptions

When the muscle is active the EMG signal can be distinguished from noise.

When the muscle is not active there is no EMG signal.
Kinesiological EMG represents the study of the function and coordination of muscles in different movements and postures in both healthy subjects and disabled, under laboratory conditions as well as in the field.
Spatial sampling with 1-D arrays

- Identification of the location of the IZ, length and orientation of the fibers
- Mapping of MUAP propagation from the IZ to the tendon endings
- Analysis of MU recruitment pattern
- High-accuracy CV estimation

Monopolar detection

Single differential detection

Tendons

Innervation zone location

10 ms
Spatial sampling with 2-D arrays

- Identification of the location of the IZ, length and orientation of the fibers
- Mapping of MUAP propagation from the IZ to the tendon endings
- Analysis of MU recruitment pattern
- High-accuracy CV estimation
Size Principle

Stretch-evoked responses of five alpha motoneurons recorded from a filament of the first sacral ventral root. Small numerals above action potentials indicate rank of units according to size.
EMG signals detected with a linear electrode array during an isometric ramp contraction of the biceps brachii muscle [from 0 to 90\% MVC in 5 seconds]  
Gazzoni M et al., 2001
EMG signals detected with a linear electrode array during a symmetric ramp of isometric contraction of the biceps brachii muscle [from 0% to 80% to 0% MVC in 20 seconds] Minetto MA et al., in press
Minetto MA, Dec 4, 2006

Full MU recruitment is affected by the speed of force increase during isometric contractions of the biceps brachii.

Decomposition of needle EMG signals not only yields information about the MUs themselves, but also about how MUs are controlled by the central nervous system in generating force.

Six MU action potential trains recorded from the right first dorsal interosseus muscle during an isometric contraction up to 50% MVC.

Minetto MA, Dec 4, 2006
Myoelectric manifestations of muscle fatigue (isometric contractions) Rainoldi R et al., 1999

Fatigue plots at 70% MVC from two subjects for the variables ARV, CV, MNF, and torque (30 s of isometric contraction of the biceps brachii)
One criticism to the use of isometric contractions is that they are far from physiological dynamic contractions.

However, in case of dynamic contractions many confounding factors affect the results in addition to those present with isometric contractions. The major problems with dynamic contractions are a) the high degree of nonstationarity of the signal and, b) the relative movement between sources and electrodes, causing major artefacts.

EMG signals may suddenly change their spectral properties during a dynamic task, and this may be difficult to investigate with classic spectral techniques.
Muscle fiber conduction velocity (CV) was estimated from surface (EMG) signals during isometric contractions (from 0% to 100% of the maximum) and during short (150–200 ms) explosive extension of the lower limb on a sled ergometer.

Minetto MA, Dec 4, 2006
Are isometric strength tests predictive of the quality of the dynamic performance?

Minetto MA et al., in preparation

Comparative analysis of fatigue profiles during intermittent isometric contraction and continuous jumping tasks

Minetto MA, Dec 4, 2006
Can exercise training modify the amount of a specific type of muscle fibre in the target muscle of muscle group?

Positive correlation between CV and the percentage of FT fibre area in sprinters and long distance runners

Sadoyama et al., 1988

Normalized values of MDF obtained from neuromuscular preparation of three rat muscles during electrical stimulation of the nerve

Kupa et al., 1995
The appearance of muscle proteins in blood after exercise provides indirect evidence of muscle damage

Electron micrograph illustrating muscle damage of the VL muscle (48 h after 300 eccentric contractions)

Plasma CK activity after downhill running and elbow flexion eccentric contractions

Clarkson PM and Hubal MJ, 2002

Minetto MA, Dec 4, 2006
Few works are available in the literature about the relationship between muscle damage and myoelectric fatigue.
Maximal voluntary contraction torque

Torque evoked by electromyostimulation at 20 and 50 Hz frequencies

CK levels before and after exercise

Muscle soreness

The time course of recovery of voluntary versus electrically evoked muscle performance after stretch-shortening exercise does not coincide

Minetto MA, Dec 4, 2006
Progressive increments of stimulation intensity elicits progressively greater M-waves. Difference between the two arrays provides the M-wave of the MUs incrementally recruited: this allows the characterization of small groups of MUs.

Courtesy of Prof. C. Orizio

Minetto MA, Dec 4, 2006
The rate of change of MNF and CV showed opposite behaviors:

CV increase with progressive MU activation was due to activation from small to large MUs

MNF decrease indicated activation from superficial to deep muscle layers
M-wave properties during progressive motor unit activation by NMES: effect of the stimulation waveform

Minetto MA & Botter A, in preparation

\[ T = 304 \mu s \]
STIMULATION MODALITIES

1. Single stimuli Monophasic or Biphasic (is the waveform important?)

1. Packets of “high frequency” sinusoids (2 - 5 kHz) (Kotz currents)

SOME POSSIBLE APPROACHES TO INVESTIGATE NEUROMUSCULAR RESPONSES TO NMES

1. Voluntary force increase
2. Electrically elicited force increase
3. Incremental M-wave to estimate recruitment order (based on CV)
4. Doublets (producing enhanced responses)
5. Myoelectric manifestations of muscle fatigue
6. Progressive widening of the M-wave in space along the motor unit fibers (reflecting the spread of conduction velocity values)
7. Modeling of the above phenomena
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Twitch summation with double stimulation

EXPERIMENTAL SET UP

EMG signal recording

Force twitch recording

Rainoldi et al., 2001
Mechanical and electrical responses evoked in the biceps brachii muscle by doublets with different intervals between the two pulses.

Rainoldi et al., 2001
The average maximal gain in peak force (PF) due to the use of doublet was estimated as 2.79±0.93, obtained for PI=3.5±0.1 ms.

The first pulse showed a conditioning effect upon the muscle membrane causing a higher CV value at the second pulse.

Rainoldi et al., 2001
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Myoelectric manifestations of muscle fatigue during electrical stimulation
Examples from two healthy subjects

Response of the Tibialis Anterior muscle of two healthy subjects to stimulation applied for 30 s at 30 pps (900 pulses).
Multichannel EMG response of biceps brachii to 10 s of stimulation at 30 pps with monophasic rectangular current pulses.
M-waves detected 10 mm apart, on one side of the innervation zone, with an electrode array.
During the stimulation the M-wave progressively widens and changes shape as it propagates.
This suggests that different motor units change their conduction velocity in different ways during sustained stimulation.

**Electrically elicited myoelectric manifestations of muscle fatigue**
NMES has a relatively minor influence on the order in which motor units are activated during a contraction. However, there is more variability in the order of activation during electrically evoked contractions compared with voluntary contractions.

Peripheral NMES evokes widespread activity within the CNS that is capable of mediating a range of adaptations.
Clinical applications of high-density surface EMG: A systematic review

Gea Drost a,b,*, Dick F. Stegeman a,b, Baziél G.M. van Engelen b, Machiel J. Zwarts a,b

Results: 146 original English articles

May 24th, 2006

• Instrumentation level 8 From
• Modeling studies 18 research
• Signal analysis and acquisition 48 to
• Physiological applications 31 practice
• Clinical applications 29

Minetto MA, Dec 4, 2006
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N = 5 Fatigue in neuromuscular disorders and chronic fatigue syndrome
N = 7 Motor neuron diseases and neuropathies
N = 4 Combined motor neuron disease, neuropathy, myopathy
N = 8 Myopathies (6 concerned channelopathies)
N = 2 Positive involuntary muscle phenomena
N = 3 Motor unit firing rate

\[
\frac{29}{146} = 19\%
\]
FATIGUE IN NEUROMUSCULAR DISORDERS AND CHRONIC FATIGUE SYNDROME (n=5)

Congenital myopathy characterized by type-I predominance
Lack of decline in CV during the fatiguing exercise

Chronic fatigue syndrome
Diminished central activation of the skeletal muscle
Reduced levels of myoelectric fatigue
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MOTOR NEURON DISEASES AND NEUROPATHIES (n=7)

Detection of signs of reinnervation of single MUs after hand transplantation

Amyotrophic lateral sclerosis

Traumatic lesions of the plexus brachialis

Obstetric lesions of the plexus brachialis

Post-poliomyelitis syndrome

Carpal tunnel syndrome

Long maximal voluntary contraction

Time (s)
COMBINED MOTOR NEURON DISEASE, NEUROPATHY, MYOPATHY (n=4)

Duchenne muscular dystrophy

Guillain-Barré syndrome

Spinal muscular atrophy

Hypertrophic leg muscle in a DMD patient

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MYOPATHIES (n=8)

- Duchenne muscular dystrophy (n=2)
- Channelopathies (n=6)
  - Hypokaliemic periodic paralysis
  - Recessive myotonia congenita
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POSITIVE INVOLUNTARY MUSCLE PHENOMENA (n=2)

Fasciculations

Involuntary muscle contractions in Satoyoshi syndrome
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MOTOR UNIT FIRING RATE (n=3)

Studies of MU firings provide a non-invasive access to central processes and their pathophysiology

Parkinson’s disease

Cerebrovascular accidents
Muscle Fiber

Motor Unit

Muscle

Needle EMG

• Spontaneous activity
• Insertional activity
• NM transmission

Multi channel SEMG

• Activity distribution
• Muscle morphology
• Membrane properties
• Fatigue

• Size
• Number
• Firing pattern

• Conduction
• Position
• Endplate zone
There is a “mismatch” between the number of practical application studies and the number of supporting bioengineering reports.

The technique is still in its infancy although the large number of “non-clinical” papers our search generated
PATIENTS WAITING ROOM

3 AILMENTS OR LESS

© Original Artist
Reproducibility and responsiveness of a noninvasive EMG technique of the respiratory muscles in COPD patients and in healthy subjects
Marieke L. Duijverman, Leo A. van Eykern, Peter W. Vennik, Gerard H. Koëter, Eric J. W. Maarsingh and Peter J. Wijkstra

**ASSESSMENT OF MUSCLE FATIGUE DURING EXERCISE IN CHRONIC OBSTRUCTIVE PULMONARY DISEASE**

DIDIER SAEG, PhD,1 CLAUDE H. CÔTÉ, PhD,2 M. JEFFERY MADOR, MD,2 LOUIS LAVIOLETTE, BSc,1 PIERRE LEBLANC, MD,1 JEAN JOBIN, PhD,1 and FRANÇOIS MALTAIS, MD1

Stress-related disorders associated with hypocortisolism

- Chronic fatigue syndrome
- Post-traumatic stress disorder
- Fibromyalgia syndrome
- Chronic pain syndromes (chronic pelvic pain, persisting sciatic pain after surgery)
- Burnout syndrome of caregivers
- Overtraining syndrome in athletes

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The clinical use of macro and surface EMG in diagnosis and follow-up of endocrine and drug-induced myopathies

Minetto MA, Rainoldi A, Jabre JF

STEROID MYOPATHY

Proximal weakness affecting the lower limbs more than the upper limbs

Impaired mitochondrial function

Loss of thick myofilaments

Neurogenic muscle atrophy

Minetto MA, Dec 4, 2006
The clinical use of macro and surface EMG in diagnosis and follow-up of endocrine and drug-induced myopathies

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**HYPOTHYROID MYOPATHY**
- Atrophy of type II fibers
- Intracellular glycogen inclusions
- Transition in the myosin isoforms

**THYROTOXIC MYOPATHY**
- Atrophy of type I and II fibers
- Fatty infiltration
- Increased branching of distal axons and reinnervation
The clinical use of macro and surface EMG in diagnosis and follow-up of endocrine and drug-induced myopathies

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ACROMEGALY

Mild to severe muscle weakness and atrophy
Normal-sized, hypertrophied, and atrophied type II fibers

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MALE GONADAL DYSFUNCTION

Muscle weakness is due to fiber atrophy (mainly of type II fibers).

It involves both the proximal and the distal limb muscles.
The clinical use of macro and surface EMG in diagnosis and follow-up of endocrine and drug-induced myopathies

Minetto MA, Rainoldi A, Jabre JF

Drugs Known to Cause Myopathy

<table>
<thead>
<tr>
<th>Alcohol</th>
<th>Chloroquine</th>
<th>Cocaine</th>
<th>Corticosteroids</th>
<th>Hydroxychloroquine</th>
<th>Lipid-lowering agents</th>
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<td>Fibric acids derivatives (clofibrate, gemfibrozil)</td>
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<td>HMG-CoA reductase inhibitors</td>
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<td>Penicillamine</td>
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<td>Zidovudine</td>
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Macro EMG can provide the diagnostic evidence of myopathic MUAP, whereas SEMG could find application in the longitudinal evaluation of the patients.
OPEN QUESTIONS

Why do the limb muscles are more affected than other muscles?

Why do the lower limbs are more affected than the upper ones?

Why does the proximal part of a limb is more affected than the distal one?

What are the reasons for the main involvement of type II fibers?

What are the reasons for the main involvement of thick filaments (myosinopathy) and mitochondria?
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