SATURATION OF THE M-WAVE AMPLITUDE WITH INCREASING STIMULATION AMPLITUDE

Rafolt D.*, Mayr W.*, Vetter K.***, Gallasch E.**, Bijak M.*, Reichel M.*, Sauermann S.*, Lanmueller H. *, Unger E.*, Hofer C.****

*Department of Biomedical Engineering and Physics, Medical University of Vienna, Austria
** Department of Systemphysiologie, Medical University Graz, Austria
*** Otto Bock Inc., Austria; ****Wilhelminenspital Vienna, Austria

Introduction

The quantification of muscle fatigue is essential for the optimization of training in sports and rehabilitation. The measurement of blood gases like lactat concentration is widely used in serious sports, but such values are reflecting the total systemic status and therefore are not representative for a single fatigued muscle. Another approach is a biomechanical one: Using various protocols a decrease in the muscle performance characterizes fatigue. These methods need to measure the force output using more or less heavy equipment and therefore mobile measurements are very complicated.

Looking for a simple to use methode to assess muscle fatigue during training, the recording and on-line analysis of the m-wave (synchronized EMG response on a electrical stimulation pulse) was considered. It is known that fatigue either caused by voluntary contraction or by FES leads to a decrease of the amplitude of the m-wave [1- 7].

Moreover the latency of the m-wave response depends on the length of the muscle and therefore from the ankle of the joint under investigation. [8]. The shift of the latency is accompained with a change in the peak-to-peak amplitude of the m-wave. Thus one must know this relation in order to assign a change in the amplitude either to fatigue or to the change of the muscle length in the correct way.

As there are a number of physical and physiological parameters beside the stimulation amplitude that influence the excitability of the muscle (electrode position and size, electrode impedance, temperature of the muscle, sweating, polarity of the stimulus etc.) our aim was to find a measurement setup and protocol to compare pre and post fatigue data with minimum influences of these parameters. The investigation was done under the condition of using the same stimulation electrode setup for both FES training and m-wave measurement.

Material and Methodes

Exceeding a certain threshold level of the stimulation voltage the amplitude of the m-wave increases very rapidly. Then at higher stimulation leves all the muscle fibers are activated and variations in the above-mentioned parameters do not change the excitation and therefore the amplitude of the m-wave saturate. The deciding factor for innervation of the muscle is the electrical field the nerve is exposed to. To keep this field above a level for supramaximal stimulation the voltage applied on the surface electrode must be sufficient high.

The question is: What amplitude of stimulation voltage is needed to detect the transition to a saturated state of the response.

From 10 persons from our university staff we recorded the twitch response (knee extension) on an isometric knee dynamometer built in our department and the EMG signal from the quadriceps muscle (vastus lateralis). The m-wave signal was measured with a commercial EMG-system (DISA-Neuromat 2000C; range 2mV/Dev.; 5-1000Hz). Ankle, knee and hip joints were immobilised for an angle of 90° each.

Stepwise increasing constant voltages pulses (biphasic, 2x300us) were applied to the muscle over self-adhesive stimulation electrodes (Schwa-Medico, 8x13cm). The positions of the stimulation electrodes was adjacent to the patella border for the distal electrode and 3cm distal to the inguinal fold for the proximal electrode - the lateral side of this electrode was turned about 30° more proximal. The stimulator was built in our department and the maximum output of the biphasic pulse was limited to 300Vpp. The orientation of the EMG-electrodes were varied and the polarity of the stimulation voltage was altered. Additionally in five subjects the angle of the knee was varied between 0° and 120° in steps of 10°. For data analysis Matlab 6 (Mathworks Inc.) was used.

Results

a. Orientation of the EMG electrodes:

In order to limit the hardware design for a transportable device (no special stimulation artifact rejection measures like blanking or filter circuits etc.) we desided to place the EMG electrodes perpendicular to the orientation of the stimulation

electrodes above the m.vastus lateralis. Lying more or less on a equipotential line of the electrical field arising from the stimulation voltage the crosstalk from the stimulus is a minimum. Nevertheless a typical m-wave curve can be detected as the vastus is a pennated muscle and has an orientation of the fibers of about 45 degrees.
In this arrangement the EMG measurement needs less space between the stimulation electrodes which could be advantageous for small or young people respectively or X-large FES electrodes. Fig.1 (left) shows the m-wave response from one subject using longitudinal electrodes. The m-wave is offset by the stimulus artefact. Fig.1 (right) shows a recording using perpendicular electrodes.

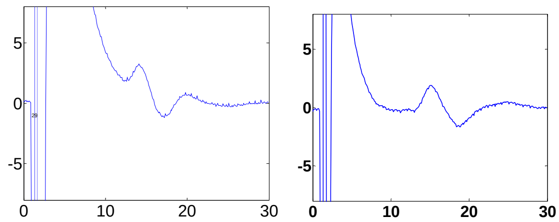

Fig:1: m-wave signals with longitudinal (left) and perpendicular (right) EMG bipolar electrodes (t in [ms]

b. Effect of knee angle:

Fig.2 shows the influence of the knee angle of the same subject with perpendicular arranged electrodes @60Vpp. The latency of the first maximum of the m-wave varies from 12ms for the stretched leg (0°) to 16ms (for a flexion of 120°). The corresponding peak-to-peak (PTP) amplitude of the m-wave shows a decrease with an increasing angle.

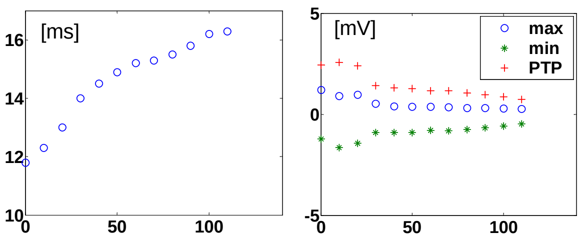

Fig.2 Latency and m-wave amplitude versus knee angle

c. m-wave amplitude in respect to the stimulation amplitude

In Fig.3 the peak-to-peak (PTP)-amplitude, the pos. and neg. maximum of the m-wave and the peak torque of the twitch was ploted against the PTP amplitude of the stimulation voltage.

For the description of the curves the following characteristic values were extracted: the threshold level (U_{th}) of the stimulation amplitude, the stimulation level (U_{sat}) at which the m-wave amplitude (M_{sat}) saturate, the stimulation level ($U_{Msat/2}$) at the half of M_{sat}. Fatigue does not only manifest in a decreased EMG amplitude but also in a disproportional shift of the EMG/Stimulation curve to higher stimulation values in some subjects. Therefore $U_{Msat/2}$ is measured. For the quadriceps the saturation of the m-wave amplitude for stimulation was: U_{sat}= 82Vpp ±9.4Vpp STD. For U_{th} we found 30V ±5.5V STD and for $U_{Msat/2}$ 52V ±7.4V STD respectively. The amplitude of the m-wave M_{sat} was found between 3mV and 9mV. (5.2mV±1.8mV STD).

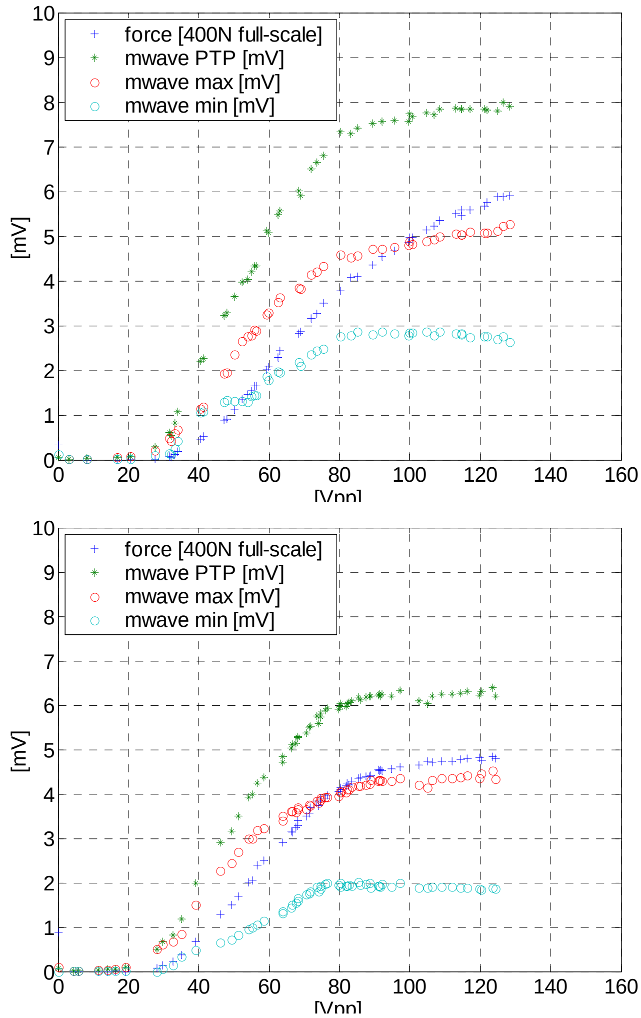

Fig.3 PTP, Max and Min of the m-wave before (upper diagram) and after (lower diagram) fatigue

d. Alteration of the polarity of the stimulation voltage: Changing the polarity of the stimulus leads to another synergy of motorunits and muscle groups respectifely as the different motorpoints are addressed in a different way. If we perform the measurements with both polarities the quadrizeps can be examined more detailed. We could found, that in most subjects the m-wave=f(stimulation) curve shifted to lower stimulation amplitudes for the cathode lateral (Fig.4).

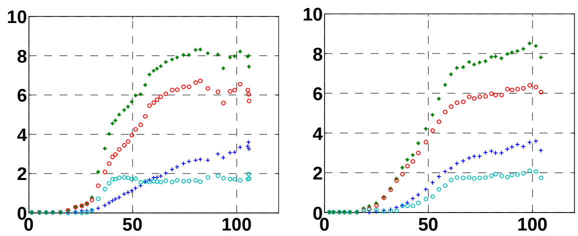

Fig.4 Cathode electrode distal (left), proximal (right) (from top to bottom: mwPTP, mwMax, Force, mwMin)

Discussion:

In sport physiology the m-wave is often monitored as an indicator for a supramaximal response of the force twitch. A saturation of the m-wave means a saturation of the twitch force response. This works for superficies muscle and small stimulation electrodes positioned over the motorpoint.

Using large electrodes (identical for m-wave test and FES training) co-contraction of synergistic muscles leads to a further increase of the twitch amplitude - even if the muscle under investigation is already stimulated supramaximal. Crosstalk of EMG signals also may lead to an increase in m-wave amplitude. If we plot the m-wave and twitch response respectively in relation to the stimulation amplitude the saturation level therefore is characterized by a higher slope below and a lower slope above this level.

Orientation of the bipolar EMG-electrodes: In the literatur we can find both: perpendicular orientation [4] and longitudinal orientation of bipolar EMG electrodes. The problem of the stimulation artefact is not the overriding of the EMG amplifier itself due to the galvanic crosstalk (input signal up to volt level – compared to the mV level for the m-wave signal). The big problem is the discharge process of the capacity of the stimulation electrode after the biphasic pulse. Due to the high gain of the amplifier, the discharge current is sensed even after milliseconds. (see exponential function in Fig.1).

Special attention must be paid for a sufficient *warming up* period. In some previous measurements we found the m-wave amplitude higher before the fatigue test than after. As this occures also in the supramaximal stimulated muscle this fact must be addressed to physiological processes in the muscle cell and therefore can't be distignuished from the fatigue process.

Conclusion:

To indicate muscle fatigue by the measurement of m-wave amplitudes we propose to use not only one teststimulus with a certain supramaximal amplitude but a series of increasing pulses up to 120V pp in steps of 5-10V in order to detect both the onset and saturation level. Repetition rate should be not higher then 2Hz to allow the mechanical response to return to zero in order to avoid movement artefacts for the following m-wave recording. The knee should be kept in a constant position as the relation between m-wave amplitude and knee angle differ very much and would demand a further calibration procedure. Last but not least the orientation of the EMG electrode perpendicular to the thigh is advantageous as the stimulation artefact is much smaller.

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Author's Address

DI. Dr. Dietmar Rafolt
Department of Biomedical Engineering and Physic
Vienna General Hospital
A-1090 Vienna, Währinger Gürtel 18-20
e-mail: dietmar.rafolt@meduniwien.at