Neuromuscular Electrical Stimulation (NMES)

There is an increasing application of long term (i.e. chronic) electrical stimulation in order to modify or change muscle function. This work was initially concentrated around athlete strengthening and function, but in recent years, the intervention has crossed the boundary into clinical practice with an increasing range of applications. There are numerous studies that indicate that such stim is capable of changing muscle function parameters e.g. strength and endurance. There are MANY different terms that are employed to describe this type of intervention, and it is suggested that a general term – like **NeuroMuscular Electrical Stimulation (or NMES)** is preferable to modality names based on specific machines.

Machines can be small, portable and battery powered, can be dedicated clinic units or indeed, NMES functions are available on almost all 'multi-function' electrotherapy machines, examples of which are illustrated below

  	
Examples of portable / battery devices	Multifunction machine which would include NMES waveforms

The mechnism of this intervention relates primarily to muscle fibre type and stimulation frequency, though there are almost certainly other parameters that have an influence (e.g. waveform, stimulation pattern, electrodes etc)

Muscle Fibre Types

MOTOR UNIT - AHC + α motor neurone + muscle fibres

Type I[SO]
slow oxidative
vascular ++
fatigue resistant
(red fibres – old term)

Type II (previously called 'fast' fibres or 'white' fibres)

Type IIa [FOG]
Fast Oxidative Glycolytic
Intermediate; some oxidative metabolism
therefore some fatigue resistance

Type IIb [FG]
Fast Glycolytic
least oxidative; least fatigue resistance
highest, fastest force production

The MU Fibre type is determined (partly at least) by neural stimulation pattern - the concept of neuromuscular plasticity, but also by other factors, most importantly, genetics.

Muscle Fibre Type - Critical Experimentation

Classical work by Buller et al (1960)
Reverse nerve supply (cat)
FG & SO muscles get reverse supply
muscle fibre metabolism changes to match the NERVE
This was repeated by means of Chronic Electrical Stimulation (Salmons & Vbrova 1969)

Physiological Sequence in Contraction

Asynchronous motor unit pattern -> smooth graded contraction
Relates to : No of motor units firing (spatial summation)
Rate of motor unit firing (temporal summation)

Normal Contraction :

Increase no of motor units in early contraction (to ↑ force)
then increase firing rate to increase force further
Type I MU fire first, then Type II. Type IIb brought in last of all

Electrical Stimulation Pattern :

SYNCHRONOUS firing pattern (all MU's fire together)
Type II neurons are LARGER (therefore have a lower threshold, therefore fire first - reverse of the natural sequence)

Effects of Electrical Stimulation :

Short Term
Contraction & altered (local) blood flow

Longer Term ('chronic')
strengthening] after Farragher &
structural changes] Kidd - the concept of
biochemical changes] Eutrophic Stimulation

Electrical Stimulation for Strengthening

Appears to be possible to get an increase in strength with ES. The best effects are achieved if NMES is combined with active exercise BUT can get demonstrable effects with ES alone.

Hon Sun Loi (1988)

3/52 ES with high & low intensity groups. Best results with High Intensity Group
Increase in ISOMETRIC strength, then CONCENTRIC. No change in ECCENTRIC
Strength increases declined at the end of Rx

BUT some maintained @ 3/52 post stimulation
ALSO some crossover effect (to untreated limb)

Balogun (1993)

Similar work - 6/52 stimulation.
24% increase MVC in treated limb. 10% increase MVC in contralateral limb

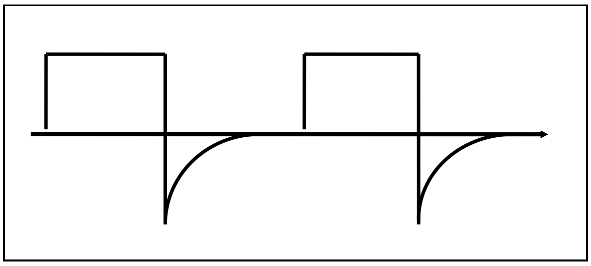
Mechanisms :

Most likely NEURAL (due to speed of response & lack of volume changes)
?spinal motor pool activation
?synaptic facilitation
?muscle motor unit firing pattern (change SO to FOG or FG?)

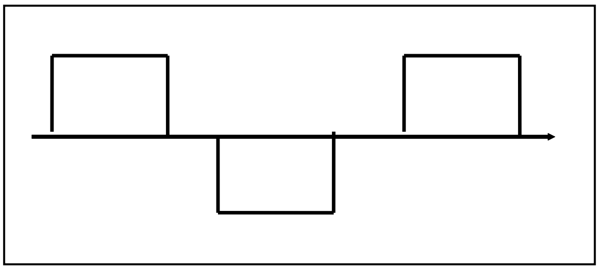
Best effects for weak muscles (Gibson et al 1988)
30Hz @ 300μs, 2 sec ON 9 sec OFF 1 hr/day for 6/52
Knee immobilisation.
Rx group no strength loss, Non Rx group 17% reduced Xsect Area

Waveforms

Biphasic seems to be the most effective



Biphasic asymmetrical



Biphasic symmetrical

Kramer et al (1984), Walmsley et al (1984), Snyder-Mackler et al 1989) have all published evidence which supports the asymmetric over the symmetric waveform (max quads force production).

Approximately linear relationship between CURRENT INTENSITY and FORCE OF CONTRACTION (Ferguson et al 1989, Underwood et al 1990)
The greatest effects with least current intensity by using BIPHASIC PULSED or BURST AC currents. Recent work by Ward et al (2006-2008) lends some support to the use of burst AC (medium frequency – Russian Stim, Aussie Stim) stimulation, though there remains some controversy, yet to be resolved.

Stronger muscle contractions with 300-400μs pulses, BUT these will also produce significant stimulation of sensory fibres.

Stimulation frequency affects FORCE GENERATION
Higher forces produced with tetanic contractions, but also more discomfort and potential for muscle damage, more especially with patients (the tetanic stim is widely researched with athletes/fit individuals rather than those with muscle dysfunction)

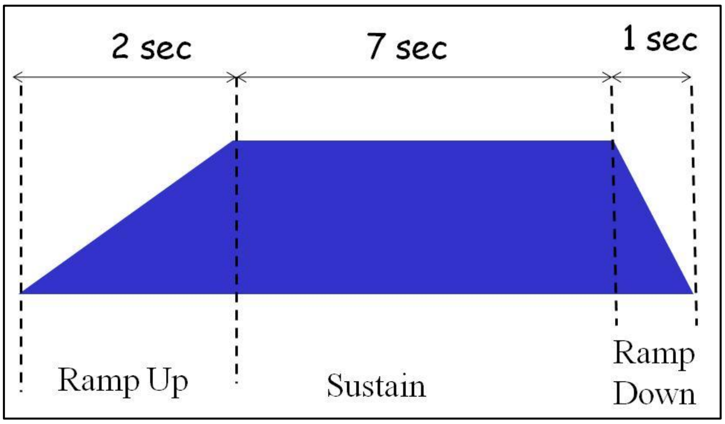
Maximum at 60 - 100Hz (Binder et al 1990), BUT also get higher fatigue
20Hz stimulation will achieve about 65% force, BUT also much less fatigue

Stimulation Parameters

Duty Cycle : (ON : OFF ratio)

Minimum is to use equal cycles (1:1) but only for the stronger / end rehab / fit patients
Use higher ratios for the weaker to allow stim with minimal chance of fatigue
Weaker / poorer state the muscles, larger rest time proportion
Might start at 1:9 for v weak patients and progressively reduce (towards 1:1)
For example, if using stim for quads in a very weak patient (post TKR) might use a 1:9 ratio, so 10 sec stim would be followed by 90 sec rest.

Ramp :



Gradually increase stimulation strength at start & gradually deacrease at end of stimulation train
?more physiological. Certainly more comfortable.
No definitive work but most use : Longer ramp up (2 - 4 sec) Shorter ramp down (1 - 2 sec)

Typical ramped stimulation pattern

Electrodes :

Best if both electrodes on muscle belly
Best if one is at or near motor point
Larger electrodes better (less current density, therefore less discomfort)
?advantage if electrodes placed in LONGITUDINAL orientation (Brooks et al 1990) - stronger contraction with less discomfort
Specialist electrodes are available for pelvic floor stimulation and also glove and sock electrodes

Strengthening Protocols

Athletes + Non Injured Subjects

2500Hz burst AC [Kramer et al 1984, Snyder-Mackler 1989, Walmsley et al 1984]
Symmetric and asymmetric biphasic pulsed [Alon et al 1987, Grimb et al 1989]
Frequency usually at around 60Hz +
Stim intensity at max tollerance
BUT can get an effect at 25-50% MVC (ISOMETRIC)
PULSE WIDTH 300-400µS may be best

Duty cycle relates to fatigue
If less fatigue resistant 1:8 - 1:5
Once less likely to fatigue drop to 1:3 - 1:2 - 1:1

Ramp - no definitive rules, BUT with stronger stimulation use longer ramp.
Usually 2-4 sec ramp up and 1-2 sec ramp down

8 - 15 max contractions / session ; 3 - 5 sessions / week ; 3 - 6 weeks for significant effect

Strengthening Protocols : Rehabilitation Programmes

Similar ideas BUT tend to use LOWER frequencies - (minimum required to get tetany - 20 - 35 Hz). Continue for longer (per session) and use a Duty Cycle which minimises fatigue (at least 1:4 or more). The most effective treatment approach (??) may employ 100 - 200 contractions per session, usually over 1 - 2 hours

Suggested Clinical Treatment Parameters

Muscle Strengthening

30 - 35Hz @ 400 μs
4 sec ON / 4 sec OFF (minimum) but usually 10 sec ON / OFF
at least 15 mins alt days, but usually 30 min / day
Need strong contraction (not just mild twitch) + voluntary as well

Muscle Endurance

20Hz @ 400 μs
2 sec ON / 2 sec OFF (minimum)
at least 1 hr day
Minimal contractions

Very Weak Muscles / Marked Atrophy

10Hz @ 400 μs
2 sec ON / 2 sec OFF (minimum)
minimum 1 hr day
Minimal contraction

Clinical and Research Examples

Musculoskeletal / Orthopaedic

Stevens et al. (2004).
Neuromuscular electrical stimulation for quadriceps muscle strengthening after bilateral total knee arthroplasty: a case series. J Orthop Sports Phys Ther 34(1): 21-9.

Callaghan, M. J. and J. A. Oldham (2004).
Electric muscle stimulation of the quadriceps in the treatment of patellofemoral pain. Arch Phys Med Rehabil 85(6): 956-62.

Lyons, C.et al. (2005).
Differences in quadriceps femoris muscle torque when using a clinical electrical stimulator versus a portable electrical stimulator. Phys Ther 85(1): 44-51.

Cardiovascular

Nuhr, M.J. et al. (2004).
Beneficial effects of chronic low-frequency stimulation of thigh muscles in patients with advanced chronic heart failure. Eur Heart J 25(2): 136-43

Maddocks, M., W. Gao, et al. (2013) Neuromuscular electrical stimulation for muscle weakness in adults with advanced disease. Cochrane Database of Systematic Reviews DOI: 10.1002/14651858.CD009419

Neuro - Stroke

Chantraine et al. (1999)
Shoulder pain and dysfunction in hemiplegia: effects of functional electrical stimulation. Arch Phys Med Rehabil 80(3): 328-31

Ada and Foongchomcheay (2002)
Efficacy of electrical stimulation in preventing or reducing subluxation of the shoulder after stroke: a meta-analysis. Aust J Physiother 48(4): 257-67

Newsam and Baker (2004)
Effect of an electric stimulation facilitation program on quadriceps motor unit recruitment after stroke. Arch Phys Med Rehabil 85(12): 2040-5.

Neuro - Spinal Cord Injury

Crameri et al. (2002).
Effects of electrical stimulation-induced leg training on skeletal muscle adaptability in spinal cord injury. Scand J Med Sci Sports 12(5): 316-22.

Crameri et al. (2000).
Effects of electrical stimulation leg training during the acute phase of spinal cord injury: a pilot study. Eur J Appl Physiol 83(4 -5): 409-15.

Creasey et al. (2004)
Clinical applications of electrical stimulation after spinal cord injury. J Spinal Cord Med 27(4): 365-75.

Scott et al. (2005)
Switching stimulation patterns improves performance of paralyzed human quadriceps muscle. Muscle Nerve 31(5): 581-8.

Sadowsky, C. (2001)
Electrical stimulation in spinal cord injury. NeuroRehabilitation 16(3): 165-9.

Other Literature

In addition to these examples, there are good reviews in Lake (1995) Neuromuscular electrical stimulation: An overview and its application in the treatment of sports injuries. Sports Medicine 13(5): 320-336 and also in two recent book chapters : Neuromuscular electrical stimulation: nerve-muscle interaction (M Cramp and O Scott – Ch 14) and Neuromuscular and muscular electrical stimulation (S McDonaugh – Ch 15) In : Electrotherapy: Evidence Based Practice (2008). Ed. T Watson. Pub : Elsevier

The Electrotherapy Newsletter (available from www.electrotherapy.org) has a commentary on past research papers in many electrotherapy fields, including NMES. Back issues are available from the website. The Newsletter has been replaced with a TWITTER feed in which I try and disseminate new research as it gets published, including numerous papers on NMES.