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

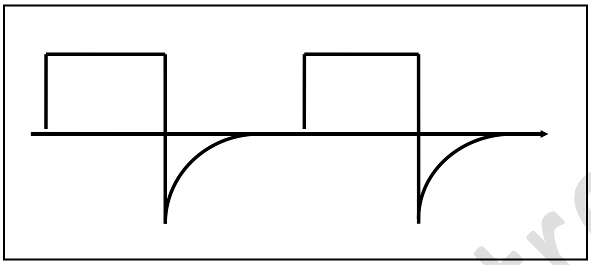
Mechanisms :

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?)

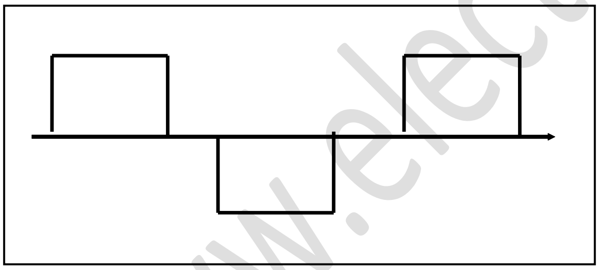
Best effects for weak muscles (Gibson et al 1988)
30Hz @ 300μs, 2 sec ON 9 sec OFF 1 hr/day for 6/52
Knee immobilisation.
Rx group no strength loss, Non Rx group 17% reduced Xsect Area

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

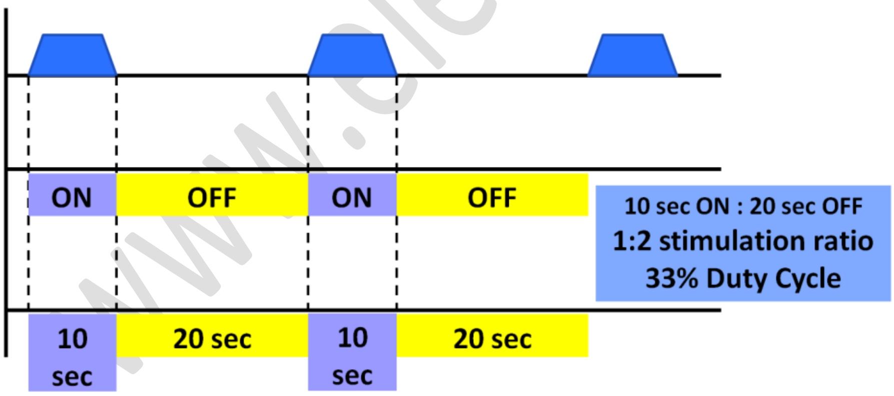
Stimulation Intensity :

This is best used on a subjective rather than an objective basis. As with TENS, Interferential and other forms of stimulation, it is not possible to say that it should be used at XxX or YyY mA stimulation intensity or that you need a particular current for a specific muscle group. It is necessary to stimulate at a level sufficient to achieve a 'good' muscle contraction. The most commonly used method to achieve this is to gradually increase the stimulation intensity (with the patient making no contribution) untill a significant contract is achieved with the machine alone. Once this level is established, the patient is instructed to 'join in' with the stimulation patters, which is straightforward if a patterned / ramped stimulation (see below) is employed.

In research and highly specific sports rehabilitation programmes, the 'amount' of muscle contraction can be related to %MVIC (using a dynanometer or Cybex type system). Some of the clinical research papers cited in the reference list will provide details if this is a relevant application system.

Duty Cycle : (ON : OFF ratio)

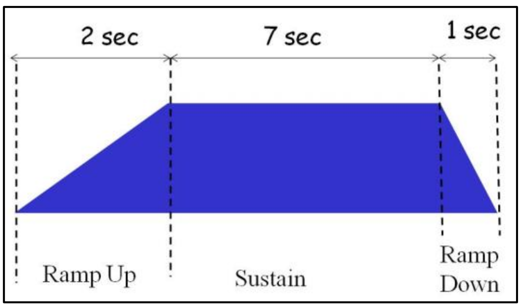
Minimum is to use equal cycles (1:1) but only for the stronger / end rehab / fit patients
Use higher ratios for the weaker to allow stim with minimal chance of fatigue
Weaker / poorer state the muscles, larger rest time proportion
Might start at 1:9 for v weak patients and progressively reduce (towards 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.



Example of a 10 sec stimulation followed by a 20 sec rest (which equates to a 33% duty cycle)

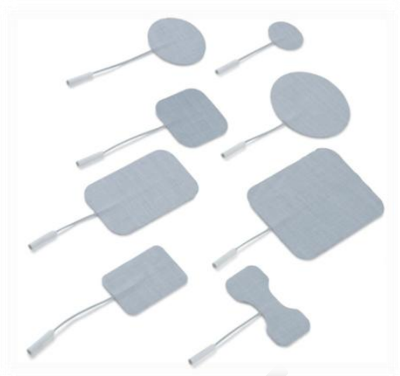
Ramp :

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, sleeve and sock electrodes

There are a wide range of electrodes available. Most practitioners (and patients) prefer the pre-gelled self adhesive type. Like their use in TENS based therapy, they are designed to be multi-use, single patient electrodes - designed to be used over and over, but not shared between patients.

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 (if you have a choice, longer pulses are advantageous over shorter pulses)
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

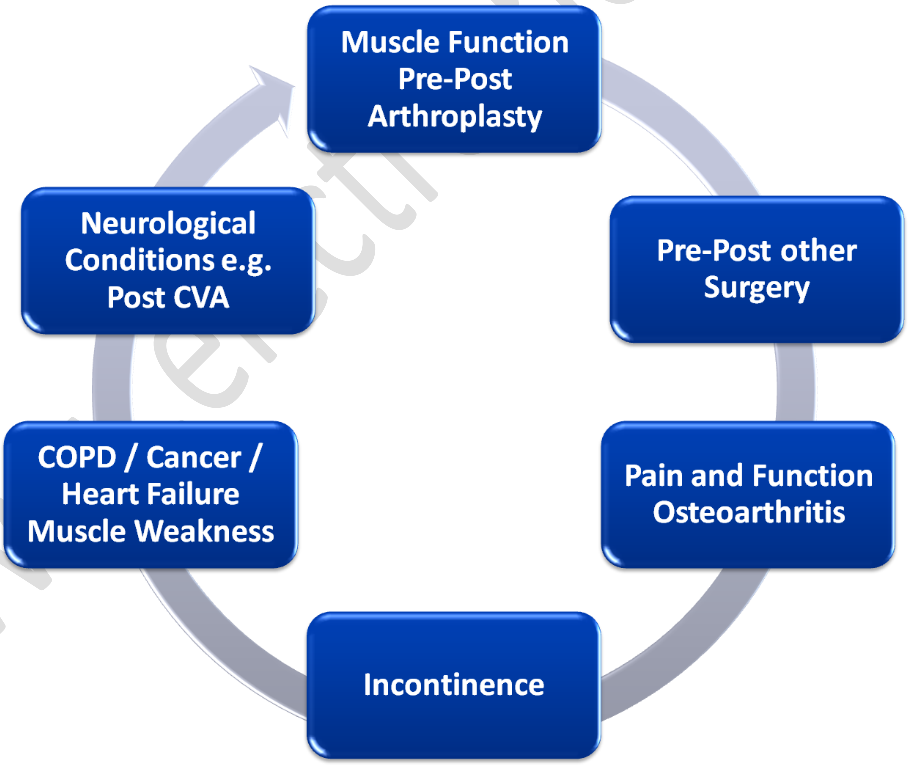
Very Weak Muscles / Marked Atrophy

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

Clinical and Research Examples

[this is by NO means an exhautive list - there are literally thousands of papers like this in my database - they are examples of the kind of resesearch which is out there in the published world]

The main areas of NMES type interventions fall into a number of broad categories which, for convenience, are summarised thus :



Pre-Post Arthroplasty

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Petterson, S. et al. (2009). Improved function from progressive strengthening interventions after total knee arthroplasty: a randomized clinical trial with an imbedded prospective cohort. Arthritis Rheum 61(2): 174-183.

Mintken, P. et al. (2007). Early neuromuscular electrical stimulation to optimize quadriceps muscle function following total knee arthroplasty: a case report. Journal of Orthopaedic and Sports Physical Therapy 37(7): 364-371.

Petterson, S. and Snyder-Mackler, L. (2006). The use of neuromuscular electrical stimulation to improve activation deficits in a patient with chronic quadriceps strength impairments following total knee arthroplasty. J Orthop Sports Phys Ther 36(9): 678-685.

Stevens, J. 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): 21-29.

Pre-Post Other Surgery

Feil, S. et al. (2011). The effectiveness of supplementing a standard rehabilitation program with superimposed neuromuscular electrical stimulation after anterior cruciate ligament reconstruction: a prospective, randomized, single-blind study. Am J Sports Med 39(6): 1238-1247.

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Iwasa, J. et al. (2006). Decrease in anterior knee laxity by electrical stimulation of normal and reconstructed anterior cruciate ligaments. J Bone Joint Surg Br 88(4): 477-483.

Kim, K. et al. (2010). Effects of neuromuscular electrical stimulation after anterior cruciate ligament reconstruction on quadriceps strength, function, and patient-oriented outcomes: a systematic review. J Orthop Sports Phys Ther 40(7): 383-391.

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Wright, R. et al. (2008). A systematic review of anterior cruciate ligament reconstruction rehabilitation: part II: open versus closed kinetic chain exercises, neuromuscular electrical stimulation, accelerated rehabilitation, and miscellaneous topics. J Knee Surg 21(3): 225-234.

Musculoskeletal / Orthopaedic / OA

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.

Durmus, D. et al. (2007). Effects of quadriceps electrical stimulation program on clinical parameters in the patients with knee osteoarthritis. Clin Rheumatol 26(5): 674-678.

Farr, J. et al. (2006). Pulsed electrical stimulation in patients with osteoarthritis of the knee: follow up in 288 patients who had failed non-operative therapy. Surg Technol Int 15: 227-233.

Fillon, M. (2006). A way to save your knees: electrical stimulation may save your knee from surgery. Arthritis Today 20(2): 70.

Gaines, J. et al. (2004). The effect of neuromuscular electrical stimulation on arthritis knee pain in older adults with osteoarthritis of the knee. Appl Nurs Res 17(3): 201-206.

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.

Mont, M. et al. (2006). Pulsed electrical stimulation to defer TKA in patients with knee osteoarthritis. Orthopedics 29(10): 887-892.

Talbot, L. et al. (2003). A home-based protocol of electrical muscle stimulation for quadriceps muscle strength in older adults with osteoarthritis of the knee. J Rheumatol 30(7): 1571-1578

Cardiovascular (COPD, Cancer, Heart Failure)

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Dal Corso, S. et al. (2007). Skeletal muscle structure and function in response to electrical stimulation in moderately impaired COPD patients. Respir Med 101(6): 1236-1243.

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Maddocks, M. et al. (2009). Randomized controlled pilot study of neuromuscular electrical stimulation of the quadriceps in patients with non-small cell lung cancer. J Pain Symptom Manage 38(6): 950-956.

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

Nuhr, M. 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

Roig, M. and W. D. Reid (2009). Electrical stimulation and peripheral muscle function in COPD: a systematic review. Respir Med 103(4): 485-495.

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Vivodtzev et al. (2006). Improvement in quadriceps strength and dyspnea in daily tasks after 1 month of electrical stimulation in severely deconditioned and malnourished COPD. Chest 129(6): 1540-1548.

Vivodtzev, I. et al. (2008). Neuromuscular electrical stimulation of the lower limbs in patients with chronic obstructive pulmonary disease. J Cardiopulm Rehabil Prev 28(2): 79-91.

Neuro - Stroke

Ada, L. and A. 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

Berner, Y. et al. (2004). The effect of electric stimulation treatment on the functional rehabilitation of acute geriatric patients with stroke--a preliminary study. Arch Gerontol Geriatr 39(2): 125-132.

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

Handy, J.et al. (2003). Meta-analysis examining the effectiveness of electrical stimulation in improving functional use of the upper limb in stroke patients. Physical and Occupational Therapy in Geriatrics 21(4): 67-78.

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Khadilkar, A. et al. (2006). Ottawa panel evidence-based clinical practice guidelines for post-stroke rehabilitation. Top Stroke Rehabil 13(2): 1-269.

Knutson, J. and J. Chae (2010). A novel neuromuscular electrical stimulation treatment for recovery of ankle dorsiflexion in chronic hemiplegia: a case series pilot study. Am J Phys Med Rehabil 89(8): 672-682.

Kobayashi, H. et al. (1999). Reduction in subluxation and improved muscle function of the hemiplegic shoulder joint after therapeutic electrical stimulation. J Electromyogr Kinesiol 9(5): 327-336.

Mesci, N. et al. (2009). The effects of neuromuscular electrical stimulation on clinical improvement in hemiplegic lower extremity rehabilitation in chronic stroke: a single-blind, randomised, controlled trial. Disabil Rehabil 31(24): 2047-2054.

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

Robertson, J. et al. (2010). The Effect of Functional Electrical Stimulation on Balance Function and Balance Confidence in Community-Dwelling Individuals with Stroke. Physiotherapy Canada 62(2): 114-119.

Neuro - Spinal Cord Injury

[these examples are larely from the literature other than FES type stimulation, which is big topic and generally outwith the material in this general NMES consideration]

Crameri, R. 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.

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

Gorgey, A. et al. (2013). Neuromuscular electrical stimulation attenuates thigh skeletal muscles atrophy but not trunk muscles after spinal cord injury. Journal of Electromyography and Kinesiology 23(4): 977-984.

Johnston, T. et al. (2011). Muscle changes following cycling and/or electrical stimulation in pediatric spinal cord injury. Arch Phys Med Rehabil 92(12): 1937-1943.

Rayegani, S. et al. (2011). The effect of electrical passive cycling on spasticity in war veterans with spinal cord injury. Front Neurol 2: 39.

Scott, W. 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