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What is functional electrical stimulation (FES)?

- FES is a therapy method where nerves are stimulated with electrical current in order to cause a muscular contraction.
- The aim is to produce a functional movement.

What's the difference between FES and other forms of electrotherapy?

<table>
<thead>
<tr>
<th>TENS</th>
<th>Usual devices for electrotherapy</th>
<th>Advantages FES with RehaMove</th>
</tr>
</thead>
</table>
| · Stimulation of blood circulation, muscle relaxation, and pain reduction  
· No or low physiological contraction/movement  
· No building up muscle strength  
· No complex stimulation | · Only few channels  
· No complex functional movement | · Stimulation of functional movements  
· Motor learning and call up of neuromuscular patterns  
· Cycling due to connection with the MOTOmed  
· External trigger (cause stimulation via manual switch)  
· Different training options: sequence, adaptive/constant mode |

Classification of FES in electrotherapy

<table>
<thead>
<tr>
<th>Current</th>
<th>Frequency</th>
<th>Pulse</th>
<th>Main application</th>
<th>Indication</th>
</tr>
</thead>
<tbody>
<tr>
<td>FES with RehaMove</td>
<td>Alternating current (AC)</td>
<td>10-50 Hz</td>
<td>20-500 µs</td>
<td>Maintenance of muscle function or limitation of atrophy</td>
</tr>
<tr>
<td>Galvanisation</td>
<td>Constant current and direction</td>
<td></td>
<td></td>
<td>Iontophoresis: improvement of motor excitability etc.</td>
</tr>
<tr>
<td>Russian stimulation</td>
<td>Alternating current (AC)</td>
<td>2.5 Hz</td>
<td>Rectangular pulses in “bursts” (pulse sequences)</td>
<td></td>
</tr>
<tr>
<td>TENS</td>
<td>Stimulation current with weak AC</td>
<td>2-220 Hz</td>
<td>Monophasic or biphasic pulses 50-200 µs</td>
<td>Especially used for pain treatment (Analgesia)</td>
</tr>
<tr>
<td>Diadynamic currents</td>
<td>Currents with direct current (DC) and pulse current proportions</td>
<td>50-60 Hz</td>
<td>Sinusoidal half-waves, pulse width 8-10 ms</td>
<td>Analgesic, anti-inflammatory, reducing nerve pain, etc.</td>
</tr>
<tr>
<td>Faradic current</td>
<td>Low-frequency stimulation currents (rectangular pulse)</td>
<td>40-80 Hz</td>
<td>Width: 0.5-5 ms, monophasic or biphasic</td>
<td>Motor stimulation</td>
</tr>
<tr>
<td>Exponential current</td>
<td>Rectangular pulse with pulses of increasing intensity</td>
<td>&lt;1000 Hz</td>
<td>100 ms-800 ms</td>
<td>Maintenance of muscle function or limitation of atrophy</td>
</tr>
</tbody>
</table>

What’s the advantage of FES Cycling compared with motion therapy without current?

<table>
<thead>
<tr>
<th>FES Cycling</th>
<th>Motion training without FES</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Physiological muscle activation with high training intensity</td>
<td>• Passive movement of paralysed muscles, thus only low or no physiological activation</td>
</tr>
<tr>
<td>• Strong effects on the cardiovascular system by using the major muscles of</td>
<td>• High neuronal input by stimulating a high number of afferences</td>
</tr>
<tr>
<td>the body</td>
<td>• Severe venous reflux</td>
</tr>
<tr>
<td>• High neuronal input by stimulating a high number of afferences</td>
<td>• Cosmetic aspects: muscle buildup</td>
</tr>
<tr>
<td>• Severe venous reflux</td>
<td>• Physiological effect: patients can ‘use’ their arms and legs again</td>
</tr>
<tr>
<td>• Cosmetic aspects: muscle buildup</td>
<td></td>
</tr>
</tbody>
</table>

For which clinical pictures the training can be used?

• generally applicable in lesions with an intact lower motoneuron
• Spinal cord injury
• Stroke
• Traumatic brain injury (TBI)
• Multiple sclerosis
• Guillain-Barré syndrome
• Parkinson’s disease
• Chronic polyarthritis (Rheumatoid arthritis)
• Cerebral palsy
• ALS (Amyotrophic Lateral Sclerosis)
• Orthopaedic diseases
• Muscle weakness and paralysis due to Impairments of the peripheral nerve

[Note: Patient’s individual physical constitution or contraindications may forbid an FES application. Please consult your doctor before!]

Which muscle groups can be stimulated?

• generally every paralysed muscle with an intact lower motoneuron
• the surface of the muscle must be large enough for electrode placement

What are the contraindications for FES therapy?

FES and the RehaMove should not be used by a few people:

• who use cardiac pacemakers
• with unhealed fractures in lower extremities if the legs shall be trained; in upper extremities, the area of the shoulder girdle and upper ribs if the arms shall be trained
• with damages of the rotator cuff or the potential luxation of the shoulder joint, if the arms shall be trained
• with epilepsy
• with known allergies to electrode gel
• with metal implants underneath or near the muscle groups which are to be stimulated
• pregnant women should desist from using stimulation because the possible adverse effects are unknown and have not yet been rigorously investigated

Which training duration is recommended?

• depending on the patient, the clinical picture, and the training aim
• patient should be able to get used to the therapy
• training start: 5-10 minutes as the muscles are untrained and fatigue quickly
• up to 1 hour training per day is possible when training regularly
• higher therapeutic effect when training 3-4 times per week for 30 minutes
How does the stimulation work?

- Electrical pulses activate the peripheral motor nerves leading to the corresponding muscles.
- Pulses pass between two electrodes and thus activate the nerves between the electrodes.
- Each nerve has a particular threshold (all-or-nothing principle) triggering an action potential.
- Activation can take place when stimulation intensity is high enough (increase pulse width or current) in order to exceed this threshold.

Important terms

- **Innervation:**
  - supply the human organism with nerves for stimulus conduction
  - intact connection between nerve and muscle

- **Denervation:**
  - no intact nervous connection between organ/ muscle and brain

- **Disuse atrophy:**
  - muscular atrophy

- **Afference:**
  - all information are transferred via neuronal afferences from the periphery (arms, legs) to the central nervous system (CNS)

- **Afferent stimulus setting:**
  - conscious and arbitrary muscle activation in order to produce a directed movement

- **Reaффerence:**
  - information from the central nervous system to the periphery

- **Muscle tone:**
  - tension of the muscle
  - can be influenced by the number of activated motor units or by excitation frequency
  - higher muscle tone in case of spasms
  - muscle tone depends on malpositions and contractures

- **Spasticity:**
  - increased muscle tension with increased muscular proprioceptive reflex

- **Adduction:**
  - movement towards the center of the body or towards body axis (e.g. foot lifting)

- **Abduction:**
  - lateral movement of a body part
Level of paralysis and related functions

- **CERVICAL Division:**
  - breathing (C1 - C4)
  - head & neck movement (C2)
  - heart rate (C4 - C6)
  - shoulder movement (C6 - C7)
  - hand & finger movement (C7 - T1)

- **THORACIC Division:**
  - Sympathetic tone (T1 - T12)
    (including temperature regulation)
  - trunk stability (T2 - T12)
  - ejaculation (T11 - L2)

- **LUMBAR Division:**
  - hip motion (L2)
  - Knee extension (L3)
  - foot motion (L4 - S1)

- **SACRAL Division:**
  - bowel & bladder activity (S2 - S3)
  - penile erection (S2 - S4)
Technical questions

How many muscles/channels can be stimulated simultaneously?
- up to 8 stimulation channels/8 muscles

Which electrode size is used for which application?
- in general: the bigger the electrode the better (more comfortable for the user due to a lower current density)
- electrode size depends on the area of the muscle to be stimulated: for small muscles it’s recommended to use small electrodes and the other way round
- electrode forms: oval or rectangular

Where adhesive electrodes have to be placed?
- centrally on the muscle belly
- for a higher therapeutic effect, electrodes have to be placed with a handbreadth between them
- shave if necessary to improve electrode adhesion and skin contact

Is it possible to use different electrodes?
- due to guarantee and warranty claims we recommend the use of HASOMED electrodes
- adhesive electrodes of the company HASOMED can be used for up to 15 applications
- application note: adhesive electrodes should not be used on skin where e.g. body lotion has been applied

Which pulse forms are used with the RehaStim2?
- stimulation with biphasic rectangular pulses
- the negative pulse ensures an active disloadding to prevent electrolytic effects or skin irritations

![Diagram of current, pulse width, frequency, and action potential](image-url)
In which way the movement is synchronised with the stimulator?
- Stimulator and MOTOmed communicate via data cable
- Data exchange of all relevant parameters (angle or position of the crank arm, rpm and rotational direction, symmetry, gear, time, distance)
- Stimulation sequences of controlled channels are triggered by angle-based MOTOmed data; thus, the stimulator “knows” when to stimulate which muscle

Which parameters are available and what do they effect?

Frequency:
- Number of pulses per second, indicated in Hertz (Hz)
- Stimulation frequency determines the type of muscle fiber, which is activated, and which muscular strength is achieved
- Optimum frequency for a muscle depends on the individual distribution of muscle fibers
- If the frequency is set too low, the muscle reacts only with twitching without strength
- Between 10-50 Hz

Current:
- Charge flowing per time, measured in Milliampere (mA)
- Between 0-130 mA
- Alternating current is used (balanced charge)

Pulse width:
- Duration of pulses, measured in Microseconds (μs)
- Between 20-500 μs

Which parameters are typically used for complete and incomplete paralysis?
- Generally depending on the clinical picture of the patient
- Start with low values and carefully increase gradually
- Aim: a smooth and powerful contraction
- In case of spasticity, better use less Hz first to avoid an excessive increase of the muscle tone (up to 30 Hz)
- It’s advisable to massage muscles before training to desensitize them, longer warm up phase
- In case of maintained sensitivity: the tolerance limit of the patient is the limit of stimulation (after familiarization phase, intensity can generally be increased gradually)

<table>
<thead>
<tr>
<th>Complete SCI</th>
<th>Stroke, TBI and spinal cord lesion with (residual) sensibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Current: 40-90 mA</td>
<td>• Current: 30–40 mA</td>
</tr>
<tr>
<td>• Pulse width: 250-500 μs</td>
<td>• Pulse width: 100-300 μs</td>
</tr>
<tr>
<td>• Current test starting with 0 mA/ 250 μs</td>
<td>• Current test starting with 0 mA/ 100 μs</td>
</tr>
<tr>
<td>• MOTOmed: servo cycling with gear 0-1</td>
<td>• MOTOmed: servo cycling with gear 0-6</td>
</tr>
</tbody>
</table>
How endurance and strength can be trained?
- for strength training higher frequencies are necessary (starting with 30 Hz)
- for endurance training only lower frequencies are used (up to 30 Hz)
- Type of muscle fiber:

<table>
<thead>
<tr>
<th>Type I fibers – slow twitch</th>
<th>Type II fibers – fast twitch</th>
</tr>
</thead>
<tbody>
<tr>
<td>contract and relax slowly</td>
<td>quick and powerful contraction</td>
</tr>
<tr>
<td>resistant to fatigue</td>
<td>white muscle fibers</td>
</tr>
<tr>
<td>for endurance-type activities</td>
<td>for “sprint” and muscular strength</td>
</tr>
<tr>
<td>well supplied with blood: red</td>
<td>2 subtypes: a) fast-fatigue-resistant</td>
</tr>
<tr>
<td>stimulation with frequencies &lt; 30 Hz</td>
<td>b) fast-fatigable</td>
</tr>
<tr>
<td></td>
<td>stimulation with frequencies &gt; 30 Hz</td>
</tr>
</tbody>
</table>

What is the ramp for?
- pulse width is built slowly and gradually
- especially suitable for sensitive and anxious patients
- example: ramp 5, pulse is built in 5 steps with increasing intensity

Is it possible to adapt the current with increasing training duration?
- depends on the patients adapting threshold and sensitivity
- during training, current can be adjusted for each channel; frequency and pulse width can be adjusted for all channels

With which motion trainer the RehaStim2 can be used?
- only use the RehaStim2 with the MOTOmed viva 2 (without light version) as arm and leg trainer

When the adaptive training is used?
- in general: therapist decides on the patient group to be treated
- adaptive training: adapts automatically to the patient’s performance
- stimulation is adapted to the residual muscle function of the patient
- mostly used in incomplete and central paralysis: stroke, TBI
- adjustment of maximum and minimum pulse width:
  - when a certain speed is reached, stimulation will stop slowly
  - stimulation starts again below this speed
When the constant training is used?
- in general: therapist decides on the patient group to be treated
- constant training: stimulation intensity remains constant even if the patient pedals faster and more powerful
- mostly used in complete paraplegia

Sequence training with RehaStim

How does the sequence training work?
- RehaStim can be used without the MOTOmed as stand-alone device
- cyclical movements of arms and legs can be trained (e.g. grasping, flexion)

When the sequence training is used?
- for activation or movement of single muscles
- in order to increase training intensity, e.g. alternating activation of quadriceps muscle and biceps muscle
- Sequence training is used where the RehaMove cannot be applied, e.g. when reinitializing complex motion sequences like grasping
- RehaStim includes templates for the most common applications e.g. FES walking, crawling, sit-to-stand or shoulder stabilization

How can I get the sequence training?
- can be activated via additional licenses for present stimulators

What is the difference between percent and second mode in sequence training?
- percent sequence training includes all templates for gait training/FES walking in percentage according to the natural gait phases in a complete gait cycle
- second sequence training includes templates in seconds (start + duration of each single muscle in seconds)

What effect has the button “Period” in the percentage-sequence training?
- duration of the complete sequence is adjusted
- periods are adjustable in seconds

What effect has the button “Interval” in the second-sequence training?
- there is always a break between single sequences
- break times can be selected in steps of one second

Which trigger types are available?
- Sequence training offers a manual or automatic triggering
- an additional external trigger software with external single or double trigger is available
RehaMove Solutions for Movement Therapy with FES

- Walking
- Arm Cycling
- Indoor Leg Cycling
- Shoulder Stabilization
- Outdoor Leg Cycling
- Stepping*
- Single Movements Such As Wrist Extension

* distributed by Hocoma

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