

HASOMED

# RehaMove<sup>®</sup> FES Cycling

## Functional Electrical Stimulation

Templates External Trigger Studies

### FES Walking Science Mode Sit 2 Stand

Electrode Cuff Sequence Training



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# Functional Electrical Stimulation (FES)

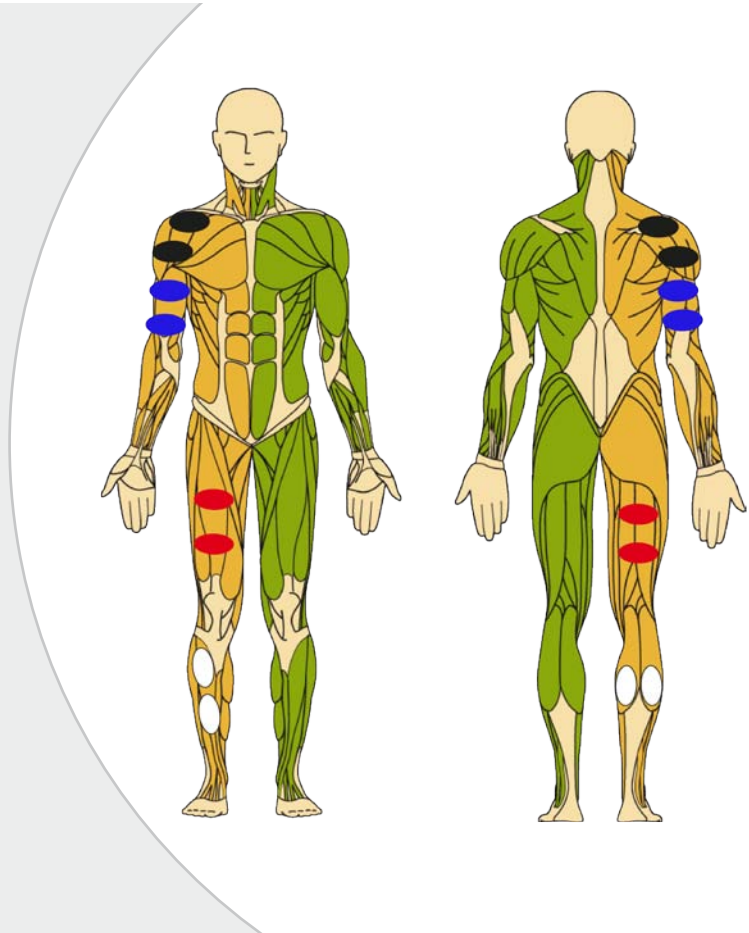
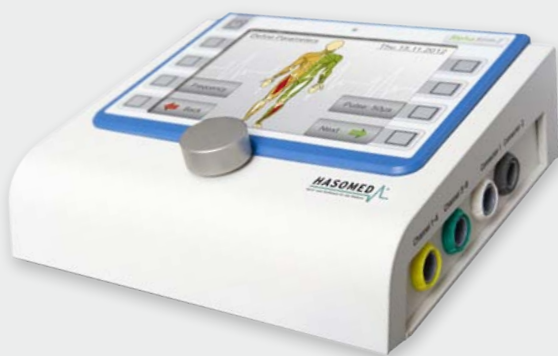
Functional electrical stimulation (FES) is a therapy method where nerves are stimulated with electrical current via surface electrodes in order to cause muscular contraction. The aim is to produce a functional movement for impaired extremities.

FES can enable muscles to be trained even if some or all voluntary control of them has been lost. Additionally, FES can support volitional muscle control to complete a functional movement or to facilitate activities of daily living.

The use of FES is scientifically proven for the following purposes:

- Relaxation of muscle spasms
- Prevention or retardation of disuse atrophy
- Increasing local blood circulation
- Maintaining or increasing range of motion

## 8 channels for various FES applications



The RehaMove is a portable electrical stimulation device that generates impulses on up to 8 channels simultaneously to activate impaired/paralyzed muscles via surface electrodes.

In addition, the stimulator software and hardware have been especially designed for use in a specific rehabilitation system using an ergometer for FES Cycling.

### Performance

- 8 color-coded free programmable stimulation channels
- frequency 1-50 Hz
- pulse width 10-500  $\mu$ s
- amplitude 1-130 mA

# RehaMove at a Glance

## Wide range of indications

Using RehaMove is indicated in neurological patients. Neurological disorders include:

- Stroke
- Spinal cord injury (SCI)
- Traumatic brain injury (TBI)
- Parkinson's disease
- Multiple sclerosis (MS)

## User friendly

A big graphical display makes it easy to interact with the device. The operation of the device happens via pressure-sensitive buttons and a rotary switch.

## Individual

Numerous parameters concerning power and temporal sequence of the impulses can be adjusted individually for each channel. The integrated database offers to save hundreds of individual training profiles.

## Flexibility

The stimulator can generally be applied to functional electrical stimulation tasks of all kinds. RehaMove is designed as portable (contains a battery) as well as stationary device for training and rehabilitation applications. It can be used on its own or in combination with a motion trainer.

## Safety first

Tapping [Stop] on the screen or pressing the emergency off button stops the movement and stimulation immediately in events when the patient feels unwell during a training session.

An electrode error detection function stops the device in case of faulty electrodes or other errors.

## Made in Germany

The RehaStim2 stimulator is made in Germany and certified according to the international standards EN 60601-1 and EN 60601-2-10 for medical technical devices and systems.





## Active arm or leg training despite complete or incomplete paralysis

FES Cycling enables active arm or leg ergometer training even with impaired muscles. The effective and feasible outcome parameters depend on individual constitutions and disorders of each user.

In either situation, the user can create multiple stimulation programs and track performance gains over time. Performance data can be viewed on the device or exported for viewing with the included Windows PC software.

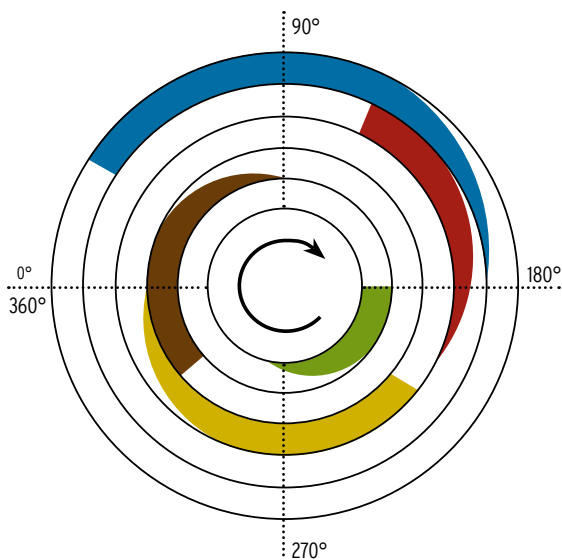
FES movement training	Movement training without FES
<ul style="list-style-type: none"> <li>· Physiological muscle activation with high training intensity</li> <li>· Strong effects on the cardiovascular system by using the major muscles of the body</li> <li>· neuronal input by stimulating a big number of afferences</li> <li>· Severe venous reflux</li> <li>· Cosmetic aspects: muscle buildup</li> <li>· Physiological effect: patients can “use” their arms and legs again</li> </ul>	<ul style="list-style-type: none"> <li>· Passive movement of paralysed muscles with low or no physiological activation for complete or incomplete paralyzed limbs</li> </ul>

# RehaMove FES Cycling



## Upgrade your MOTomed with FES

RehaMove and MOTomed communicate via a data cable which allows 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” the right stimulation time of each muscle.



- M. quadriceps fem.
- M. gluteus max.
- M. biceps fem.
- M. tibialis ant.
- M. gastrocnemius

Video  
FES-Cycling



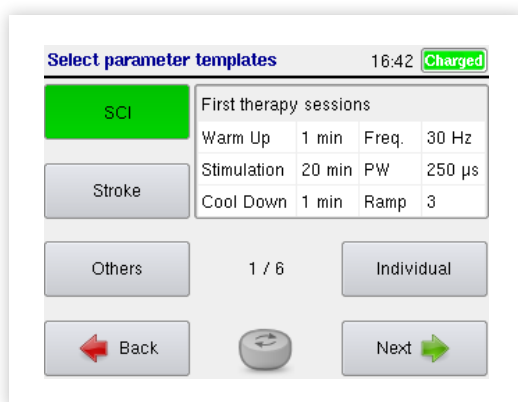
## RehaMove Letto2 - FES Cycling for ICU and early rehabilitation

The RehaMove Letto2 may help to balance lack of movement in users confined to bed. Users can train actively from a bed or therapy chair. The RehaMove Letto2 provides well-rounded therapy to users in stationary care as well as at home.



## Training templates with pre-defined parameter configurations

RehaMove offers a large number of stimulation templates for various applications. All templates are based on clinical studies and experiences, and provide different channel/muscle configurations paired with indication-specific parameter settings.



For initial trainings, stimulation intensity should start low and be carefully increased to generate smooth and powerful contractions without pain or fast muscle fatigue.

In cases of spasticity, the use of lower frequency values (Hz) is indicated to avoid an excessive increase of muscle tone. It's advisable to massage muscles before training to desensitize them. Alternatively, a longer warm up phase is recommended. In cases of maintained sensitivity, the tolerance limit of the user should be the limit of stimulation (after a familiarization phase, intensity can generally be increased gradually).



# RehaMove FES Cycling

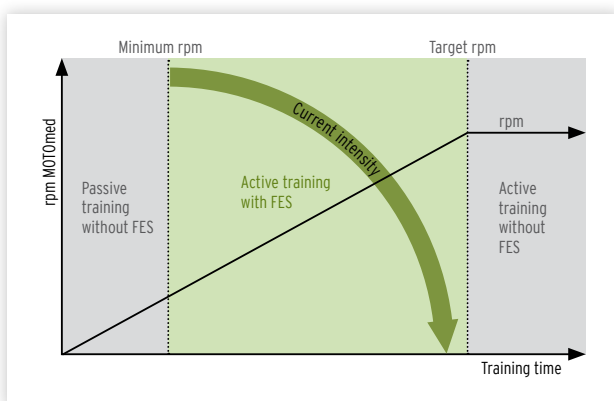


## Different forms of training with the RehaMove in adaptive and constant mode

### Adaptive mode

In adaptive mode, the current intensity adapts to the active rpm of the user.

Aim: support the residual muscle function of the user and adapt the stimulation depending on muscle fatigue.

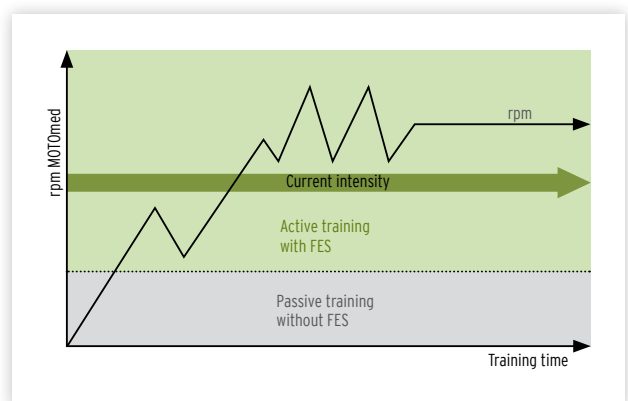


Settings of the RehaMove in adaptive mode

### Constant mode

In constant mode, the current remains the same regardless of the active performance of the user.

Aim: active movement even with residual muscle function.



Settings of the RehaMove in constant mode



Video  
FES-Walking



# RehaMove Sequence Training

## 8 stimulation channels for various FES applications

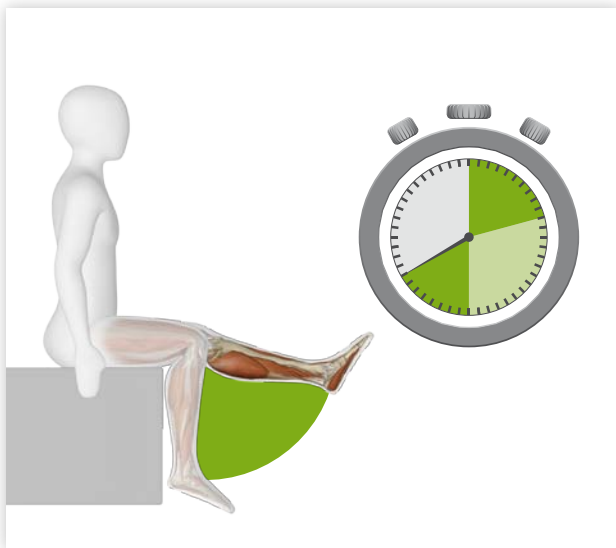
The RehaMove Sequence Mode offers the stimulation of various functional movements, such as, 1-channel wrist extension up to 8-channel gait training. All stimulation channels can be individualized related to user and clinical needs. RehaMove Sequence Mode can be activated via additional licenses for present stimulators.

As well as for RehaMove FES Cycling, Sequence Training includes templates for the most common applications e.g. FES walking, crawling, sit-to-stand, or shoulder stabilization.

## Advanced setting of stimulation sequences

### Second Mode:

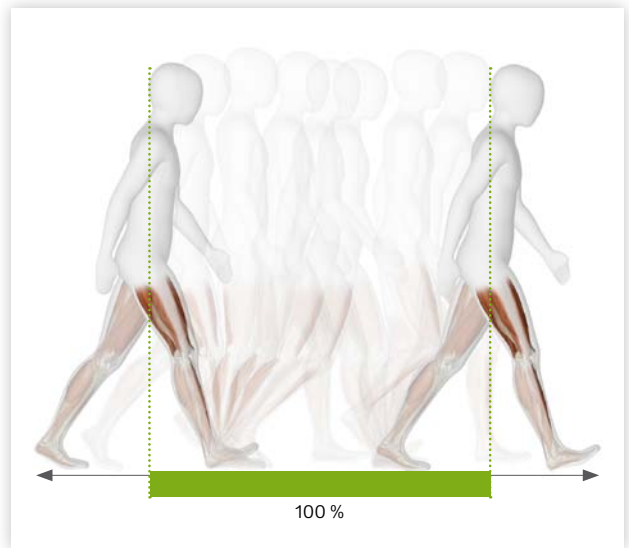
The duration of each individual sequence is indicated by the start and end time in seconds. The resting time between the individual sequences results from the end and starting points of two consecutive sequences.



*Second Mode: Perfect for simple and non-cyclical stimulation sequences, i.e. wrist extension training*

### Percent Mode:

One complete movement (e.g. one gait cycle) corresponds to 100%. The duration of the period indicates the movement duration. The user defines the relative proportions of the individual sequences of the complete movement in percent. The resting intervals are generated automatically.



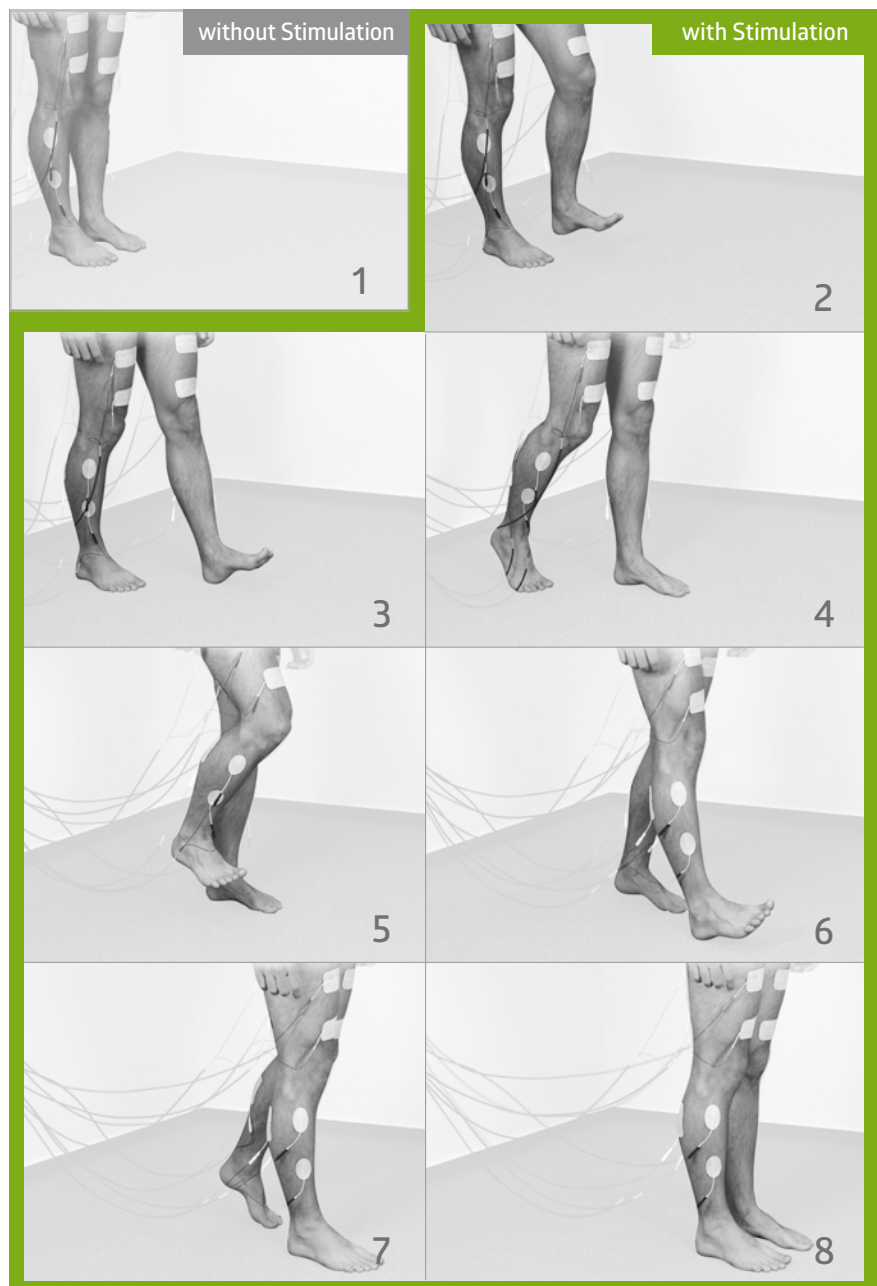
*Percent Mode: Perfect for cyclical stimulation sequences, i.e. gait training*

## Which applications fit physical therapist's needs?

In physical therapy, the focus is on motor initiation, training of atrophied muscles, general preservation of mobility and compensation of impaired/paralyzed muscles. Muscle atrophy can restrict therapy success extensively. With additional FES, especially of the large (leg) muscles, an important contribution related to preservation of strength and mobility as well as improvements in motor skills can be ensured.



*Support of activities of daily life, i.e. sit to stand exercises.*



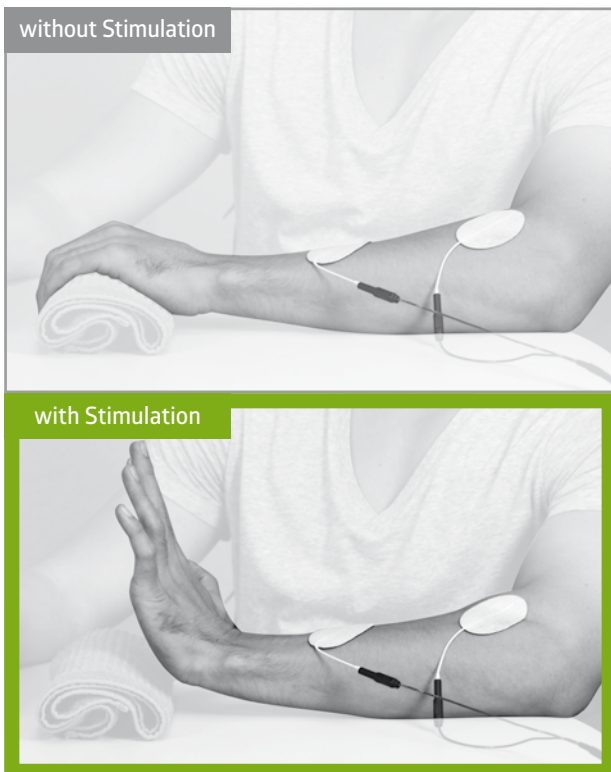
*FES Gait training i.e. on bars*

# RehaMove Sequence Training

## Which applications fit occupational therapist's needs?

After stroke or quadriplegia, upper extremity therapy can be a high priority. Missing motor or sensory functions can be recovered with high and frequent training efforts.

FES increases the afferent and efferent input of the stimulated muscles and can help to support motor exercises and sensory recovery.



*Wrist-extension-stimulation for hemiplegic or quadriplegic patients.*



*Stimulation of the rotator cuff to improve arm lift movements and prophylaxis of subluxation.*

For a detailed listing of the most common FES applications please see the RehaMove application brochure.



Simple and secure  
placing of electrodes

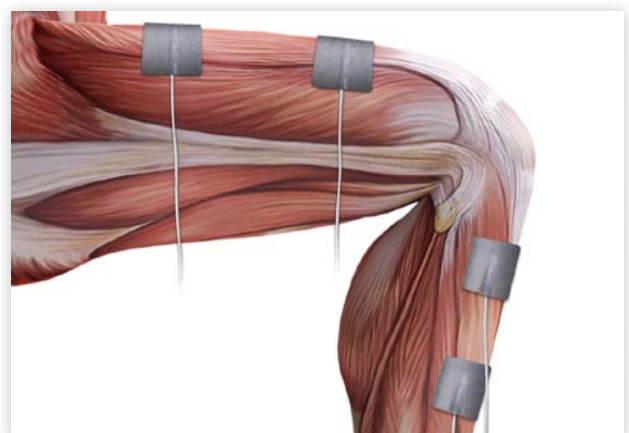
## The correct electrode position

Different muscles require different electrode sizes and positions. Muscle fiber direction and other muscles close by with antagonistic functions have to be considered. For example, a too-large electrode for the Tibialis Anterior muscle could cause an unwanted stimulation of the antagonistic Soleus muscle.

The electrodes should be placed over the belly of the muscle along the muscle fiber with a distance of at least one electrode between them.

A 100% exact and reproducible positioning of the electrodes is almost impossible due to the different location of the motor nerves.

If required, or in case of an unsatisfactory stimulation result, the electrode position can be adjusted any time.



# Electrode Applications



## RehaMove electrode cuff

The RehaMove electrode cuff is a new alternative for femoral stimulation applications like FES gait training or FES cycling. The cuff consists of two textile layers with integrated 5x9 cm (2"x3.5") rubber electrodes. This electrode size is most suitable for the stimulation of large leg muscles while a long-lasting and exchangeable gel layer guarantees optimal skin contact.

For a flexible and accurate fit to different leg circumferences, the cuff provides two freely movable electrode pads. All materials are comfortable to wear and compatible for users with sensitive skin.

### Benefits at a glance

- Stimulation of knee flexor and extensor with one cuff
- Quick and safe electrode application
- Cost effectiveness
- High-quality materials for user comfort
- Optional usage of adhesive electrodes for 2 additional channels



## Research Application

### ScienceMode – central tool for FES research & development

The effect of Functional Electrical Stimulation (FES) is topic of scientific investigations worldwide. Research requires high performance stimulators with multiple options concerning individual adjustment and external control.

Succeeding RehaStim1 and RehaStim2, HASOMED presents RehaMove3 – the 3rd generation within 15 years to satisfy clinical and research needs.

The ScienceMode protocol for scientific FES applications was developed in close cooperation with the Technische Universität Berlin.

ScienceMode enables the communication between a PC or external device and the Stimulator wirelessly with Bluetooth or via USB using an extensive protocol. The PC or external devices can control all stimulation tasks and measurements.

#### Performance

- 4 stimulation channels
- Frequency 1-500 Hz
- Pulse width 10  $\mu$ s - 4 ms (1  $\mu$ s steps) amplitude 0-150 mA (0,5 mA steps)
- Adjustable stimulation waveform (16 characteristic points)
- Compatible for Demux/Array applications
- MatLab/Simulink library & pre-compiled library for several compiler (e.g. MSVC, GCC)

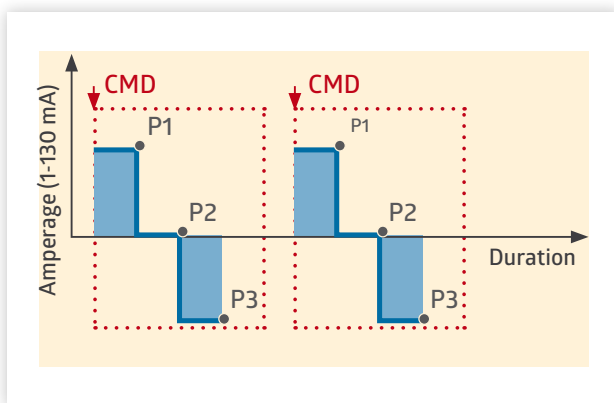


## New Low-Level & Mid-Level communication protocol

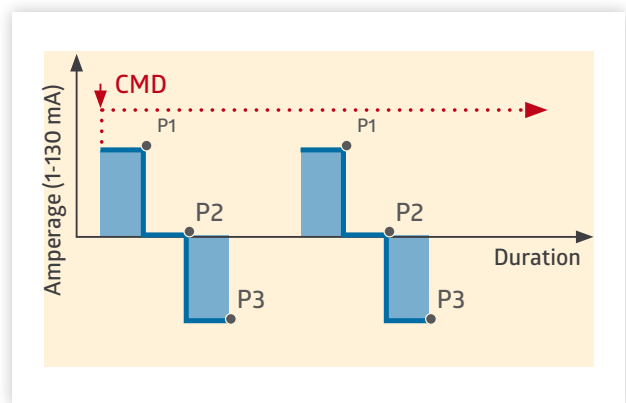
RehaMove Pro with ScienceMode offers advanced communication levels for superior scientific FES performance.

The Low-level Layer allows explicit manipulation of every aspect of the stimulation waveform and the stimulation timing. Each stimulation impulse must be initiated by the control program, which enables individual non-periodic stimulation patterns. The Mid-level Layer implements a minimalistic command set with most common stimulation parameters. Corresponding stimulation commands are generated directly by the RehaMove3 with the favored stimulation frequency.

### Low-Level



### Mid-Level

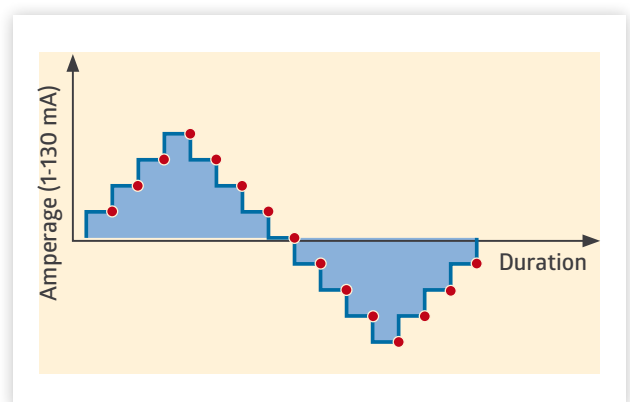


## C-library for a simplified integration

Low- and Mid-level protocols were directly supported by a pre-compiled C-library. This library simplifies the integration in customer-specific applications or computer programming environments such as Matlab/Simulink, Scilab/Xcos or Python.

## Free adjustable waveform

A new and important feature of RehaMove3 is the extensive level of control over the waveform, which can be illustrated by up to 16 characteristic points. Each point is defined by a duration and a current. Any number of waveforms can be created this way. The duration of each point can be chosen in 1  $\mu$ s steps between 10  $\mu$ s and 4095  $\mu$ s. The current has a resolution of 0.5 mA and is limited to 150 mA at the highest setting.



ANNALS OF REHABILITATION MEDICINE

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repeated measures analysis of variance (ANOVA) were used to examine the intervention effects. A main effect was found. The significance of the interaction was also analyzed. The size of the effect was calculated using eta squared ( $\eta^2$ ) for each outcome variable. A large effect represented a greater magnitude of treatment. An effect was considered large at  $\eta^2 \geq 0.36$ , moderate at  $\eta^2 \geq 0.25$ , and small at  $\eta^2 \geq 0.10$ . Statistical analyses were performed with SPSS 19.0 (Inc., Chicago, Illinois).

baseline characteristics of the participants are summarized in Table 1. There were no statistically significant differences between the 2 groups. Group differences of all the outcome measures at baseline were also analyzed. The mobility domain of the SIS revealed a significant group difference ( $p = 0.039$ ) at baseline, while no significant differences were found in other outcome measures (Table 2).

**Motor Impairment**

For the UE-FMA score, repeated measures ANOVA showed no significant group  $\times$  time interaction ( $F_{2,74} = 0.010, p = 0.955, \eta^2 < 0.001$ ). A significant time main effect was found ( $F_{2,74} = 11.852, p = 0.001, \eta^2 = 0.243$ ), with no significant group main effect ( $F_{1,74} = 1.635, p = 0.209, \eta^2 = 0.022$ ). This result after the bimodal RT intervention, but the 2 groups did not differ in the amount of improvement (Table 2).

For the MAS score of the wrist flexor, there was a significant group  $\times$  time interaction ( $F_{1,74} = 4.161, p = 0.049, \eta^2 = 0.051$ ), with no significant time or group main effect (Table 2). Post-hoc analyses of the interaction revealed that while the MAS of the RT + Sham group significantly improved ( $p = 0.017$ ), no significant change was found for the RT + FES group ( $p = 0.308$ ). Aside from the wrist flexor, no significant changes were observed for the MAS scores of forearm pronators, forearm supinators, and wrist extensors after the interventions.

**Motor and Daily Function**

The RT + ES and RT + Sham groups improved significantly in the WMFT-Timed ( $p = 0.017$ ) but no significant time interaction or group main effect ( $F_{1,74} = 6.874, p = 0.011, \eta^2 = 0.085$ ). A significant group  $\times$  time interaction was observed for the RT + FES group ( $F_{1,74} = 5.571, p = 0.021, \eta^2 = 0.071$ ), with no significant time or group main effect ( $F_{1,74} = 0.010, p = 0.955, \eta^2 < 0.001$ ).

# Study Protocol

Objective:

Method:



**HASOMED RehaMove 3**  
Functional Electrical Stimulation

**NEW**  
3 channel EMG measurement  
algorithm available



Research Application

**ACRM** Archives of Physical Medicine and Rehabilitation

ORIGINAL ARTICLE

## Functional Electrical Stimulation Cycling—Therapeutic Effects in Hemiparesis From 7 Days to 6 Months: A Randomized Controlled Pilot Study

Petra Bauer, MSc,<sup>a,b</sup> Carmen Krewer, PhD,<sup>a</sup> Eberhard Koenig, MD,<sup>a</sup> Friedemann Müller, PhD,<sup>a</sup>

From <sup>a</sup>Schön Klinik Bad Aibling, Bad Aibling, Germany; <sup>b</sup>Paracelsus Clinic, Department of Neurology and Neuroscience Institute, Paracelsus Clinic, Salzburg, Austria.

**Abstract**  
**Objective:** To determine whether functional electrical stimulation (FES) could improve walking and balance. Specifically, walking ability was evaluated for static and dynamic balance tasks.  
**Design:** Multicentric, randomized, single-blinded, controlled trial.  
**Setting:** Neurologic rehabilitation hospital.  
**Participants:** Patients with severe hemiparesis due to stroke (N = 20).  
**Interventions:** Twenty minutes of active leg cycling with or without FES.  
**Measurements and Main Results:** Functional ambulation classification (FAC) and the Berg Balance Scale (BBS) were significantly better in the FES group for both the FAC (p = 0.002) and the BBS (p = 0.001). The MI leg did not reach statistically significant P values. The MI leg did not reach statistically significant P values. The MI leg did not reach statistically significant P values.  
**Conclusions:** FES-assisted active cycling seems to be a promising approach to improve walking and balance in patients with severe hemiparesis.  
© 2015 by the American Congress of Rehabilitation Medicine

## Studies

In recent years, various functional electrical stimulation (FES) techniques have been developed. The main goal was to provide alternative and efficient solutions for achieving the activities of daily living (ADLs) and to improve muscle function and physical fitness of paralyzed patients.

The applications can be divided into four areas: Stimulation of upper extremities, Standing, Walking, and Cycling.

RehaMove can be used for the main FES applications in all fields and has been applied in worldwide scientific projects for more than 10 years.

Your contribution is warmly welcomed for investigations regarding the effectiveness of FES with RehaMove. HASOMED will support research activities.

Support us with your ideas, projects, studies, and databases!

## Four weeks of functional electrical stimulated cycling after spinal cord injury: a clinical cohort study.

International Journal of  
Rehabilitation Research  
The Official Journal of the European Federation for Research in Rehabilitation

D. Kuhn, V. Leichtfried, W. Schobersberger, K. Röhl

International Journal Rehabilitation Research 2014, Vol 37 No 3:243-250

**BACKGROUND:** An increasingly shorter inpatient stay accents the need for the best possible support and consequently the effectiveness of function-oriented physiotherapy. Predominantly in patients with spinal cord injury therapy devices may complement the intervention and therefore should be scientifically specified and further evaluated. Functional electrical stimulation could be such a complement; however, previous studies investigated only primarily measurable effects.

**OBJECTIVE:** This prospective cohort study evaluated the FES-cycling's impact on functional abilities and performance parameters as well as the subjective pain and health perception of patients with spinal cord injury.

**METHOD:** 30 patients (13 with tetraplegia, 17 with paraplegia) participated in the FES-cycling programme. Before and after each session pain perception was assessed using the Numeric Rating Scale (NRS). In addition, activities of daily living (Spinal Cord Independence Measure III, SCIM III), health-related well-being (Short Form 36 Health Survey), and performance data of the leg ergometer were collected.

**RESULTS:** After 4 weeks' training, the SCIM rose from 42 to 51 points ( $p = 0.004$ ). The results of the SF-36 (subjective pain perception, vitality, mental well-being) improved significantly ( $p < 0.001$ ). In Patients both with complete as well as incomplete paraplegia the average active performance ( $p = 0.035$  vs.  $p = 0.002$ ) and physical work ( $p = 0.025$  vs.  $p = 0.001$ ) increased significantly.

**CONCLUSIONS:** The results suggest that FES-cycling can support acute functional rehabilitation as well as motivation for continuing self-exercise in patients with spinal cord injury.

## Functional electrical stimulation-assisted active cycling: therapeutic effects in patients with hemiparesis from 7 days to 6 months after stroke.

Archives of  
Physical Medicine  
and Rehabilitation

Bauer P, Krewer C, Golaszewski S, Koenig E, Müller F;

Arch Phys Med Rehabil. 2015 Feb;96(2):188-96

**OBJECTIVE:** To determine whether functional electrical stimulation (FES)-assisted active cycling is more effective than active cycling without FES concerning walking and balance. Specifically, walking ability was classified as to the amount of personal assistance needed to be able to walk and balance was evaluated for static and dynamic balance tasks.

**METHOD:** Monocentric, randomized, single-blinded, controlled trial. Patients with severe hemiparesis due to stroke (N=40). Twenty minutes of active leg cycling with or without FES applied to the paretic vastus medialis and rectus femoris of quadriceps and to the biceps femoris and semitendinosus muscles, 3 times/wk for 4 weeks.

**RESULTS:** After the intervention, the FAC, POMA, and the MI ( $P < .016$ ) for both intervention groups improved significantly. The FAC of the control group increased by a median of 1 category and that of the FES group by 2 categories. The median change in POMA was 2 and 4 points for the control group and the FES group, respectively. The Mann-Whitney U test between-group comparisons revealed that these gains were significantly better in the FES group for both the FAC ( $U=90$ ;  $z=-2.58$ ;  $P=.013$ ;  $r=-.42$ ) and the POMA ( $U=60$ ;  $z=-3.43$ ;  $P<.0004$ ;  $r=-.56$ ).

**CONCLUSIONS:** FES-assisted active cycling seems to be a promising intervention during rehabilitation in patients with stroke.

## Cycling induced by electrical stimulation improves motor recovery in postacute hemiparetic patients: a randomized controlled trial.

### Stroke

Ambrosini E, Ferrante S, Pedrocchi A, Ferrigno G, Molteni F.

Stroke. 2011 Apr;42(4):1068-73

**OBJECTIVE:** This study assessed whether cycling induced by functional electrical stimulation (FES) was more effective than passive cycling with placebo stimulation in promoting motor recovery and walking ability in postacute hemiparetic patients.

**METHOD:** In a double-blind, randomized, controlled trial, 35 patients were included and randomized to receive FES-induced cycling training or placebo FES cycling. The 4-week treatment consisted of 20 sessions lasting 25 minutes each. Primary outcome measures included the leg subscale of the Motricity Index and gait speed during a 50-meter walking test. Secondary outcomes were the Trunk Control Test, the Upright Motor Control Test, the mean work produced by the paretic leg, and the unbalance in mechanical work between paretic and nonparetic legs during voluntary pedaling.

**RESULTS:** Repeated-measures ANOVA ( $P < 0.05$ ) revealed significant increases in Motricity Index, Trunk Control Test, Upright Motor Control Test, gait speed, and mean work of the paretic leg after training and at follow-up assessments for FES-treated patients. A main effect favoring FES-treated patients was demonstrated by repeated-measures ANCOVA for Motricity Index ( $P < 0.001$ ), Trunk Control Test ( $P = 0.001$ ), Upright Motor Control Test ( $P = 0.005$ ), and pedaling unbalance ( $P = 0.038$ ).

**CONCLUSIONS:** The study demonstrated that 20 sessions of FES cycling training significantly improved lower extremity motor functions and accelerated the recovery of overground locomotion in postacute hemiparetic patients.

## A randomized trial of functional electrical stimulation for walking in incomplete spinal cord injury: Effects on walking competency.

### The Journal of Spinal Cord Medicine

Kapadia N, Masani K, Catharine Craven B, Giangregorio LM, Hitzig SL, Richards K, Popovic MR.

J Spinal Cord Med. 2014 Sep;37(5):511-24

**OBJECTIVE:** To investigate short- and long-term benefits of 16 weeks of thrice-weekly multi-channel surface FES-assisted walking program, while ambulating on a body weight support treadmill and harness system, versus a non-FES exercise program, on improvements in gait and balance in individuals with chronic incomplete traumatic SCI, in a randomized controlled trial design.

**METHOD:** Individuals with traumatic and chronic ( $\geq 18$  months) motor incomplete SCI (level C2 to T12, American Spinal Cord Injury Association Impairment Scale C or D) were recruited from an outpatient SCI rehabilitation hospital, and randomized to FES-assisted walking therapy (intervention group) or aerobic and resistance training program (control group). Outcomes were assessed at baseline, and after 4, 6, and 12 months. Gait, balance, spasticity, and functional measures were collected.

**RESULTS:** Spinal cord independence measure (SCIM) mobility sub-score improved over time in the intervention group compared with the control group (baseline/12 months: 17.27/21.33 vs. 19.09/17.36, respectively). On all other outcome measures the intervention and control groups had similar improvements. Irrespective of group allocation walking speed, endurance, and balance during ambulation all improved upon completion of therapy, and majority of participants retained these gains at long-term follow-ups.

**CONCLUSIONS:** Task-oriented training improves walking ability in individuals with incomplete SCI, even in the chronic stage. Further randomized controlled trials, involving a large number of participants are needed, to verify if FES-assisted treadmill training is superior to aerobic and strength training.

## The effects of body weight support treadmill training with power-assisted functional electrical stimulation on functional movement and gait in stroke patients.



Lee HJ, Cho KH, Lee WH.

Am J Phys Med Rehabil. 2013 Dec;92(12):1051-9

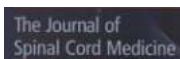
**OBJECTIVE:** The aim of the current study was to examine the effect of body weight support treadmill training (BWSTT) with power-assisted functional electrical stimulation on functional movement and gait in stroke patients.

**METHOD:** Thirty stroke patients were randomly assigned to either the experimental group (n = 15) or the control group (n = 15). The experimental group participated in BWSTT with power-assisted functional electrical stimulation for 30 mins per day, five times a week, for 4 wks, and those in the control group participated in BWSTT for 30 minutes per day, five times a week, for 4 wks. Functional movement was assessed using the Berg Balance Scale, the Timed Up and Go test, and the Stroke Rehabilitation Assessment of Movement. Gait ability was assessed using an electrical walkway system.

**RESULTS:** Significant differences in the time factor for functional movement and gait ( $P < 0.05$ ) were observed in the experimental and control groups. For the group  $\times$  time interaction, significant improvements were observed in the functional movement (Berg Balance Scale [10.93 vs. 6.00], Timed Up and Go test [-9.25 vs. -5.25 secs], and Stroke Rehabilitation Assessment of Movement scores [14.07 vs. 9.80]) and gait (velocity [40.07 vs. 18.64 cm/sec], cadence [30.57 vs. 17.75 steps per minute], paretic side step length [19.36 vs. 8.46 cm], and stride length [30.57 vs. 12.71 cm]) ( $P < 0.05$ ).

**CONCLUSIONS:** The findings of the current study demonstrated the efficacy of BWSTT with power-assisted functional electrical stimulation on the functional movement and gait ability in stroke patients. Therefore, the authors suggest that power-assisted functional electrical stimulation may be an effective method for the improvement of functional movement and gait ability of stroke patients when added to BWSTT.

## Changes in pulmonary function measures following a passive abdominal functional electrical stimulation training program.



McLachlan AJ, McLean AN, Allan DB, Gollee H.

J Spinal Cord Med. 2013 Mar;36(2):97-103

**OBJECTIVE:** To demonstrate the effect of a passive abdominal functional electrical stimulation (AFES) training program on unassisted respiratory measures in tetraplegia.

**METHOD:** Twelve patients with tetraplegic spinal cord injury, who could breathe independently, with reduced vital capacity and no visible abdominal movement. Three weeks of abdominal muscle conditioning using transcutaneous AFES. The increase in FVC over the training period and the absence of change before or after training suggest that passive abdominal FES training can be used for respiratory rehabilitation in tetraplegia.

**RESULTS:** Mean (SD) FVC increased by 0.36 l (0.23) during training ( $P = 0.0027$ ). Mean (SD) FEV1 and PEF tended to increase by 0.18 l (0.16) and 0.39 l/seconds (0.35), respectively, but this was not significant. No significant change was found in the outcome measures during a 1-week pre-training control phase and during a 3-week post-training phase.

**CONCLUSIONS:** The increase in FVC over the training period and the absence of change before or after training suggest that passive abdominal FES training can be used for respiratory rehabilitation in tetraplegia.

## Contralaterally Controlled Functional Electrical Stimulation Improves Hand Dexterity in Chronic Hemiparesis.

### Stroke

Knutson JS, Gunzler DD, Wilson RD, Chae J

Stroke. 2016 Oct;47(10):2596-602.

**OBJECTIVE:** It is unknown whether one method of neuromuscular electrical stimulation for poststroke upper limb rehabilitation is more effective than another. Our aim was to compare the effects of contralaterally controlled functional electrical stimulation (CCFES) with cyclic neuromuscular electrical stimulation (cNMES).

**METHOD:** Stroke patients with chronic (>6 months) moderate to severe upper extremity hemiparesis (n=80) were randomized to receive 10 sessions/wk of CCFES- or cNMES-assisted hand opening exercise at home plus 20 sessions of functional task practice in the laboratory for 12 weeks. The task practice for the CCFES group was stimulation assisted. The primary outcome was change in Box and Block Test (BBT) score at 6 months post treatment. Upper extremity Fugl-Meyer and Arm Motor Abilities Test were also measured.

**RESULTS:** At 6 months post treatment, the CCFES group had greater improvement on the BBT, 4.6 (95% confidence interval [CI], 2.2-7.0), than the cNMES group, 1.8 (95% CI, 0.6-3.0), between-group difference of 2.8 (95% CI, 0.1-5.5),  $P=0.045$ . No significant between-group difference was found for the upper extremity Fugl-Meyer ( $P=0.888$ ) or Arm Motor Abilities Test ( $P=0.096$ ). Participants who had the largest improvements on BBT were <2 years post stroke with moderate (ie, not severe) hand impairment at baseline. Among these, the 6-month post-treatment BBT gains of the CCFES group, 9.6 (95% CI, 5.6-13.6), were greater than those of the cNMES group, 4.1 (95% CI, 1.7-6.5), between-group difference of 5.5 (95% CI, 0.8-10.2),  $P=0.023$

**CONCLUSIONS:** CCFES improved hand dexterity more than cNMES in chronic stroke survivors.

## Effects of combining robot-assisted therapy with neuromuscular electrical stimulation on motor impairment, motor and daily function, and quality of life in patients with chronic stroke.



Lee YY, Lin KC, Cheng HJ, Wu CY, Hsieh YW, Chen CK.

J Neuroeng Rehabil. 2015 Oct 31;12:96

**OBJECTIVE:** Robot-assisted therapy (RT) is a widely used intervention approach to enhance motor recovery in patients after stroke, but its effects on functional improvement remained uncertain. Neuromuscular electrical stimulation (NMES) is one potential adjuvant intervention approach to RT that could directly activate the stimulated muscles and improve functional use of the paretic hand.

**METHOD:** This was a randomized, double-blind, sham-controlled study. Thirty-nine individuals with chronic stroke were randomly assigned to the RT combined with NMES (RT+ES) or to RT with sham stimulation (RT+Sham) groups. The participants completed the intervention 90 to 100 minutes/day, 5 days/week for 4 weeks. The outcome measures included the upper extremity Fugl-Meyer Assessment (UE-FMA), modified Ashworth scale (MAS), Wolf Motor Function Test (WMFT), Motor Activity Log (MAL), and Stroke Impact Scale 3.0 (SIS). All outcome measures were assessed before and after intervention, and the UE-FMA, MAL, and SIS were reassessed at 3 months of follow-up.

**RESULTS:** Compared with the RT+Sham group, the RT+ES group demonstrated greater improvements in wrist flexor MAS score, WMFT quality of movement, and the hand function domain of the SIS. For other outcome measures, both groups improved significantly after the interventions, but no group differences were found.

**CONCLUSIONS:** RT+ES induced significant benefits in reducing wrist flexor spasticity and in hand movement quality in patients with chronic stroke.

## Cooperative hand movements in post-stroke subjects: Neural reorganization.



Schrafl-Altermatt M, Dietz V.  
Clin Neurophysiol. 2016 Jan;127(1):748-54.

**OBJECTIVE:** Recent research indicates a task-specific neural coupling controlling cooperative hand movements reflected in bilateral electromyographic reflex responses in arm muscles following unilateral nerve stimulation. Reorganization of this mechanism was explored in post-stroke patients in this study.

**METHOD:** Electromyographic reflex responses in forearm muscles to unilateral electrical ulnar nerve stimulation were examined during cooperative and non-cooperative hand movements.

**RESULTS:** Stimulation of the unaffected arm during cooperative hand movements led to electromyographic responses in bilateral forearm muscles, similar to those seen in healthy subjects, while stimulation of the affected side was followed only by ipsilateral responses. No contralateral reflex responses could be evoked in severely affected patients. The presence of contralateral responses correlated with the clinical motor impairment as assessed by the Fugl-Meyer test.

**CONCLUSIONS:** The observations suggest that after stroke an impaired processing of afferent input from the affected side leads to a defective neural coupling and is associated with a greater involvement of fiber tracts from the unaffected hemisphere during cooperative hand movements.

## Coordinating Upper and Lower Body During FES-Assisted Transfers in Persons With Spinal Cord Injury in Order to Reduce Arm Support.



Jovic J, Azevedo Coste C, Fraisse P, Henkous S, Fattal C.  
Neuromodulation. 2015 Dec;18(8):736-43

**OBJECTIVE:** The goal of this study is to minimize arm forces applied during sit-to-stand (STS) transfers in persons with spinal cord injury (SCI) by using functional electrical stimulation (FES) applied to lower limbs muscles.

**METHOD:** Six participants with chronic SCI participated in the study. Participants with SCI were recruited to complete STS movement using a new system for FES-assisted STS transfer. All participants attended one muscle mapping session to test their muscles condition, two training sessions to become familiarized with the experimental setup, and two measurement sessions using the proposed system for FES-assisted STS movement. The applied arm forces during STS movement were recorded and analyzed for different stimulation onset values with respect to the maximal trunk acceleration signal using one-way ANOVA statistical test. Post-hoc analysis was performed using Tukey's method.

**RESULTS:** The results of this study showed that the moment of the stimulation onset has an influence on the arm forces applied during the STS motion. The lowest values of arm forces were obtained for STS movements where the electrical stimulation was triggered before and around the time corresponding to the maximal value of the trunk acceleration signal.

**CONCLUSIONS:** Lowest arm forces values were obtained for STS motions that were similar to those of healthy persons in terms of trunk movements and beginning of lower limb movements in regards to maximal trunk acceleration signal. The FES system was able to mimic the rising motion of a healthy individual by triggering the FES at the appropriate moment. This method could prove useful for pivot transfer, therapeutic or functional verticalization.

## BGU Murnau

### Spinal Cord Injury Center, Physiotherapy Department



“We apply RehaMove for patients with incomplete spinal cord injury (AIS C) from C4 to L5. The main therapy goal is to support and strengthen existing motor functions, muscle force and endurance. The treatment requires intact lower motor neurons of the stimulated muscles and the FES compliance of each single patient. FES Cycling with RehaMove is recommended as home therapy to support the pre-clinical rehabilitation concerning a focused activation and increasing of muscle performance.”

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## Asklepios Neurological Clinic Falkenstein

### Clinic for Neurology and neurological Rehabilitation



“Generally our patients get treated twice a week with this effective therapy form. RehaMove is characterized with a smart usability and simple patient data management. This offers an independent home usage after the clinical treatment. Particularly patients after stroke get treated with RehaMove in addition to their conventional therapy to improve functions and mobility of paralyzed lower limbs.”

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## MEDIAN Clinic Magdeburg

### Neurological Rehabilitation Center



“RehaMove primarily shows [...] quick effects regarding increasing coordination skills of paralyzed patients. This generates positive impressions for persons concerned and supports the effectiveness of their own effort in the accompanying therapy. Consequently, the overall impression of the application is positive throughout following usability and feedback of patients.”

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## Westerwald clinic Waldbreitbach

### Rehabilitation Center for Neurology



“FES Cycling is mainly used for patients with neurological disorders and paresis after stroke, multiple sclerosis or polyneuropathy. FES with RehaMove is a meaningful addition to our physiotherapy due to its functional activation and effective tonus regulation of paralyzed muscles. Comparing with single-muscle activation of many common electrical stimulators, RehaMove offers an individual configuration and manual triggering of up to eight channels which allows the stimulation of movements similar to daily activities.”



## Swiss Paraplegic Center Department of Therapy Management



“FES with RehaMove is applied for patients with complete or incomplete spinal cord injury (AIS A-C). Regulation of muscle tone, decreasing of spasticity and cardiovascular training are main therapy goals for the treatment of complete SCIs. Patients with incomplete paraplegia or quadriplegia use FES to improve deep sensation for relaxation of muscle spasms and endurance training. Therapists can pre-set training parameters for an easy application as home therapy.”

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## Heidelberg University Hospital Spinal Cord Injury Center at the Department of Orthopedics



“FES Cycling is an evidence-based therapy for patients with complete or incomplete spinal cord injury. RehaMove is used as part of our clinical routine to reduce spasticity of patients with spastic paraplegia or quadriplegia. If continuously and frequently applied, spasmolytic medication can be reduced. In addition, we use FES Cycling for further indications like cardiovascular training.”

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## BG Clinic Halle Spinal Cord Injury Center and Clinic for Orthopedics



“Patients with motor and sensory complete spinal cord injuries as well as incomplete ones get treated with RehaMove FES. One of the most problematic secondary diseases following a spinal cord injury is spasticity. FES Cycling influences spastic hypertonicity positively and local blood flow of our treated patients improves significantly. Particularly, preventing thrombosis is one of our therapy goals which we can achieve with the support of FES.”

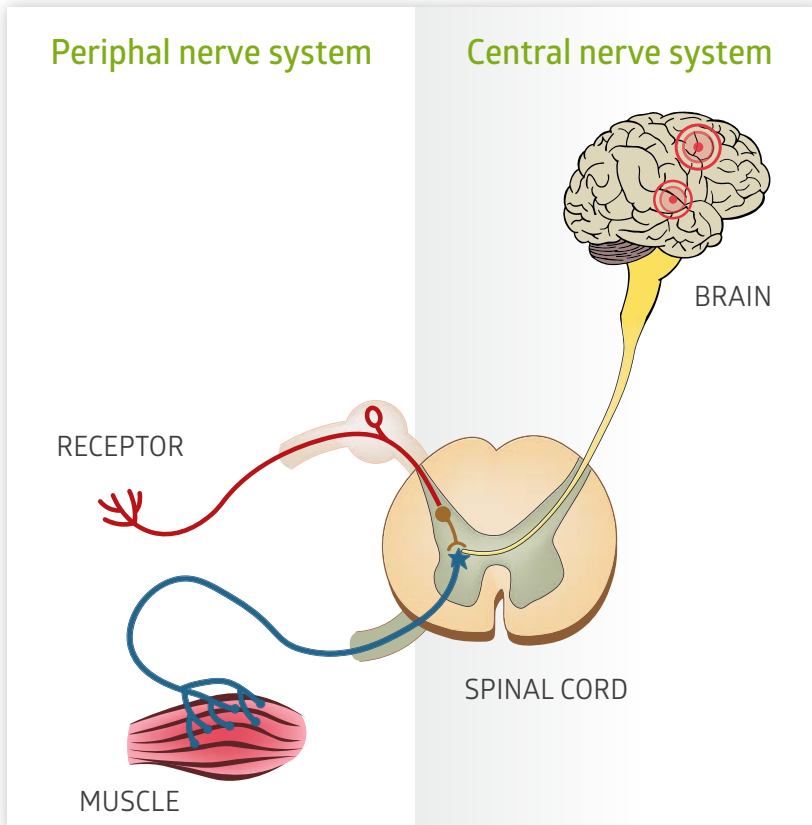
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## Mittelbayerisches Rehabilitationszentrum Klinik Maximilian - Clinic for Neurology



“Experiences of daily use show that FES Cycling is a helpful intervention to increase a self-dependence life of people with neurological impairments. Primarily, patients with disorders of the central nervous system can profit by FES Cycling additionally or after the clinical treatment. Astonishingly, patients with neglect after stroke show significant improvements of their perception and motor functions during walking exercises.”

## For which disorders might the training be useful?



- Generally applicable in lesions with an intact lower motoneuron
- Spinal cord injury
- Stroke
- Multiple sclerosis
- Parkinson's disease
- Cerebral palsy
- Traumatic brain injury (TBI)
- Guillain-Barré syndrome

## What are the contraindications for FES therapy?

- Use of cardiac pacemakers
- Unhealed fractures in lower extremities (only applicable if the legs are trained); in upper extremities, the area of the shoulder girdle and upper ribs if the arms shall be trained
- Damage to the rotator cuff or the potential luxation of the shoulder joint, if the arms shall be trained
- Epilepsy
- Known allergies to electrode gel
- Metal implants underneath or near the stimulated muscle groups
- Pregnant women should desist from using stimulation; the possible adverse effects are unknown and have not yet been rigorously investigated

**Note:** Patient's individual physical constitution or contraindications may forbid an FES application. Please consult your doctor before use of the device.  
In the USA, federal law restricts the sale of FES devices unless by or ordered by a practitioner licensed by law of the state in which he/she practices to use or order the use of the device.

## 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:

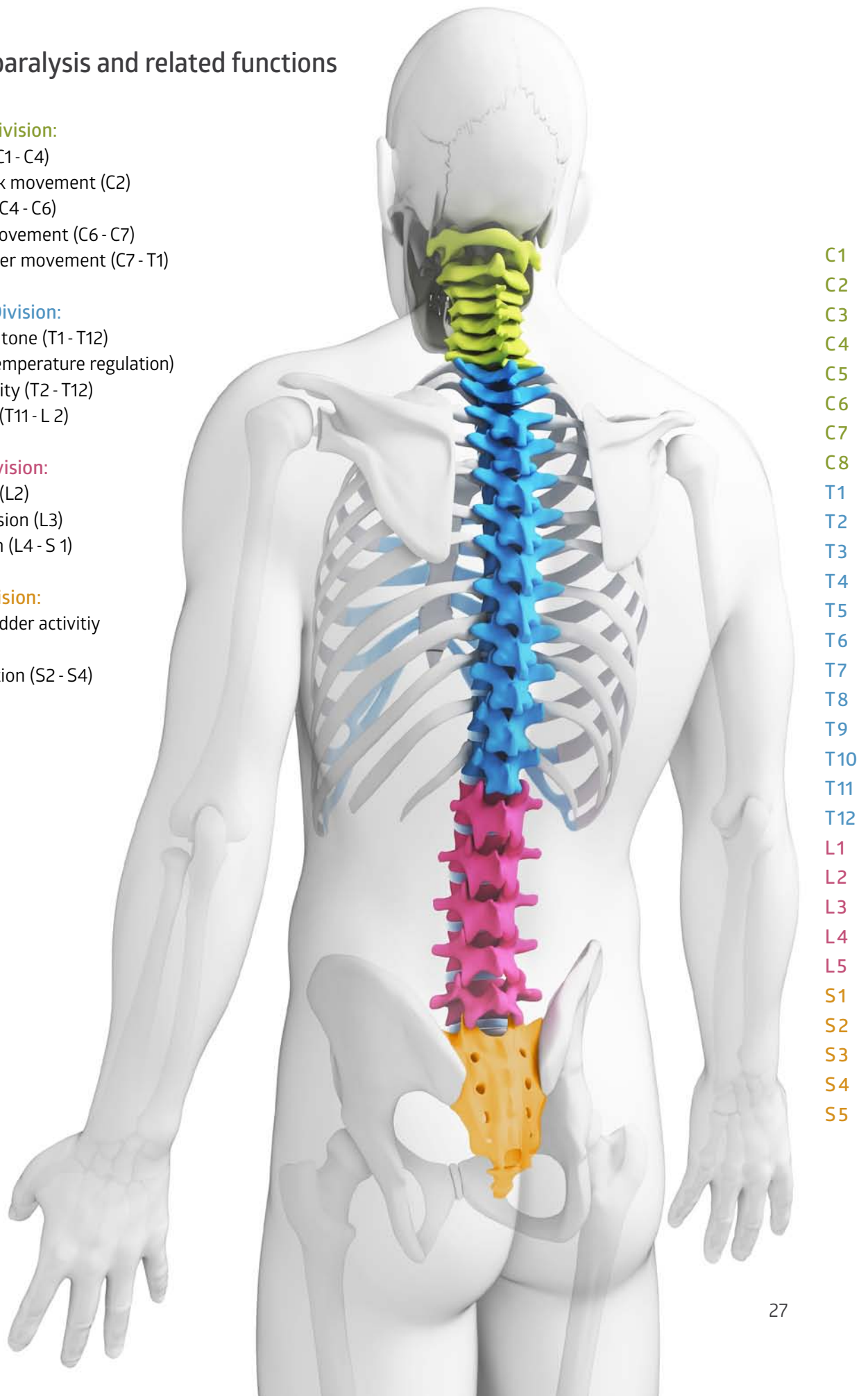
- Sympatetic tone (T1 - T12)  
(including temperature regulation)
- Trunk stability (T2 - T12)
- Ejaculation (T11 - L 2)

### LUMBAR Division:

- Hip motion (L2)
- Knee extension (L3)
- Foot motion (L4 - S 1)

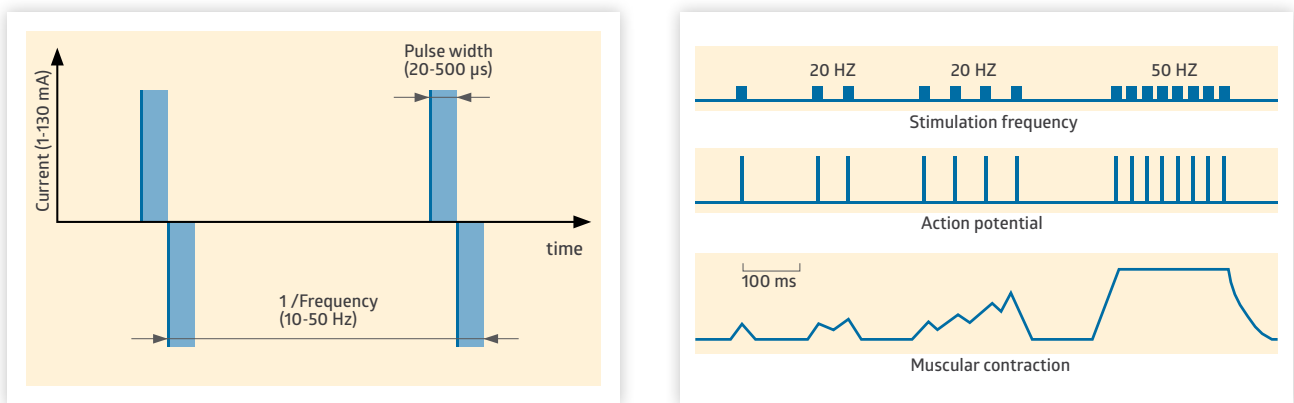
### SACRAL Division:

- Bowel & bladder activitiy  
(S2 - S3)
- Penile erection (S2 - S4)



## Which pulse forms are used?

Most of the available FES devices, including RehaMove, are working with biphasic rectangular pulses. The negative pulse ensures an active discharge/unloading to prevent electrolytic effects or skin irritations.



## Which parameters are available and what do they effect?

People are different in terms of their muscular constitution, physical nature and their individual stimulus thresholds. Therefore, parameters for electrical stimulation must always be adjusted individually.

- Frequency:**
- Number of pulses per second, indicated in Hertz (Hz)
  - Stimulation frequency determines 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
- Current:**
- Charge flowing per time, measured in Milliampere (mA)
  - Alternating current is used (balanced charge)
- Pulse width:**
- Duration of pulses, measured in Microseconds ( $\mu$ s)

## How endurance and strength can be trained?

- For strength training higher frequencies are typically necessary (starting ~ 30 Hz)
- For endurance training only lower frequencies are used (up to ~ 30 Hz)
- Type of muscle fiber:

Type I fibers – slow twitch	Type II fibers – fast twitch
<ul style="list-style-type: none"> <li>• Contract and relax slowly</li> <li>• Resistant to fatigues</li> <li>• For endurance-type activities</li> <li>• Well supplied with blood: red</li> <li>• Stimulation with frequencies &lt; 30 Hz</li> </ul>	<ul style="list-style-type: none"> <li>• Quick and powerful contraction</li> <li>• White muscle fibers</li> <li>• For “sprint” and muscular strength</li> <li>• 2 subtypes: a) fast-fatigue-resistant, b) fast-fatigable</li> <li>• Stimulation with frequencies &gt; 30 Hz</li> </ul>

## Which parameters are typically used for FES Cycling sessions?

Stimulation parameters depend on the intended therapeutic goals. Lower intensities allow for longer stimulation periods while high intensities should only be applied for a short period.

Parameters of 20 Hz and 250  $\mu$ s for frequency and pulse width are recommended for initial training sessions. The value for current intensity (amplitude, mA) should be adjusted to each individual motor threshold.

Starting parameters could be:

	Complete SCI	Stroke, TBI and spinal cord lesion with (residual) sensibility (residual) sensibility
Current:	40-90 mA	30-40 mA
Pulse width:	250-500 $\mu$ s	100-300 $\mu$ s
Current test starting with:	0 mA/250 $\mu$ s	0 mA/100 $\mu$ s
MOTomed:	servo cycling with gear 0-1	servo cycling with gear 0-6

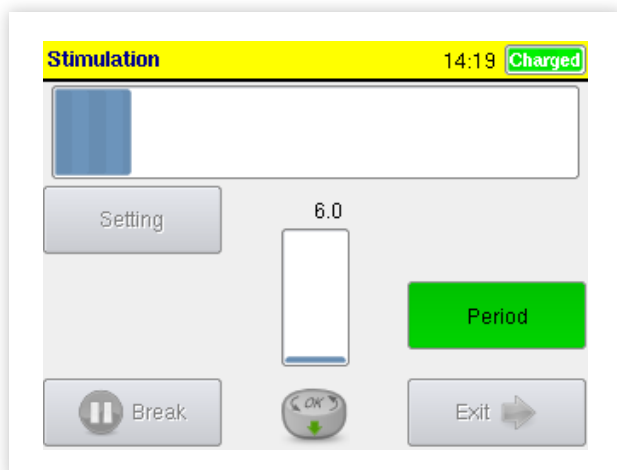
## What is the ramp?

- 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



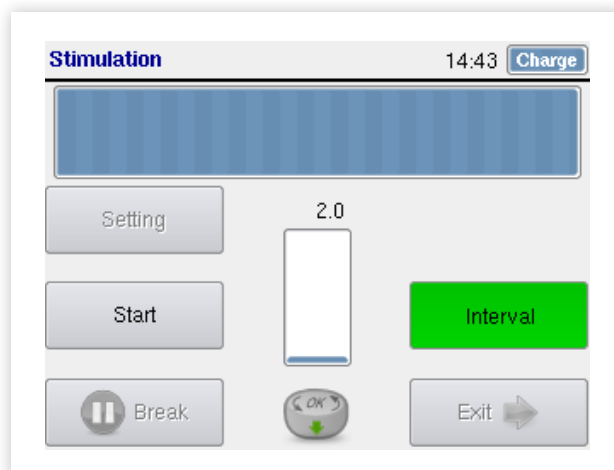
## What is the setting of “Period” in sequence training?

- In percent mode, the „Periode“ adjusts the duration of the complete sequence
- Periods are adjustable in seconds



## What is the setting of “Interval” in sequence training?

- in second mode, the „Interval“ adjusts the break duration after the last stimulation sequence
- break times can be selected in steps of one second



## How FES differs from other forms of electrical therapy?

	Current	Frequency	Pulse	Main application	Indication
FES with RehaMove	Alternating current (AC)	10-50 Hz	20-500 µs	Maintenance of muscle function or limitation of atrophy	Movement disorders after SCI and central lesions
Galvanisation	Constant current and direction			Iontophoresis: improvement of motor excitability etc.	Arthrosis, Spondylosis, Tendinosis, Ligamentosis, Neuralgia, etc.
Russian stimulation	Alternating current (AC)	2,5 Hz	Rectangular pulses in "bursts" (pulse sequences)	Muscle power	Muscle Atrophie
TENS	Stimulation current with weak AC	2-220 Hz	Monophasic or biphasic pulses 50-200 µs	Especially used for pain treatment (Analgesia)	Chronic, causally untreatable pain
Diadynamic currents	Currents with direct current (DC) and pulse current proportions	50-60 Hz	Sinusoidal half-waves, pulse width 8-10 ms	Analgesic, anti-inflammatory, reducing nerve pain, etc.	Rheumatic diseases, pain, Sudeck's Atrophy in case of disuse atrophy
Faradic current	Low-frequency stimulation currents (rectangular pulse)	40-80 Hz	Width: 0,5-5 ms, monophasic or biphasic	Motor stimulation	Normally innervated, weak muscles, mild paresis
Exponential current	Rectangular pulse with pulses of increasing intensity	<1000 Hz	100 ms–800 ms	Maintenance of muscle function or limitation of atrophy	Completely denervated muscles

Sources: Bossert (2006) *Guideline Elektrotherapie*; Robertson et al. (2006) *Electrotherapy explained-Principles and practice*

## What is the difference between TENS and FES with RehaMove?

TENS	Advantages FES with RehaMove
<ul style="list-style-type: none"> <li>· Stimulation of blood circulation, muscle relaxation and pain reduction</li> <li>· No or low physiological contraction/movement</li> <li>· No building of muscle strength</li> <li>· No complex stimulation</li> </ul>	<ul style="list-style-type: none"> <li>· Stimulation of functional movements</li> <li>· Motorlearning and call up of neuromuscular patterns</li> <li>· Cycling due to connection with the MOTOMed</li> <li>· External trigger (cause stimulation via manual switch)</li> <li>· Different training options: sequence, adaptive/constant mode</li> </ul>

For exact details on duration and frequency of a particular application, please consult with a therapist and physician.

## Imprint

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