FUNCTIONAL STIMULATION OF FLACCID PARAPLEGIC MUSCLE USING MULTICHANNEL STIMULATORS

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For therapeutical and functional electrostimulation of spastic paralysis indirect stimulation of a muscle via ascending and descending nerve fibres is used for quite some time with good success (5,6). In this case both the myokinetic units and the reflex path are functioning.

With flaccid paralysis on the other side the conductance of the membranes has disappeared and hypersensitivity to ACh occurs. The muscle atrophies and degenerates. Additionally secondary injuries as dekubiti occur. To prevent these injuries and to keep the muscles for functional electrostimulation the affected muscles have to be trained intensively.

High electrical currents are required for electrostimulation of flaccid paraplegic muscle. To avoid injuries from excessive currents the current density may not get too high. According to our opinion the necessary quasi-homogeneous current fields may be applied only using surface electrodes which size is adapted to the cross-sectional area of the muscle to be treated (Fig.1). Implanted electrodes are necessarily smaller in size, so the required current density may not be applied or the tissue surrounding the electrode will be damaged (Fig.2).

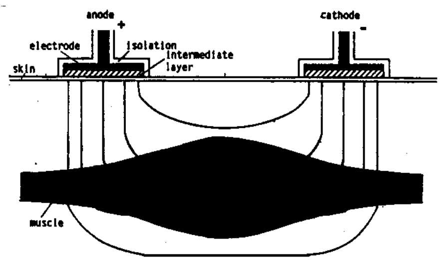

Fig.1: Quasi-homogeneous current density under large surface electrodes

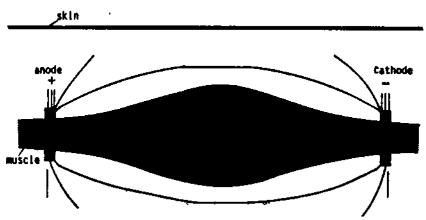

Fig.2: Inhomogeneous current density between implanted electrodes

For functional electrostimulation muscles in different distances from the skin must be stimulated selectively. According to Fig.3 muscles close to the surface may be activated by a series connection of several stimulation circuits as the current fields do not penetrate deep in the muscle, because the distance between the electrodes is small (3). Fig.4 shows this. The mechanical summing reveals especially advantageous; the electrical pulses are transposed and do not overlap. A muscle deep from the skin can be stimulated by reverse oriented current fields (Fig.5). The maximum applicable current density on the electrodes sets a limit.

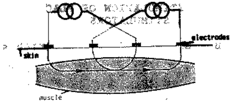

Fig.3 electrode arrangement for stimulation of muscle close to the surface

Bidirectional currents are especially suited (2). For functional electrostimulation a controlled motion and stimulation of several different muscles is necessary. A simple coordinated movement for patients suffering from paralysis of the lower limb is pedaling with the legs on a bicycle or a stationary bicycle-trainer. Here the movements clearly depend on the pedal angle. Using a controlled counter-moment during pedaling the muscles, joints and ligaments are trained likewise. Our microcomputer-controlled multichannel stimulator has been developed for this purpose. Fig.6 shows a block diagram. Using our measuring- and training system bicycle-trainer the usage is as follows: a moment-curve is recorded. Fully automatic at every angle position for muscles of the thigh, the m. quadriceps femoris and m. ischiocrurales left and right, are stimulated using different current amplitudes and each time the stimulation parameters for the highest generated moment are recorded (Fig.7). With these data the computer generates a cycle diagram (Fig.8). During the training the system adapts itself for the fatigue effect by varying the stimulation parameters for this. The system bicycle-trainer enables us to produce simple pedal movements which are generated only by one muscle per leg at a time, that is, no force chains can be gained. A one hour per day training for two weeks of the femoral musculature increased the generated

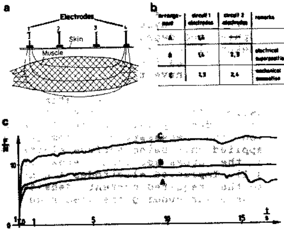

Fig.4 Direct muscle stimulation with several arragements: a) arrangements b) electrical arrangement c) mechanical moments

force by several times (Fig.9). As we could stimulate only one muscle per leg at a time, for a successful pedaling and optimum moment generating a very careful and accurate positioning of the feet on the pedals and the patient on the saddle was essential.

A conclusion from this has been the development of the multiprocessor based bicycle-trainer. Now the generated forces are measured dynamically during cycling. This system is not split in the measuring and cycling mode any more. The mechanics are close to those of the old bicycle-trainer but the electronics are adapted to the new requirements of the significant expanded electrical control and regulation circuits. For the substantially increase of data throughput a multiprocessor system based on i8085 has been designed. The different tasks are allocated to the different processors, that is, each processor has a given task and does the required communication with the others using a mail-box arbitration system (Fig.9). The control interface to the operator is still a pc.

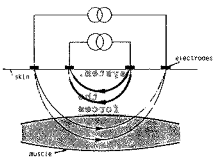

Fig.5 Electrode arrangement for stimulation of muscle far from the surface

Now not only for each leg a stimulator with multiplexer is available but for each agonist/antagonist pair a own stimulator with multiplexer is provided. This enables us to use the lower legs and the m. glutaeus-maximus, too. Fig.10 shows the activity of the corresponding muscles of a healthy test person as a function of the pedal angle. They have been measured using the EMG method (4). These data are used as a start value for our adaptive control system.

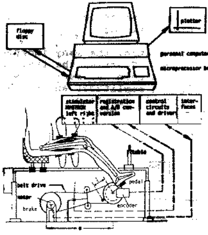

Fig.6 Arrangement of our bicycle-trainer

This new system saves a significant amount of time. Through the concurrent stimulation of several muscles per leg the generation of force chains to create increased moments is possible now. It revealed that the positioning of the patient on the saddle and the feet on the pedals is far not as

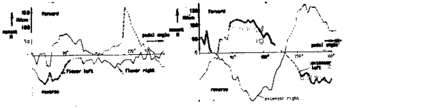

Fig.7 Generated moments depending on pedal angle and muscle

critical as on the old system. Dynamically measuring the generated forces and the acceleration enables us in conjunction with adapting the stimulating parameters to the actual fatigue effect to achieve a higher and smoother moment. All parameters are kept except one and exactly this one is dynamically varied and measured. This is done with the system in motion, not statically as with the old trainer. This way it is possible to control the many independencies a system of this kind offers. Starting the training the activity angles of the muscles are used as measured with the test person an the stimulation amplitudes and signalforms are set according to the paralytic symptoms.

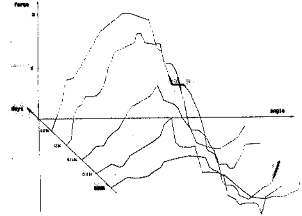

Fig.8 Augmentation of generated force by intensive training

The bicycle-trainer must be mechanically adapted and adjusted for each individual patient and is, as a feedback system electronics-human-mechanics-electronics, not easy to control. This counteracts a widespread usage. Furthermore for the sole training of the muscles this system is far too complex. As a cheap and simple alter-

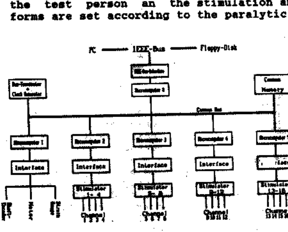

Fig.9 Block diagram of the multiprocessor system

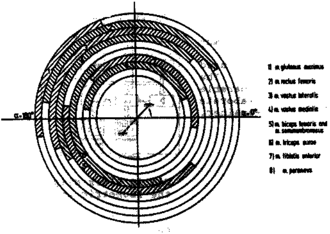

Fig.10 Driving diagram of the left leg

native the isometric trainer for upright standing has been designed. A readily available trainer for upright standing is used in conjunction with the new designed multichannel stimulator. The leg muscles of the upright standing patient **are stimulated. These are** the m. quadriceps femoris, m. **ischiocrurales,** m. triceps surae, m. tibialis anterior, **m. gastrocnemius and m.** glutaeus maximus. The stimulated **contractions are isometric.** This arrangement has a further **advantage as the time in** the trainer is used twice for **daily upright standing of the** handicapped is anyhow imperative to **train the vesica and the** intestinal tract. The spine and the **back muscles are loaded** in a positive way, too. This is also **a good starting-point for** excercising the muscles and joints, **as with flaccid paralysis no tonus is** given. **With the** multichannel stimulator the muscles **are** treated serially **using a** cycle time of about 10 to 50 seconds and isometric **tetanic** contractions are **achieved.** With the advantageous **bidirectional currents and by long pauses after short** stimulation no fatigue effect can be seen. To **cope with the** long required therapy of one hour per day and more, the unit is so designed that it con be used at the place of work or **in school.** The muscles **of a** patient suffering from flaccid **paralysis can be build up and trained in a way that future** functional electrostimulation is possible.

The stimulator is built for the many different purposes **as a** modular system. It consists for the isometric trainer **for** upright standing of an operator's console and three equal **stimulating units, having each 8 outputs** via a multiplexer. **Loose coupled microprocessors i8085 control each of the unit and the generating of the stimulation signals. Fig.11 shows a block diagram. For each of the 24 output channels the parameters as the amplitude and the signal form are individually programmable. This enables an optimum adjustment for the needs of each individual patient. The stimulator is a self-contained compact unit and designed for easy operation by therapeuts and even the patient himself. Through the omission**

of the feedback system with the mechanics no adaption to the patient is necessary, except the selection of the stimulating signals.
A first sample is already used in clinical practice. The achieved results are comparable to those from the elaborate multiprocessor bicycle-trainer.

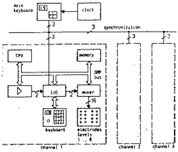

Fig.11 Block diagram of the isometric trainer

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