APPLICATION OF ELECTRICAL STIMULATION TO CLINICAL REHABILITATION

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ABSTRACT

This paper deals with the practical clinical application of the electrical stimulation in a number of about 100 patients with different symptoms of paralysis. Over a period of 4 years experiences were gathered, not only in the use of stimulation for functional purposes as standing and walking, but also as a method for prevention and restoration of deteriorations developing as a consequence of paralysis in the course of the years.

INTRODUCTION

Electrical stimulation, (ES), has already been applied to patients with paralytic symptoms for a long time [9,11]. The success of the treatment was judged so far negative as well as positive, because it was difficult to deduce a consistent therapeutic methodology. The method has to a large extend, not made its entry into modern rehabilitation medicine. This may be due to three reasons: a) The sites to which stimulation was applied were chosen too small; b) the duration of the session was too short, and c) the sessions were not repeated frequently enough (about one to three times a day).

In course of the introduction of Functional Electrical Stimulation, FES, in the sixties, fundamental models for the application have been developed [6, 7, 15].

Pursuing the goal of FES to restore movements of paralytic limbs, the attention was focused on this aspect and the handicapped were selected carefully to meet this purpose.

Some rehabilitation centres raised the question how FES could be incorporated into the daily rehabilitation routine e.g. the University Rehabilitation Institute, Ljubljana, Yugoslavia or Rancho Los Amigos, Downey, USA [11, 22].

Four years ago in cooperation of the Institute for Biomedical Engineering of the University of Karlsruhe and the Rehabilitation Hospital Karlsbad-Langensteinbach, of Rehabilitation Foundation Heidelberg, FES was introduced in daily clinical practice and the use at home. This paper gives an overview of possibilities of integration of electrical stimulation in a traditional rehabilitation procedure and its practicability with respect to

time consumption and patient compliance. The cases treated with FES cover a period of 12 years.

We learned, as others reported also [1,3,11], that FES patients suffering from paralysis due to an upper motor neuron lesion (UMNL) may benefit from the stimulation in three main areas:

1. Maintaining the status of the paralysed section i.e.:
   Training the musculature and by this way restoring the muscle cushion, improving the capillarisation, and with it the blood supply including the intercellular fluid exchange. Improving the skin condition, preventing osteoporosis and joint contractures and deformities.
   Stabilizing the trunk.
   Regaining an aesthetic shape of the limbs and the trunk.
2. Reducing or abolishing disfunctions as: The predisposition to decubitus, contractures, scoliosis (of a moderate degree), spasticity, osteoporosis and muscular imbalance.
3. Restoration of movements, FES in its true sense.

First two goals are obviously subjects of this clinical evaluation. The first one, with its training procedure is overlapping the initial phase of the FES (area 3) and its benefits listed are normally regarded as side effects of this routine. But depending upon the objective or in special cases, for instance of very weak muscles, the training procedure has to be designed carefully and may obtain its own rank.

The reduction of disfunctions and deficiencies (area 2), will be the main task. In this group spasticity plays the most important role, it will be dealt with in a separate research and presented in another paper. Out of the third group paraplegic handicapped may also be treated under this aspect. FES assisted walking is still of very limited relevance in daily life, whereas a lot of handicapped have incorporated standing by mechanical means in their daily fitness training. However quite often there will be an overlapping of stimulating for maintaining the general state of tissue (muscles, bones, ligaments) and for functional purposes.

Besides these three groups the one comprising the patients with lower motor neuron lesions (LMNL) is of importance. Muscles effected by LMNL are very often loosing their contractile properties. But in the recent years it became more and more evident that this is not regularly the case as believed in former times [2,10,16].

To patients with this type of paralysis it might be very important to keep the residual muscle functions alive to prevent from the loss of tissue, tendon degeneration, contractures, and so on.

STIMULATION METHODOLOGY

The stimulation protocol consists of application of rectangular, constant current, charge balanced pulses with variable amplitude and fixed pulse duration set between 50 and 500 μs. Normally we use pulses of 300 μs, varied according to special situations, e.g. the stimulation of children, of sensitive areas, or critical areas as the neck. We use commercially available microprocessor controlled, battery operated and portable 8-channel stimulators. The stimulator is menu operated and allows to program special

training and movement sequences. Each patient has his personal stimulator prescribed by the clinical research team. In special cases, we provide stimulators being developed in our Institute. The stimulation is normally applied via surface electrodes. IN some cases we use percutaneous electrodes.

GENERAL CLINICAL ASPECTS

Before admission to the FES program a physician, a physiotherapist and the team of the Institute examine and document a full profile of each patient.

This includes the clinical assessment, examination of the functional status covering the skeletal and neuromuscular system, assessment of the present rehabilitation status compared with the expectations given by the nature and level of injury, and finally the perform the test routine to examine the degree of excitability of the paralyzed musculature by electrical stimulation.

Taking all results into account, as well as the compliance of the patient and his cooperativeness a rehabilitation concept is determined in a joint decision. The recommendation is discussed with the patient and matched to the routine of his daily life. Before starting with the stimulation the patient has to meet at least the following prerequirements. The acute symptoms of the injury or disease must have been overcome and there should be no heteroscopic ossifications. The patient has to show sufficient motivation and reliability.

After the preconditions are fulfilled the stimulation is installed by determining the sites of stimulation and the stimulation regime. During this phase the patient is hospitalized and trained by physiotherapists in the proper use of the stimulator, at the same time the traditional rehabilitation program is conducted. When the patient is ready for dismissal, and there are no doubts that he is able to operate the stimulator safely, he will take the unit with him and continue with the stimulation at home. For rechecking the status and for readjusting the stimulation routine, the patient has, at the beginning, to visit the investigators team frequently, later on only once or twice a year.

Before moving to the next therapeutic step, the patient is always hospitalized for a shorter period.

TRAINING PROCEDURE

The patient proceeds with a preliminary exercise program. In order to allow a sufficient time for the development of blood supply, the strengthening of the ligaments, joints and bone structures together with the gain in muscle force we conduct the exercises in a rather moderate way.

Initially, we start the program with continuous stimulation of 2 Hz and limited time per session in such a way that the fatigue onset is avoided. The training takes place twice a day. The stimulation time per session is extended up to 20 minutes, as soon as the fatigue resistance allows this. At that point the frequency will be raised to 4 Hz and the procedure will be repeated. From 8 or 10 Hz on we start an intermittent stimulation pattern: ramp up, stimulus plateau, ramp down (3 seconds each).

The final frequency is reached at 20 Hz, at this point we extend the stimulation plateau from 3 seconds up to 20 seconds, when the training for more endurance is required.

If the muscles are very weak we can extend the time at each frequency for one or two weeks over the minimum.

With this training procedure we are obtaining good results and no set back. The latter was observed, again and again, when patients enforced the training on their own.

Even if a muscle develops reasonable good contraction at the first test with 20 Hz, we start the training with 10 Hz.

CLINICAL APPLICATION

The objective of ES in the clinical routine is on one side the support of the rehabilitation curriculum. Another aspect is to give the handicapped a therapeutic method at hand for improving and preserving the physical state of the paralyzed part of his body in his daily life.

Besides the side effects of stimulation mentioned above some fields of application are often difficult to deal with, e.g.:

Improving of the muscle bulk of the gluteal region and as a consequence, the resistance of the tissue against pressure ulcers. In some cases we designed a special seat shell fitted to the backside with the electrodes incorporated allowing the patient to stimulate it with donning and doffing in a simple way. The muscle gluteus maximus is often rather weak being constantly overstretched, therefore its retraining may need a rather long time of six months or more.

Another application is the support of physiotherapy in the treatment of contractures. In cases of contractures caused by severe spasticity, physiotherapy may only be employed successfully after the spasticity is diminished by stimulation.

Especially quadriplegic handicapped often show an instability of the trunk with deviations of the spine. By strengthening its dorsal muscles the trunk is stabilized and the sitting position in the wheelchair can be very much improved. Simultaneously the range of the arm movements is extended. Initial experiences indicate that the progress of the deviation may be stopped or that these even may be redressed up to the point where an osseous blocking starts. However, in this context an inspection of the wheelchair is essential to ensure a correct posture of the handicapped in the seat. If the level of injury is high cranial, the upper arms may slip out of the shoulder joint socket. Stimulation of the m.deltoids and if necessary the ones of the upper arm may stop this process and secure the arm in its socket.

In 1961 Liberson already reported that the function of dropped foot was improved even after the session when the stimulation of the peroneal muscle group had ceased, the sol called carry over effect [8]. Other authors reported similar results. We observed this too, but the effect had sometimes the appearance of an unblocking of a still preserved but sleeping central connection. For example, a female hemiplegic patient was suffering from a dropped foot 2 years after the event of a vascular stenosis in the brain. After stimulation with a frequency of 2 Hz of the peroneal muscle groups

in a long leg seat, she regained at once some control during walking and reached complete control after continuing this treatment for a couple of months.

Quite a number of paraplegic handicapped have incorporated the standing in their daily training routine. The precondition for a well-balanced upright position is a sufficient stabilisation of all involved joints. This might be achieved passively by bracing. The better way is an active stabilisation by stimulation [22]. It allows the patient a better standing, standing-up and sitting-down routine. In order to achieve correct posture, the patient is trained to develop his sense of balance with those parts of the body still voluntarily controllable, and he is taught to avoid unphysiological positions with the danger of permanent damages.

At least the knee and hip joint and if required the abdominal region have to be antagonistically stabilised. An intensive physiotherapeutic training for standing-up and sitting-down and keeping a well balanced position while standing is essential as experiences with patients demonstrate who tried to train themselves.

The result of a (LMNL) lesion, is a flaccid denervated muscle with progredient loss of the contractile elements and conversion of the muscle fibres into sinewy and connective tissue. A limb develops a pronounced tissue loss with severe contractures the skin becomes very thin and vulnerable, the blood flow is very much reduced. Therefore the possibility to maintain some of the muscle substance still might be of benefit to the patient. Eichhorn [2] proved that it is possible to sustain not innervated muscles in spina bifida patients by application of electrical pulses of 20 ms to 100 ms duration. Over the years we also observed once in a while a patient - as others did - whose denervated muscles have still been excitable with long pulses and pulse amplitudes up to 60 mA. The long pulse durations elicit strong pain, therefore patients with intact sensation are barred from the treatment. The few patients starting from 1982 on, who are demanding the treatment, received 2 or 4-channel stimulators developed by ourselves. The specification are: Pulse duration 1 to 300 ms, variable pulse amplitude $\leq$ 100 mA constant current charge compensated, the frequency - depending upon the pulse duration - up to 20 Hz surface electrodes, security circuit [4], battery operated. In our patients we are using now pulse durations in range of 20 to 50 ms and amplitudes up to 50 mA.

RESULTS

Altogether, we examined about 200 patients who had applied for a treatment with ES. 165 of these patients were examined in cooperation between the Institute of Biomedical Engineering and the Rehabilitation Center Langensteinbach, the others in a consulting arrangement between the Institute and hospitals in Germany and other European Countries. 96 of those patients were suitable for ES.

This group consists of 84 patients with UMNL, 7 with LMNL, and 5 with different neuro-muscular diseases, some of them with multiple symptoms. Therefore, the number of cases treated sums up to 114. For each patient we determined a stimulation program for his particular desire and necessity.

In 33 cases we stimulated for restoring the grip, or/and we applied the stimulation in 5 cases as a therapy for strengthening paralysed trunk and shoulder musculature, when marked deteriorations, following the paralysis, already were developing.

According to the already mentioned benefits of stimulation, we always stated an improvement of the trophic the muscle shapes, and the joint positions of the stimulated arm compared with the non stimulated one. This is true respectively when stimulating the trunk and the lower limbs.

Occasionally we observed the improvement of the voluntary function of a stimulated muscle as a permanent effect. The general status and mobility of the voluntarily controlled part of the body was improved. As a result of the restoration of functional movement sequences, the involved voluntarily preserved muscles are relieved from inactivity. Stimulating the trunk the motions especially of the arms are improved due to the stabilized abutment.

In cases of developed atrophies which occurred more often in partly paralysed muscles, the affected muscles were trained by stimulation until their functions could by produced by themselves.

31 paraplegic participated in the program of FES. Out of those 12 are still in the training phase. 12 proceeded up to standing using it for their daily fitness training and 7 continued further on, for walking.

Out of this group, two subjects with lesions at level T_1 and T_5 are suffering from circulatory instability. Because one of them has this instability also during sport activities in the wheelchair, he is under surveillance of a cardiologist.

50% of the subjects showing more pronounced spasticity reported reduction of it, while the others remained unchanged. In none of the patients spasticity was increased.

42 cases have been treated primarily for therapeutic purposes. Out of this group 30 patients have been stimulated to reduce spasticity, this topic is covered in a separate presentation. 5 subjects were treated especially for prevention of pressure ulcers of the backside. The training procedure had to be executed very slowly and carefully, because overstretched muscles should be only retrained very slowly. As the muscle bulk returned the patients improved their sitting endurance and are now able to sit all day long without any sign of skin irritation. Within one or two years the staining of the skin disappeared.

In 7 patients with flaccid paralysis some of the muscles could still be stimulated with pulses of long duration (10 -100 ms, amplitudes up to 50 mA).

If the muscles were very weak we started at a frequency of 2 Hz slowly increasing the stimulation time and later on the frequency up to 5 -10 Hz. We are so far able to sustain a good contraction of the muscles over the years and prevented the paralysed part of an extremity from the further reduction of the tissue, however, no augmentation of circumference could be achieved. The skin situation and blood supply was improved only in the small area of direct stimulation. We have so far not been able to generate enough force by stimulation to serve a functional purpose. Only one quadriplegic handicapped with peripheral denervation of the m. flexor digitorum on both sides, could use the stimulation functionally to execute a grip. But he stopped stimulation after one year.

CONCLUSION

After four years of experiences of ES in clinical practice we can confirm that ES offers a new methodical way in rehabilitation. Whenever specific activation of paralyzed muscles has its own contribution to rehabilitation, this may be achieved in a unique and controlled way by electrical stimulation. Therefore ES may serve the field in a much broader and more sophisticated context as it has been used so far in the clinic and in general practice.

At home the patient is given a method on hand which enables him to execute it daily or at least regularity in his own management. By doing so he supports his active participation in the rehabilitation procedure, which might be a positive psychological back up.

On the other side, its use might be a time consuming procedure, whereby the patient might get tired of it.

In any case the patient should not start the program with to high expectations, because an early disappointment reduce his motivation.

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