WALKING AFTER PARAPLEGIA - A PRINCIPLE CONCEPT §

H. Thoma, J. Holle, E. Moritz, H. Stöhr

Biotechnical Laboratory and Plastic Surgery Dept.
2nd Surgical University Clinic Vienna, Austria

1. INTRODUCTION

Aim of the research project is to develop a method by which it is possible for the paraplegic patient, to stand and walk erect. The priciple of this method is the electrical stimulation of nerves responsible for the apparatus of locomotion. The basis of this program was founded 1973, when the long-term stimulation of nerves and muscles was invented and patented.

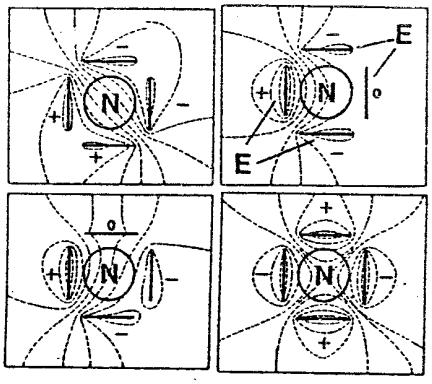

Fig. 1 : Flux line distribution in the electrolyte. Selection of electrode combination determines the local potential differences in the nerve cross-section.

N...nerve
E...electrodes

§...supported by the austrian ministry of health

2. METHOD OF FATIGUE-FREE STIMULATION

To overcome the well-known fatigue of muscle functions we developed a new method of nerve stimulation (called "Karussellstimulation"), which simulates the natural rotation of activity with the aid of an electric field around the nerve /1,2,/. To obtain the wanted effect, the stimulation current has to be low enough to prevent stimulation of the whole nerve, and high enough to stimulate a sufficient number of fibres; the electric field must be inhomogene. If the stimulating electrodes are positioned closer to the nerve, the electric field becomes more inhomoge (fig.1). If, for example, four electrodes are placed around the nerve, one can achieve an intensity variation of the local electric field by different electrode polarization. An automatic switching logic causes a rotating electric field in the cross-section of the nerve; hence "Karussellstimulation". Animal experiments proved the positive effect of this method (fig.2): four electrodes were positioned around the right phrenic nerve. Muscle action of the diaphragm was measured by means of needle electrodes. Two myograms were registered. The electrode-switching mode influences diaphragm muscle reactions.

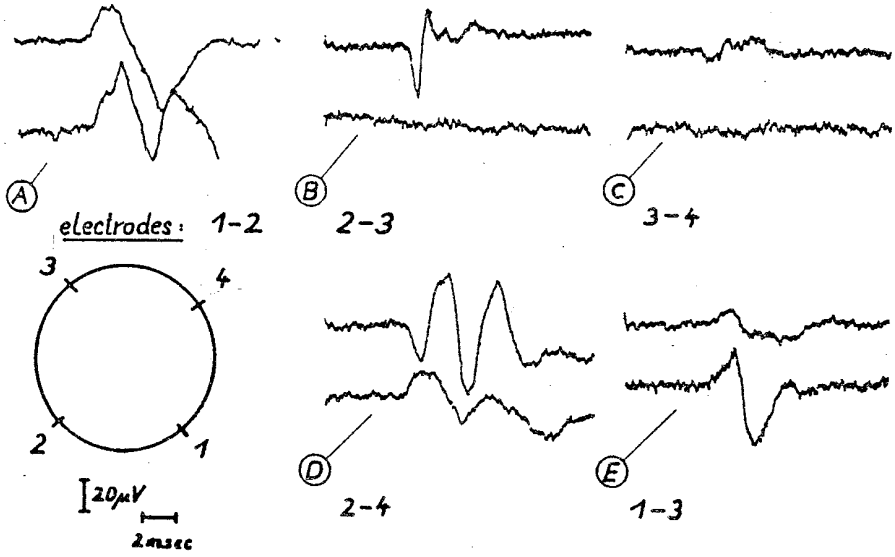

Fig. 2: Muscle reaction due to "Karussellstimulation". Selection of electrode combination causes stimulation of various muscles.

3. CONCEPT FOR WALKING AFTER PARAPLEGIA

The whole mobilisation program is divided in several research and development programs; a graph shows the functional interconnections between various program parts (fig.3). The "Implantation" program deals with selection of muscle groups, which have to be stimulated for desired extremity motion. Our experience shows, that motion of lower extremities can be achieved only by combined stimulation of several muscle groups. Second, optimal stimulation electrode positions have to be found. Clinical experiences are shown later.

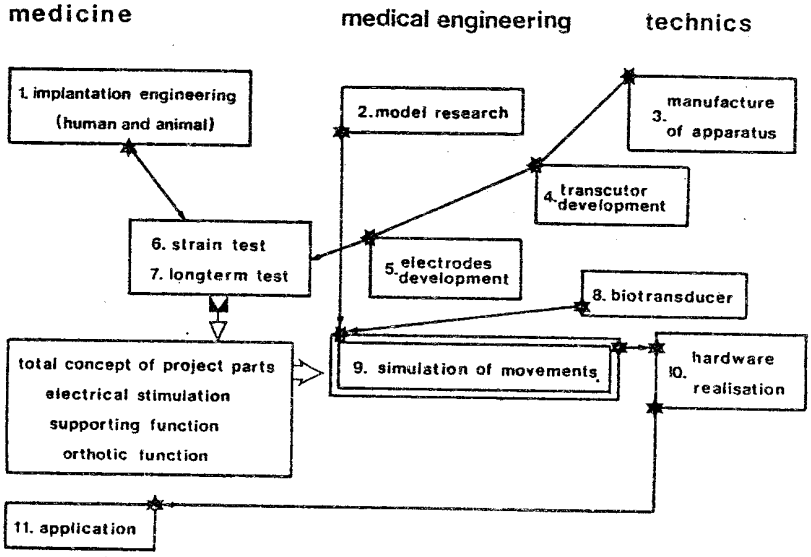

Fig. 3: Program survey

The "Model Research" program includes the development of a remote-controlled mechanical model, which simulates extremity motions. It consists of a model puppet with complete servo mechanism. Motions are carried out by electrical servo-motors, each motion is fed back to the central logic. To realize the desired motion, two fingers of the right or left hand are used for control (fig.4). Each finger represents one leg. Our concept requires index and middle finger of the left hand for motion simulation. "Mechanical Construction" is a development program only. For clinical application, animal experiments and long-term tests it is necessary to construct several control units based on the "Karussellstimulation" principle. Due to our

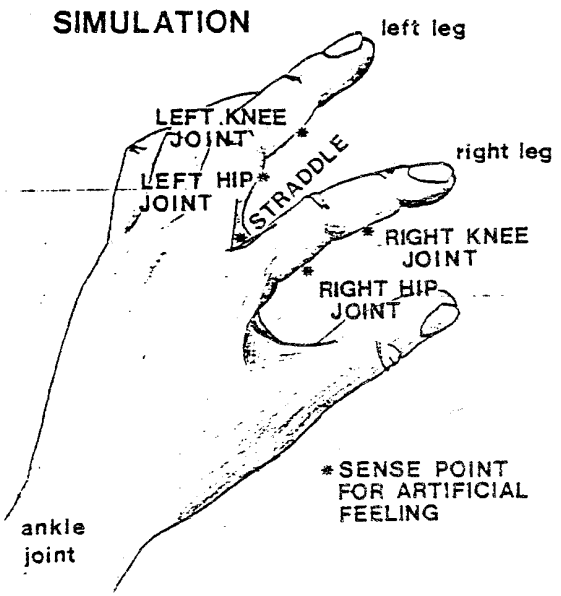

Fig. 4:

"LEARN TO WALK WITH FINGERS"

experiences it is not justified to use direct skin lead-ins (except for intensive care applications); therefore the development of suitable "Karussellstimulation" transcutors is necessary.

The mechanical and chemical stress on a "stimulation electrode" must not be underestimated. But stimulation electrodes for pacemaker applications have been improved in the last ten years. The dimensions of those electrodes is one of the problems encountered with nerve stimulation.

The previous description of research programs leads to an overall concept with the following functions:

- ./. electro-stimulation
- ./. support function
- ./. orthotic function.

It is very unlikely, that all necessary functions will be achieved by electro-stimulation in the first approach. Therefore supporting elements will be of great importance in the beginning.

The"Movement Simulation" program is based on results from the "Model Research" program (no.2) and experiences acquired by other program steps. According to the current plan the title of this new program is

LEARN TO WALK WITH FINGERS.

Aim of this program is to gain first experience during application of the method described in no. 2 (of course, it is necessary from here on to work with the patient) and development of a suitable apparatus, which makes it possible for the patient to stand and walk erect. Technical realization of such an apparatus is the main task of development program no. 10.

4. PRESENT STATUS

During a clinical experiment we started electrode implantation on a 25-year old patient after paraplegia. Five or more electrodes were positioned around each nerve. Results are: extension of knee joint (fig.5) and flexion of ankle joint was functionally

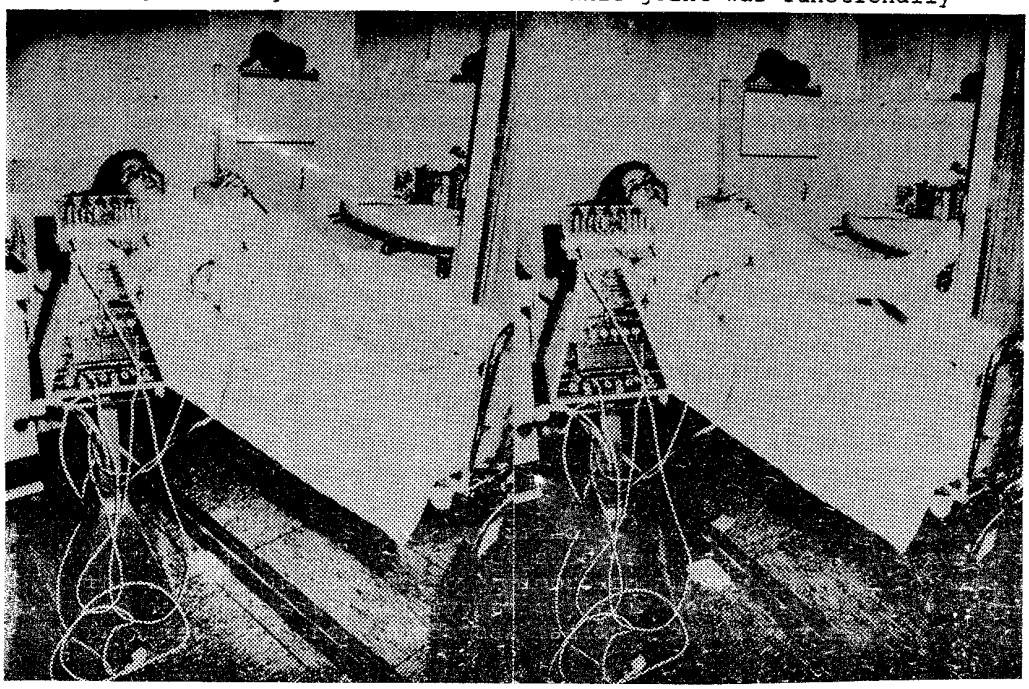

Fig. 5: Functional electro-stimulation of the femoralis nerve

sufficient. Flexion of knee joint and extension of ankle joint could be done only partially and with increased stimulation current. Therefore optimal electrode positioning is the subject of current research. For flexion of the ankle joint a training apparatus was built (fig.6). It consists of a guide rail, where a rotable

Fig. 6: Functional electro-stimulation of the tibialis nerve.

foot rocker is mounted. Two strong springs pull the foot rocker to the extendend position of the ankle joint. Exercise was done under supervision of a medical-physical assistant. Due to this muscle training the circumference of the calf muscles increased by 2,5 cm. This experiment was carried out for four months and proved the efficiency of the "Karussellstimulation" method. The positive effect of this exercise is the conservation of muscle substance, but it is not deniable, that this was a clinical experiment requiring permission of the patient. Motivation of patients is surely one of the important factors. In this case the physiological effect was easily recognizable. The patient was able to move her foot by means of the joystick. Therefore the "eternal paralysis syndrome" disappears in a most important and critical patient's situation, the first month after the accident. It is clear, that such experiments must be carried out with great care, but they are necessary, at least for finding optimal electrode positions for human application; this is not possible with animal experiments.

For some clinical cases the phrenic nerve stimulation is absolutely indicated. Therefore we have more experience in that direction. We distinguish "electrophrenic respiration" (EPR) from "pneumoelectric respiration " (PER). EPR uses phrenic nerve stimulation only; PER means synchronization with the respirator. The advantage is, that the patient doesn't suffer under common problems faced with long-term positive-pressure respiration, such as increased right circulation pressure, bad distribution of breathing gas, etc. In one case EPR was used up to 4o days continuously in our clinic (fig. 7). The effect of the method was supervised by blood gas analysis.

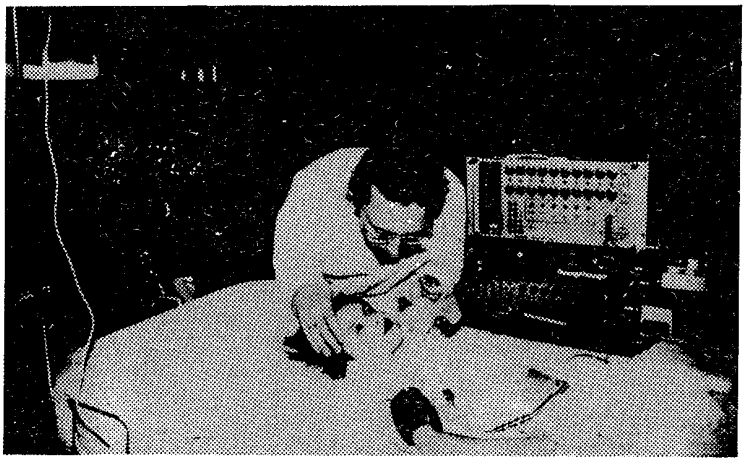

Fig. 7: Clinical application of electrophrenic respiration

In another case pneumo-electric respiration (PER) was used for 160 days continuously in a case of tetraplegia after fraction of the dens axis. Because the right nerve was damaged, it was only possible to stimulate the left nerve. The stimulation caused an inspiration volume of 250 ml, which was sufficient for a decrease of the pressure plateau; therefore the quoted advantages were achieved.

Talking about the technological part, we just finished a new multichannel stimulation unit (fig. 8). Right now it is capable of driving eight electrodes, but this can be easily expanded. Via a microprocessor program we can determine the electrode combination from one impulse to the next, stimulation current, stimulation duration, frequency and polarity.

Features are:

./. microprocessor-controlled, freely programmable stimulation;
./. radio frequency-controlled transcutor;
./. possibility of stimulating 2 nerves simultaneously in the "Karussellstimulation" mode (right and left lung); otherwise stimulation of up to 4 nerves;
./. avoidance of inefficient electrode combination;
./. power failure alarm;
./. battery -powered for portable applications;
./. triggerable by external respirator.

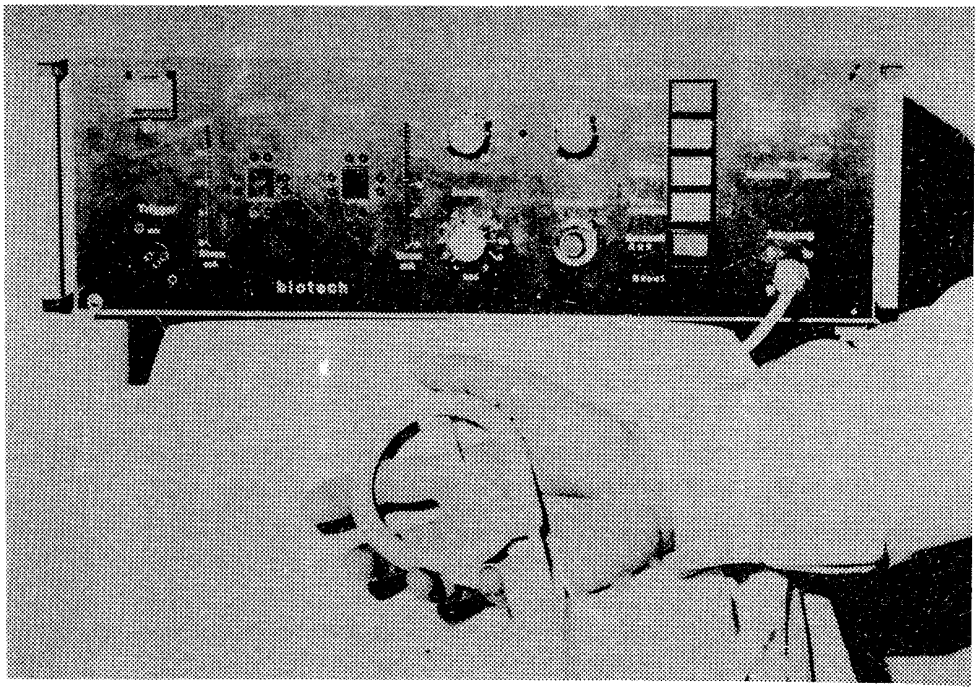

Fig. 8: Multichannel electro-stimulation device

At present, the implanted transcutor is constructed with discrete parts; further models will be built in hybride technology.

5. FINAL REMARKS

Today we're just at the beginning of functional electro-stimulation. By means of our method we overcome the barrier of the nerve-muscle complex and new problems need to be solved. A practical realization will surely take a couple of years, but with the aid of suitable stimulation systems it should be possible to mobilize the paraplegic and support the tetraplegic patient in respect to his life quality.

Several research groups are working on that problem having also a great humane aspect, and this supports my opinion. Therefore I conclude with the proposal, that all research groups should have organized and continuous exchange of experience, because that's the most economical and fastest way to achieve our goal.

6. SUMMARY

Aim of the research project is to develop a method, by which it is possible for the paralysed patient to stand and walk erect. The principle lies in the electrical stimulation of the nerves responsible for the apparatus of locomotion. The basis for this program was founded 1973, when the long-term stimulation of nerves and muscles was invented, developed and patented. In the last years the method has been optimized, so that it is possible now to use it up to five months continuously on patients in the clinic, for electrophrenic respiration.

The whole project deals with various problems; part of them have been successfully solved during the past two years.

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H. Thoma

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J. Holle, E. Moritz, A. Lischka, H. Thoma

Wiener klinische Wochenschrift, Band 86 (1), 1974

Univ.Doz.Dipl.Ing.Dr. Herwig Thoma
2. Chirurgische Universitätsklinik Wien
Spitalgasse 23
A-1090 Wien
Austria