NEW APPROACHES OF BIOELECTRIC ARM REHABILITATION

H. Henninger

Since 1967 at Stollhof the rehabilitation service has used the Austrian-made bioelectric prosthesis system manufactured by Viennatone. To date 81 arm amputees have been rehabilitated in Stollhof. Meanwhile fitting and training of below-elbow amputees became routine. Our experiences can be considered fairly good in average, and they have been reported in various scientific periodicals. I would like to give you a short, comprehensive report to-day about two special problems treated in Stollhof.

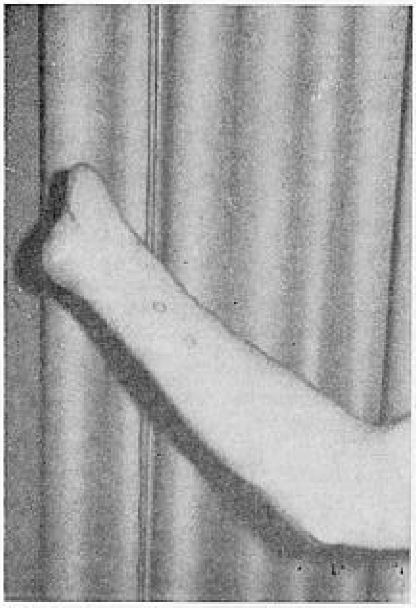

Fig. 1. *A right extremely long forearm stump with preserved metacarpal.*

Fig. 2. *Patient with the prosthesis.*

In Stollhof we were mainly occupied in rehabilitating persons recently amputated. Later we treated patients, who had been amputated years ago, for suitability of the myoelectric system. We found that even with atrophic stumps, due to systematic training, we had amazingly good success with myoelectric control. Even amputees who had been supplied for many years ago with rotatory arms, system Zavodnik, whose forearm rotators were strongly developed, could be successfully corrected, even though flexor and tensor muscles were already inactive and atrophic. Of course, concentrated training isometric contraction was necessary for a really successful fitting.

The following illustrations show four cases of rehabilitation as a successful result besides routine work:

Due to the positive successes we had with below-elbow amputees, we started to fit above-elbow amputees last year. Difficulties arise in finding a replacement for lost tensor and flexor muscles. Isometric training is obviously more difficult in such cases, however, satisfying results have been achieved.

Fig. 4. The difficulty with this stump was to match the length of the artificial hand to the length of the healthy left hand. Due to the extremely long stump it was necessary to shorten the distal portion of the hand, and a special wrist unit had to be developed. By that, enough space was left in the plastic inner glove for the preserved metacarpal which results in a satisfying cosmetic appearance. It should be mentioned that due to this successful effort a further amputation of the metacarpal, already considered, could be avoided.

Fig. 3. *Prosthesis in function.*

The following illustrations show two special fittings of above-elbow amputees.

Besides the efforts to accomplish complicated fitting with the available Austrian-made bioelectric prosthesis system Myomot MM-2, the rehabilitation centre Stollhof checked a new VIENNATONE development, the proportional controlled prosthesis system Myomot MM-3P.

The control of bioelectrical prostheses can be made by two different principles, the digital control or the proportional control.

In using the digital principle, the myoelectrical signals turn on the motor like a switch. Independently of the muscle contraction, the motor has always the same velocity and the movement of the fingers is constant. As soon as the fingers touch a subject, the motor will be stopped up to stand-still. The given stand-still-torque and also the gripping force between finger tips is independent of the contraction of muscles. Moderated through recurring impulsive tightness of the control muscle, it is possible to reach a certain delicate gripping force, but it is not similar to a physiological natural control. A digital controlled motor does not allow for a very natural motion of the fingers because of the uniform machinery -like movement. Therefore a part of the good cosmetic effects gets lost in using the prostheses.

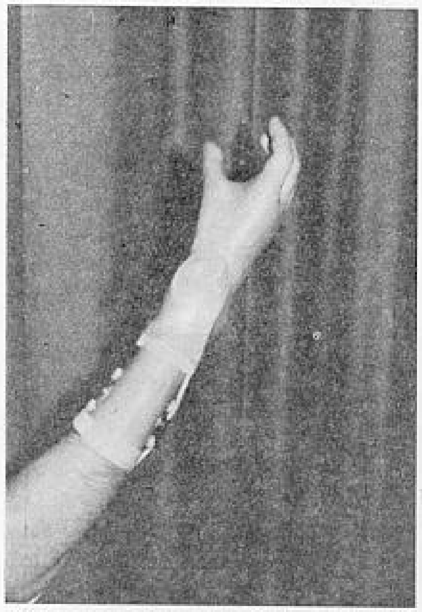

Fig. 5. The socket is constructed as a so-called short socket. This means, that it encloses the stump only insofar as it is required for the attachment of electrodes. Thereby the elbow joint remains free and allows a completely natural use of the prosthesis without affection of the myoelectric control in any position of the hand.

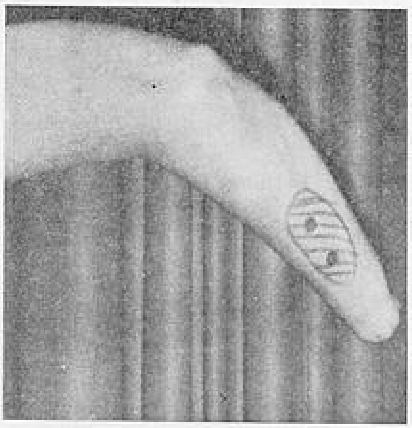

Fig. 6. This and the following figures refer to another patient fitted with a short-socket prosthesis. It shows an amputated forearm with a preserved wrist joint.

With the second possibility, the proportional control, the above prescribed disadvantages will be avoided. The rotational speed of the motor and therewith the velocity of the fingers is dependent on tightening the controlled muscles. If the muscle is only contracted weakly the speed of the fingers is slow. If the patient increases the contraction, the speed of the finger motions increases also. When the fingers touch an object, the motor will be completely stopped and stand-still-torque respectively the gripping force is larger dne to more tightening of the muscle. Therefore, with proportional control the fingermotion speed and gripping force are proportional to the strength of the muscle contraction.

Fig. 7. *Patient with the prosthesis*

Fig. 8. Even in an extremely flexed position the prosthesis functions properly.

The variable speed of the fingers allows a really natural motion. The measured gripping force is adequate to a physiological natural control.

The principle and fundamental difference in both systems can only be found in the amplifiers. In the digital control system the motor will be turned on and off by a switch. The proportional system requires an amplifier which does not only switch on and off the motor, but also, signals for power in proportion to the amount of muscle contraction.

It would be very simple to develop a proportional amplifier that works in a manner similar to a variable series resistor to the motor depending on the muscle contraction. However, that means that the proportional amplifier consumes more or less dissipation power; this electrical energy gets lost for the drive of the motor. The efficiency of this proportional control principle is in average very low. The efficiency depends on the value of the muscles contraction and reaches its maximum in moments of the most muscle actions only. With middle and weak muscle actions (slow fingerspeed and low gripping force) this system operates with extremely poor efficiency. To utilize energy in the battery efficiently a proportional control system must have an extremely high efficiency at low myosignals (slow fingerspeed and low gripping force) as well. This fulfils the proportional amplifier with pulse—width modulation developed by the Austrian company. The now available Austrian bioelectric arm prosthesis system MM-3P incorporates a proportional amplifier with pulse-width modulation.

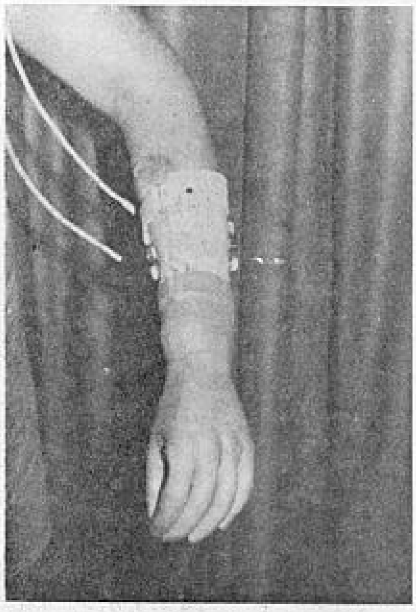

Fig. 9. *Prosthesis in function.*

Fig. 10. *An amputee with a long upper-arm stump.* Because of a plexusparalysis it was impossible to control the hand prosthesis by myosignals from biceps and triceps. The patient controls the prosthetic hand by muscles from the shoulder region.

The principle of this control consists therein, that the electromotor will not be, as is usual, supplied with direct current of different levels, but with periodic quickly repeating current pulses of constant peak value, but various duration. The duration of this current pulses depends on the muscle contraction.

Although we knew about the functional advantages of an artificial hand with proportionally controlled speed and pinch force, we still were rather sceptical in handling such a device. We expected difficulties in application because of the limited range of proportional control and our lack of experience in adapting this type of control to patients. But, to our surprise, no serious difficulties arose.

Fig. 11. *Patient with the prosthesis*

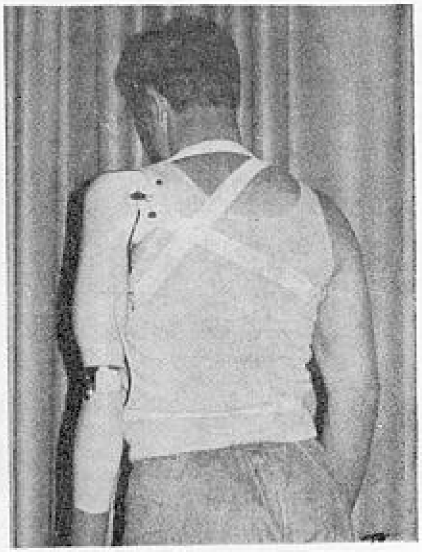

Fig. 12. *Patient with the prosthesis*

In the course of a check-up of 15 below-elbow amputees who had already been fitted with a digitally controlled biolectric arm a couple of years before, tests were made with the new proportional control system. The tasks for the patients consisted of moving nine objects of different size, form, material and weight from one place to another using both control systems. The patients were allowed to use their own sockets. The time required was measured.

Thirteen patients performed their tasks in a shorter time using the proportional control system. Performance time was about 20% shorter with proportional control than with digital control.

The advantage of proportional control can doubtlessly be improved by special training. No patient had the opportunity to practice with proportional control before the test. All fifteen subjects are very closely attached to the digital control, two of them were even unable to operate the proportional control system at all.

They said: "The hand is running away". Apparently these two had difficulties in changing from the well trained simple contracting and relaxing of their control muscles to a more delicate use.

Fig. 13. This socket variates from the usual above-elbow socket by being open on top. As a result of the plexusparalysis the patient could not abduct his stump. Therefore the patient was unable to put on his prosthesis with a closed socket on top. Flexion as well as locking of the elbow joint is operated by cables in conventional manner.

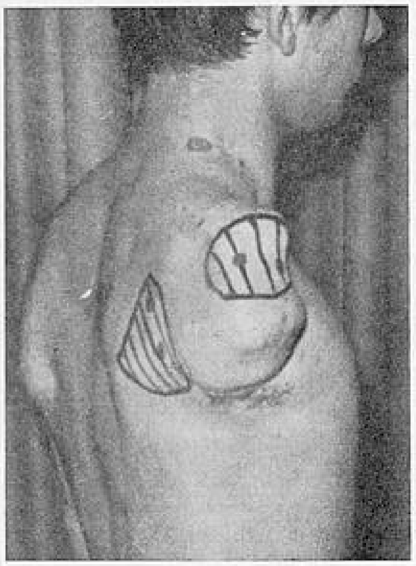

Fig. 14. *Patient with an extremely short above-elbow stump*

The subjects were asked which system they would prefer. Eight of them preferred proportional control for reasons of a quicker and more delicate prehension as well as a significant reduction in muscle effort.

This success encouraged us to check the system on above elbow amputees too, but three patients which we thought were able to operate proportional from biceps and triceps or from muscles of the shoulder region failed.

However, in principle, rehabilitation of above-elbow amputees with proportional control systems seems possible. We found a bilateral above-elbow patient who was able to operate proportional control from biceps and triceps immediately after the first trial. He used it in a very convincing manner.

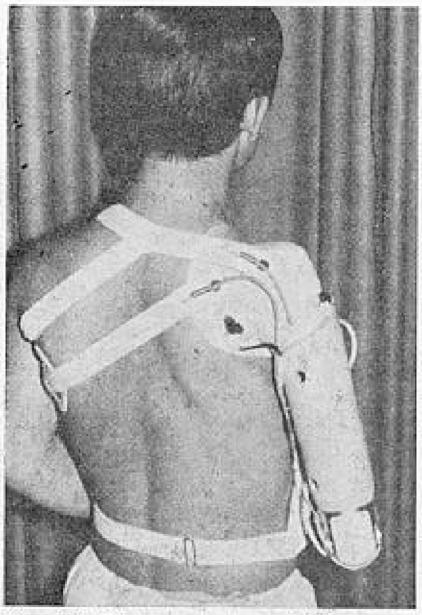

Fig. 15. This patient could be successfully fitted with an inner socket enclosing the shoulder joint. Myoelectric control of the hand prosthesis is operated by muscles from the shoulder region.

Fig. 16. Flexion as well as locking of the elbow joint, as shown in the preceding case is done with cables. Due to a very sensitive nevus on the neck, it was necessary to change the usual way of harnessing and this explains the harness around the chest, a type which normally is avoided.

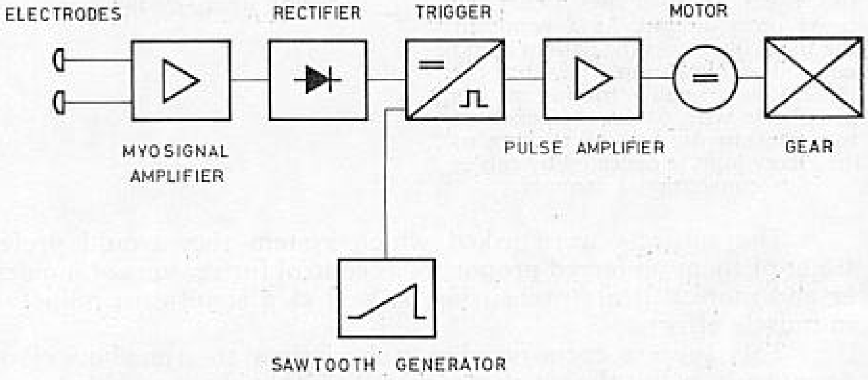

Fig. 17. *Block diagram of the proportional control system with pulse-width modulation.* A generator provides a sawtooth voltage of approximately 1 KHz. The peak value of this auxiliary alternating voltage is just below the level of the trigger circuit, so that without a control signal trigger the pulse amplifier will not operate. The motor stays switched off. When the muscle is contracted the myosignal will be amplified by the pre-amplifier, rectified, and added to the saw-tooth voltage. Therefore a voltage arises at the input of the trigger which is higher than the trigger level. The trigger and the pulse amplifier switch the motor on.

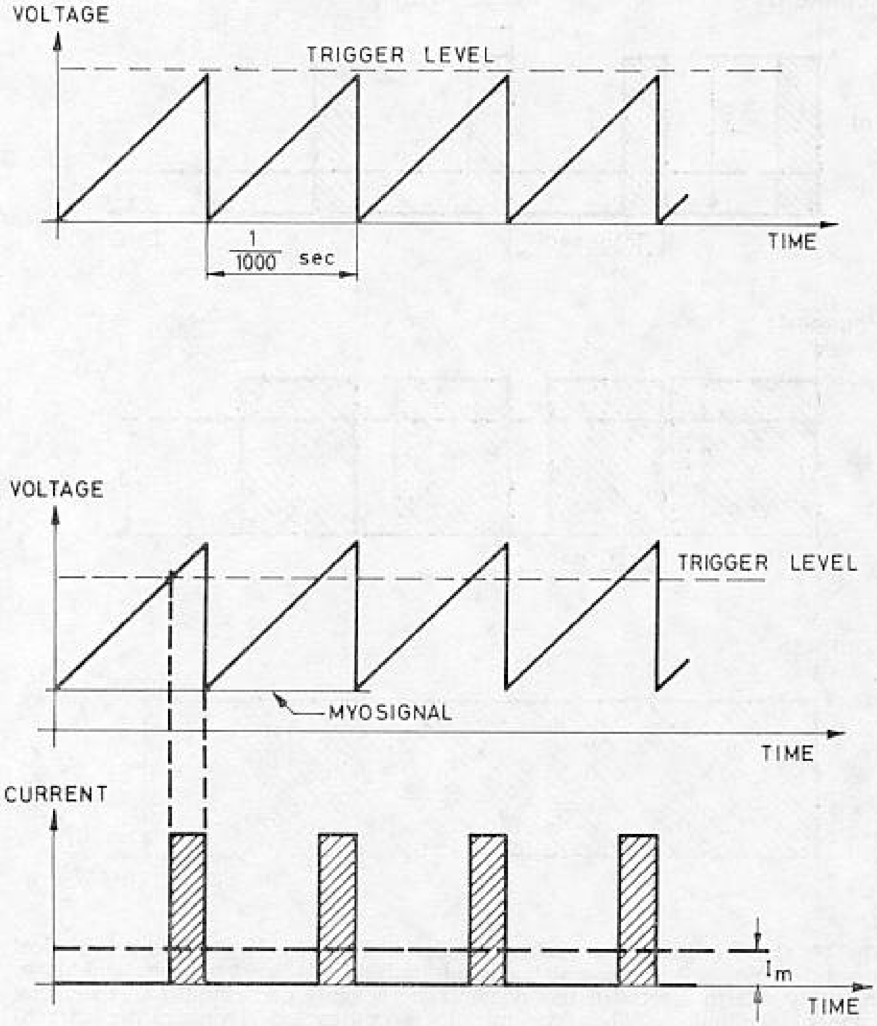

Fig. 18. *Principle of the pulse-width modulation.* If the myosignal is low, the motor will be switched on for a short moment. This occurs always when the momentary trigger input voltage is higher than the trigger level. When muscle contraction is increased the periodic repetition of the switch-on duration gets longer and therefore the pulse width increases.

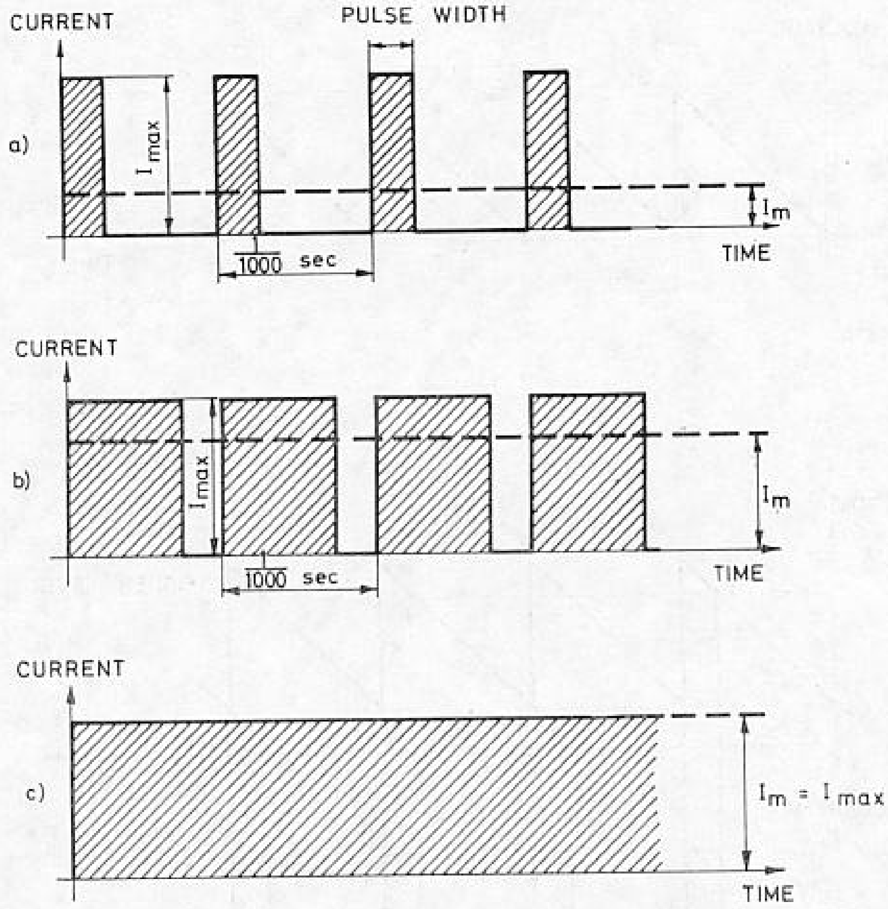

Fig. 19. *Current pulses at various levels of the myosignals.* The mechanical fingers do not follow the quick current pulses in a jerky manner but move smoothly due to inertia of the system. The velocity corresponds to the mean value of the pulses. When the muscle is contracted stronger, the current pulses get wider, but at the same maximum value. These wider pulses are compiled with higher DC mean value which drives the motor faster. If the amputee contracts the muscle stronger, the pulse width is increased more and more. Finally pure constant direct current runs through the motor. The motor has reached a speed which could not be increased even if the muscle contraction gets stronger.