

Walking rehabilitation of the paraplegic patient by means of surface electrical stimulation.

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Abstract

The aim of this study was to optimize the stimulation parameters, for "walking" rehabilitation by means of surface electrical stimulation. This study was conducted for two years in a 25 paraplegic patients population. An 8 channels electrical stimulator (PROSTIM, Neuromedics, Claret, France) was used. Five patients participating to the walking stage, used the walking frame without any other orthotic help. The particular choice of the stimulated muscles, lead us to optimize the electrodes location and the current parameters. Gait was much more efficient and elegant than the one obtained with the "Parastep" system (Sigmedics). We defined a precise methodology to obtain a walking sequence under optimal conditions : careful examination of the medical data, detailed physical check up where "mapping" had a relevant place, then, the first verticalization tests were done, having as a main goal, the correction of the lumbar hyperlordosis. For certain paraplegics, a "walking program" is conceivable using surface electrical stimulation. We always stimulated the quadriceps and the tibialis anterior associated to the peroneus. One of the remaining channels is used to correct the hips anteversion (usually semitendinosis and semimembranosus), the other is for the step (usually the sartorius).

However, it is evident that for the patient with a medullar lesion, reinsertion is more a question of an optimization of his/her autonomy using the wheelchair rather a rehabilitation by restoring some "walking" abilities. At the PROPARA Center, we set out to work towards that.

1. Introduction.

Walking rehabilitation is a subject that has always had many teams all around the world working on it. There were many solutions proposed and each team uses them in a more or less successful manner. The first orthosis were mostly mechanical, then some teams started using surface electrostimulation sometimes coupled with a "mechanical" orthosis (hybrid orthosis)

A system entirely based on surface electrostimulation is, as the present time, commercialized. It is the PARASTEP system (Sigmedics) which is a ready-to-wear solution to walking rehabilitation for the paraplegic patient.

During a two-year period, in the framework of the European Project SUAW, we have worked with an 8-channels stimulator type "PROSTIM" (Neuromedics) and we succeeded, in 5 complete paraplegics (Franckel A), in creating a "walk" much more esthetic than the one obtained with the Parastep system.

Here are some elements that we deemed important in the research for a quality deambulation using surface electrostimulation.

However, it is evident that for the patient with a medullar lesion, reinsertion is more a question of an optimization of his/her autonomy using the wheelchair rather a rehabilitation by restoring some "walking" abilities. At the PROPARA Center, we set out to work towards that. MATERIAL

The study was conducted for the past two years at the PROPARA Center in Montpellier (France) in the framework of the SUAW project. This study was based on 25 paraplegics. 10 of those patients were verticalized, walking rehabilitation was only a reality for 5 of them. The material used is an independent 8-channels stimulator, current-regulated, of PROSTIM type (Neuromedics, France). This stimulator, linked to the patient by a cable is itself controlled by a computer via an RS link. This software was specifically developed for this application by the engineers of Neuromedics. The surface electrodes used are adhesive "Saint Cloud" brand. Their sizes vary (45cm² to 3 cm²), according to the various muscles to be stimulated. The walking-frame used is standard with an easily-accessible push-button system located at the wrist level, which is adjustable through the software.

2. METHOD:

For each of the 25 paraplegics, the method used was the same in its successive phases. Some were not able to -- or simply didn't want to -- go to the "walking" level.

1) Study of the Medical Data.

First of all, we need to eliminate the medullar patients, for whom the neurological lesion level is too high. Reasonably we can only include levels inferior to T6.

Paraplegia must be complete on a sensitive level, in order to “cope” with the inconvenience of the current being used. The orthopedic level must be good with a perfect integrity of the lower limbs. We tolerate a certain hypo-extensibility of the T.F.L. Psoas, right anterior or Triceps surae, very frequent at those levels of medullar lesions.

The patients’ accident was a while back and they have already optimized their usage of the wheelchair.

2) Mapping.

During this exam we can evaluate : on one hand the potential of surface electrostimulation and on the other hand the best placing of electrodes according to the muscle or the muscle groups considered.

The considered muscles are:

- quadriceps
- Gluteus maximus and gluteus medius
- T.F.L.
- sartorius
- hamstrings
- triceps surae
- Foot extensors (Via S.P.E.)

For each we note:

- The intensity level at which we observe a response 1 (international testing quotation)
- If not, the level of diffusion to other muscles
- The maximal response obtained (international testing quotation)
- The localization of electrodes for an optimal response.

3) Verticalization

The first verticalization test is directly done in a walking context. The patient is verticalized solely by the stimulation of the quadriceps. The muscle recruitment for correcting the lumbar hyperlordosis is slowly introduced in order to better understand their real correcting power.

This correcting phase is essential, it is useless to go onto the next phase if the pelvis stays anteversed.

Besides the electrical adjustments, the patient must also manage his/her posture in the walking frame. It will lead to a more elegant walk but most importantly to a lesser fatigue.

4) Deambulation.

We can distinguish two type of adjustments : static and dynamic.

- **Adjustment of the “static” parameters .**

(choice of muscles, electrodes’ placing, intensity, frequency and current impulsion width) during the various phases of the “walk” rehabilitation we have to modify those various parameters to adjust the

observed “walk”. However we only play on the intensity or current width, considering that the electrodes’ placing has already been optimized..

- **Adjustment of the “dynamic” parameters .**

The possible adjustments are:

- Step duration.
- Upward and downward curves for each channel
- Delay or advance for each canal. (Fig. 1)

This phase is very complex, because the modification of only one of these parameters on only one of the 8 channels, has repercussions on the entire “walk” dynamic. These adjustments must be prudent and at each modification we must give to the patient time to integrate it. For this final phase a good cooperation with the patient is mandatory, his feelings are very important and guide the physiotherapist for the corrections to be made.

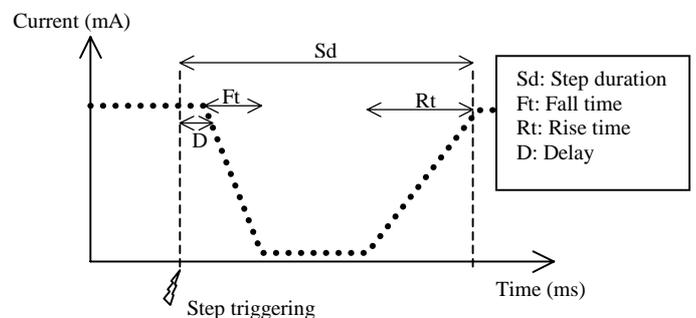


Fig. 1: Dynamic parameters

5) TRAINING

For the patients who want to go on further, we propose a training program with three parts :

- **Orthopedic and muscular maintenance :**

It focused mostly on postures, which help to fight the hypo-extensibility of certain muscles (mainly TFL, right anterior and psoas)

We also work on maintaining if not reinforcing the muscular potential of the lower limbs.

- **Electrical Training**

In order to improve endurance, we set up an electrostimulation training for the muscles most subject to fatigue during walking, quadriceps, even gluteus maximus when used.

- **in situ Training**

The patient undergoes progressively longer strides using the system, while respecting the adequate resting times.

3. Results / discussion.

1) *Muscles' choice:*

- The quadriceps remains the main actor for verticalization. It is necessary, however, to focus on the three mono-articular chiefs for the rectus femoris, which is much more anteversed for the pelvis than an extensor for the knee in a closed kinetic chain. This is why we prefer to look for a stimulation of the crural nerve rather than use a "classic" stimulation with large electrodes on the muscular body. In that case we recruit in priority the Rectus Femoris.
- The hamstrings have always been for us, better pelvis retroversors in an upright position than any other muscular combination. Whatever the cause, surface electrostimulation for the gluteus maximus is not enough to correct the hyperlordosis during verticalization. For 3 patients out of the 10 that were verticalized, we stimulated concomitantly the hamstrings and the gluteus maximus, based on the patient's response. The introduction of a stimulation on the gluteus maximus in a verticalized patient is not for an additional correction of the pelvis. However, their stimulation gives the low-level paraplegics (T12) a sensation of pelvic control. Regarding step passage, we wanted to go away from the flexion scheme (triple withdrawal) which is used in the PARASTEP system. It seems very important to us to control the step for functional reproducibility reasons as well as esthetic ones. For the step triggering, we use two channels for each lower limb.
- The SPE stimulation allows us to obtain a very good dorsiflexion of the ankle (tibialis anterior) but also a foot eversion (peroneus) which "shortens" a little the lower limb, but mostly prevents any ankle spraining when putting the foot on the floor. The second channel is used for hip flexion. The couturier muscle has appeared, along time, to be the ideal muscle to fulfill this mission. We would like to point out that it is delicate to stimulate it efficiently and separately from the adductors, that is why we use a small-sized distal electrode. Since we can not recruit it very easily, let's not forget that its stimulation will be more efficient if the pelvis retroversion and thus the contralateral hip flexion are controlled in an efficient manner.

Regarding Surface electrostimulation, the muscles' choice is easily made. There are not many alternatives. However, for difficult cases, two additional channels for each side would be welcomed. It would have been interesting for some of our patients to be able to recruit the gluteus medius, the TFL, or even the abdominal muscles.

If we project our experience onto implanted stimulation, it is important to make sure to obtain a fail-proof recruiting of the hamstrings in order to ensure a good correction of the pelvis anteversion.

Moreover, the Psoas, which seems so interesting for the hip flexion, needs to be taken with precautions. A too aggressive recruiting can lead to a lordosis of the lumbar rachis, rather than a real hip flexion. It seems to us more prudent to look at a softer hip flexion and mostly coordinate it with the knee flexion using the couturier muscle.

2) *Adjustment of static parameters:*

- **Frequencies:**
The frequencies used are generally in the order of 18 HZ for the tonic muscles (quadriceps, hamstrings and gluteus), we sometimes "went up" to 30 Hz for the phasic muscles (foot extensor, sartorius and TFL).
To increase by 4Hz the stimulation frequency of the tonic muscles allowed us sometimes to go away from a too important tonic scheme in extension (patient standing on tiptoes)
- **Impulsion widths:**
For the tonic muscles, the standard width is 300 μ s we sometimes stimulated with widths of 500 μ s, this allowed us to either decrease intensity, or go on with the training at the end of the day when fatigue was most important for those muscular groups.
For phasic muscles, fatigue being less, we mostly used widths of 150 μ s or even 100 μ s. This allowed us not to have a triple withdrawal which was highly uncontrolled and totally unpredictable.
- **Intensity:**
It is more often the parameter by which we control and adapt, lastly, the amplitude and muscular response.

There exist very many publications on current "static" parameters' optimization in relation to fatigue. However the gains obtained using a "classical" stimulation are weak in absolute value, or at least unsatisfactory for a durable deambulation in our patients.

In our experience we well understood the importance of fundamental neuromotor schemes.

The muscle's response to an electrical stimulation will be more efficient if it is simultaneously coupled with the stimulation of a muscle or muscular group belonging to the same neuromotor scheme.

For example, if you need 90 mA to obtain a response for the couturier graded at 2, it will be

sufficient to use 40 mA to obtain the same response during a concomitantly stimulation of the SPE.

3) Adjustment of the dynamic parameters:

They are the adjustments that needs the most attention, in relation to the observed walk. The esthetical side and step efficiency both depend on those parameters. Even if the parameters are totally different for each patient, figure 2 represents a "standard" envelope curve.

At first we only had the possibility to vary the upward and downward slopes of the various channels.

The possibility of introducing, afterwards, advances and delays considerably altered the "stride" of the step, both on an esthetical side and on the amplitude of the steps. Both are a proof of higher efficiency..

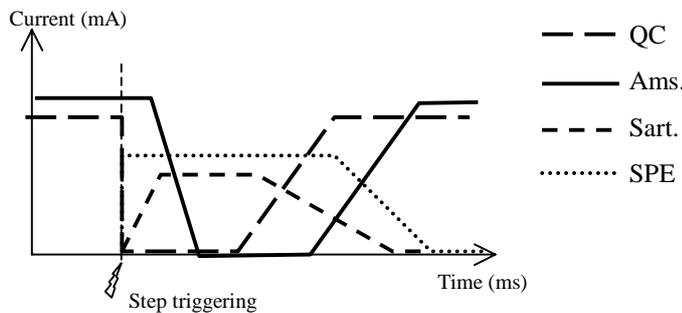


Fig. 2: "Standard" dynamics parameters.

4. Conclusion:

Even if for us the rehabilitation of the medullar patient goes necessarily through an optimization of his functional abilities in using the wheelchair, it is also our goal to offer a walking rehabilitation program for some paraplegics which have a desire as well as the required capacities for it.

A 2-time 4-channels stimulator seems a good compromise between feasibility and results. Such a system, of course portable, with a walking frame could be use in an autonomous mode, after a phase of personalization of parameters by some medullar patients. It is essential to underline that such a tool must be considered more like an additional help in the patient's life rather than a system allowing him/her to be autonomous.

Such a system, which could be individually adjusted would be more applicable in incomplete patients for which sometimes "a little pitch" can help better their walk..

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