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Original Article

Driven gait orthosis for improvement of locomotor training in paraplegic patients

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Design: Single cases.
Objective: To compare the effects of manually assisted locomotor training in paraplegic patients with the automated training by a driven gait orthosis.
Setting: ParaCare, University Hospital Balgrist in Zurich, Switzerland.
Methods: Treadmill training with manual assistance and by a driven gait orthosis was applied to two spinal cord injured patients. The first patient had an incomplete lesion at C3, the second a complete lesion at C5. They were selected by convenience sample. The EMG activity of the leg muscles rectus femoris, biceps femoris, gastrocnemius medials (GM) and tibialis anterior (TA) was visually compared for the two training methods. GM and TA activity was also quantified by calculating the variation ratio between the EMG of the patients and a set of healthy subjects.
Results: No significant difference between the two training methods was found according to the leg muscle EMG activity.
Conclusion: Neuronal centers in the spinal cord become activated in a similar way by the manually assisted and the automated locomotor training. With the driven gait orthosis training sessions can be prolonged and workload of therapists can be reduced, and therefore, the automated training represents an alternative to the conventional therapy.
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Keywords: locomotor training; spinal cord injury; paraplegia; locomotion; orthosis

Introduction

The purpose of this work is to give a first assessment about the effectiveness of a new automated treadmill training for paraplegic patients using a driven gait orthosis (DGO).

Manually assisted walking on a treadmill combined with body weight support has been used for more than 10 years in the locomotor rehabilitation of paraplegic patients. It could be shown that in incomplete spinal cord injured patients (SCI) this training improves walking capabilities.[1,2] Up to now the assistance of the leg movements usually required at an early stage of training was done by physiotherapists. This manual assistance of the patient's legs can be exhaustive because it has to be carried out in an ergonomically unfavorable position. Therefore the DGO has been developed to allow an automated moving of the legs of non-ambulatory patients during locomotor training on the treadmill. The goal of this endeavor was to facilitate the work of the therapists, to prolong the duration of the training sessions and to achieve a reproducible gait pattern for the leg movements.

The aim of this study was to show how far the manually assisted locomotor training can be replaced by the automated one. This was done by comparing the leg muscles EMG activity of two patients while they were trained either with the manual or the automated training method.

Methods

All experiments were made with informed consent by the patients and approved by the local ethical committee. In five incomplete and one complete SCI with different levels of lesion the locomotor training was performed.

Two patients were evaluated in detail with EMG recordings; one was a patient who suffered an incomplete lesion at C3 (Frankel C) the other one a motor complete lesion at C5 (Frankel B). The patient with the incomplete lesion could already move the legs

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*Correspondence: G Colombo, ParaCare, Institute for Rehabilitation and Research, University Hospital Balgrist, Forchstrasse 340, CH-8008 Zürich, Switzerland on his own in an upright position but could not walk by himself at the time of the recordings. Both patients suffered from moderate to severe spasticity.

During both approaches, the manually assisted and the automated locomotor training, the patients were standing on a moving treadmill, supported by a harness (see Figure 1). Unloading a part of the body weight was achieved by a pneumatic suspension system. The unloading of the patients was kept constant for the two training approaches and amounted to 40 kg out of 80 kg body weight in the incomplete, and 60 kg out of 90 kg in the complete patient. In the conventional, manually assisted training therapists were sitting on either side of the patient walking on the treadmill. Nowadays, this method is used in many rehabilitation centers, for detailed description see Dietz *et al*.[2]

The automated training was performed by a DGO, the 'Lokomat'. It was developed by Hocoma AG, medical engineering in Staefa at the rehabilitation center ParaCare of the University Hospital Balgrist in Zurich (both Switzerland). Figure 1 shows a patient during a training session with the DGO, which is adjustable to the anatomy of each subject. The device was fixed to the patient by several straps fastened around the chest, waist and legs. The following parameters were variable, in order to allow an optimal fitting of the orthosis to the individual patient: The width of the hip orthosis, the length of thigh and shank and the position as well as the size of the leg braces. The orthosis was connected to the rigid frame of the treadmill with a four bar linkage, ie the patient was fixed in respect to the moving treadmill belt. This fixation provided additional vertical stability to the trunk of the patient. Two drives on each leg were moving the hip and knee joints of the orthosis and consequently the legs of the patient.

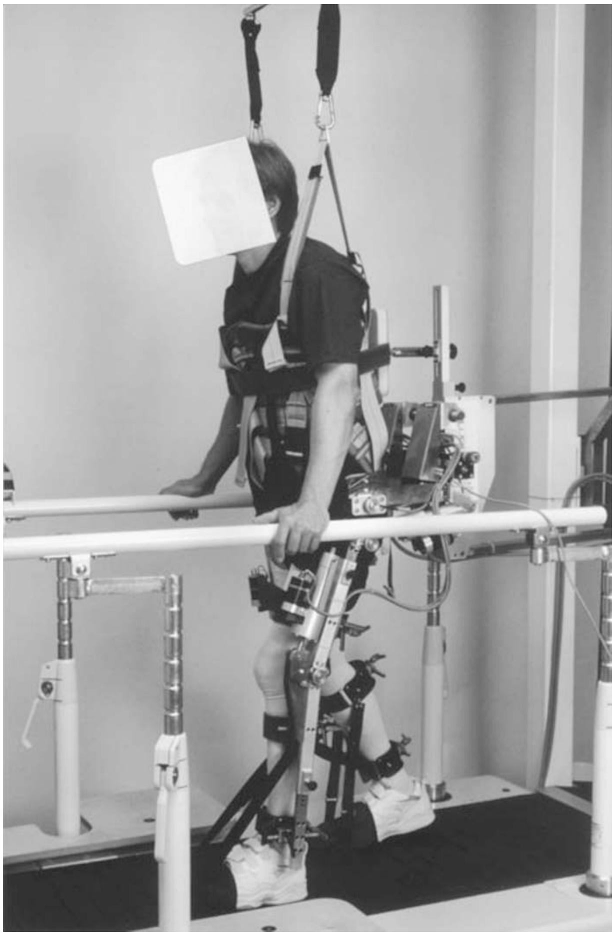

Figure 1 Illustration of a patient with incomplete paraplegia during an automated locomotor training with the DGO

The drives were controlled by a real-time system that was running on a personal computer in such a way, that the legs became moved by a physiological gait pattern on the moving treadmill. The flexion of the ankle joint during swing phase was achieved by a passive foot lifter (for details see Colombo *et al*[3]). In all trials with the DGO no manual assistance was necessary.

To interpret the effects of the locomotor training on the neuronal circuits within the spinal cord, which are thought to be responsible for the generation of the locomotor pattern, the EMG activities of four leg muscles were compared. The EMG was recorded by surface electrodes fixed over the muscle belly on each leg of the patients in rectus femoris (RF), biceps femoris (BF), gastrocnemius medials (GM) and tibialis anterior (TA). The EMG signals were amplified and transferred to a personal computer. They were recorded by a data acquisition tool (SolEasy by Aleasolution GmbH, Zurich, Switzerland) with a sampling frequency of 600 Hz. Then the EMG data was rectified and cut into single steps starting with the onset of stance phase. The signal of a goniometer attached to the lateral aspect of the right knee was used to determine the different phases of a step cycle. After cutting the single steps they were normalized to a step length of 1000 samples and then a set of 20 steps was averaged for every muscle. The data of the manual and the automated training were recorded in the same session (for detailed descriptions see Dietz *et al*[4]). The treadmill speed in all recordings was kept at 1.9 km/h.

For the quantification of the EMG data recorded during the two training methods, the variation ratio (VR) between the EMG signals obtained from the two patients during training and a set of signals obtained from healthy subjects during walking was calculated. As described recently[5] the VR provides a measure about similarity of several waveforms. Sixteen single stride EMG profiles for each of the patients and 16 mean EMG profiles of healthy subjects were pooled to calculate the VR for each recording session. The calculation of the VR was performed by statistic software (SAS, SAS Institute Inc., Cray, NC, USA) on a personal computer. For similar EMG patterns, the VR tends to a value of zero, while in basically different patterns the VR tends to be one.

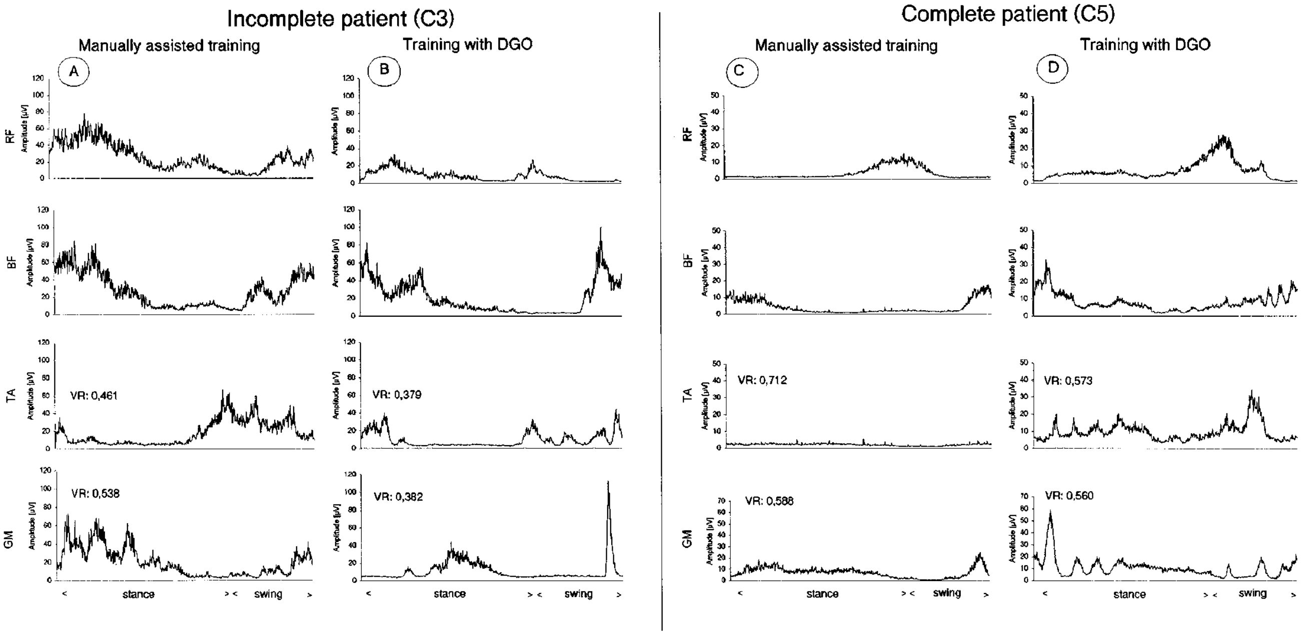

Figure 2 Rectified, averaged ($n = 20$) and normalized (to one step cycle) electromyographic activation of leg muscles during locomotor training at 1.9 km/h treadmill speed is displayed. For an incomplete (**a** and **b**) and a complete SCI patient (**c** and **d**) during manual training (**a** and **c**) as well as during automated training (**b** and **d**). RF = rectus femoris; BF = biceps femoris; GM = gastrocnemius medials; TA = tibialis anterior

Results

Figure 2 shows the leg muscle EMG activity of the two patients during the two training methods. In A and B the data of the right leg is shown for the incomplete patient and in C and D the corresponding values for the complete patient. The data of the left leg is not shown but was similar to the one shown here. The EMG patterns recorded during the manually assisted training are displayed in A and C while the recordings for the training with the DGO are shown in B and D. The maximal EMG amplitude of the four leg muscles was slightly larger during the manual therapy compared to the automated one. The contrary was true for the complete patient. A visual comparison between the modulation of the leg muscle EMG pattern in the patients with that of healthy subjects published elsewhere[6] led to the following result: Except for RF all muscles were more physiologically modulated during the automated training for both patients. This impression is supported by the VR values that were calculated for the lower limb muscles. The VR of TA as well as that of GM were smaller in both patients during the automated training. The absolute VR values are indicated in the corresponding EMG graphs. For healthy subjects the VR of TA ranges between 0.280 and 0.466 and that one for GM between 0.159–0.280.

All patients that have been trained with both methods of leg assistance reported the automated training being more comfortable than the manually assisted one. The main reason for this might be the more regular and physiological gait pattern achieved using the DGO. The patients also appreciated that longer training sessions became possible with the automated gait trainer. While a manually assisted training usually lasted up to 20 min, the automated training could be performed for up to 60 min.

Discussion

The locomotor training was shown during the last few years to improve the locomotor function of patients with incomplete SCI.[1,2] This improvement is achieved by the activation of spinal locomotor centers using the appropriate proprioceptive input during the locomotor training.[7] While part of the training effects can be achieved by conventional muscle training, the locomotor training provides physiological movements of the legs.[2] The prerequisite for the success of the locomotor training on the treadmill therefore seems to be the activation of neuronal centers within the spinal cord (possibly the so-called 'central pattern generator') by an appropriate, cyclical afferent input. It is supposed that this input should be similar to that one generated during normal stepping movements. Comparing the trajectories of the manually assisted training with those during automated training would therefore be of interest. However, recordings of the movement trajectories during the manually assisted training appeared to be difficult. The biomechanical gait pattern that was induced by the DGO was obtained from healthy subjects and could well be reproduced during the training of the patients. Therefore, the gait pattern imposed during the automated training most probably is more physiologic compared to that obtained by the manually assisted leg movements.

The data presented here focus on the activation of the leg muscles. Especially the data of the complete SCI is of interest. In these patients the supraspinal input is missing and therefore no voluntary intervention of leg muscle activation and consequently of movements was possible but the recorded activity should be generated by the spinal neuronal circuits only. Therefore, the difference in modulation of leg muscle activation between the two training methods was compared in the complete SCI to prove the effectiveness of the two approaches. The data obtained seems to demonstrate that with the DGO a similar or even better result can be achieved in comparison to the conventional training. It is therefore concluded, that with the automated treadmill training a similar or even better afferent input can be produced.

Of course this conclusion concerns only training sessions during the first weeks of rehabilitation, when a strong assistance is required. With the progress of the training most incomplete patients improve in their locomotor function. Therefore later a manually assisted training, adapted to the actual patients' needs by the therapist, can become again important.

Conclusion

Several of the advantages of the automated locomotor training are obvious. (1) The assistance of the leg movements is reproducible. This makes it possible to test and optimize the biomechanical gait pattern (speed, step length, amplitude) in order to get an optimal effect. This gait pattern can easily be reproduced by the DGO, while therapists usually have to practice for longer time to become specialized to perform an optimal training. (2) A further advantage is that training sessions can be prolonged and walking speed can be increased. There are indications[8] that a more intensive training enhances the effect and motor outcome of the locomotor ability in SCI. The presented data indicate at least that the effect of the training with the DGO is similar to that obtained by the conventional therapy. (3) It seems logical to replace the therapist by a robot for the locomotor training: A monotonous and repetitive work that has to be done in a well-defined manner for a relatively long time is certainly predestined work for a machine. Especially as the work for the therapist is neither attractive nor ergonomic.

The DGO will not replace the therapist as this training can only be performed with the supervision of a qualified person, but nevertheless the therapist will be relieved from the physical work and will gain more time for other rehabilitation procedures.

Acknowledgments

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