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HYBRID ORTHOSES FOR PARAPLEGICS

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Recently, a number of groups have reported advances in applying functional electrical stimulation (FES) to facilitate standing/sitting and simple forms of bi-pedal locomotion in spinal cord injured patients.

If the patient can be offered useful functional goals such as standing or simple locomotion then the application of FES will be attractive and the associated therapeutic benefits may be achieved.

However, there are practical limitations with the presently used FES techniques. Some of these are outlined below:

Applicability:
The techniques are contra-indicated in some patients presenting lower motor neuron lesions, obesity, joint contractures or certain skin conditions.

Patient Safety:
There are a number of factors affecting the overall reliability of the system. These involve the electrode/tissue interface, patient controls, electronic circuitry and associated interconnections. Continuous stimulation is required to maintain upright stability and this will inevitably produce neuromuscular fatigue. This may in turn, compromise the efficiency or safety of the application. For example, some patients, although able to stand using FES, can only remain so for relatively short periods due to fatigue effects.

Repeatability:
The electrical stimulus will produce a variable response dependent upon the relative movements of structures interposed between the stimulating electrodes and the excitable target neurones. In the case of transcutaneous stimulation, a variable response is also observed due to the time varying electrochemical nature of the electrode/tissue interface.

Training Time:
Present FES systems for paraplegic ambulation require a considerable amount of gait training time to use effectively. In addition a high degree of perseverence from both the patient and his family is required. Independent, free range FES assisted ambulation in the community for the complete thoracic level paraplegics has yet to be achieved.

Efficiency of Locomotion:
Only simple gait patterns can be synthesised with surface FES because of the practical limits to the number of muscles stimulated and the control techniques presently used.

In an attempt to improve the possibilities for locomotion we are investigating the combined use of electrical stimulation, mechanical bracing and appropriate control systems. The mechanical component serves to support the subjects body weight as well as providing stability and joint motion constraint. The electrical stimulation is used primarily for propulsion and to improve the overall effectiveness of the locomotion. This combined or hybrid (Tomovic et al, 1973) approach potentially offers several practical advantages including:

Applicability

The use of a mechanical component to provide support allows for some flexibility in the choice of muscles used for propulsion. This may extend the techniques to patients presenting with certain combinations of innervated and denervated muscles. Continuous stimulation to support body weight may not be required thus circumventing some of the problems of neuromuscular fatigue. Mechanical components may also serve to correct certain gait abnormalities by restricting or guiding joint motion.

Patient Safety

When using electrical stimulation alone there are many situations in which the paraplegic patient may stumble or collapse, for example, if the stimulus becomes less effective or interrupted. However with a hybrid system the mechanical component may prevent this or offer some failsafe mechanism.

To illustrate this hybrid approach the principles of operation of three of our hybrid orthoses are outlined below. (These systems are at an early stage of development therefore this article is preliminary and serves to only to illustrate some of the points raised at the symposium round table discussion on Hybrid Orthoses).

Hybrid Orthosis(1)

A training version of the orthosis is illustrated in figure 1. This shows a (34 years 76kg, 180cm, T10 complete) patient gait training in parallel bars. The mechanical component shown is a simple plastic splint used to maintain the knee in full extension. This gait has some similarities with the 'four point' gait described by Guttmann 1978. Electrical stimulation is used to improve effectiveness giving a 'tip toe' type of gait. Two channels of electrical stimulation are applied to the surface of each leg. One pair of electrodes are positioned over the Gastrocnemius and Soleus muscles to provide ankle plantar flexion. The second pair of electrodes are placed over a sensory nerve such as the common peroneal nerve in the region of the popliteal fossa to produce a flexion reflex resulting in foot dorsiflexion and hip flexion.

The stimulation sequence for one step of the left leg, shown in figure 1, was as follows. The subject first shifts his body weight onto the right leg. Electrical stimulation is then applied to the plantar flexors of the right leg and also to the common peroneal nerve of the left leg. This causes the right heel to rise from the floor and the left leg to flex at the hip and dorsiflex and evert at the ankle joint as a result of the afferently stimulated reflex pathway. The subject stabilises his pelvis using his upper limbs and muscles Latissimus dorsi and Trapezius. The left foot is thus cleared from the floor allowing the leg to swing forward. The step is completed by first removing simulation from the right plantar flexors and then the left common peroneal nerve. The right step is performed in a similar manner. Double stance support and standing require no stimulation. A high degree of safety is provided by the fact that the knees remain locked throughout the gait cycle. The definitive orthosis has a lockable knee joint in the mechanical component.

Hybrid Orthosis(2)

This system comprises a KAFO type mechanical component and two channels of electrical stimulation per leg. The surface electrodes are positioned over the quadriceps muscles and a sensory nerve such as the common peroneal nerve. Stimulation of quadriceps causes knee joint extension. Stimulation of the peroneal nerve is again used to produce a synergistic flexion response. The mechanical brace incorporates knee joint locks that are remotely controllable by means of a solenoid actuator, or a bowden cable. A typical step sequence is shown in figure 2. During double support the knee joints of both legs are locked and no stimulation is required to maintain standing (figure 2(a)). The subject initiates a step by transferring body weight onto the stance leg and unlocks the knee joint on the swing leg using a switch or handgrip. During the initial part of swing phase stimulation is applied to the peroneal nerve on the swing leg causing simultaneous flexion at the hip and knee together with dorsiflexion and eversion of the ankle (Fig. 2(b)). During the later part of swing phase stimulation is applied to the quadriceps and removed from the peroneal nerve causing the knee to extend as shown in figure 2 (c). When the knee joint extends, the lock is then engaged, the quadriceps stimulation removed thus completing the step. This sequence is repeated on alternate legs. Standing/sitting may also be facilitated by simulation of quadriceps and appropriate control of the knee locks by the subject.

Hybrid Orthosis(3)

The Hip Guidance Orthosis (HGO) shown in figure 3 was developed at the Orthotic Research and Locomotor Assessment Unit (ORLAU) in Oswestry ,U.K., (Major et al,1981) This device was designed to provide low energy reciprocal ambulation for paraplegics. A number of possibilities have been identified for improving the function of this orthosis using FES. One such possibility is to stimulate the quadricep muscles to enable the patient to stand. Figure 3 (a) shows a paraplegic subject (25 yrs, 74kg, 190cm) in a position to commence standing with the knee lock disengaged. Once upright, the knee joints lock automatically. In order to sit the subject applies full quadriceps stimulation, releases the knee lock using a cable and then the stimulation is progressively reduced until the subject is seated. The stimulation is then stopped. Once standing in the orthosis a paraplegic can typically ambulate independently with crutches for distances up to 1 km figure 3(b). Further FES applications to the HGO are planned in collaboration with the ORLAU group to further improve the device's effectiveness during locomotion and transfers.

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References

Guttman L (1976) 'Spinal Cord Injuries: Comprehensive Management and Research'. Blackwell Scientific Publications, U.K.

Major R E, Stallard J., Rose G. K., (1981) 'The Dynamics of Walking Using the Hip Guidance Orthosis with Crutches'. Prosthetics and Orthotics International 1981, 5, 19 - 22.

Tomovic R., Vukobratovic M., Vodovnik L., (1973) 'Hybrid Actuators for Orthotic Systems Hybrid Assistive Systems'. Proc. 4th Internat. Symp. on Ext. Contr. of Hum. Extr. Dubrovnik, Aug./Sept., 1972.

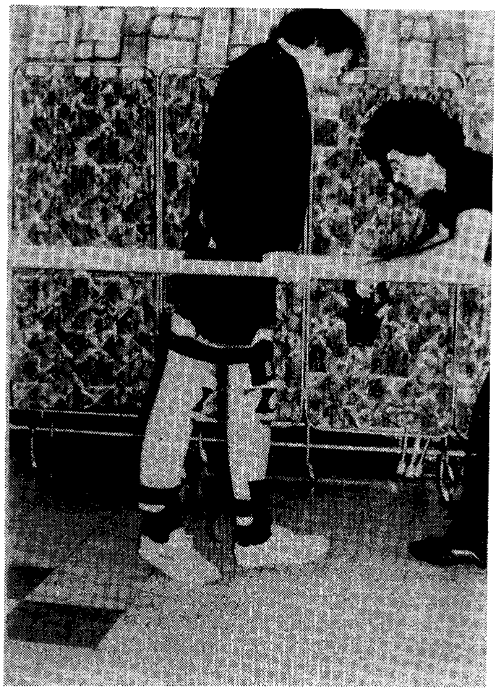
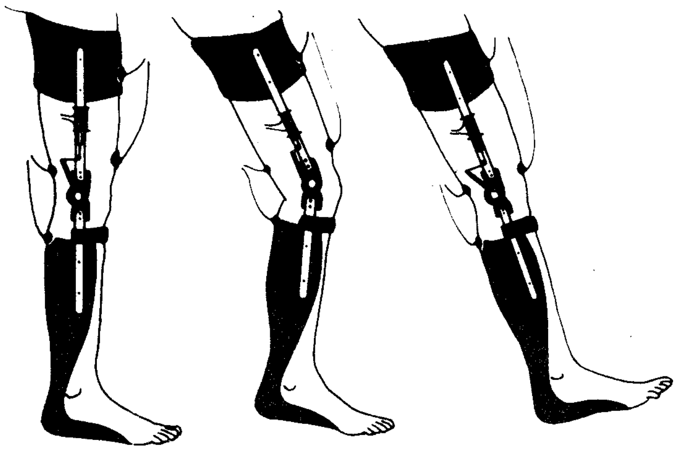
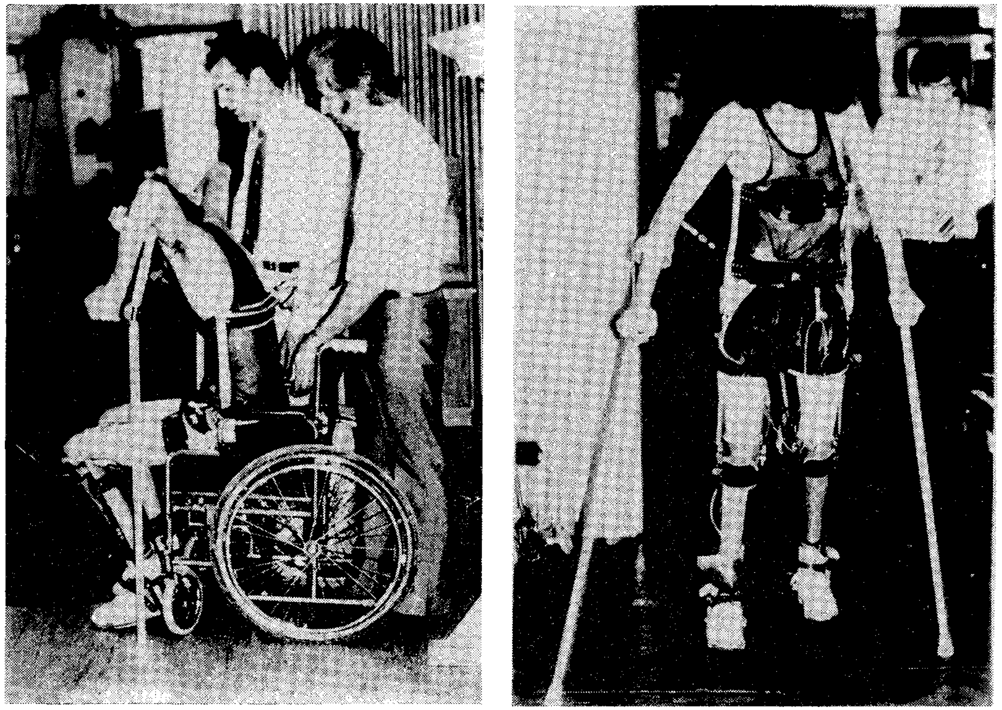


Figure 1 Gait training version of the Hybrid Orthosis type 1



(a) (b) (c)

Figure 2 Schematic diagrams of a Hybrid Orthosis type 2
(a) Double Stance (b) Swing Phase (c) Heel contact



(a) (b)

Figure 3 Hip Guidance Orthosis with transcutaneous stimulation of the knee extensor muscles for stand/sit assist