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Development of single upright knee ankle foot orthosis to achieve natural gait training

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ABSTRACT: In the field of rehabilitation after such as a stroke, it is essential to have the patient walking as soon as possible. In order to make this possible for patients who suffer partial body paralysis some form of leg orthosis is required. This paper proposes a full leg orthosis that is controlled at the knee joint in order to make this possible. The mechanical orthosis has been tested at a hospital in Nagasaki and proven to be effective in providing rehabilitation during the acute phase of treatment of stroke patients. It is expected that the proposed controlled orthosis will further enhance the effectiveness of this rehabilitation.

1. INTRODUCTION

In the case of stroke patients it is critical that they are mobilized as soon as possible after initial treatment. Typically elderly people are at risk to disuse syndrome including deterioration of brain activity, sensing abilities, lung and heart degradation, bone shrinkage and hardening of joints. In order to avoid this syndrome patients are required to have rehabilitation training even during the acute stage. One important part of rehabilitation is walking. However in the case of stroke patients they often lose the ability to control one side of their body. In this regard an assistant and assisting mechanism is required. One such mechanism is a controlled leg orthosis. The authors have initiated walking training for stroke patients during the acute stage using an original orthosis as shown in Fig.1. where the patient is supported by an assistant (M. Ninomiya et al.). The patient's physical ability on their right hand side is impaired on account of the stroke. The assistant grasps both hands from behind the patient; also the assistant pushes the patient's right leg by using their own right leg. To ensure stable support the assistant wears a belt which holds the patient. One end of the belt is connected to the neck of the assistant and the other end is connected under the groin of the patient. The patient wears a single upright knee ankle foot orthosis. A feature of the orthosis is that the movement of the knee joint is limited depending on the walking gait phase. With the physical

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support of the assistant and also limitation of the knee joint angle the patient is able to imitate walking movement even during the acute stage of stroke rehabilitation. The patient and the assistant walk (train) for about 30 meters using the posture shown in Fig.1.

Fig. 1. Gait training during the acute stage

The orthosis employed in this gait training satisfies the following conditions assuming the patient's physical condition is serious. The conditions required to achieve effective and safe gait training are:

(1) The orthosis must be light and yet have enough strength.
(2) Movements of the knee joint must be controlled to achieve natural gait movement.
(3) The orthosis must be easy to attach to the patient's leg.
(4) The orthosis must be adjusted to suit the patient's leg size and shape.
(5) Considering the fabrication process, rapid orthosis fabrication and custom adaptivity to the patient's leg shape and size must be possible.

In this paper a single upright knee ankle foot orthosis is proposed. The orthosis can be used in the acute stage of medical treatment of apoplexy (stroke).

2. A LIGHT - WEIGHT AND STRONG ORTHOSIS

Employment of rehabilitation training using the knee ankle foot orthosis is expected to activate the muscles around the groin. As a result physical functions of lower limbs are rehabilitated. The orthosis can be used during the acute stage and as well as during the recovery stage. However, regarding the orthosis there are a number of issues remaining to be resolved.

Currently knee ankle foot orthoses are custom fabricated to order. Therefore, sizes of the orthoses are designed to fit the user's individual requirements. Furthermore, attachment of the knee

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ankle joint orthosis requires fitting. The fitting must be simple and not time-consuming. In addition, the aspect of safety tends to add weight to the orthosis making it heavy.

In order to overcome these problems the proposed orthosis employs state of the art carbon material (Tepex®). The proposed orthosis is shown in Fig.2. Using this carbon material the orthosis can be light-weight and have sufficient strength. A significant feature of this carbon material is that it can be easily hardened thermally into a three-dimensional shape and that it can also be reshaped to fit other users. This means the orthosis can be re-used by other users despite differing sizes. The fabrication process of the orthosis is simple as it does not require molding. Also the carbon material enables the design of the orthosis to be simple and flexible. The orthosis proposed is also designed to make the fitting process easier.

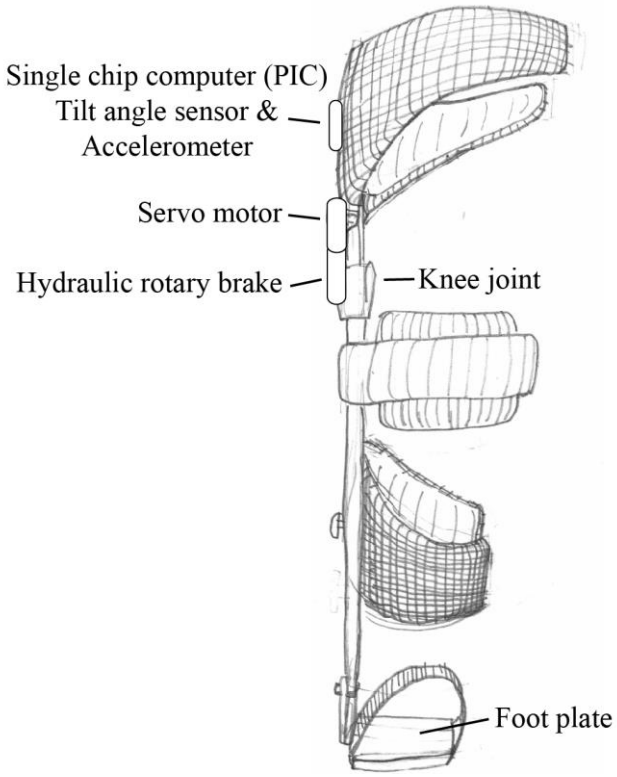
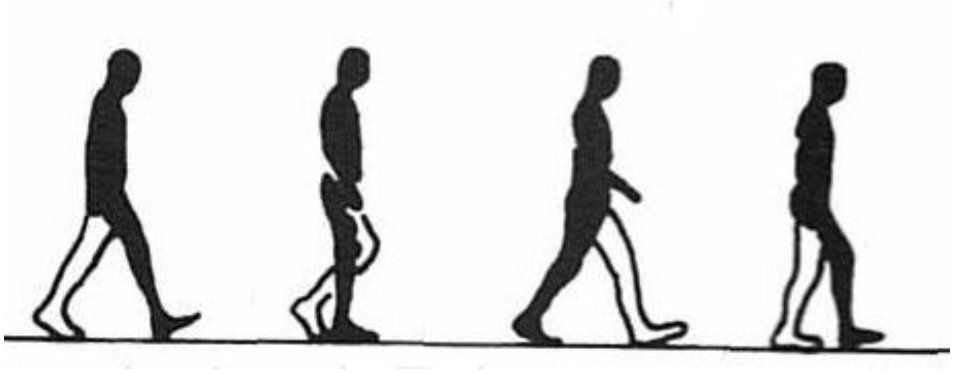


Fig. 2. Orthosis made from carbon material (Tepex®) and control mechanism

3. COMPUTER CONTROLLED NATURAL GAIT MOVEMENT

Stroke patients are often physically disabled to some extent on one side of their body. In the gait training of such patients the movement of the orthosis needs to be natural. In order to achieve the natural gait training, a computer controlled locking mechanism is employed at the knee joint. Key movements of the leg and the knee joint during natural phases of walking are shown in Fig.3. Considering this natural walking our proposed orthosis employed a control system for the knee joint. The control algorithm of the knee joint control is explained as follows; Once the leg in the orthosis is

moved forward resulting in the heel tip touching the ground (Fig. 3a), the knee joint is locked at near 180 degrees. This locking situation is sustained until weight is placed on the leg and it is moved to the rear (Fig. 3c). At the end of the rear movement, the knee joint is released from the mechanical lock. This release is sustained until the leg is moved back until the heel tip touches the ground once more (Fig. 3a).



a. Heel contact b. Foot flat c. heel off d. toe off

Fig. 3. Natural walking gait (VT. Inman et al)

Configuration of our knee joint control system is shown in Fig.1. The movement of the leg is detected by an acceleration sensor and a gyro sensor attached on the thigh. Using these sensors the movement and tilt angle of the leg can be estimated. Based on the data the servo motor is controlled to manipulate the hydraulic rotary brake. The hydraulic cylinder brake locks and releases the movement of knee. The tilt angle during the gait training is shown in Fig.4.

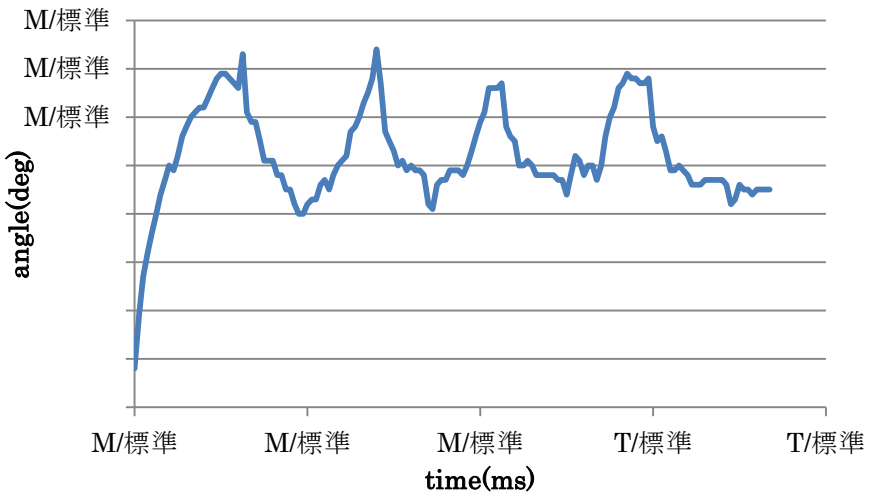


Fig. 4. Tilt angle data

4. CONCLUSION

In this paper a single knee ankle foot orthosis is proposed. The orthosis is being developed to support efficient gait training during the acute stage of apoplexy. The orthosis is light-weight and

strong using a new carbon material (TEPEX 3mm) which has thermal hardening characteristics. Furthermore, the knee joint movement during the walking cycle can be controlled by a hydraulic rotary brake. This functionality makes natural gait training possible.

Features of our orthosis are as follows.

1) The orthosis is light-weight and strong. The strength is equal to that of stainless-steel.
2) Fitting is simple using the state of the art carbon material.
3) Natural gait training can be achieved by controlling the knee joint.
4) The orthosis can be adapted and readapted to fit the user.
5) The orthosis can be used on the left or right leg.

The orthosis (without the knee control mechanism) has been tested in a medical hospital (Nagasaki Rousai hospital in Sasebo). It is expected that the proposed controlled orthosis will be an effective tool for the gait training of apoplexy patients.

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