Development and application of a cycling device for Functional Electrical Stimulation patients

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Introduction

We have designed a tricycle that enables paraplegics to move by Functional Electrical Stimulation (FES) and train the stimulated muscles/muscle groups at the same time. The two basic components of the tricycle are a standard wheelchair with a cycle attachment (Figure 1).

Figure 1 a: Scheme of the cycle; b: A paraplegic test person on the tricycle

Extensive research has been done on the use of FES with paraplegics (Gföhler et al., 1998; Mayr, 1992; Petrofsky et al., 1983; Petrofsky & Smith, 1992). Three- and four wheel cycles have been developed. Our main interest was to use a standard wheel chair. With the use of the optimized pedal path a new level of independence for paraplegics is reached.

Muscle training by Electrical Stimulation is necessary before hand so that the patients obtain enough strength to use the bike. Therefore, the patients must train their quadriceps and gluteus maximus for about 8 months one hour daily. Additionally the hamstrings are stimulated and also trained because of the current distribution during the stimulation of the quadriceps muscle. The peronaeus reflex is also used. The tricycle should be easy to assemble and should fit in a car.

Methods

To adjust the tricycle to the length of the patient’s legs, slide bars are fitted on our modified standard wheelchair. In these bars the cycle attachment can be variably adjusted and secured. The circular path,
which is used by common bikes, prevents an ideal power transfer by the patient. Therefore we used the optimized pedal path as described in the article “Development of an optimised pedal path by using Functional Electrical Stimulation” in this Conference Proceedings book. Because of this pedal path higher efficiency is achieved. This optimized pedal path is realized by a four-bar linkage (Figure 2).

![Four-bar linkage for optimized pedal path](image)

**Figure 2:** Four-bar linkage for optimized pedal path

The wheelchair’s four-bar linkage would make it complicated for the patient to get seated because its levers are between the legs. This problem was solved by incorporating a quick release system which allows the entire linkage to be moved out of the way. Patients with coxa valga and/or genu valgum and/or big musculus soleus would rub against the four-bar linkage. The coupler is therefore cranked and the connection between couple and lever is moved to the middle.

The applied torque is transferred by the crank of the four-bar linkage to the front wheel. The ankle of the patient is fixed by a shank-attachment, so the pedal has to move in the natural parasagittal plane. The patient is able to steer without his legs having to leave the parasagittal plane. To enable a steerable front wheel, the applied torque is transferred over a cog belt to an intermediate shaft. It consists of two cardan joints, that let the chain gear slew. The asynchronous rotation is small because we used two cardan joints. The chain gear drives the front wheel with a built-in four gear hub.

This hub can be hand operated or used as an electric four gear automatic transmission. This is necessary, because the patients are not able to feel the sensor-neural response which would tell them when to switch gears.

Tests have showed, that the patients got less spasms, when moved passively before FES. This is done by the auxiliary motor. The pressure load on the front wheel is high, because the motor is fixed on the front wheel and the back wheels of the wheelchair are set farther backward than on a normal wheelchair. The motor torque is transferred to the intermediate shaft with an additional cog belt. By using a clutch the patient has the possibility to stop the four-bar linkage in case of muscle fatigue or in case of spasms. At the same time, of course, the movement of his legs is stopped and the patient continues his ride using the auxiliary motor.

If the patient gets spasms, the motion has to be stopped immediately so that the risk of injuries is reduced. This is possible because of force-measurement in the crank. The force is measured with strain gauge units, that give information about all three vectors of force. The data is transferred from the moved crank to the bogie assembly over contactless capacitive data transmission and transferred to the computer. If the adjustable allowable stress is overshot, both the motor and the FES is stopped. Additionally an absolute angle decoder reads the position of the crank, which is used for the calculation of the angular velocity. The data is sent to the computer and is used for the stimulation pattern. This stimulation pattern is based on the results of the simulated calculations and the results of the test bed measurements (Angeli et al., 1998). The stimulation parameter can be changed on a laptop during the ride.
The bike has parking brakes on the back wheels and a front wheel brake. The handle bar can be fitted to the body dimensions of the patient by quick release and can be folded to get on the bike comfortably. The handle bar ends with a twist grip with which the motor is controlled.

Results

10 N are enough to accelerate the tricycle with a 70 kg person from standstill. When we slew the four-bar linkage the necessary hip angle became smaller than the one on the common circle path. As on the test bed (tests with the isolated four-bar linkage), we could reduce the spasms. Unfortunately this slewing causes a smaller power output and should therefore only be used when spasms appear. Therefore the patients feel more comfortable on this slewed pedal path. The spasms can also be reduced by using ramp change of voltage. In the plain the patients could drive without using the motor, but they needed it to get over gradients. If the patients got spasms, they could be reduced by shortening the stimulation time. This shortening causes less power output so this data is changed individually for each patient according to the momentary constitution of the patient.

Discussion

The mass of the whole construction is rather big, because many of the pieces on this prototype are adjustable. We are trying to reduce the mass in our further researches, so that gradients can be managed without the auxiliary motor. Additionally the cycle attachment should be changed, so that it could be fixed quickly and easily on a standard wheelchair by the patients themselves and it could also be transported in a car without any trouble.

Conclusion

We will improve the points mentioned in the discussion in the near future. In addition we are in contact with a wheelchair producer, who has supported this project and will hopefully produce this tricycle.

References


Acknowledgement

This work is supported by:

'FWF - Austrian Science Foundation'

Otto Bock Austria