Authors:

Natalia M. López, PhD
Nicolás de Diego, BME
Rafael Hernández, BME
Elisa Pérez, PhD
Gustavo Ensinck, EE
Max E. Valentinuzzi, PhD

Affiliations:

From the Gabinete de Tecnología Médica, Facultad de Ingeniería, Universidad Nacional de San Juan, San Juan, Argentina.

Correspondence:

All correspondence and requests for reprints should be addressed to: Natalia M. López, PhD, Gabinete de Tecnología Médica, Facultad de Ingeniería, Universidad Nacional de San Juan, Av. Libertador 1109 (oeste), Ciudad de San Juan, 5400, Argentina.

Disclosures:

Supported by the Universidad Nacional de San Juan.
Financial disclosure statements have been obtained and no conflicts of interest have been reported by the authors or by any individuals in control of the content of this article.

0894-9115/13/9210-0000/0
American Journal of Physical Medicine & Rehabilitation
Copyright © 2013 by Lippincott Williams & Wilkins

DOI: 10.1097/PHM.0b013e3182a51c95

CASE REPORT

Customized Device for Pediatric Upper Limb Rehabilitation in Obstetric Brachial Palsy

ABSTRACT

López NM, de Diego N, Hernández R, Pérez E, Ensinck G, Valentinuzzi ME: Customized device for pediatric upper limb rehabilitation in obstetric brachial palsy. Am J Phys Med Rehabil 2013;92:00–00.

A 12-yr-old child, with a history of gestational Erb-Duchenne palsy and, later, musculoskeletal injuries in the left arm caused by a car accident, inspired the design of a customized exoskeleton-like device. Such piece, intended for rehabilitation, has one degree of freedom because the exercise routine involves elbow flexion-extension, which was indicated for the damaged muscular group. The device has two functioning modes, passive and assisted, in which the patient can trigger the movement by a biceps contraction, thus promoting the active role of the user in the rehabilitation process. The results were evaluated in terms of qualitative measures of the biceps and the triceps performed by the medical staff and by a questionnaire related to functional activities of the upper limb. A significant improvement in the arm movement and elbow angle was observed after 3 mos of assisted therapy, complementary to conventional exercises. In conclusion, a simple and low-cost device was designed and tested to complement the rehabilitation process of a pediatric patient with physical impairment.

Key Words: Brachial Plexus Palsy, Erb-Duchenne Palsy, Robotics, Upper Limb

Brachial plexus palsy is an uncommon injury during birth development [1–3] (one to two births per 1000). When injury of the fifth and sixth cervical roots is involved, it is known as Erb-Duchenne palsy. In this case, it results in paralysis of the deltoid, infraspinatus, and flexor muscles, keeping the affected extremity internally rotated and straight and the shoulder posteriorly subluxated. There is good prognosis for recovery with early surgical intervention, adequate treatment, and physiotherapy.[4] During infancy, it is important to promote muscle lengthening and normal range of motion, performing gentle stretching and passive exercises, which requires assistance of a specialist.

Robotic training has emerged in the last years as a suitable alternative to physical therapies, especially for patients who have had a stroke. These robotic devices are used to recover arm movement through repetitive exercise after stroke and allow the quantification of the therapeutic process. Different control strategies can be found in the devices used clinically, such as the MIT Manus,[5] the

Mirror Image Movement Enabler,[6] the GENTLE/s,[7] and the Assisted Rehabilitation and Measurement Guide.[8] Repetitive exercise and simple motor tasks are the basis of their operation, obtaining promising results and allowing their application as rehabilitation tools.

Here, the authors report the case of a child with Erb-Duchenne palsy, who somewhat later in his life also had musculoskeletal injuries caused by a car accident that worsened the clinical symptoms and interrupted the rehabilitation for 1 yr. Because of the young age of the patient (12 yrs) and the psychologic consequences of daily contact with people with worse pathologies, on top of the already complex state, a home care alternative was suggested, and a customized robotic rehabilitation device emerged as a suitable choice.

CASE DESCRIPTION

Subject

A 12-yr-old boy with Erb-Duchenne palsy, axonotmesis level of injury, early surgery at 9 mos, and a history of left humeral shaft fracture at 3 yrs of age caused by a vehicular accident, was the main subject of this study. The aftermath of the accident and subsequent immobilization unfortunately discontinued the rehabilitation process for 1 yr. After orthopedic surgeries, the electromyography (EMG) showed the following muscles to be affected: deltoid, supraspinatus, infraspinatus, serratus, teres minor, coracobrachialis, biceps brachii, triceps brachii, and brachialis. The most damaged muscles are those belonging to the arm flexor-extensor group, hence preventing full extension of the forearm and complete supination, along with an abnormal resting position. After two surgeries including the reinsertion of the biceps tendon and daily rehabilitation, the patient showed a functionally and qualitatively significant recovery in the upper limb movements, especially in the forearm and the hand. However, the biceps and the triceps remain shortened, requiring repetitive flexion-extension movements to achieve muscular tone and complete elongation in a voluntary way.

The parents (both are physicians, well knowledgeable in this particular subject, and fully cooperative) signed the consent form approved by the local institutional review board. A preliminary Disability of Arm, Shoulder and Hand test[7] was performed to assess the possible outcome of the upper limb rehabilitation, producing a score of 41.3. This test is a 30-item questionnaire (scored 1–5) related to functional activities and symptoms in activities of daily living and is converted into a 0–100 scale, and scores rise with increasing disability. The assisted therapy was programmed under the guidelines of the physiotherapist. The parents contributed to the daily monitoring of therapy, and another weekly monitoring was conducted by the physiotherapist, who evaluated the exercises planned in the previous visit and determined the values (angles, speeds, number of repetitions, and operating mode) for the next days. In addition, manual flexoextension exercises to a point of slight discomfort and movement of the arm through its full range of motion were performed in these visits.

Robotic Rehabilitation Device and Training Protocol

The rehabilitation device is a 1–degree of freedom electrically actuated exoskeleton, especially designed for this patient. The main objective was to recover muscular strength and the range of motion of the elbow joint. The robotic device can be subdivided into four main parts:

(1) A metal exoskeleton to accomplish the patient's upper limb flexion-extension
(2) A direct current (DC) power supply
(3) A myoelectric signal acquisition module
(4) A control module

The exoskeleton has a joint for elbow flexion-extension, attached to two metallic links (Fig. 1). F1 The links were designed according to the upper limb size (arm, 21.5 cm; forearm, 24.5 cm; hand, 18 cm) and as a proportion of the patient's weight (37 kg). The maximum angle for flexion-extension was set at 140 degrees, and the minimum angle is limited to 10 degrees by the contact between the anterior muscles of the upper arm and the forearm, whereas the maximum and minimum exercise velocities were software fixed. The regulation of the velocity is linearly and continuously carried out by a potentiometer connected to the DC motor control circuit.

The device has a base and an articulated steel section (fixed with manual nuts), arranged in such a way that the arm can be positioned and rotated, allowing its operation even with abnormal arm positions. A custom-made polymeric splint is placed over the metallic structure to adjust the arm and provide a comfortable support. Aluminum gears are attached to a DC motor and a microcontroller (MC68-HC908-GP32, Freescale Semiconductor) to determine velocities and angles in the flexion-extension exercise routine. The user can easily choose the appropriate parameters (therapeutic mode, velocities, flexion angle, and number of repetitions)

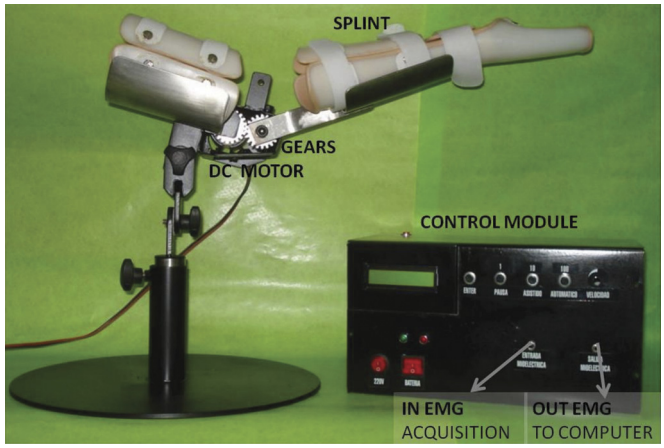

FIGURE 1 *Overview of the customized rehabilitation device.*

per session, through a liquid-crystal display and a simple keyboard. Two therapeutic modes can be used with this device.

In the passive mode, the exoskeleton carried out the movement by itself, according to the parameters previously stated (flexion angle and velocity). In this mode, the patient has no control over the device because the assisted therapy replaces the repetitive exercise executed by the physiotherapist.

In the assisted mode, instead, the patient starts the movement with a muscular contraction of the biceps, and the exoskeleton completes the programmed range of motion at controlled angles and velocities. Furthermore, the patient can visualize in the liquid-crystal display if it was recognized as a triggered muscle contraction. If no action is ordered by the operator, the system performs a flexion exercise after a preset time, to ensure the effectiveness of the therapy session. In this mode, the surface EMG signal is recorded with disposable electrodes on the biceps and processed to obtain a triggering signal to the DC motor. For this purpose, an acquisition module was designed, with a front-end amplification stage implemented by the INA129 from Texas Instruments, optical isolation, notch filter, band-pass filter (10–500 Hz), and a trigger circuit based on a flip-flop and an operational amplifier.

Moreover, the surface EMG signal was saved in a personal computer; for that matter, an ad hoc software was designed to estimate the muscular force and fatigue, making use of the signal root-mean-square and its integral of the absolute value, too. Evaluation of these parameters allows quantitative assessment of the therapy, thus contributing to reprogramming future exercises.

Overall safety was ensured by two systems:

A mechanical limit that prevents displacement of the movable sections beyond the anatomic angle

An electrical system composed of two limiting switches (reed switch sensors) that interrupt power to the DC motor, should these exceed the maximum flexion and extension angles. Besides, a stop button can be activated if the user experienced any discomfort or just wanted to quit the session.

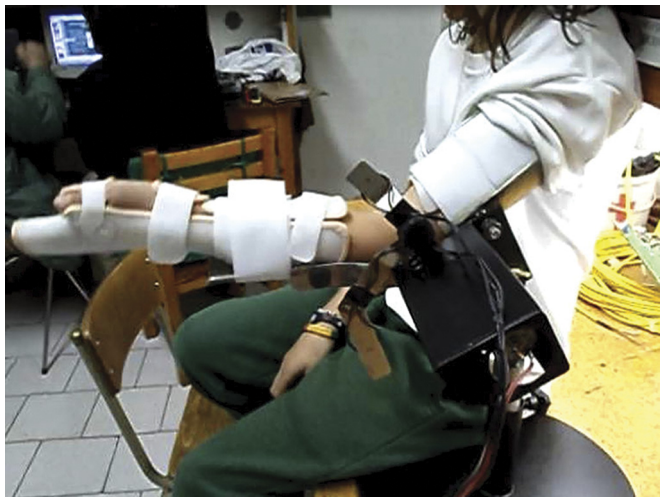

FIGURE 2 *Laboratory testing of the customized device.*

RESULTS

Preliminary tests were performed in the laboratory by a pediatric healthy volunteer and by the patient, always under medical supervision (Fig. 2). These tests were necessary to adjust the system and the trigger level related to EMG activity. The physiotherapist and the medical adviser determined the adequate velocity of the flexion-extension exercise and initial angles of the therapy, agreeing with the parents with regard to the exercise routine and the programming of the device. They established a training routine of 30 mins, three times a week.

Periodic evaluations were performed by the physiotherapist, focused mainly on the biceps muscular force, angle of elbow extension, and qualitative inquiry to the child. In addition, a rehabilitation program of one visit per week to the clinic was maintained. The results were evaluated qualitatively in terms of angle of flexion-extension without effort and by the Disability of Arm, Shoulder and Hand test performed before and after 3 mos of assisted therapy. In the EMG signal recorded at the end of the treatment, the biceps-triceps pair appeared as better trained, showing a significant increase in muscular force and qualitative evaluation suggesting endurance to fatigue. The EMG signal was not always recorded during home therapy, avoiding the quantitative assessment of the muscular fatigue by continuous EMG analysis. The final Disability of Arm, Shoulder and Hand test score was 29.4, showing a significant recovery in the arm functionality.

DISCUSSION AND CONCLUSIONS

After 3 mos of use of the customized device as support to conventional therapy, the authors cannot firmly conclude that the encouraging evolution was a result of the complementary exercise. However, and cautiously, the authors state that this assisted therapy constitutes a quantitative and controlled support to classic rehabilitation, suitable for patients with physical or psychologic limitations for routine exercise in a rehabilitation center. This rehabilitation device can be used to enable the quantification of the motor therapy and patient outcome, through the use of sensors and analysis of data sessions.

It is important to note that the surface EMG signal recording is necessary to the quantitative assessment of the muscular force and fatigue, but this monitoring was not performed efficiently by the patient or their parents. In future trials, this aspect must be considered as restrictive for the use of the rehabilitation device.

The patient's age must be taken into account (a preteenager, 11 yrs old, when the therapy was instituted), for it is important to motivate and involve him as much as possible in the exercise because an active role is essential for a successful rehabilitation. Unfortunately, his compliance to the rehabilitation protocol was less than perfect, and often he complained, saying that it was a waste of time, although several times he also said it was fun and easier than the physical therapy performed by a parent. The personal history of this child and the teenage rebellion have motivated the alternative of the customized device, allowing the personal motivation for the rehabilitation program.

Another somewhat unexpected aspect was how the patient grew physically: from being a tiny child 1.40 m tall and 37 kg, he stretched to 1.70 m and almost 60 kg in weight; that is, at 16 yrs old, he absolutely outgrew the customized device. Finally, he travelled with a student fellowship at 15 yrs old, and customs restrictions did not allow him to carry the device, stopping the rehabilitation process.

The authors conclude that, even with this single and incomplete rehabilitation period with the herein described device, it may have possibilities under specific circumstances and always as a custom-made unit. The authors do not have commercial purposes, and the authors expect to provide useful information for similar cases.

REFERENCES

1. Dubuisson AS: Clinical studies: Brachial plexus injury. A survey of 100 consecutive cases from a single service. *Neurosurgery* 2002;51:673–83
2. Midha R: Epidemiology of brachial plexus injuries in a multitrauma population. *Neurosurgery* 1997;40:1182–8
3. Tung TH, Mackinnon SE: Brachial plexus injuries. *Clin Plast Surg* 2003;30:269–87
4. Grossman John AI: Early operative intervention for birth injuries to the brachial plexus. *Semin Pediatr Neurol* 2000;7:36–43
5. Krebs HI, Ferraro M, Buerger SP, et al: Rehabilitation robotics: Pilot trial of a spatial extension for MIT-Manus. *J Neuroeng Rehabil* 2004;1:1–15
6. Lum PS, Burgar CG, Van der Loos HF, et al: MIME robotic device for upper-limb neurorehabilitation in subacute stroke subjects: A follow-up study. *J Rehabil Res Dev* 2007;43:631–42
7. Loureiro R, Amirabdollahian F, Topping M, et al: Upper limb mediated stroke therapy—GENTLE/s approach. *Autonomous Robots* 2004;15:35–51
8. Kahn LE, Zygman ML, Rymer WZ, et al: "Robot-assisted reaching exercise promotes arm movement recovery in chronic hemiparetic stroke: A randomized controlled pilot study". *J Neuroeng Rehabil* 2006;3:1–13