MATEC Web of Conferences **53**, 01062 (2016)
DOI: 10.1051/matecconf/20165301062

Review on Upper Limb Continuous Passive Motion Devices

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Abstract. The paper is devoted to a survey on the state of the art of elements and parts for the upper limb rehabilitation. As a matter of fact, the use of technological, and specifically of robotic, devices is entering in the habits of clinical approaches, due to their ability to work efficiently and to be able to obtain, at least, the same rehabilitation results of manual therapy. At the same time, the therapists can change his/her role in rehabilitation activity from a physical contribution to an intellectual/motivational one.

1 Introduction

As shown in literature, mobilization is effective in rehabilitation to improve the motor function and to reduce pain [1, 2]. These results can be obtained for different pathologies: stroke [3], cerebral palsy [4], osteoarthritis [5, 6], etc. Under these hypotheses, Salter, who proposed the continuous passive motion (CPM), derived this concept on the basis of a series of experimental investigations and well thought-out rationale. Salter and Field [7] showed in 1960 that immobilization of a rabbit knee joint under continuous compression, provided by either a compression device or forced position, resulted in pressure necrosis of the cartilage. In 1965, Salter et al. reported deleterious effects of immobilization on the articular cartilage of rabbit knee joints and the resultant lesion that they termed “obliterative degeneration of articular cartilage”. Salter believed that “The relative place of rest and of motion is considerably less controversial on the basis of experimental investigation than on the basis of clinical empiricism”. He reasoned that because immobilization is obviously unhealthy for joints, and if intermittent movement is healthier for both normal and injured joints, then perhaps continuous motion would be even better. Because of the fatigability of skeletal muscle, and because a patient could not be expected to move his or her own joint constantly, he concluded that for motion to be continuous it would also have to be passive.

2 State of the art

CPM devices are mechatronics systems [8], or, in the most complex solutions, a robotic device [9-14] able to implement automatically a CPM rehabilitation. A large number of devices and methods for CPM rehabilitation is well known in literature. The aim of this paper is to show the most interesting devices currently used for the rehabilitation of wrist and hand. Some of these devices are designed to perform both a coordinate movement and different exercises. Many of these do not realize a complete

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movement, for example, only flexor–extensor or abdo–adduction. Two list of CPM devices are shown (Table 1-2), respectively, for the wrist and for the hand rehabilitation.

Table 1. List of devices for CPM wrist rehabilitation. E.D. Electrical driver.

Device name	Ref.	Year	Exercises	ROM	Other
Hand Mentor - Kinetic muscles, inc.	[15]	2008	Flex and ext wrist and fingers.	Flexor limit 90°, extensor limit 90°.	Control security system, rotation reverse. P. D.
Patent US 5,458,560	[16]	1995	Flex and ext wrist	-	E.D.
Patent US 7,618,381	[17]	2009	Flex-ext abdo-addu of wrist	-	E.D.

Table 2. List of CPM devices for hand rehabilitation. E.D. Electrical driver, V.F. visual feedback. CPM continuous passive motion, CAM continuous active motion.

Device name	Ref.	Year	Exercises	ROM	Other
Gloreha	[18]	2011	Flex and ext finger.	Compete of flex or ext exercise	Moves fingers smoothly, both individually and simultaneously. V.F.
Tyromotion Amadeo	[19]	2011	Flex and ext fingers (Active and passive exercises).	Compete of flex or ext exercise	V.F., individual and contemporary exercises, forces calibration.
Artromot-F	[20]	2008	Flex and ext finger.	Compete of flex or ext exercise	LCD display for monitoring, microcomputer for control system.
Patent	[21]	1987	Flex and ext finger	Compete of flex or ext exercise	Security system control. E.D.
Patent	[22]	1990	Flex and ext finger	Compete of flex or ext exercise	Spiral motion, Security control system E.D.
Patent	[23]	2010	Flex ext finger CPM CAM	90° Flex-Ext	Security control system, E.D

Different actuator systems are shown in literature [24-26] and are classified with different criteria; one of the most common classifications is based on the used technology: piezoelectric devices [27, 28], electric motors [29, 30], shape memory actuators [31-37], etc. The most commonly used devices are electric ones that represent also the most common choice in rehabilitation devices.

3 Electrical driver's rehabilitation

When a designer starts a project, the first specification is on electrical drivers. There is two possible solution, on the patient body or separate from body. For the first one, the electrical drivers have to be light and small, because the size can impede the movement. For the second solution, the driver's size is not important but transmission is essential. On the market there are two principal families of electrical drivers: rotary motors and linear motors.

Rotary motors. The use brushless motors is more frequent in biomechanics [29] because they are efficient with intermittent movement. Usually the electrical devices are used with a speed reducer [30]. Nowadays these devices are cheap. Another kind of rotary motors are DC drivers. These drivers are usually employed for their easy control. Asynchronous motors are used for repetitive movements because changing the speed is difficult and expensive. The final results are shown in Table 3.

Table 3. Difference between rotary motors.

Type	Max torque	Movement type	Driver electronic	Cost	Maintenance
Brushless	Average-high torque	Not periodic movements	Necessary and complex electrical circuit	High	Sometimes
DC	Low torque	Not periodic movements	Not necessary and easy	Low	Frequent
Asynchronous	High torque	Periodic movements	Necessary for speed regulation	Low	Rarely

Linear motors. The relative position of the armature and stator of a linear motor is controlled using the output of two optional transducers in phase quadrature from an optical grid disposed along the length of the stator. This device is very expensive and little used.

4 Mechanical transmission

The movement's generation is based on electrical drivers with high-speed. Transmission is used for reducing and changing movement of end-effectors. In sequence, after the motor there is a speed-reducer. The most used are divided into main classes: ordinary reducer, epicyclical reducer, Harmonic-Drive reducer and RV-A reducer. The first is less used for low efficiency. The most used system is epicyclic reducer because it is cheap and it has a good efficiency. The Harmonic-Drive has a high ratio but it does not allow the retrograde movement. The final results are in Table 4.

Table 4. Difference between reducers.

Type	Ratio	Efficiency	Retrograde motion	Cost
Ordinary reduc.	1/10 max	Very low	Yes	Low
Epicyclic reduc.	1/10 ÷ 1/200	Sufficient	Yes	Intermediate
Harmonic-Drive	1/50 ÷ 1/400	High	No	High
RV-A reduc.	1/50 ÷ 1/400	Very high	No	Very High

After the reducer usually there is the transmission's movement. For this problem there are a lot of solution: belt, machanisms system, cogwheel, flexible shafts [38] and chain. Interesting solutions are characterized by a fluid media as power transmission system [39-41]. Flexible shafts can divide the part where there are the electrical motor and the limb of patient.

5 Future developments

The main problem is that the science is not secure of methods and exercises for a correct rehabilitation. This uncertainty does not allow a singular way for the designing rehabilitation devices. The first work is defining correct exercises and methods, for specifics pathologies with the collaboration of medical staff. Once they will be defined, research could start the mechatronic design. Nowadays we are still looking for these suggestions from medical staff to implement a proper solution for rehabilitation designing a complete device, both for the wrist and for the hand. Two important characteristics are:

- the coordinating exercise, that is when the patient use more than one degree of freedom in an exercise, i.e. to move the wrist in flexo-extension and abdo-adduction together.
- the visual feedback of exercise for the patient is very important in rehabilitation, because, if the patient watches the virtual movement on the monitor, it is possible to activate intact neuronal systems that provide direct stimulation to motor areas affected by brain lesions.

An interesting demanded function for these systems is the possibility of realizing a specific motion profile [42-46], whereas the common state of the art is based on the possibility of assigning an actuation motion, thus a proper system must realize a kinematic inversion [47-49] to transform a finger motion in an actuator motion and, then, properly optimize [50-53] the motion profile of the actuator to realize the desired finger motion, with an adequate control system [52-54].

6 Conclusions

In conclusion of this paper, on the market there is not a complete device for the wrist and hand rehabilitation with coordinated movements, that could be used for a large range of pathologies from neuronal to orthopedic disease. The rehabilitative research is very important, because only they are able to suggest the exact way for realizing instruments and methods for rehabilitation.

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