Cutting-Edge Actuating Systems of the Upper Limb Rehabilitation Devices

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Abstract: - The minimization of the discomfort and of the expenses arising from rehabilitation exercises may be obtained by performing recovery exercises with robotic systems, which leads, among others, to the partial replacement of the therapist’s work. This paper submits an analysis of the current construction stage of the upper limb rehabilitation equipment, based on the continuous passive motion technique. Although most devices are driven by electric motors, the pneumatically actuated devices have lately been used increasingly more, the latter taking advantage of compliant behaviour.

Key-Words: - CPM, rehabilitation equipment, upper limb, driving systems

1 Passive motion in kinesitherapy
In case of prolonged immobilisation, the body may experience muscle hypotrophy, metabolism decrease, bone demineralization, as well as dysfunctions of the circulatory or respiratory apparatus [1].

Muscle hypotrophy stands for the diminution of the muscle microfiber diameter, the muscular atrophy being reached in severe cases. Muscle atrophy irreversibly affects the muscle function and may lead to paralysis.

In Fig. 1, a comparison is shown between a normal muscle and an atrophied muscle because of longer immobilisation. Note that, in the case of the atrophied muscle, its dimension is reduced, the developed force is lower and the arm mobility is diminished.

Fig. 1 Comparison between a normal muscle and an atrophied muscle

To avoid health problems, in the case of the patients that cannot move by themselves, passive motion is recommended for them. An important part within this treatment is played by continuous passive motion. It may be performed by a kinesitherapist through direct actuation on the patient or through rehabilitation equipment.

The continuous passive motion prevents the formation of intraarticular adhesions and stimulates the faster recovery of the joint cartilage defects [2]. Figure 2 shows the defects in the knee joints of some rabbits immobilized for 3 weeks (series Ia), respectively for 10 weeks (series Ib), in the case of some rabbits intermittently mobilized for 3 weeks (series II) and in the case of rabbits with continuous passive mobilization for 3 weeks (series III).
Fig. 2 Defects appeared in the case of the immobilization, intermittent mobilization and continuous passive mobilization.

To avoid the formation of such deposits on the joints, it is necessary to use rehabilitation exercises with equipment especially designed to this end.

1.1 Need for the use of rehabilitation equipment

Rehabilitation devices play an important part in passive kinesitherapy. Although passive kinesitherapy can be achieved by experts without these devices, they are resorted to because they facilitate the specialists’ work; the movement of the sick limb being imposed by these rehabilitation systems. Most devices sold at this time allow programming the various exercises at movements and speeds adapted to each patient.

Kinesitherapeutic treatment is achieved in hospitals or private specialized clinics. Patients who need longer kinesitherapeutic treatment may undergo home treatment. In the case of the patients who cannot mobilize by themselves their sick limb at home, the passive kinesitherapy exercises are achieved by another family member or, at worst, they are interrupted and restarted at a new hospitalization. The exercise interruption may lead to definitive immobilizations and, in the case of the bedridden, to cardiovascular disorders, bone demineralization, muscle hypotrophy etc.

The use of the rehabilitation devices may prevent the abovementioned situations. After appropriate training, the patient may use the equipment to perform the exercises recommended by the kinesitherapist. In this case, the patient may modify by himself the exercise parameters (motion amplitude, its speed, pause time between cycles), in accordance with the evolution of his health. The exercise execution is much more flexibly programmed, as it is no longer related to the kinesitherapist’s program.

The use of the recovery devices in hospitals may facilitate the kinesitherapists’ activity and may point their attention towards more serious cases. The care for the patients who perform the exercises by themselves may therefore be achieved with less specialized staff.

Passive kinesitherapy addresses the musculoskeletal apparatus, cardiovascular system, neurological system and respiratory system. Rehabilitation devices mainly address the musculoskeletal apparatus and the nervous system disorders that influence the musculoskeletal apparatus.

Passive mobilizations are used for the fractures that require or not continuous extension, in the case of the rheumatic and neurological disorders. In the case of the neurological disorders, although the treatment is long lasting, the patient may recover almost completely his/her previously lost mobility.

2 Rehabilitation equipment

2.1 Electrically driven rehabilitation devices

As follows, an overview of the current stage as regards upper limb rehabilitation equipment available on the market will be submitted. Following research in the literature, note that most devices are driven with electric motors, only a few being yet pneumatically actuated.

OttoBock Company, established in 1919, with extensive experience in prostheses and rehabilitation equipment, produces various electrically driven systems of upper limb recovery, as follows [3]:

- W2 Wrist CPM Device – is a device for wrist rehabilitation. With its help, flexion and extension, or abduction and adduction exercises may be performed.

  ![W2 Wrist Device](Image)
  Fig. 3 W2 Wrist Device

- E3 Elbow CPM Device – is used both for the flexion and extension motions and for the pronation and supination of the forearm.

  ![E3 Elbow Device](Image)
  Fig. 4 E3 Elbow Device

- PS1 Pronation/Supination CPM Device – is a device destined to the rehabilitation of the pronation and supination functions of the forearm.

  ![PS1 Pronation/Supination](Image)
  Fig. 5 PS1 Pronation/Supination Device

- 600 Shoulder CPM Device – is used for the rehabilitation of the shoulder joint.

  ![600 Shoulder CPM Device](Image)
  Fig. 6 600 Shoulder CPM Device
2.2 Pneumatically actuated rehabilitation devices

All devices submitted above are driven with electric motors, which regulate the motion amplitude, speed and pause duration between cycles.

Another category of rehabilitation equipment resorts to pneumatic actuation. Compressed air is nowadays one of the most effective means to actuate and automatize the working equipment. The use on an ever-large scale of the compressed air in industrial applications is due to its advantages, such as convenient generation and storage possibility, non-flammability, as well as minimal risk of explosion, minimal effort in maintenance etc.

A relatively new category of upper limb rehabilitation equipment resorts to pneumatic actuators with rotary elastic chambers. These actuators are placed in the rehabilitation equipment joints and they generate the torques necessary for actuating the upper limbs. Fig. 9 shows the constructive principle of such an articulation, (torque), based on the existence of two rotary elastic chambers that operate in compliance with an antagonistic principle (while the former relaxes under the compressed air pressure, the latter folds) [6].

Figure 10 shows such a rehabilitation device, actuated by rotary elastic chambers [7].

A modified variant of the previously submitted equipment is shown in Fig. 11, wherein multiaxial elastic chambers are used [8].

Compactness, passive compliance and low weight are the most important benefits of pneumatic soft-actuators with rotary elastic chambers. Rehabilitation equipments (robots) with these natural back-drivable actuators are well suitable for safe physical interaction tasks, where human and robots operate in direct contact.

Another example of rehabilitation equipment is achieved by Kinetic Muscles Inc. company, which produces a hand rehabilitation system named The Hand Mentor (Fig. 12). Unlike the equipment submitted above, this device is actuated by a pneumatic muscle. A medical study conducted with this device and its description are submitted in the paper [9]. This company likewise holds a patent for

- WaveFlex Hand CPM – is a portable device used for finger rehabilitation. It is based on several patents obtained in the 90’s [4], [5].

Fig. 7 WaveFlex Hand CPM  
Fig. 8 Flex-Mate S500

Fig. 9 Antagonistic set up with two working chambers

Fig. 10 Equipment for the rehabilitation of the shoulder and arm disorders

Fig. 11 Utilization of multiaxial rotary chambers
an upper limb rehabilitation device, which is actuated by pneumatic muscles (Fig. 12) [10].

The pneumatic actuation of the upper limb rehabilitation equipment is a subject also covered by a few patents. Some achievements of the sort are presented below.

Jiliang University of China proposes, for the elbow rehabilitation, a joint actuated by a pneumatic muscle [11]. The muscle contraction leads to the rotation of the articulated bar on the left. If the force of resistance to the movement exceeds a certain value, a spring will stretch, stopping the rotation of the articulated bar. The spring 24 brings the articulated bar 1 in initial position when the muscle pressure is zero (Fig. 13).

The following device is used for the passive motion of the hand and is actuated by a rotary pneumatic muscle, too [13]. It consists of four plates connected by three torques. On the opposite side of the surfaces whereon the palm is seated, on the four plates, an inflatable little bag is attached. Depending on the pressure inside the bag, the four plates will rotate the palm and fingers.

4 Conclusion

The passive or active mobilization of the upper limb joints prevents the formation of tendon adhesions and articular deposits that lead to mobility diminution.

Joint mobilization leads to pain relief, to the shortening of the recovery period and to the diminution of the costs necessary for treating patients.

The use of the rehabilitation equipment allows more patients to be treated under a kinesitherapist’s care. Rehabilitation devices may be used both in rehabilitation centres and at the patient’s domicile.

Most upper limb rehabilitation devices sold at this point resort to electric motors in order to generate the recovery motions. Knowing that rehabilitation devices driven by electric motors are expensive and have rigid, human-unfriendly behaviour, the pneumatic actuation is considered a valuable alternative.

Considering the advantages of pneumatic actuation, an increase of the researchers’
preoccupations towards the development of rehabilitation devices based on compressed air has been lately noted. The study of the patents published in recent years allows us to draw the conclusion that the linear or rotary pneumatic muscle becomes an increasingly important alternative to the electric motor.

References: