ACTUATING SYSTEMS OF ELBOW REHABILITATION DEVICES

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Rezumat. *Echipamentele de reabilitare ce folosesc mișcarea pasivă continuă reprezintă un real ajutor în cazul pacienților cu afecțiuni posttraumatice care nu își pot mobiliza ei înșiși membrele, reușind atât să substituie munca depusă de kinetoterapeut, cât și să majoreze confortul pacienților. Mișcarea pasivă continuă constă în exerciții lente și neîntrerupte aplicate articulației lezate. Acest articol prezintă stadiul actual al echipamentelor de reabilitare a articulației cotului, sisteme care folosesc acest procedeu. Majoritatea au sistemul de acționare electric, dar datorită avantajelor constructive ale sistemului de acționare pneumatic, în ultima perioadă s-a constatat o creștere a aplicabilității lui în acest domeniu.*

Abstract. *Rehabilitation equipment using continuous passive motion is useful in the case of patients with posttraumatic disorders that cannot move autonomously, succeeding in both replacing the kinesiotherapist's work and increasing patient comfort. Continuous passive motion consists in applying a slow and uninterrupted movement to injured joints. This paper presents an analysis of the current stage of the elbow rehabilitation equipment developed by the authors, based on this technique. While most devices are driven by electric motors, due to the constructive advantages of pneumatic actuating systems, lately an increase of its applicability in this field has been recorded.*

Keywords: CPM, rehabilitation equipment, elbow, actuation systems

1. Introduction

Following surgery, the mobility of the joint operated on is diminished, possibly even causing chronic pain. It has been clinically demonstrated immobilization following joint surgery increases the recovery time and slows down the healing process, favouring the development of adherences and scar tissues, which can lead to long term or permanent restrictions of movement [1].

Passive kinesiotherapy is designed for patients lacking the necessary biological resources for commanding and executing the movement [2]. The problems outlined above can be addressed by continuous passive motion (CPM), a therapeutic procedure consisting of applying a range of motions to the affected joint, without self-straining of the patient's muscles. CPM can be achieved by means of kinesiotherapy's or specially designed equipment.

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It is a known fact that the lack of movement impacts on muscles as well, which, by immobilization, atrophy. Figure 1 shows a comparison between a normal muscle and an atrophied one. A decrease in size, strength and mobility can be noticed in the case of the atrophied muscle.

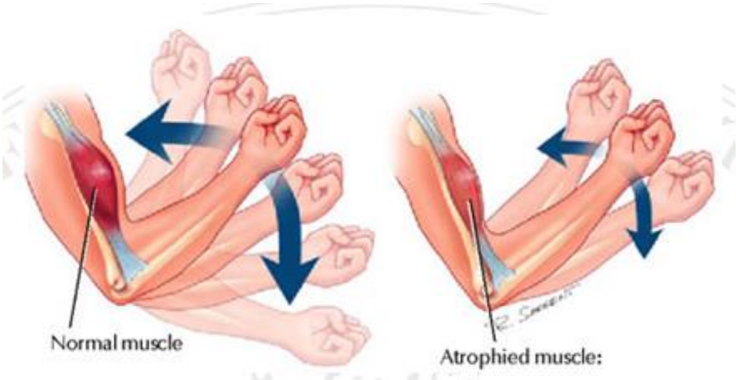

Fig. 1. Effects of atrophy on muscles.

While natural recovery of mobility can take several months, the use of continuous passive motion not only accelerates healing, but prevents scar tissue formation, and lightens joint stiffness.

2. The movements of the elbow joint

The elbow joint includes three bones: humerus, ulna and radius, as illustrated in Figure 2. It could be considered that by associating, in turn, two of these three bones, three joints are formed (humeroulnar, humeroradial and radioulnar). However, because of the existence of a single capsule, lined by a single synovial, some authors argue that a single joint is formed [3].

Fig. 2. The elbow joint.

Physiologically, the elbow performs two movements: flexion-extension and pronation-supination. Therefore, it follows that the elbow has two joints: the humeroulnar joint, for the flexion-extension movement and the radioulnar joint, for the pronation-supination movement. The humeroradial joint follows the motions made by the humeroulnar joint.

Further the two motions conducted by the elbow joint will be discussed.

The flexion, shown in Figure 3, is obtained by rotating the forearm towards the arm, the maximum angle of rotation being 145°.

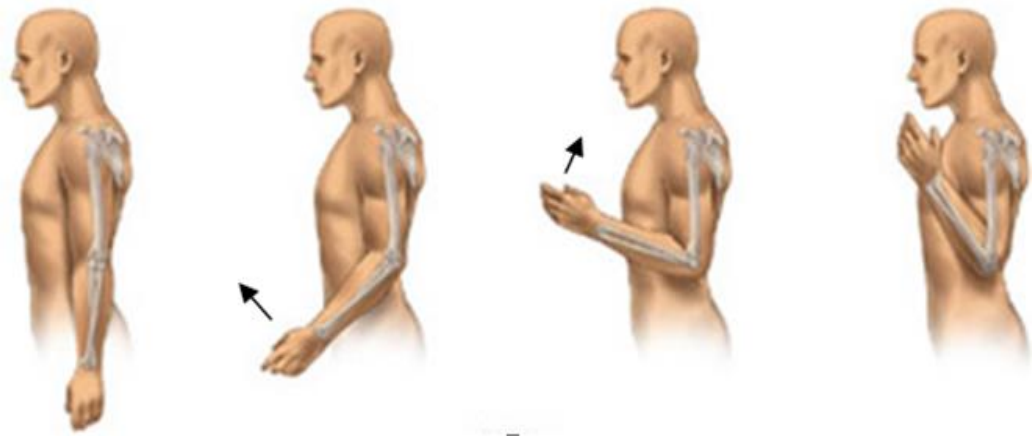

Fig. 3. Flexion.

The extension is obtained by rotating the arm in the opposite direction (Figure 4). The extension ranges from 5° to 10° (hyperextension).

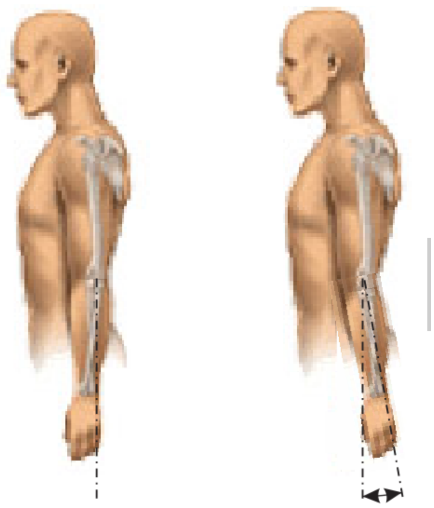

Fig. 4. Extension.

The pronosupination consists in rotating the forearm by its longitudinal axis. Figure 5 shows position zero of pronosupination, the arm being positioned along the body and the forearm flexed at 90° with the thumb turned upward.

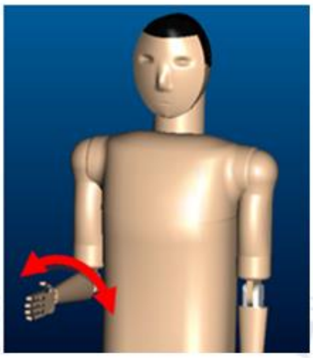

Fig. 5. Zero position.

Fig. 6. Pronation.

Fig. 7. Supination.

Figure 6 shows the pronation movement, which is obtained by rotating the forearm by its longitudinal axis, the thumb moving closer to the body. The maximum angle of rotation is 90°, when the palm of the hand becomes parallel to the ground.

Figure 7 shows the supination movement, which is obtained by rotating the forearm by its longitudinal axis, the thumb being turned away from the body. The maximum angle of rotation is 90°.

In flexion, the muscles of the arm work in an agonist-antagonist manner. Although both muscles work simultaneously, they have opposite roles: the agonist muscles are the ones who carry out the movement and the antagonist muscles are relaxing, opposing the motion.

Figure 8 shows the triceps, the muscle responsible for the extension of the forearm, is contracted and the biceps is relaxed. Once flexion has been initiated (Figure 9), the biceps, the muscle responsible for the forearm flexion, contracts as the triceps relaxes.

Fig. 8. Arm extension.

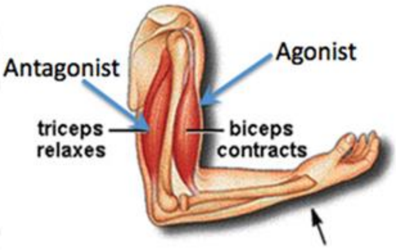

Fig. 9. Arm flexion.

Since following joint surgery these movements cannot be achieved by patient, for various reasons (joint, muscular), passive motion performs the necessary mobilization without contracting the muscles.

In this way, the postoperative pain can be controlled and the swelling can be decreased.

This technique can be used immediately after surgery, with the possibility of increasing the amplitude of the motion in time.

3. Rehabilitation equipment

3.1. The utility of CPM elbow rehabilitation equipment

Among the reasons for a continuous passive motion device to be preferred to a kinesiotherapist in posttraumatic recovery is the comfort and the safety provided by such equipment [4].

These devices were developed with the very aim of replacing the kinesiotherapist's physical work, by applying slow, rhythmic and continuous movements to joint. The benefits further include in addition to a reduced recovery period, also computer controlled safe and easy utilization.

The rehabilitation of the patient aims at full recovery of the diminished or lost motor functions. This healing process starts in hospital, immediately after surgery and, if necessary, continues at the patient's home.

These devices can be used in both medical units and in the patients' home, where they can customize their own rehabilitation programme, by adjusting the motion amplitude, the velocity, etc., according to the posttraumatic recovery programme recommended by the physician or the kinesiotherapist.

Rehabilitation devices can be mono-articular (for single joint recovery) or pluri-articular (for the recovery of several joints).

3.2. Electrically driven rehabilitation devices

Further on an overview of the current state of elbow rehabilitation equipment will be presented.

At present most devices are driven by electric motors, which allow movement and velocity adjustment according to the respective treatment plan.

Otto Bock, a German company with nearly 100 years of experience in prostheses and rehabilitation equipment, manufactures the following two devices for elbow rehabilitation: [5]

- E3 Elbow CPM Device, illustrated in Figure 10, which allows both flexion/extension and pronation/supination.
- PS1 Pronation/Supination CPM Device, shown in Figure 11, which allows only pronation/supination.

Fig. 10. E3 Elbow CPM Device.

Fig. 11. PS1 Pronation/Supination Device.

The next presented rehabilitation equipment is a product of Kinex Medical Company, an American medical equipment provider, specializing in various postoperative therapies (CPM, Cold Therapy, DVT Therapy, TENS Units, Braces/Slings) [6].

Figure 12 shows the KE2 Elbow CPM device, designed to achieve flexion/extension (Figure 12, a.) and pronation/supination (Figure 12, b.) separately, not simultaneously.

Fig. 12. Kinex KE2 Elbow CPM Device
a. Flexion-extension motions. **b.** Pronation-supination motions.

The French company Kinetec produces two elbow rehabilitation devices:

- Kinetec 6080 Elbow CPM, presented in Figure 13, which can perform two types of movements: flexion/extension or flexion/extension with synchronized pronation/supination.
- The Kinetec Centura Elbow Module, presented in Figure 14, allows flexion/extension with fixed pronation/supination, and can also be used in all planes of shoulder abduction (that is moving the arm away from the body) [7].

Fig. 13. Kinetec 6080 Elbow CPM Device.

Fig. 14. Kinetec Centura Elbow Module Device.

The Italian company RIMEC also produces two elbow rehabilitation devices:

- Fisiotek LT-G, represented in Figure 15, used both for flexion/extension and pronation/supination of the forearm.
- Fisiotek HP2, shown in Figure 16, achieves via specific accessories both motions, flexion/extension and pronation/supination [8].

Fig. 15. Fisiotek LT-G Device.

Fig. 16. Fisiotek HP2 Device.

The next device included in this analysis is Pankaj Elbow CPM, illustrated in Figure 17. The LED control panel allows flexion/extension (see Figure 17, a.) based on a pre-set range of motions to be conducted over a certain period. The device comes with accessories for both pronation/supination (see Figure 17, b.) and wrist rotation [9].

Fig. 17. Pankaj Elbow CPM Device
a. Flexion/extension. **b.** Pronation/supination

Figure 18 presents Artromot E2 Elbow CPM, a piece of equipment that facilitates complete flexion/extension and pronation/supination [10].

Fig. 18. Artromot E2 Elbow CPM Device.

3.3. Pneumatically actuated rehabilitation devices

Another category of rehabilitation equipment concerns pneumatically actuated devices, where the force and the motion are produced by compressed air. Compressed air is a resource used in many fields, including industry, for pneumatic actuation systems. Recently these systems have been used increasingly, due to their specific characteristics and many advantages, such as the possibility of safe intensive deployment entailing frequent starts and stops, reduced overall size due to wide component location customization possibilities, easy production, storage and transport of compressed air, which is environment friendly and non-flammable, and the low maintenance of the installations.

The pneumatic muscle is one of the motion generators of used in pneumatic systems. It is an elastic element that increases its diameter and reduces its length under air pressure. Thus, the compressed air supply enables it to move a load in a certain direction, performing a stroke directly proportional with the fed pressure. Upon the feeding of compressed air is discontinued, the muscle resumes its initial shape and dimensions (Figure 19).

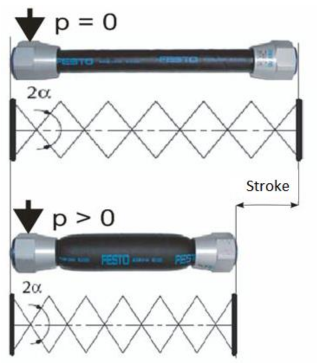

Fig. 19. Working principle of the pneumatic muscle.

Should one muscle not be able to perform the desired movements, various solutions for series or parallel mounting of several muscles are available, as is the use of auxiliary elements like pulleys, as illustrated below.

Further on, a few examples of patented pneumatic muscle actuated equipment for elbow rehabilitation will be presented.

Chinese Xi'an Jiaotong University developed the pneumatic muscle actuated elbow medical rehabilitation device shown in Figure 20. This includes an upper-arm fixing device, a forearm supporting device, a connecting shaft, the pneumatic muscle with an attached thread and a gear, connected to the shaft and the forearm supporting device by means of a belt [11]. Thus, the contraction of the pneumatic muscle, via the pulley, causes the forearm supporting device to move.

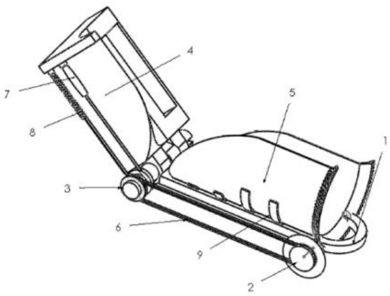

Fig. 20. Patent CN203263743.

Another patent obtained also by Xi'an Jiaotong University is a simple structure elbow rehabilitation training device (Figure 21), designed for recovering limb functions [12]. Like in the previous device, it is the contraction of the pneumatic muscle that drives the elbow movement.

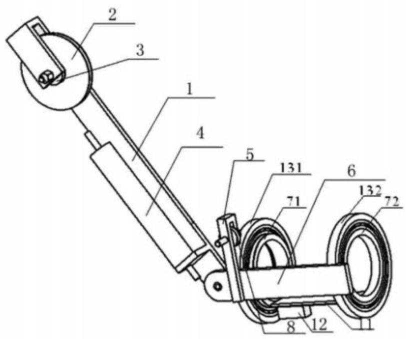

Fig. 21. Patent CN103976852.

Jiliang University of China developed a pneumatic muscle actuated joint. (Fig. 22). The joint comprises two connected bars, a rotating shaft and a shared bearing, a flexible sleeve, a pneumatic muscle, a buffer system and a compression spring [13].

The air pressure causes the pneumatic muscle contraction/relaxation, which generates the rotation of the left hand side jointed bar by a certain angle allowed by the spring.

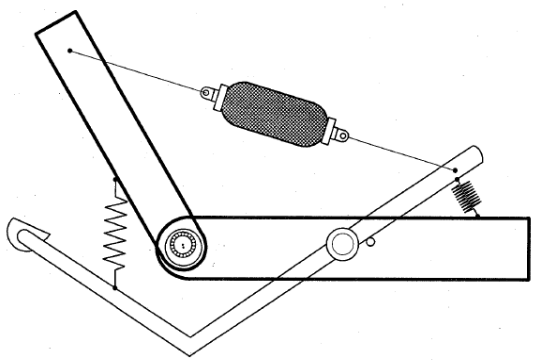

Fig. 22. Patent CN202071080.

Zhejiang University of China has developed for the rehabilitation of the elbow a device actuated by two pneumatic muscles (Figure 23), which performs the rotation of the elbow and of the upper-arm [14]. This movement is possible by controlling the air pressure fed to the two pneumatic muscles.

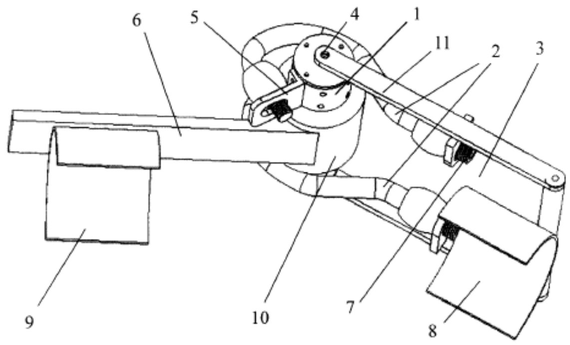

Fig. 23. Patent CN200984250.

Next, the patent obtained by Huazhong University of China concerns a piece of pneumatic equipment used for assisting the rehabilitation training of the elbow (Figure 24).

This is used for simulating the freedom of the elbow's motion and for providing larger working space for the joint. The device is light, easy to manipulate and wearable, thus directly assisting the injured joint [15].

The device is commanded by the patient, and the actuation force is controlled via the pressure distributed to the two parallel-mounted muscles.

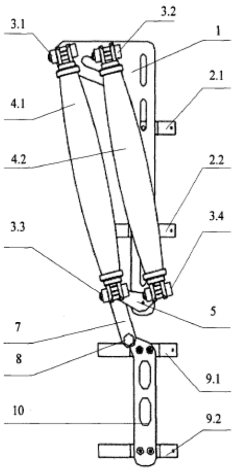

Fig. 24. Patent CN201108566

Conclusion

Prolonged immobilization has negative effects on the human body. In case of patients who following surgery cannot move autonomously, the recommended solution is continuous passive motion, a postoperative treatment protocol which entails mechanized training of the joints, without tensing of the muscles.

The use of rehabilitation equipment has numerous advantages. These include comfort and safety, the shortening of the recovery period, the possibility of using the devices in both medical units and in patients' homes, and successfully replacing the kinesiotherapist's work.

At present most elbow rehabilitation equipment are electrically actuated. The benefits of pneumatic actuation, like simple construction, increased flexibility, lower cost, render pneumatic equipment eligible to replace the electrical devices.

The study presents the research conducted on the current state of CPM based elbow rehabilitation equipment construction. Based on this analysis further research will focus on developing a new solution for elbow rehabilitation equipment. The actuation will utilise pneumatic muscles working in agonist – antagonist mode, similar to the functioning of the human biceps and triceps. This new type of equipment will thus be designed, computer simulated, built and tested as to verifying the compliant behaviour specific for these actuators. Upon completion of these stages, a patent application will be submitted for protecting the intellectual property rights for the developed equipment, which is to be offered to industrial companies interested in its series manufacturing.

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