

# KINEMATIC ANALYSIS OF ELBOW REHABILITATION EQUIPMENT

G. VETRICE<sup>1</sup>    A. DEACONESCU<sup>1</sup>

**Abstract:** *The aim of this paper is to present the kinematic analysis of a constructive solution of rehabilitation equipment designed for helping patients with posttraumatic afflictions of the elbow joint. For patients who cannot move their elbows autonomously, continuous passive motion is used, consisting in applying slow and uninterrupted movements to the affected joint. The equipment has two rotational degrees of freedom, one for each movement performed by the elbow joint, in order to ensure a complete recovery (flexion-extension and pronation-supination).*

**Key words:** *rehabilitation equipment, elbow joint, kinematic analysis.*

## 1. Introduction

International studies have revealed that each year worldwide about 15 million individuals are affected by strokes, 5 million of whom retain a permanent invalidity of the upper and/or lower limbs. In a large part of these cases the functional utilization of the limbs cannot be achieved even following prolonged rehabilitation treatment. The rehabilitation treatment has become possible by the development of several variants of robotic systems for the recovery of the upper and lower limbs, thus partially replacing the therapist's work [1].

This paper presents research related to a constructive variant of rehabilitation equipment, for the posttraumatic rehabilitation of patients suffering from elbow disorders. The elbow joint is responsible for two movements: flexion-extension and pronation-supination [3]. If any of these movements is difficult or currently not possible, the equipment will help the patients to restore the initial functions safely. Regular passive movements are provided to the affected joint in order to facilitate recovery. The equipment has two revolute joints, one for each movement performed by the elbow joint, but can be used only one a time, not simultaneously.

For a better understanding, knowledge about the anatomy and biomechanics of the elbow is required.

As stated above, the elbow is responsible for two movements: flexion-extension and pronation-supination. The flexion, shown in Figure 1, consists in rotating the forearm towards the arm, the maximum angle of rotation being 150°. The extension, shown in Figure 1 too, consists in rotating the arm in the opposite direction, the maximum angle of rotation being 10° (hyperextension). In Figure 2 the pronation and supination movements are presented, obtained by rotating the forearm by its longitudinal axis. In the case of

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<sup>1</sup> Dept. of Industrial Engineering and Management, *Transilvania* University of Braşov.

pronation the thumb moves closer to the body and the palm becomes parallel to the ground and in the case of supination the thumb is turned away from the body. In both cases the maximum angle of rotation is  $90^\circ$ .

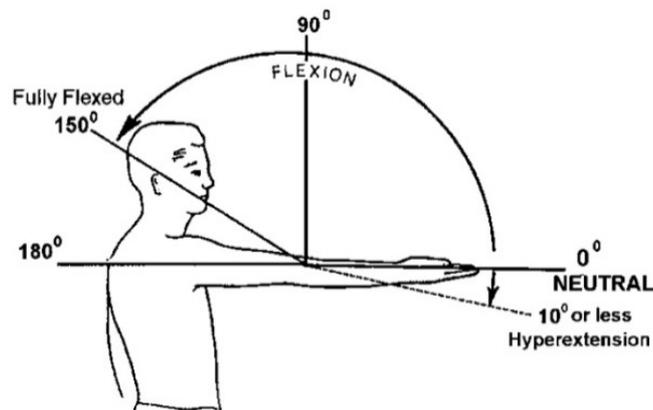


Fig. 1. *Elbow flexion-extension* [8]

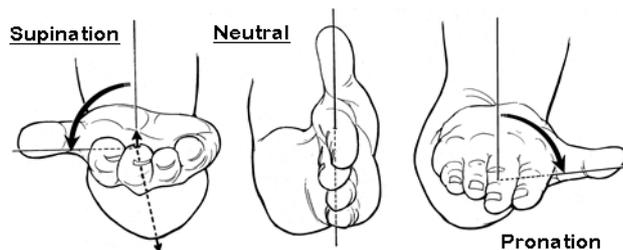


Fig. 2. *Elbow pronation-supination* [9]

## 2. Elbow Rehabilitation Equipment

Dedicated equipment is used frequently in rehabilitation medicine, succeeding in both replacing the physical therapist's work and increasing patient comfort. The discussed equipment was conceived to allow the recovery of the joint's original functions, by applying constant motion to the joint, without requiring any effort from the patient, a method known as continuous passive motion.

Numerous types of such equipment are available on the marketplace, for the rehabilitation the lower limb or of various joints of the upper limb. The prices, however, are high, often exceeding the financial possibilities of the potential users. In consideration of the above it appeared necessary to conceive high performance and cost effective elbow joint rehabilitation equipment.

These devices can be used in both medical units and in patient homes, and therefore must provide safety, comfort and easy utilization. In order for that to happen, the linkage of the equipment has to be compatible with the linkage of the human upper limb, meaning the axes of the joint of the equipment have to be identical to the human joint axes. Thus, an ergonomic human-machine interaction is guaranteed [6].

## 2.1. Proposed Rehabilitation Equipment

The proposed rehabilitation equipment (Figure 3) uses continuous passive motion, for the recovery of patients with affections of the elbow joint. The equipment is built in such manner that it performs exactly the elbow movements that need to be recovered, as presented above (flexion-extension and pronation-supination).

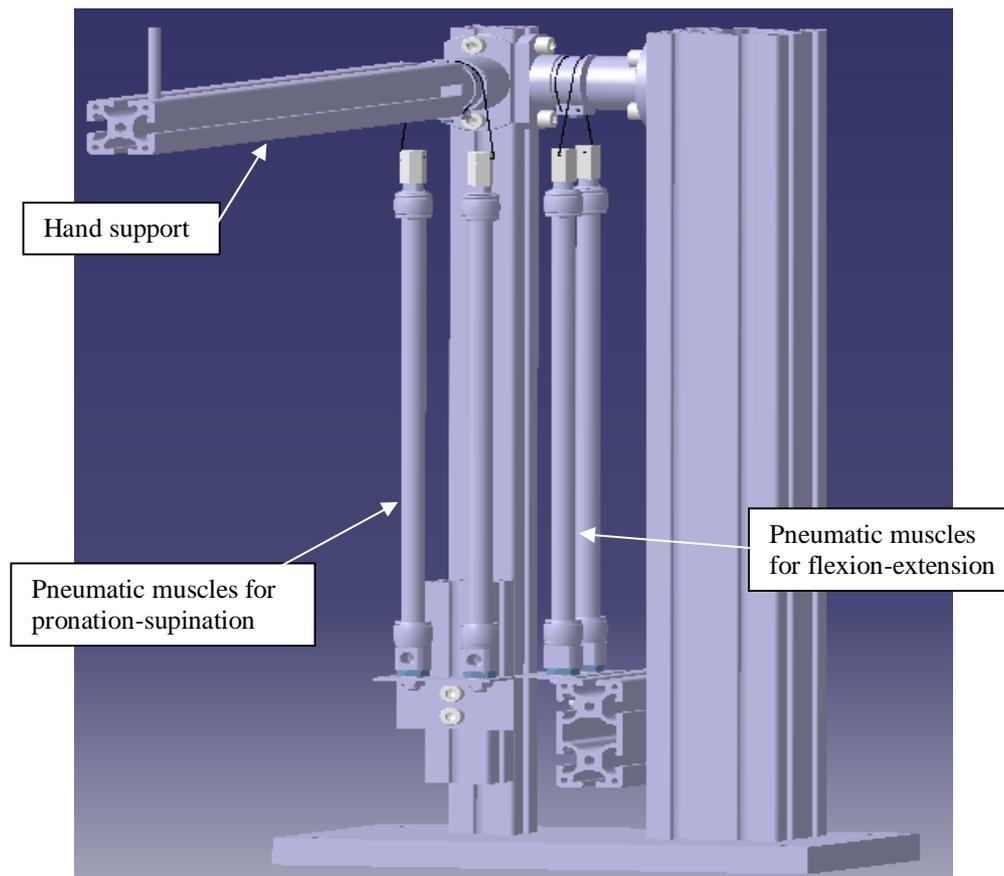


Fig. 3. *Proposed rehabilitation equipment* [5]

The characteristics of the equipment are low weight, due to the use of lightweight materials (aluminium), simple and robust construction and swift response to commands. The efficiency of the utilization of this kind of equipment results from its constructive simplicity, reduced recovery period, ergonomics and safety.

The equipment has a hand support of adjustable length, for different sizes of the upper limb. For rehabilitation exercising the patient places the forearm on this hand support and holds the handle, as shown in Figure 4.

Figure 4 shows that each of the two motions carried out by the elbow is generated by a rotation module. Each of the two rotation modules functions by the same principle.

Thus, considering any one of the two rotation modules, the lower ends of the pneumatic muscles are fixed to a small metal sheet that glides along the aluminium profile that supports the entire mechanism [7].

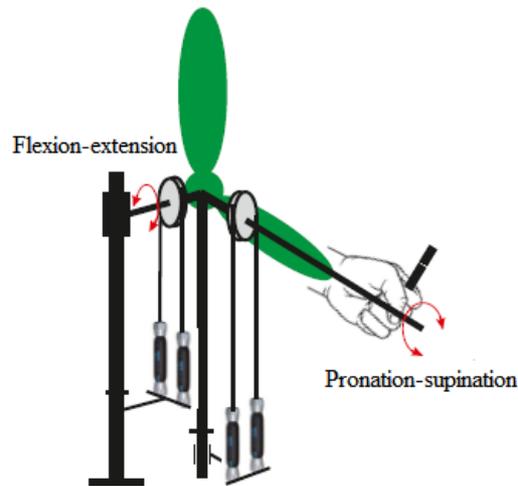


Fig. 4. Position of the patient upper limb on the equipment [5]

Steel cables are connected to the upper ends of the pneumatic muscles; the cables are drawn over a pulley and fixed on it. These cables convey the motion from the pneumatic muscles to the joint. The rotation of the pulley ensures the rehabilitation motion (flexion-extension, or pronation-supination, as the case may be). The components of the rotational assembly are presented in Figure 5.

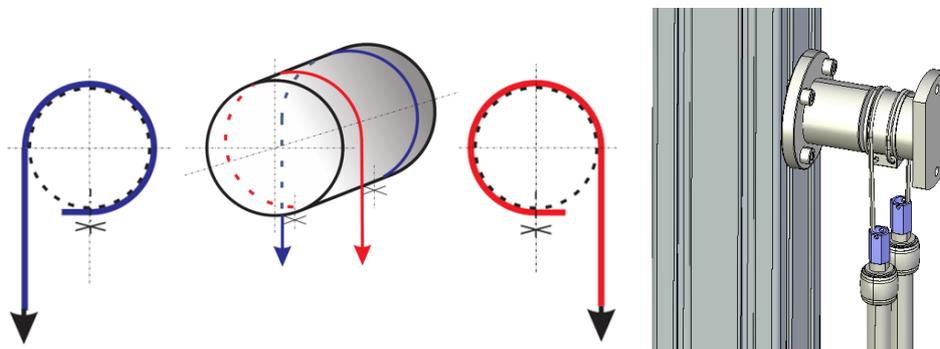


Fig. 5. The rotational assembly

## 2.2. Kinematics of the Rehabilitation Equipment

The kinematics of the rehabilitation equipment must reflect the kinematics of the elbow joint, which is shown in Figure 6.

For a secure recovery of the patients, specific requirements have to be complied with when designing the equipment, such as allowing the replication of human movements, an ergonomic design and ensuring safety [2].

The equipment has the two revolute joints, with their respective axes perpendicular one to another. Each of them is activated by means of a pair of pneumatic muscles, working

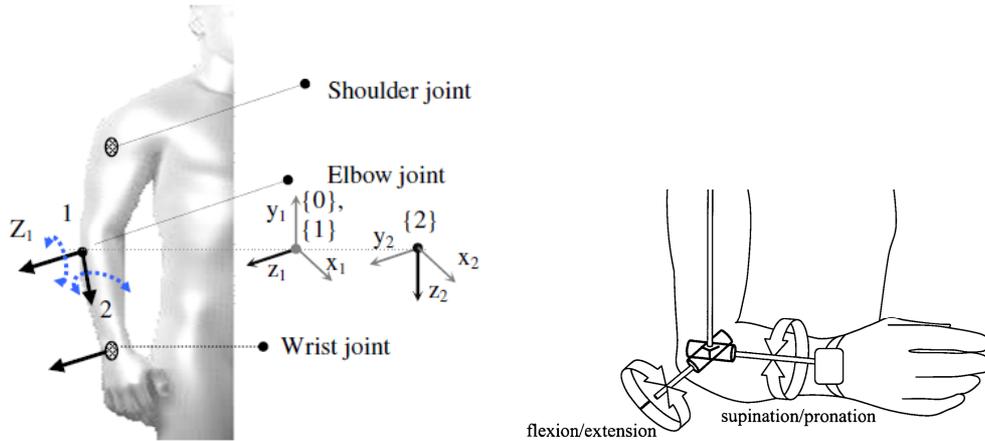


Fig. 6. Kinematics of the elbow joint [4]

in agonist-antagonist mode, as shown in Figure 7. The neutral position is obtained when both muscles are fed the same pressure. The compressed air supply enables the muscle to move a load, performing a stroke directly proportional with the fed pressure. The equipment uses four pneumatic muscles of 10 mm interior diameter and 300 mm initial length. The maximum possible stroke that can be achieved is of approximately 20% of the relaxed muscle length (60 mm).

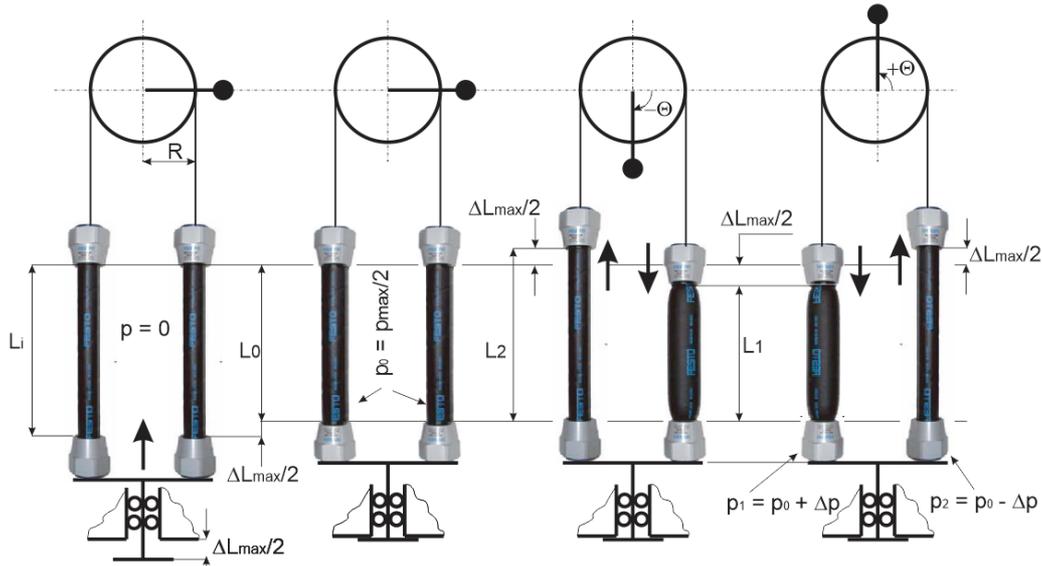


Fig. 7. Pneumatic artificial muscles working in agonist-antagonist mode

### 3. Conclusion

This paper presents an alternative design of two-degrees-of-freedom rehabilitation equipment based on continuous passive motion. The need for conceiving such equipment is justified, as the devices developed so far are electrically driven and therefore have a rigid structure.

Upper limb joint rehabilitation equipment actuated by pneumatic muscles represents a viable alternative, capable of replacing successfully the electrically actuated variants. The developed prototype proves the high capability and performance of the proposed rehabilitation equipment, the pneumatic muscle being eligible for becoming an adequate actuator of medical recovery systems.

The research leads to the development of a mono-articular device with a linkage similar to that of the upper limb, which ensures a complete recovery of the injured joint. Using this equipment, a larger range of motions can be achieved (extension/flexion:  $-10^{\circ}$ ... $-150^{\circ}$  and pronation/supination:  $+90^{\circ}$ ... $-90^{\circ}$ , one at a time, not simultaneously). The design is based on knowledge from anatomy, biomechanics and kinematics.

Coming into direct contact with patients, the equipment has to ensure maximum comfort to the patient and must not compromise or restrict in any way the patient's ability to perform natural motions. Therefore the rehabilitation equipment must allow the replication of human motions and must provide safety and compliance in utilization, along with an ergonomic design.

The research discussed in this paper will be continued with an in-depth analysis of the mechanism and of a number of alternative constructive solutions.

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