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Pronosupination mechanism adaptable to a rehabilitation device of the upper extremity

Mecanismo de pronosupinación adaptable a dispositivos de rehabilitación de la extremidad superior

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Abstract

Rehabilitation robotics is a tool to support rehabilitation therapist that reduces the patient's recovery time and improve the exercises repeatability. Arm rehabilitation devices have been developed to perform the exercises in the horizontal plane; however, most devices do not consider arm pronosupination. This paper presents the design of a pronosupinator that can be mounted to the end effector of some existing devices. The pronosupinator consists of a sling and a cylinder that allows forearm rotation, this rotation can be: manual, the patient may rotate it; or automatic through a motor. The pronosupinator features, in combination with the arm rehabilitation devices, contribute to the improvement of rehabilitation therapies and reduces costs in general for the healthcare sector.

Keywords: pronosupination; human arm rehabilitation; medical robotics.

Resumen

La robótica de rehabilitación es una herramienta para asistir al terapeuta; reduce el tiempo de recuperación del paciente y mejora la repetitividad de los ejercicios. Los dispositivos para rehabilitación del brazo se han desarrollado para emular ejercicios en el plano horizontal; sin embargo, la mayoría de los dispositivos no considera la pronosupinación del brazo. El presente artículo expone el diseño de un dispositivo que se puede implementar en el efector final de algunos de los dispositivos existentes. El pronosupinador consiste en un cabestrillo y un cilindro que permite la rotación del antebrazo. Puede ser manual, en cuyo caso el paciente lo puede rotar; o automático, operado mediante un motor. Las características del pronosupinador, en combinación con los dispositivos de rehabilitación para el brazo, contribuyen a mejorar las terapias de rehabilitación y reducen costos en general para el sector de la salud.

Palabras clave: pronosupinación; rehabilitación del brazo humano; robótica médica.

1. Introduction

At present, new technologies such as rehabilitation robotics have emerged for physical therapies. It has been shown [1] [2] that using such alternative for rehabilitation reduces the patient's recovery time, the repeatability of the exercises is improved, and the therapist fatigue caused by mobilizing heavy limbs is reduced.

Since work in the industry is usually performed manually, arm injuries are the most frequent in workplaces. For example, in Mexico, a total of 157 667 patients were diagnosed with an upper extremity injury in 2017; according with IMSS (Instituto Mexicano del Seguro Social), 6 910 people were declared to suffer some type of disability. Most were hand and wrist injuries (28.1%), followed by shoulder, lower and upper arm injuries (10.3%) [3][4]. Discarding finger injuries, a

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total of 1 609 267 people were affected; according with The USA accident guide [5], a person diagnosed with disability and unable of performing their activities can receive between 60 and 70% of their salary. With the use of alternatives such as the combination of rehabilitation robotics and virtual reality, the rehabilitation time is reduced [5][4]. The work presented in [7] demonstrates that the MIT-MANUS robot effectively reduces the patient's recovery time. Robotic devices for rehabilitation are classified into three types: robotic [8-10], exoskeleton [11-13] and end effector [14-16]. The work presented in this paper concerns end effector devices.

2. Arm rehabilitation exercises

The basic exercises for upper extremity therapy are: horizontal shoulder flexo-extension (Figure 1(a)), elbow flexo-extension (Figure 1 (b)) and pronosupination (Figure 1 (c)).

Using these basic movements some routines or trajectories can be described, such as tracing the number "8", a line, an arc, the letter "L", a circle, among others. All the previous exercises are done on the horizontal plane.

The pronosupination consists of the forearm rotation around its longitudinal axis, according with Kapandji [17], it requires the participation of two connected joints: the proximal radio-ulnar joint and the distal radio-ulnar joint. This forearm rotation introduces a third degree of freedom at wrist joint level. Consequently, the hand, can be placed at any orientation to catch or hold an object. The intermediate position is determined by the thumb up and the hand inward palm (Figure 2 (a)). The supination position (Figure 2 (b)) is performed when the hand palm is directed upwards with the thumb outwards. The pronation position is performed when the hand palm "looks" down and the thumb inwards (Figure 2 (c)).

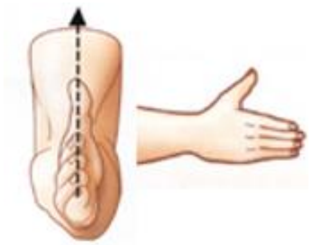
This series of movements allow for the rehabilitation of the different arm muscles [17]; in addition, to the combination of flexo-extensions, a trajectory can be achieved as in Figure 3. Most devices that are currently used for pronosupination are mechanical, see Figure 4.

a)

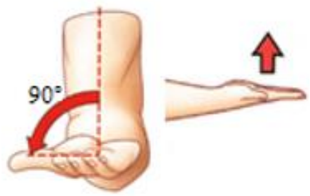
b)

c)

Figure 1. a) Flexo-extension of the shoulder b) Flexo extension of the elbow, c) Pronosupination.



a)



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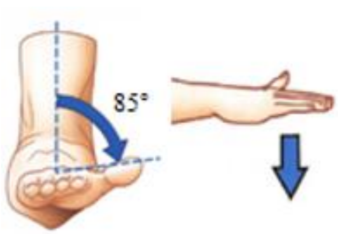


c)

Figure 2. a) Intermediate position, b) supination Position, c) pronation position [4].

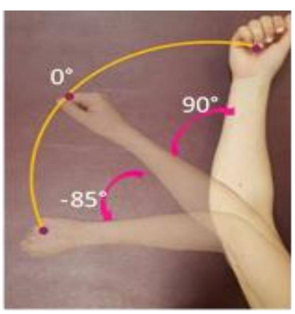


Figure 3. Pronosupination with arc motion.

Figure 4. Pronosupination mechanical devices.

There are some pronosupination devices such as Pronation/Supination Forearm CPM Device [18], Prono-Supination Mechanism for Activities of Daily Living [19], Orthos for wrist supination-pronation [20], among others.

3. Arm rehabilitation devices

Some robotic devices for upper extremity rehabilitation have been developed, the most relevant been reported in [1]. The most known are InMotion Arm [14] (Figure 5 (a)), Gentles [21] (Figure 5 (b)), Braccio Di Ferro [22] (Figure 5 (d)), Adler [23] and Portable Assistive Mechanism for Human Arm Exercises [24] (Figure 5 (c)), all the previous ones of end effector type. Among the devices already mentioned, only the InMotion Arm considers pronosupination; however, this movement is performed independently of the rehabilitation exercises, while the others are limited to flexo-extension movements, adduction and abduction.

The exercises performed by these devices can be complemented by pronosupination to perform more complete therapies. For this purpose, the pronosupination device design is presented below.

4. Design of a pronosupination device

The proposed design for pronosupination, to be located at the end effector, consists of an arm support (holder) and a cylinder that allows the patient's forearm rotation. The rotation can be done manually or automatically since the patient can turn it with his own force, or through a motor rotating the cylinder to a desired orientation. Figure 6 (a) and 6 (b) show the main elements of the pronosupinator design. The intermediate hand position in the pronosupinator can be visualized in Figure 7 (c) while the supination and pronation positions are visualized in Figure 7 (a), (b), respectively. This pronosupinator-end effector can be used in the two stages of rehabilitation, passive and active. In the passive stage, where the patient is assisted to perform the movement, it rotates through a motor to perform pronosupination in combination with flexo-extension and adduction. Also, the orientation can be locked with a bolt if a fixed orientation is needed during the exercise. In the active rehabilitation stage, where the patient can perform a movement without assistance, this device rotates freely so that patient can perform the exercises freely with his arm strength.

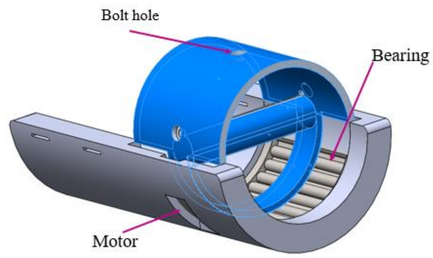
a)

b)

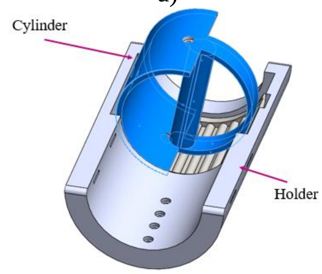
c)

d)

Figure 5. Arm rehabilitation devices: a) InMotion Arm, b) Gentles, c) Portable assistive mechanism for human exercises, d) Braccio Di Ferro.

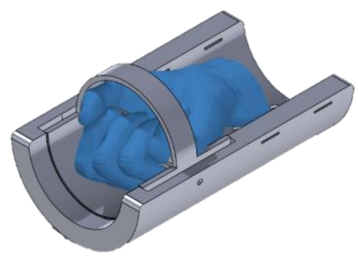


a)

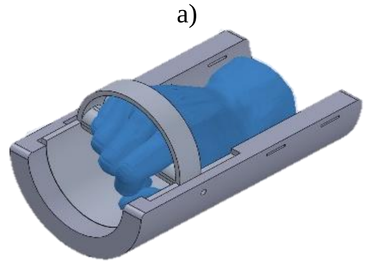


b)

Figure 6. Pronosupinator design: a) Simplified view, b) Front view



a)



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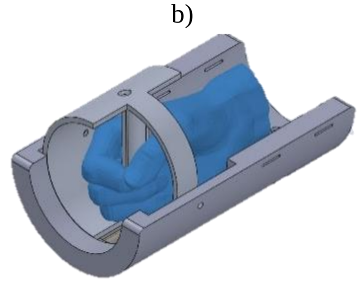

c)

Figure 7. Pronosupination positions: a) Supination, b) Pronation, c) Intermediate.

The pronosupinator can be provided with an optical sensor adaptable to the mechanism end effector to register the movements made during the therapy and thus be able to provide feedback to the therapist, and saving the motion in a computer, as well as allowing the patient to interact with a graphical user interface.

Figure 8 shows how the pronosupinator can be mounted on the InMotion Arm device [14] (provided with two motors M1 and M2), which the patient can handle and then perform arm therapy.

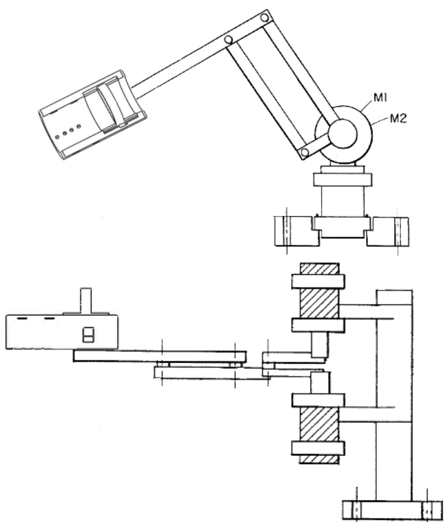

Figure 8**.** Pronosupinator on inMotion arm device.

5. Finite Element Analysis

A Finite Element Analysis (FEA) has been performed on the cylinder, on the hand holder (where the patient holds the pronosupinator), to test the feasibility and to verify the response to the applied forces (figure 9 (a), (b), (c), (d)). Two material types were considered for the cylinder manufacture: Aluminum 1100 alloy and ABS, common materials for medical devices. The maximum force, acting during FEA, has been assumed as 70 N (average weight of an upper extremity), and it is uniformly located on the hand holder. The mesh information is shown in Table 1.

Table 1. Mesh information for FEM analysis.

Mesh type	Solid mesh
Mesher used	Standard mesh
Jacobian points	4
Element size	5.32 mm
Tolerance	0.26 mm
Total nodes	15140
Total elements	8134

6. Final design

After FEA, design modifications were performed to include elements for motor support as well as the pinion and circular rack to transmit the movement to the cylinder. Also, four holes to fix the cylinder in a predefined orientation were added. These modifications allow for pronation and supination in two modes, automatic and manual. The detailed design is shown in Figure 10.

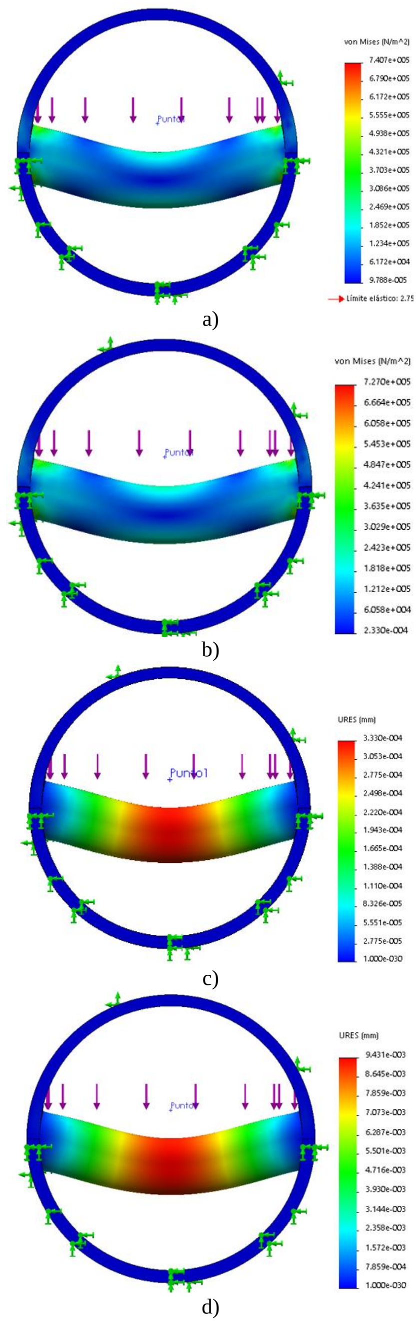

Figure 9. FEA results: Stress a), b); Displacement c), d); Aluminum a), c); ABS b), d).

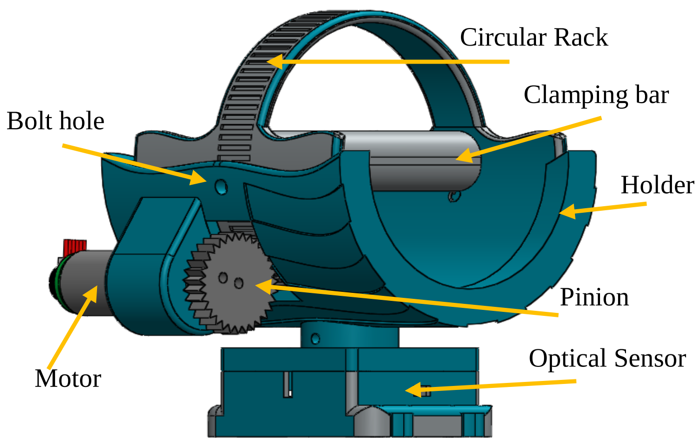

Figure 10. Detailed design of pronosupinator.

7. Conclusions

The arm rehabilitation devices can perform flexo-extension exercises and adduction of the upper extremity which includes: shoulder, elbow and forearm. By integrating our proposed pronosupinator in rehabilitation devices (end effector type), the patient will be able to work also different muscles and ligaments involved in pronosupination since it is a combination of movements, either with the elbow flexed or with the elbow extended. Kapandji [17] points out that among the seven degrees of freedom that the joint chain of the upper limb involves (from shoulder to hand), pronosupination is one of the most important since it is essential for controlling the hand attitude; for example, it is essential for the feeding function. The cylinder FEA shows almost negligible deformation for both materials, Aluminum and ABS, so either of two can be used to manufacture the device.

The complete system, pronosupinator and arm rehabilitation device, will be validated to perform the most common arm exercises previously described. An actuator will be integrated to pronosupinator to rotate the patient's forearm according to recommended therapy. During the active phase of rehabilitation, a virtual graphic interface will be integrated so that patients can interact with it, making the rehabilitation process more effective and friendly.

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