Improving the Joint Mobility of Acute Rotator Cuff Injury by Portable Rehabilitation Device

Laura Jiménez Guzmán, Mariana Torrente Rocha and Hernando Leon-Rodriguez
Bio-Engineering Department, Faculty of Engineering, El Bosque University, Bogota, Colombia

Keywords: Acute Injury, Rotator Cuff Rehabilitation, External-internal Rotation, Soft-rehabilitation Robot, Portable Robot.

Abstract: The incidence of shoulder pain in the general population is around 11.2 cases per 1,000 patients per year. It is considered to be the most prevalent soft tissue pathology, with an estimated incidence of rotator cuff injuries of 3.7 per 100,000 per year. The deterioration of the components of the rotator cuff is one of the most frequent causes of musculoskeletal pain and disability in the world. The conditions of the rotator cuff increase with the age and overuse of the joint, therefore, elderly patients are more affected. This paper presents the development of one soft and portable rehabilitation prototype robot that aims to be evaluated with patients in near future as a suitable device for rehabilitating acute rotator cuff injuries through clinical examinations. The portable robot presented was design from biomechanical analysis and ranges of kinematics and joint dynamics; aspects that determined important requirements for obtaining greater functionality of the prototype´s portability and with the identification of pre-set tasks that executes two types of specific movements: flexion / extension and external / internal rotation by means of a soft rehabilitation and portable robot device.

1 INTRODUCTION

The component´s deterioration of the rotator cuff is one of the most frequent causes of musculoskeletal pain and disability in the world. The incidence of shoulder pain in the general population is around 11.2 cases per 1,000 patients per year. It is considered to be the most prevalent soft tissue pathology, with an estimated incidence of rotator cuff injuries of 3.7 per 100,000 per year. The rotator cuff is composed of four muscles: supraspinatus, infraspinatus, minor round and subscapularis, and its functions are to offer mobility, strength and stabilization to the glen-humeral joint, due to the relationship between the glen-humeral ligaments and the joint capsule. The conditions of the rotator cuff increase with the passage of time, since they have a direct relationship with a process of deterioration rather than with a traumatic event, so the problem increases with age and overuse of the joint, therefore, elderly patients are more affected. However, the incidence of shoulder pain in workers reaches up to 18.3%. In order to decrease pain and recover shoulder movement, patients are usually treated by regular sessions with a physiotherapist.

The pathology of the rotator cuffs is associated with the overuse of the joint, either by work, sports, vascularity, mechanical failure located in the supraspinatus tendon, ruptures caused by deterioration or even by the entrapment that the tendon suffers between the humerus and the acromion. There are other risk factors that can lead to a rotator cuff injury, such as obesity, hypercholesterolemia, smoking, genetic factors, anatomical variations, scapular dyskinesia and glen-humeral instability. (Orth, Paré, 2017)

Rehabilitation has always been a social concern in the fields of health study and engineering. The effects of disability due to rotator cuff injuries decrease a person's productivity in areas such as population interaction, so the need for improvement goes beyond an ideal biomechanical state.

Currently, the rehabilitation of rotator cuffs starts from the application of conventional therapies, to the use of robotics as alternative mechanisms, which integrate engineering concepts such as compensation of force, motor control at speeds calibrated according to the motor functions of each individual and sensory contributions that through the repetition of exercises in intensive training programs manage

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to recover mobility limitations. (Sicuri, 2014) (Gonçalves, 2016) Some of the referents are Armeo Spring who by providing support for the weight of the arm, allows patients to use any remaining motor function and encourages them to reach a greater number of reach and grip movements based on specific therapeutic objectives, from an arm grab exoskeleton (Gijbels, 2011) (Armeo, 2018); In-Motion Shoulder-Elbow Robot allows to quantify the control of the motor of the upper extremities and with the recovery of the movement, which allows the doctors to distinguish the real recovery from the compensation of the patient (Cannan, Hu, 2012) (InMotion, 2018); shoulder exoskeletons; Cable-Robots who have very good kinematic and dynamic characteristics, and also show other properties such as: portability and economy of costs, which also make them suitable for medical applications and rehabilitation even though based on the physical nature of the cables that can only pull and not push (Nunes, 2011); isokinetic force machines such as Humac Norm Testing and Rehabilitation System that allows the diagnosis and treatment of the performance of muscles and joints of orthopaedic patients, starting from the principle of isokinetic force, under the correct anatomical positioning and a positive stabilization to examine the musculature that surrounds the shoulder. (Habets, 2018) Based on the aforementioned developments, the new technologies point to the use of soft materials, which improve the ergonomics of the rehabilitation system, within the exponents of bio-robotics is active soft orthotic system (Kesner, 2011; Ciarán, 2017; Galiana, 2012).

However, standard rehabilitation methods require the attention of trained physiotherapists to help patients through a series of movement exercises in order to stimulate the regeneration of their muscle control, a process that is slow, expensive, high demand , and it requires the transfer of the patient to a rehabilitation clinic to do a regular job with the therapists and have a significant improvement, therefore, the objective of this work is to design an affordable and portable device that uses actuators and sensors, and also , act through the movement in the sagittal, ventral and coronal plane for the rehabilitation of the patient from his own home without a dedicated therapist, in order to elevate the self-efficacy of the subject and the restoration of the dynamics of interaction of the same with its activities every day and with the people around him.

2 BIOMECHANICAL EVALUATION OF PATIENT

The biomechanics establishes a specific protocol to certain angles according to each movement as a pattern of healthy patients presented in table 1, the flexion from 0° to 180°, the extension from 0° to 60° for the sagittal plane; adduction from 0° to 45°, abduction from 0° to 180° in the frontal plane; the flexion of 130° to 5°, extension of 40° to 50° with respect to the horizontal plane; external rotation from 0 ° to 40° to 60° and internal rotation from 0° to 90°; and external and internal movements, both up to 70°. Although the biomechanical analysis allows limit the total movement angles of the articulation, the functional ranges of mobility are the representatives of movement with minimum balance in the comfortable execution of daily activities, angles that for this case, represent acceptable ranges considering a process of Joint rehabilitation due to an injury. From this, the mechanism of operation of the prototype is designed, being specific in movements of flexo-extension (A), and internal and external rotation of the Shoulder (B).

Table 1: Ideal biomechanical ranges of the gleno-humeral joint and functional ranges.

	A		B	
Motion	Flexion	Extension	Internal rotation	External rotation
Biomechanical range	0-180º	0-60º	0-90º	0-40º 60º
Functional Range	0-120º	0-45º	0-70º	0-50º
Differential	60º	15º	20º	10º

In order to analyse biomechanically the Gleno-humeral joint, two isokinetic strength tests are performed on a patient with Shoulder injury, at BodyTech Sport Medicine. The tests are related to movements of flexion and extension, and external and internal rotation. Because we want to make a preliminary analysis of the shoulder muscle response in terms of strength; two tests of movements were performed to measure the concentric forces. (Tables 2 and 3)

Table 2: Isokinetic force evaluation report. Flexion and extension shoulder (supine).

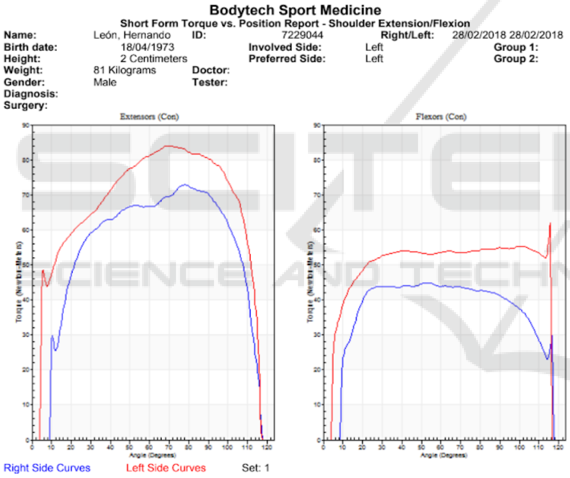
	Speed	Force	Repetitions
	60/60 degrees/ seconds	Sub Maximum	5
		Maximum	5
	180/180 degrees/ seconds	Sub Maximum	4
		Maximum	15

The results obtained are showing in figure 1 and 2 as follow: Curves of ratio of angles (degrees) and torque (Newton by meters) for left and right extremity. Tabulation of evaluation parameters for left and right limbs in extension and flexion movement, internal and external rotation: peak torque, total work done, range of movement, deficits.

Table 3: Isokinetic stress evaluation report. Internal and external shoulder (standing) rotation.

	Speed	Force	Repetitions
	60/60 degrees/ seconds	Sub Maximum	5
		Maximum	5
	180/180 degrees/ seconds	Sub Maximum	4
		Maximum	15

Bilateral evaluation of extensors and flexors in bilateral shoulder joints (supine) was performed on Humac Norm Isokinetic dynamometer equipment, complete range of motion is showing in figure 1.



Bodytech Sport Medicine
Short Form Torque vs. Position Report - Shoulder Extension/Flexion
Name: León, Hernando ID: 7229044 Right/Left: 28/02/2018 28/02/2018
Birth date: 18/04/1973 Involved Side: Left Group 1:
Height: 2 Centimeters Preferred Side: Left Group 2:
Weight: 81 Kilograms Doctor:
Gender: Male Tester:
Diagnosis:
Surgery:

Figure 1: Graphic of torque vs position shoulder extension/flexion.

Table 4: Results evaluation of flexo test-shoulder extension in speed of 60°/sec.

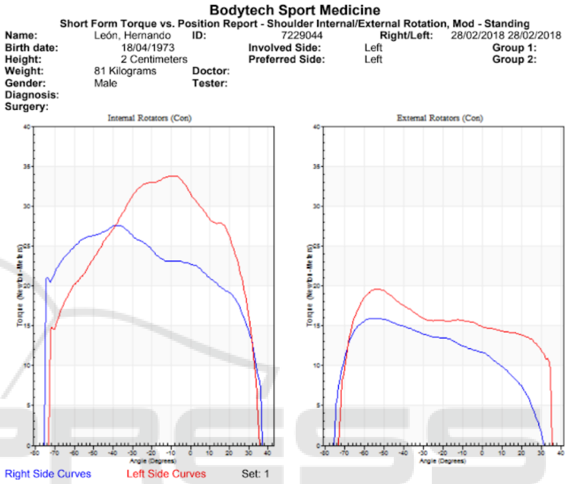
Speed	Muscular Group	Right	Left	Deficit
60°/sec	Concentric Extenders	73 N/m	84 N/m	13%
60°/sec	Flexors Concentric	45 N/m	65 N/m	31%

Table 5: Results flexo test-shoulder extension in speed of 180°/sec.

Speed	Muscular Group	Right	Left	Deficit
180°/sec	Concentric Extenders	45 N/m	52 N/m	18%
180°/sec	Flexors Concentric	35 N/m	65 N/m	50%

The results in the isokinetic evaluation, maximum torque and total work of shoulder flexors-extensors are identified in concentric contractions (60, 180 degrees). Concentric isokinetic evaluation was performed, given the following results. (Tables 4 and 5).

The second test was performing in bilateral assessment of internal and external rotation in bilateral shoulder joints (standing °) was performed on Humac Norm isokinetic dynamometer equipment, complete range of motion is showing in figure 2.



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Height: 2 Centimeters Preferred Side: Left Group 2:
Weight: 81 Kilograms Doctor:
Gender: Male Tester:
Diagnosis:
Surgery:

Figure 2: Graphic or torque vs position shoulder internal/external rotation.

In the isokinetic evaluation, maximum torque and total work of shoulder flexors-extensors are identified in concentric contractions (60, 180 degrees). Concentric isokinetic evaluation was performed, given the following results. (Tables 6 and 7)

Table 6: Results of evaluation in test of internal and external rotation of shoulder in speed of 60°/sec.

Speed	Muscular Group	Right	Left	Deficit
60°/sec	Concentric Internal Rotation	27 N/m	34 N/m	20%
60°/sec	External rotation Concentric	16 N/m	19 N/m	14%

Table 7: Results of evaluation in test of internal and external rotation of shoulder in speed of 180°/sec.

Speed	Muscular Group	Right	Left	Deficit
180°/sec	Concentric Internal Rotation	19 N/m	23 N/m	18%
180°/sec	External rotation Concentric	8 N/m	11 N/m	25%

3 PROTOTYPE CONCEPTS AND REQUIREMENTS

The design of the prototype to achieve shoulder rehabilitation, should consider the following requirements:

The first requirement corresponds to the way in which the prototype adapts to the anatomical variations of people with an age range of 49 to 60 years, starting at 95% of the percentiles, it is possible to determine the average of the magnitudes of each segment articulate, in order to obtain an adjustable prototype for people who are within that age range.

The second requirement is based on the fact that the design must be ergonomic in order to allow its portability and comfort at the moment of the execution of the therapies.

The third requirement refers to the affordability of the prototype since its low robustness decreases the acquisition value, as well as decreases in costs, which leads to the displacement of people to healthcare entities by a therapy, since the proposal goes focused on a type of independent therapy developed in the home.

The fourth requirement is based on the appropriate selection of actuators, whose function is to mobilize the arm and forearm in 4 different types of movements: flexion, extension, internal and external rotation according to the degrees of functionality of the patient. The movement is continuously passive, since the high torque is inversely proportional to the speed of the actuator.

The fifth requirement relates the benefits provided by the prototype in terms of the execution of therapies to improve the joint mobility of rotator cuff injury and the investment that is made.

4 PROTOTYPE DESIGN

The methodology developed for the prototype design starts from the population delimitation to which it is addressed. This is how the dimensions of this, are based on the average of Latin American percentiles of men and women from 49 to 59 years, based on the prevalence of injury in women for their fourth decade of life and in men from the fifth.

Based in the biomechanical evaluation and the mentioned requirements a concept prototype showing in figure 3 is designed under the operation of a portable system driven by two gear-motors. The kinematic and dynamic analyses are based on two of the movements adapted by the articulation: flexion / extension, external / internal rotation which activate two degrees of freedom respective to the movements of flexion and extension, and internal and external rotation. The prototype consists of two supports for the arm and the forearm, which will maintain the extremity in the ranges of joint movements, required performing the different rehabilitation exercises. (Nef, 2011; Kim, 2017; Hunt, 2013).

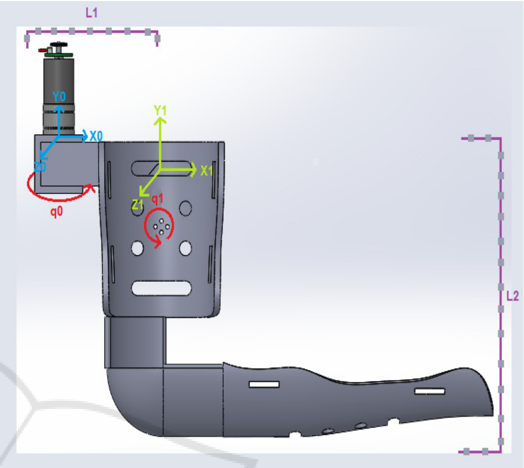

Figure 3: Design of shoulder rehabilitation robot first joint.

4.1 Kinematic Design

The kinematic system was obtained from a reference axis of the shoulder, which was proposed for the design of the system in the arm. (figure 3)

$$R_{Y,\,q0}=\begin{pmatrix}\cos(q0) & 0 & \sin(q0)\\ 0 & 1 & 0\\ -\sin(q0) & 0 & \cos(q0)\end{pmatrix}\quad Tras_{z,l1}=\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\\ 0 & 0 & 1 & l1\\ 0 & 0 & 0 & 1\end{bmatrix}\qquad (1)$$

The rotation matrix RY, q0 gives the projection of the coordinates in two coordinate systems. The equation 1 is the first rotation matrix it is evident that the system rotates on the Y axis and the articulation that rotates on this axis is the one called q0. In the translation matrix Tras z, l1 we can see which link is transferred for the first system and on which axis the movement is observed. In this case, link 1 moves on the z axis.

$$A_0^1=\begin{bmatrix}c_{q0} & 0 & s_{q0} & 0\\ 0 & 1 & 0 & 0\\ -s_{q0} & 0 & c_{q0} & -l1*s_{q0}\\ 0 & 0 & 0 & 1\end{bmatrix}\qquad (2)$$

The equation 2 is the homogenous transformation matrix A01, we can see the projection of system 0 in system 1 and we can see the sum or product point between the matrices of rotation and translation. The breasts and cosines that are evident in the rotation matrix, are the projections of the vectors in both x and y.

$$R_{Z,\,q1}= \begin{pmatrix} \cos(q1) & -\sin(q1) & 0 \\ \sin(q1) & \cos(q1) & 0 \\ 0 & 0 & 1 \end{pmatrix} \quad Tras_{x,l2} = \begin{vmatrix} 1 & 0 & 0 & l2 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix} \tag{3}$$

The rotation matrix RZ, q1 gives the projection of the coordinates in two coordinate systems. In the first rotation matrix it is evident that the system rotates on the Z axis and the articulation that rotates on this axis is the one called q1. In the translation matrix Tras $_{x,l2}$ you can see which link is transferred to the second system and on which axis the movement is observed. In this case, link 2 moves on the x-axis.

$$A_1^2 = \begin{bmatrix} c_{q1} & -s_{q1} & 0 & l2*c_{q1} \\ s_{q1} & c_{q1} & 0 & l2*s_{q1} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{4}$$

In the homogeneous transformation matrix A12, we can see the projection of system 1 in system 2 and we can see the sum or product point between the matrices of rotation and translation.

$$A_0^2 = \begin{bmatrix} c_{q0}s_{q1} & -c_{q0}s_{q1} & 0 & l2*c_{q1} \\ s_{q1} & c_{q1} & 0 & l2*s_{q1} \\ 0 & 0 & 1 & -l1*s_{q0} \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{5}$$

After obtaining the homogeneous transformation matrix of the system q1 and q0, multiplication or cross product of both homogeneous matrices is performed to find the position of the end terminal, with respect to the whole system.

$$X= l2*Cos(q1);\ (\frac{d}{dt}x) = \frac{d}{dt}(l2*Cos(q1)) \Rightarrow Vx=(-\dot{q}1 * l2 * Sin(q1))$$
$$Y= l2*Sin(q1);\ (\frac{d}{dt}y) = \frac{d}{dt}(l2*Sin(q1)) \Rightarrow Vy=(\dot{q}1 * l2 * Cos(q1))$$
$$Z= l1*Sin(q0);\ (\frac{d}{dt}z) = \frac{d}{dt}(l1*Sin(q0)) \Rightarrow Vz=(\dot{q}0 * l1 * Cos(q0)) \tag{6}$$
$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \end{bmatrix} = \begin{bmatrix} 0 & -l2*\sin(q1) & 0 \\ 0 & l2*\cos(q1) & 0 \\ l1*\cos(q0) & 0 & 0 \end{bmatrix} \begin{bmatrix} q0 \\ q1 \\ q2 \end{bmatrix}$$

The Jacobian matrix is used to determine the speed of movement in each of the axes, which is solved by the partial derivative of the last column of the total homogeneous transformation matrix, which represent each of the axes in descending order.

The dynamic system develops from the description of the movement together with the forces involved in the system. To determine the kinetic energy, it was necessary to calculate the velocity vector, which is composed of the sum between the vector derivative of r_{CM} centre of translational mass plus the angle of rotation, by the cross product of the vector r_{CM} of centre of mass.

Once the velocity vector is found, the kinetic energy and the potential energy are found.

$$\vec{v} = \dot{\vec{r}}_{CM\ traslacional} + \overrightarrow{\omega}_{1\ CM} \times \vec{r}_{1\ CM} \tag{7}$$

$$K=\frac{1}{2}m|\vec{v}|^2 + \frac{1}{2}\omega^T I\omega \tag{8}$$

$$u=mgh=0 \tag{9}$$

The vector r_1 is composed of a medium of link 1 in the direction i0, while the vector w1 is given by the rotation q0 in the opposite direction to the movement $-j_0$, the vector v_1 is given by a means of link1 by the rotation q0 in the address k.

$$\begin{aligned} \overrightarrow{r1} &= \frac{l1}{2}\,(\hat{\imath}_0) \\ \overrightarrow{w1} &= q_0(-\hat{\jmath}_0) \end{aligned} \tag{10}$$

After determining each of the variables ($\vec{r}1$ y $\vec{w}1$), we find the velocity, which gives us as a result, since the derivative of R1 with respect to q0 is 0.

$$\overrightarrow{v1}= \frac{l1}{2}q_0(\hat{k}) \tag{11}$$

Once the velocity is found, the value is replaced in the kinetic energy equation, where WT is the transpose of the vector $\vec{v}1$ and I is a matrix of inertia.

$$K1 = \frac{1}{2}m\,(\frac{l1}{2}q_0)^2 + \frac{1}{2}\begin{bmatrix} 0 \\ q_0 \\ 0 \end{bmatrix} I[0 \quad q_0 \quad 0] \tag{12}$$

In addition to this, the potential energy is found where m1 corresponds to the mass of the first link and g to the value of gravity.

$$u = m1g\frac{1}{2} \tag{13}$$

For the second joint articulation of the system showing in figure 3, the same methodology was carried out, with which the energies were obtained in the first articulation. With the difference that for the second system the articulation had to be taken into account to find the value of the variable $\vec{r}2$.

4.2 Design and Operation Characteristics

As shown in Figure 4, the operation of this prototype starts from a 12V power supply that ensures its portability, which supplies the L298N (Bridge H) that gives the control of rotation of two motors, which act as actuators of the system. Because it is necessary to determine the ranges of extension / flexion movement, external / internal rotation, the angles are sensed by using two encoders, one for each motor. The control of the motors, is given by means of a processor Raspberry PI 3B, controlled by the software compiler Thonny Python IDE. A 7805 voltage regulator is implemented because the software voltage should not exceed 5V.

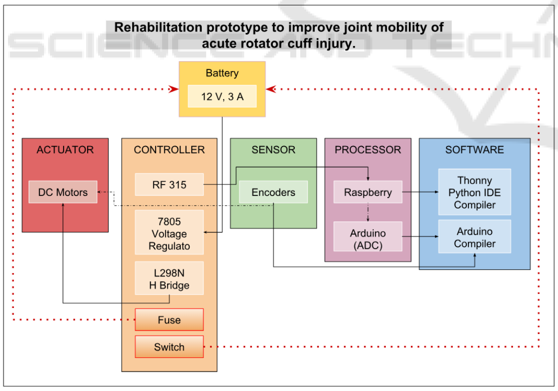

Figure 4: Schematic diagram of control architecture.

The prototype involves direct contact with patients to be scaled at an industrial level, therefore, and thinking about the safety of the patient, requires a fuse that has the function of dampening the high currents that the circuit can reach; Added to this, it has an emergency button (Switch), which will be activated by the patient in case of alarm, causing the entire system to shut down completely and stop its operation. The movements will be controlled and executed by an emitter-receiver radio frequency system, which will carry with it the pre-established therapy routines.

4.3 System Prototype

Once the requirements are known, this prototype is designed to perform specific therapies by means of an emitter receiver control system, which the patient will have to resort to perform a specific task that starts from the movement of flexion, extension, internal and external rotation within the angles of functionality of the joint. The prototype consists of two stabilizing components showing in figure 5.

The first component consists of a piece that supports the forearm and the arm, and has an elongation fabric that allows the user to have mobility in the elbow (A). The second component is an abdominal stabilizer, which brings stability to the back, and so that the therapy is exercised upright, without complications to the spine, in addition, the trellis has two shoulder straps or stabilizers that they allow the weight of the actuators to dissipate through them, in addition, the trellis has a pocket that groups the electronic components, in order to make it easy to access adjustments or even remove the battery to charge it (B). The figure 6 is showing the actuator that exerts the movement of flexion - extension, has a support that is connected directly to the trellis and a connector that intertwines the other actuator, which performs the external and internal rotation movement and is connected to the forearm support by a piece which lengthens as the flexion movement (C) is performed.

Figure 5: Prototype of shoulder rehabilitation robot system. (A) front and (B)posterior sagittal axis of the device placed on patient. (C) Right view. (D) Stabilizing components. (E) Control accessories.

Figure 6: Prototype of shoulder rehabilitation robot system. Side view of the device in movement of extension to 45 ° (A), position of anatomical zero (B) and movement of flexion to 120 ° (C) of Shoulder. Front view of the device in movement of external rotation at 50 ° (A), anatomical zero position in 90 ° elbow flexion (B) and internal rotation movement at 70 ° (C) of Shoulder.

4.4 Control System

The coupling that has the encoders in the motors allows us to know the position angle in which the stabilizing support is, this is a main part in the control system of the prototype, however, the therapy protocol is organized by time and execution angles, which is programmed through the raspberry microcontroller Pi 3B that has as operator the remote control, which executes the specific tasks according to the therapy that the user wishes to perform.

The kinematic and dynamic conceptual system developed are based on two of the movements adapted by the articulation: flexion / extension, external / internal rotation, which represent a need for assistance with the aim of achieving efficient rehabilitation, following patterns of movements that although they start of international therapy process, allows the proper monitoring of them. From the kinematics, the velocities and total accelerations of the system are obtained from the position of the terminal end of the forearm.

5 DISCUSSION RESULT AND CONCLUSIONS

The rupture of the components of the rotator cuff is one of the main causes of musculoskeletal pain as well as disability. Rehabilitation is understood as the set of methods that aims to recover a function or activity that has been diminished or lost due to illness or trauma; When talking about robotic rehabilitation, various approaches are found such as robotics for mobility, for personal rehabilitation, developments of prostheses and orthoses, of social assistance and as observed in the present development, for upper and lower extremities. It should be noted that all these approaches are based on the use of conventional therapies at the beginning, that over time and the influence of alternative mechanisms, engineering concepts are integrated for medical purposes. The new technologies point to the use of soft materials, which improve the ergonomics of the rehabilitation system, within the exponents of bio-robotics is Active Soft Orthotic System, the main reference for the execution of this device.

The difficulty in the application of technologies for the rehabilitation and joint mobility of the rotator cuff was born in two main causes, technological and medical. The technological causes, because the current robotic advances are complex and based on kinematic chains of rigid links that lead to little ergonomics, hand in hand with the implements used in the maintenance of the same that represent high costs, increasing prices for institutions providers and providers of related services. The medical causes, in addition to being a degenerative process that triggers abrupt tensions on the supraspinatus tendon or dislocations, which lead to the increase of musculoskeletal diseases, are also related to the stress generated by repetitive work, reflected in direct pathologies to the shoulder and pain joint, increasing injuries in upper limbs.

The analysis of the kinematic system of the shoulder allowed differentiating the movements produced by the five joints (the acromioclavicular joint, the sternoclavicular joint, the scapula-thoracic joint and the gleno-humeral joint) that make up the shoulder, the passive limitations that offer stability to the joint complex, Static stabilizing elements such as anatomical differences in joint surfaces and ligaments. On the other hand, dynamic analysis states that the main stabilizers of the shoulder are the muscles that belong to the gleno-humeral joint. Likewise, we identified the two types of forces exerted by the shoulder (compression and shearing), and the anatomical rotations exerted by the gleno-humeral joint such as: adduction / abduction, internal / external rotation, flexion / extension by Euler angles.

The tests performed on the isokinetic dynamometer Humac Norm allowed to analyse the complete biomechanical ranges of movement by means of the bilateral evaluation of flexors and extensors of the shoulder, as well as internal and external rotators of the joint. Isokinetic contractions refer to maximum contractions of the muscle groups involved with constant velocities along the radius of joint movement, which allowed during the design of operation of the device, to establish optimal ranges of speed according to pre-established requirements, together with the design of sets in terms of repetitions and angular variation, discriminating each type of movement. The complete protocol was followed for the tests mentioned above in the Humac, accompanied by medical personnel trained in facilities of the BodyTech Sport Medicine Center. The patient chosen for the execution of the test is within the age range related to the prevalence of the appearance of the pathology associated with rotator cuffs, that is, between 40 and 50 years of age.

The isokinetic strength assessment reports, provide relationship curves between the right and left sides of the shoulder for each movement, and quantification of evaluation parameters such as: peak torque or maximum force moment, which indicates the maximum capacity of the muscle to generate strength and comparison of agonist and antagonist muscles determined in the five initial repetitions for each movement; Total work done, defined as the torque product per distance traveled, that is, the areas under the presented curves that indicate the capacity of the subject to produce torque and the estimation of muscle resistance indexes; and the Power that determines the torque produced depending on an angular distance traveled in a time of execution of movement, which expresses the relationship between the value of work produced in the time required to complete the exercise.

Based on the quantitative study of the anthropometry of the working population in Colombia, with an age range of 20-59 years and a percentile of 95% which determines that below that measurement value the population is found, the measures were determined necessary to build the device, however, because the anthropometric tables are separated by sex, an average of each measurement was made between man and woman to have a value per measurement, so that the device was not exclusive regardless of the gender.

Once the prototype was built according to the anthropometric measurements, it was possible to demonstrate that it is an ergonomic prototype, since the actuators adapt to the anatomical characteristics of the Glenohumeral joint, because the insertions of the actuators are similar to the anatomical insert that exists between the humerus and the omoplate. However, the joint module constructed generates an additional weight because the plate that holds it has a smaller size compared to the size of the module, which indicates that an additional piece must be created that keeps the module rigid on the trellis, this to reduce the additional weight generated by the lack of support.

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REFERENCES

Armeo® Spring-Hocoma, [Online accessed: 18/3/2018]; https://www.hocoma.com/solutions/armeo-spring

Ciarán T. O'Neill, Nathan S. Phipps, Leonardo Cappello, Sabrina Paganoni and Conor J. Walsh; 2017, A Soft Wearable Robot for the Shoulder: Design, Characterization, and Preliminary Testing; *IEEE Int Conf Rehabil Robot.*

Domien Gijbels, Ilse Lamers, Lore Kerkhofs, Geert Alders, Els Knippenberg, Peter Feys; The Armeo Spring as training tool to improve upper limb functionality in multiple sclerosis: a pilot study; *Journal of Neuro Engineering and Rehabilitation 2011, 8:5.*

Galiana Ignacio, Hammond Frank L., Howe Robert D. and Popovic Marko B. 2012; Wearable Soft Robotic Device for Post-Stroke Shoulder Rehabilitation: Identifying Misalignments*; IEEE/RSJ International Conference on Intelligent Robots and Systems October 7-12, 2012. Vilamoura, Algarve, Portugal.*

Gonçalves Rodrigo, Antunes Cerejo; 2016, A Robotic System for Musculoskeletal Rehabilitation of the Shoulder; *Biomedical Engineering - Universidade de Lisboa*.

InMotion ARM™ Interactive Therapy System - Bionik Labs; http://bionikusa.com/healthcarereform/upper-extremity-rehabilitiation/inmotion2-arm/. [Online accessed: 18/03/2018].

Habets Bas, Staal J. Bart, Tijssen Marsha and Cingel Robert van; 2018, Intrarater reliability of the Humac NORM isokinetic dynamometer for strength measurements of the knee and shoulder muscles*; Res Notes (2018) 11:15.*

Hunt Justin, Lee Hyunglae, Artemiadis Panagiotis; A Novel Shoulder Exoskeleton Robot Using Parallel Actuation and a Passive Slip Interface*; Journal of Mechanisms and Robotics; 2017.*

James Cannan and Huosheng Hu, 2012. Upper Body

Rehabilitation A Survey; *University of Essex, Colchester CO4 3SQ, U.K; ISSN 1744-8050*.

Kesner, S., Jentof, L., Hammond III, F., Howe, R., & Popovic, M.; 2011, Design Considerations for an Active Soft Orthotic System for Shoulder Rehabilitation; *33rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*.

Kim Bongsu and Deshpande Ashish D; 2017, An upper-body rehabilitation exoskeleton Harmony with an anatomical shoulder mechanism: Design, modeling, control, and performance evaluation; *The International Journal of Robotics Research; 1–22*.

Nunes W., Rodriguez L. and Oliveira L.; 2011, Cable based parallel manipulator for rehabilitation of shoulder and elbow movements; *IEEE Int Conf Rehabil Robot*.

Nef Tobias, Guidali Marco and Riener Robert; 2009, ARMin III – arm therapy exoskeleton with an ergonomic shoulder actuation; *Applied Bionics and Biomechanics Vol. 6, No. 2, June, 127–142*.

Orth T., Paré J., Froehlich J. E.; 2017, Current concepts on the genetic factors in rotator cuff pathology and future implications for sports physical therapists. *International Journal of Sports Physical Therapy. 2017;12 (2):273-285*.

Sicuri Chiara, Porcellini Giuseppe, Merolla Giovanni; 2014, Robotics in shoulder rehabilitation; *Muscles, Ligaments and Tendons Journal 2014; 4 (2): 207-213*.