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Development of a device for measuring the amplitude of linear displacement of the humerus during abduction

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Abstract. In the human body, the skeletal structure provides mechanical support for movement. The shoulder joint has the greatest number of degrees of freedom in our body, allowing the arm to move in virtually all directions and angles. Physiotherapy treatment applied in the rehabilitation of movements is usually based on repetitive physical activities, and the evaluation of progress and recovery is a process conducted by physiotherapy professionals. For the evaluation of treatment progress, these professionals mostly use subjective visual criteria, and the use of automated equipment that generates numerical values or trajectory fields is only applied in some cases and usually in specialized centers. The article proposes the development of a device for measuring the range of motion of arm shortening in the movement of the glenohumeral joint, and the study of the results of associating the device with an existing passive exoskeleton positioned over the shoulder, which should perform the shortening movement reading specific electronic elements

Keywords. *Exoskeleton, humerus, upper limb, and measuring system.*

Introduction. In recent years, the field of medicine focused on motor rehabilitation has taken advantage of technological advances, leading to an increase in research and development of projects to apply robotic therapy in movement rehabilitation (Souza, 2015). With the advent of robots, monitoring movements more accurately and effectively became possible, and applied to rehabilitation therapies (Emanuel, 2015). These technologies allow for greater efficiency in the evaluation of human movement (Theodório, 2013).

Diseases and conditions in the upper limb region can result from various activities associated with ergonomic and occupational issues, as well as everyday movements. The growing concern with these motor health issues, especially in the upper limb, is due to aging, or rather, the longevity of society (Fumagalli, 2020). According to the latest Brazilian census, there has been a significant increase in the population aged 65 or older, going from 4.8% in 1991 to 5.9% in 2000 and 7.4% in 2010. In other words, the number of elderly people in Brazil today is around 14 million (Gonçalves, 2014).

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The application of robots in rehabilitation and treatment evaluation has become more commonplace and has been the subject of several research studies in the field of health and technology (Santos, 1995). Rehabilitation robots have been explored for training patients with damaged neural functions or for assisting people with weakened limbs (Wu, 2005).

The use of robotic therapies, combined with specific computer programs, allows for an immediate perception of the achieved results and turns repetitive tasks into playful actions (Marques, 2003). This contributes to increasing the motivation of patients undergoing these treatments and allows for the possibility of measuring movements. Thus, monitoring progress obtained in various degrees of movement favors the development of new therapeutic and treatment approaches.

A standard posture of the human body has been standardized for a better interpretation of the movements in anatomical position and the nomenclature of the body segments. This posture is called the anatomical position (KENDALL et al., 1995).

In this reference position, the human body is in an upright posture, facing forward, arms at the sides, palms facing forward, fingers and thumbs extended, and feet together and facing forward. This position is also called the zero position of the human body. The three planes are the coronal plane, which virtually separates the body into anterior and posterior halves, the sagittal plane, which hypothetically divides the body into left and right lateral halves, and finally, the transverse plane, which divides the body into superior and inferior halves.

The glenohumeral joint is located in the complex that forms the shoulder, being the joint with the freest movements in the human body, allowing flexion, extension, hyperextension, abduction, adduction, horizontal abduction, and adduction, and medial and lateral rotation of the humerus (Hall, 1993).

To develop the proposed device, it is necessary to learn about biomechanical models, which are a simplified representation of a dynamic system providing an understanding of the kinematics of the entire analyzed system. In the development of a model, premises about how the elements are connected and their interaction in the set of functional structures are used. The simplification of the system through a reduced model facilitates the understanding of the entire system (Thedório, 2013).

With biomechanical models, it is possible to predict positioning conditions in space of the entire system, having only the knowledge of some segments, without the need for experimentation of various positions in different coordinates. This work proposes the development of a device for measuring the range of motion of arm shortening in the movement of the glenohumeral joint and the study of the results of the association of the device with an existing passive exoskeleton positioned on the shoulder and should make use of specific electronic elements to read the shortening movement.

Materials and Methods. According to Klopcar et al. (2007), the musculoskeletal three-dimensional models of the scapular girdle and elbow developed by Van der Helm (1997) for

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dynamic simulations are very precise. With these models, forces and moments can be calculated for a defined arm position. Understanding the three-dimensional positioning, that is, the workspace that the wrist would reach with all possible degrees of freedom of the upper limb and elbow is important.

Klopcar's research aimed to develop a mathematical model for the upper limb, as shown in Fig.1, which could obtain an understanding of the accessible workspace of the arm, that is, to develop an assistive tool for evaluating the evolution of upper limb pathologies. However, this mathematical model does not include movements of "shrinking", which are the focal point of this article.

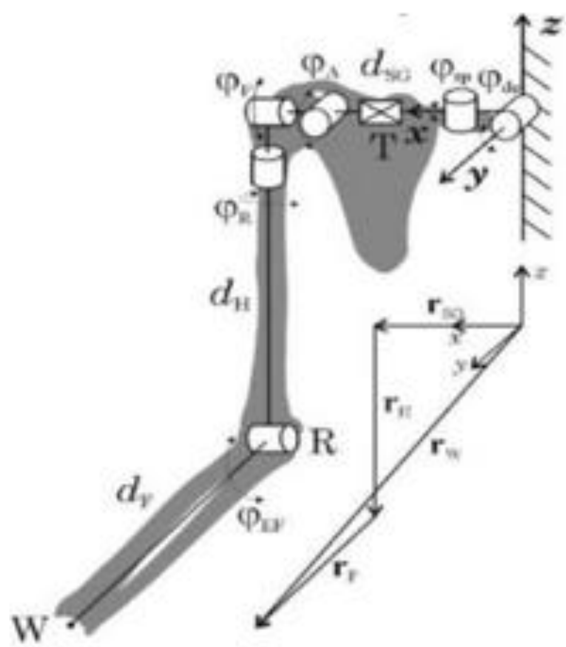

Figure 1 - Kinematic representation of the shoulder girdle and elbow joints.

Source: Klopcar (2007).

Therefore, the proposed objective is to develop a mechanical and electronic system capable of measuring the displacement of the humerus in the glenohumeral joint corresponding to arthrokinematic movements, to complement an existing passive upper limb exoskeleton with six degrees of freedom, enabling the measurement of a new dimension of movement in the system, making it operate with greater complexity and returning more information.

For this purpose, several system possibilities were raised until the use of a rotary encoder associated with a mechanical system for converting its original movement into linear was defined, and thus extracting data from it and converting it into a simple interface with the use of software for quick understanding by healthcare professionals. To this end, the device for validating encoder measurements was constructed, as shown in Fig.2.

Figure 2 - Validation device

In the acquisition process of linear movement measurements by the encoder, the acquired values are verified using the graduated scale for equipment validation, the minimum values for reading the centesimal device (0.000 cm) and the maximum reading value is 15 cm.

Thus, the system shown in Fig.3 was created, which converts linear displacement motion into rotary motion, through the insertion of an encoder on the rotary axis. A movement synchronization system using a gear and rack was the best solution on the linear axis; the rack movement presents a pitch of 0.000 cm. The operational system of this device consists of converting synchronized linear motion into rotary motion, where the encoder attached to this axis collects the motion, converting it into an analog signal, which is later translated into a digital signal and presented in numerical form (linear dimension) on the software interface.

Figure 3 - Device designed.

Using the Visual Studio® development software, it was possible to create the user interface of the application, which is compatible with any Windows version and is both user-friendly and easy to use while displaying real-time linear displacement results.

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Results and Discussions. As the objective of this research is to incorporate a system that captures a new measurement in the passive exoskeleton of Souza (2015), as shown in Fig.4, aiming to determine the free range of motion of the rod during the process of shoulder shrugging, anthropometric measurements were performed on several volunteers.

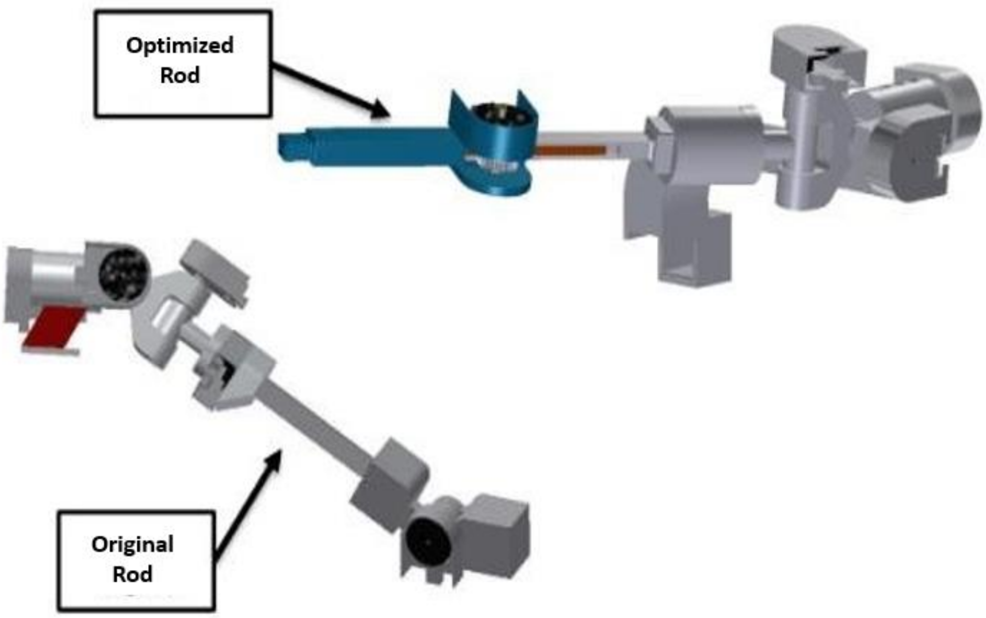

Figure 4 - Before and after the proposed optimization.

Starting from the data obtained, it was noticed in our sample that regardless of arm's length or height, the variation in "shrinkage" will always remain in the same range of around 3 cm. With this realization, it was determined that the free course of the telescopic rod movement should have at least this value.

Thus, in the development project of the new telescopic rod, all the information obtained in the anthropometric measurement was taken into consideration, making the device adjustable to the human body. In the validation test of the linear movement reading and measurement that the telescopic rod is capable of performing, the validation of the device that simulates the real conditions that the rod would be subjected to, along with the signal collection software interface, was obtained.

After performing the system preparation and initialization procedures, several recordings of the car displacement were made, simulating abduction and adduction movements, as shown in Fig.5. Several recordings were made in different directions, and the results of this displacement were checked on the computer interface compared to the physical scale of the mechanical system. These records generated data for Tab.1 and Tab.2 and were technically acceptable.

Figure 5 - Simulation a) of abduction and b) of adduction.

Table 1. Comparison of abduction measurements

Mobile Cart Displacement	Ruler	Software
0 - 0,5 cm	0,5 cm	0,49 cm
0 - 1 cm	1,0 cm	1,0 cm
0 – 2 cm	2,0 cm	2,0 cm
0 – 5 cm	5,0 cm	5,01 cm
0 – 10 cm	10,0 cm	10,01 cm
0 – 15 cm	15,0 cm	15,01 cm

Table 2. Comparison of adduction measurements

Mobile Cart Displacement	Ruler	Software
0,5 – 0 cm	0,5 cm	0,52 cm
1 - 0 cm	1,0 cm	1,03 cm
2 - 0 cm	2,0 cm	2,01 cm
5 - 0 cm	5,0 cm	5,03 cm
10 - 0 cm	10,0 cm	10,02 cm
15 - 0 cm	15,0 cm	15,01 cm

All measurements during the tests followed the technical protocol of initialization, which is to place the carriage in the zero position and apply the reset to the system, as shown in Fig.6.

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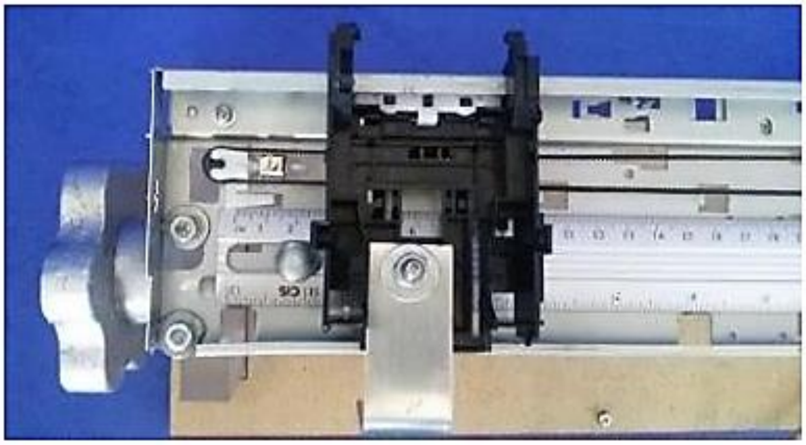

Figure 6 - Initial position of the movable carriage.

At the end of the results, it was verified that the values obtained compared to the application and the graduated scale were close, and the use of statistical calculation on the results of the measurements obtained in Tab.3, resulted in a coefficient of variation values lower than 2%.

Table 3. Displacement of the mobile car.

Ruler	Test 1	Test 2	Test 3	Test 4	Test 5	Standard deviation	Average
0 cm – 2 cm	2,02	2,01	2	1,99	1,98	1,58%	2,00
2 cm – 0 cm	0,01	0,01	0,01	0	0	0,55%	0,006

Thus, the validation device developed met the needs for data collection and conversion of linear motion into rotary motion, thus allowing for future implementation, with a configuration to make the wearable exoskeleton capable of performing a new systematic measurement through the proposed telescopic rod.

Conclusion. As we propose in this research to improve this prismatic joint by attaching a rotary encoder to read linear displacement through the use of a rack and pinion system, measuring the range of motion of the glenohumeral joint of the upper limb. The movements of abduction and adduction of the humerus were measured. The system was fully validated through a mechanical device developed exclusively to simulate the motion of the upper limb.

The acquired signals are processed with a computational tool and the data are presented in real-time, with values in centimeters shown on the graphical interface. The results of the tests performed on the validation device demonstrate that the readings were performed properly, according to the calibration tests carried out, enabling reliable readings for the movement.

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According to Hair (2009), the reliability of measurement is related to the coefficient of variation of the standard deviation. According to this literature, if a measurement has a coefficient of variation of the standard deviation below 15%, it demonstrates that the device performs precise measurements since the instrument used for comparison was a graduated scale.

The coefficient of standard deviation was below 2% for all measurements taken, which validates the collected data. Consequently, this demonstrates that the system for converting linear motion through the rack and pinion coupled with the rotary encoder is reliable and can be used in the proposed telescopic joint rod.

Disclosure. The authors report no conflicts of interest in this work.

References.

(1) SOUZA, C.M.P, et al. Dispositivo de aquisição do movimento para membro superior. Revista Caleidoscópio, v.1. P.45-60, 2015.

(2) THEDÓRIO, N. E. M. Desenvolvimento de um Dispositivo para Reabilitação e Avaliação dos Membros Superiores. 2013. 119 f. Tese (Doutorado em Engenharia Biomédica) - Universidade Mogi das Cruzes, Mogi das Cruzes, 2013.

(3) EMANUEL, P.C.S. Dispositivo de um exoesqueleto modular passivo para medição de movimentos do membro superior e avaliação das atividades da vida diária. 2015. P. 77. Tese (Doutorado em Engenharia Mecânica) - Universidade de Mogi das cruzes. Mogi das cruzes, 2015.

(4) FUMAGALLI, M.A et al. Comparison of function of passive modular exoskeletons for analysis of abduction movement and horizontal abduction of the upper limb. The Academic Society, v.4 n.4, 210-218, 2020.

(5) GONÇALVES, A.C.B.F. Estado da arte em reabilitação robótica de membros inferiores de pessoas com AVE. Sare, 2014.

(6) SANTOS, O. S et al. Síndrome do impacto: resultados do tratamento cirúrgico. Rev. Bras. Ortop. 1995.

(7) WU, G. E. Recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion - Part II: shoulder, elbow, wrist, and hand. Journal of Biomechanics, 38, 2005, p. 981-992.

(8) MARQUES, A.P. Ângulos articulares dos membros superiores: manual de goniometria. 2 ed. São Paulo: Editora Manole. 2003.

(9) KENDALL, F. P et al. Músculos: provas e funções. 4a ed. São Paulo: Manole, 1995.

(10)OATIS, C. A. Kinesiology: the mechanics and pathomechanics of human movement,

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Lippincott, Williams and Wilkins, Philadelphia, 2004.

(11)HALL, S. J. Biomecânica Básica. Rio de Janeiro: Guanabara Koogan, 1993.

(12) KLOPCAR, N. A kinematic model of the shoulder complex to evaluate the arm-reachable workspace. Journal of Biomechanics.40, 86–91, 2007.

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