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QUANTIFICATION OF FORCE IN SPECIFIC MUSCLE GROUPS DURING THE FLEXION AND EXTENSION MOVEMENT OF THE ELBOW AND KNEE JOINTS OF THE HUMAN BODY

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Abstract. This work shows the development of a biomechanical model, the design of a measurement device and the creation of a computer platform, which all together allow to obtain the numerical value of the muscle force applied by a person on the flexion and extension movement of the upper and lower limb differentiated by each muscular group involved. The purpose of this project is to aid the specialist in the medical diagnosis, presenting accurate data, and keep a record of the evolution of the patient in a quantified manner.

Keywords: Biomechanical model, Flexion-extension movement, muscle force, measurement device, medical diagnosis.

1. INTRODUCTION

In the physiotherapy's field is crucial to quantify the force exerted by the muscles for the draw up of clinical condition of the patients as well as for assess his progress. At present, specialists use two ways to measure the force, by qualitative methods, which depends of the specialist expertise, or by quantitative methods that include measurement instruments. The first one rely on standard protocols where the evaluation is developed by means of the physiotherapist-patient interaction that provides the specialist's perspective regarding the perceived force, that is imprecise. The quantitative method involves the numerical description of the user's response to the applied force. Nevertheless, any of these methods differentiate the force by specific muscle groups responsible of the movement.

The biomechanics allows to make a physical-mechanical representation of the functioning and behavior of the human body through the implementation of different analytic, numerical and experimental models (Martínez Urrialde, et al. 2003) (Philip, 2012) (Schneck and Bronzino, 2003) (Sánchez-Lacuesta and Valencia, 2005). This work presents a strategy where a group of biomechanical models are developed and integrated into computer platform, which in turn interact with a mechanical device where forces and movements are exerted. This set allows quantifying isotonic forces for specific muscle groups of the upper and lower limb, during the flexion-extension movement for healthy and spastic users, given to the physiotherapist a precise tool for the diagnosis.

2. METHODOLOGY

As is shown in Figure 1, the project involves the development of a set of elements for quantification of forces in the individual's specific muscle groups. The complexity of, this development, made necessary to present a subdivision in several phases:
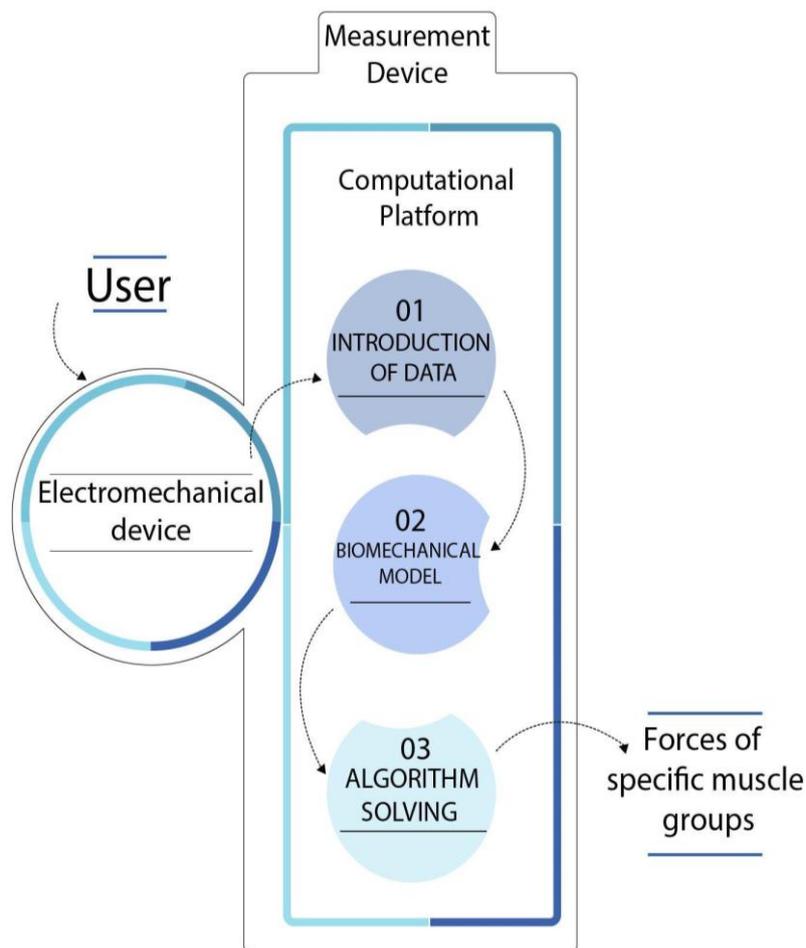
Figure 1. Device Structure diagram.

2.1 PHASE 0 (Contextualization)

Bibliographic compilation of lower and upper limb biomechanics was required, including the anatomy (Schunke, et al., 2011) (Gray, 2011), joint physiology (Kapandji, 2012), mathematical and numerical models developed (Comín, R. D. M., 1998) (Mesfar and Shirazi-Adl, 2008) (Mansouri and Reinbolt, 2012) (Ravera,et al., 2013) and generalities about spasticity (Aguilar, et al. 2009) (Benítez, et al., 2009).

2.2 PHASE 1 (Biomechanical model development)

In this phase, static models of the flexion and extension movement were proposed, one for the lower limb and another for the upper limb based on rigid articulated segments (Comín, R. D. M., 1998) . For this, an anthropometric scaled model has to be developed (Comín, R. D. M., 1998). Using mathematical modeling and motion simulation software such as Opensim, MATLAB and OriginLab pro a mathematical function that describes the variation of the muscles origins and insertions coordinates respect to the angular variation of these during the execution of the movement was proposed. For biomechanical models, main muscles involved at flexion/extension movement were chosen in advance. Muscles were modeled as forces oriented at origin–insertion direction. Fig. 2 shows the musculoskeletal model used for the coordinates taking in Opensim.

Figure 2. Musculoskeletal model of the user's posture (software Opensim).

2.3   PHASE 2 (Computational platform)

In this phase, a processing algorithm was realized to give solution to all the analytical approaches developed in phase 1. The algorithm gives as result the isotonic forces discriminated by muscle group. In addition, is given a graphic interface that helps the specialist to read and understand the results and make an appropriated diagnosis of the patient.

2.4   PHASE 3 (Design)

In this part, the design requirements and specifications of the electromechanical component (device) are established. Based on the Pahl & Beitz design methodology (Pahl and Beitz, 2007) the alternative solutions are devised, selecting the optimal. Subsequently, is executed the detail design with its refinement, to complete the construction of the measuring device.

3.   RESULTS

Due of unknown variables (muscles involved in the movement of upper and lower limb and the representation of shoulder and hip joints) are more than equations available for a simple free body diagram, it was necessary to develop 14 biomechanical models, which involve the upper and lower limb. Figures 3 and 4 show a free body diagram (FBD) of each limb, with the different muscle groups involved in the movement, which are the computer platform's output, the other FDB are not presented. The static equilibrium following the Newton laws equations for the Upper and lower limb FBDs indicated are shown in the Eqs. 1 and 2, and Eqs. 3 and 4 respectively.
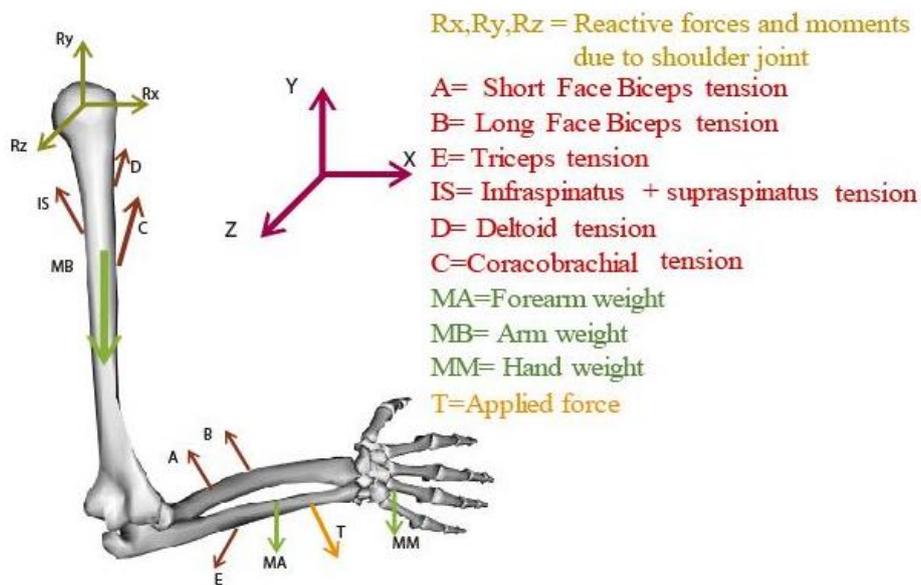

Rx,Ry,Rz = Reactive forces and moments due to shoulder joint
A= Short Face Biceps tension
B= Long Face Biceps tension
E= Triceps tension
IS= Infraspinatus + supraspinatus tension
D= Deltoid tension
C=Coracobrachial tension
MA=Forearm weight
MB= Arm weight
MM= Hand weight
T=Applied force

Figure 3. Upper limb FBD.

$$\sum \vec{F} = 0 = \overrightarrow{R_x} + \overrightarrow{R_y} + \overrightarrow{R_z} + \overrightarrow{IS} + \vec{D} + \vec{C} + \vec{A} + \vec{B} + \vec{E} + \vec{T} + \overrightarrow{MB} + \overrightarrow{MA} + \overrightarrow{MM} \qquad (1)$$

$$\sum \vec{M} = 0 = R_{R_x} \, x \, \overrightarrow{R_x} + R_{R_y} \, x \, \overrightarrow{R_y} + R_{R_z} \, x \, \overrightarrow{R_z} + R_{IS} \, x \, \overrightarrow{IS} + R_D \, x \, \vec{D} + R_C \, x \, \vec{C} + R_A \, x \, \vec{A} + R_A \, x \, \vec{B} + R_E \, x \, \vec{E}$$
$$+ \, R_T \, x \, \vec{T} + R_{MB} \, x \, \overrightarrow{MB} + R_{MA} \, x \, \overrightarrow{MA} + R_{MM} \, x \, \overrightarrow{MM} \qquad (2)$$
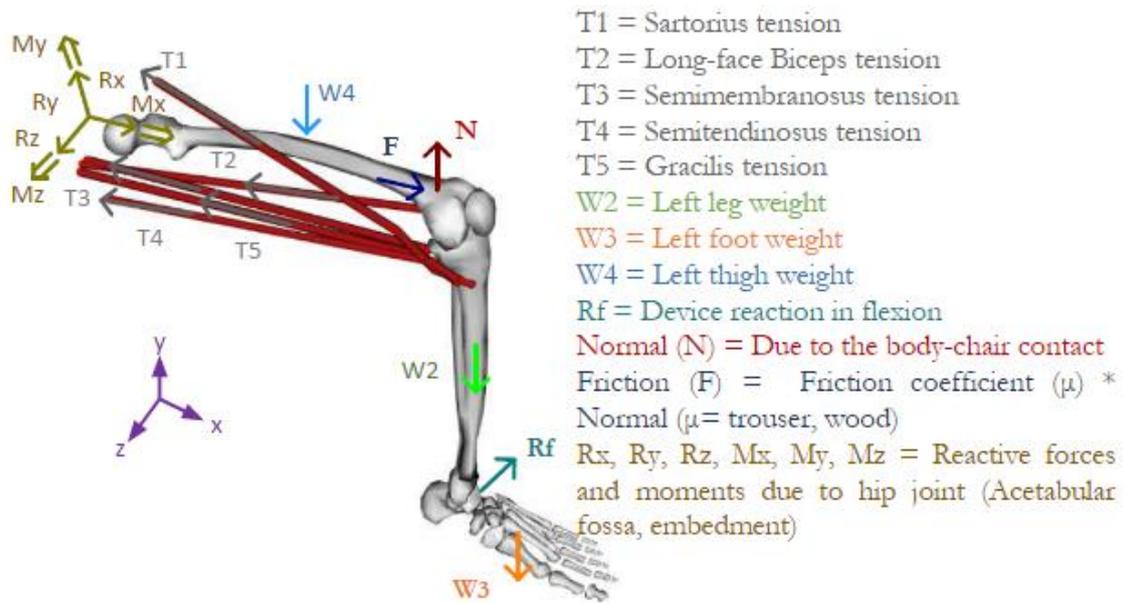
Figure 4. Lower limb FBD.

$$\sum \vec{F} = 0 = \overrightarrow{R_x} + \overrightarrow{R_y} + \overrightarrow{R_z} + \overrightarrow{T_1} + \overrightarrow{T_2} + \overrightarrow{T_3} + \overrightarrow{T_4} + \overrightarrow{T_5} + \overrightarrow{W_2} + \overrightarrow{W_3} + \overrightarrow{W_4} + \overrightarrow{R_f} + \vec{N} + \vec{F} \qquad (3)$$

$$\sum \vec{M} = 0 = R_{R_x} \, x \, \overrightarrow{R_x} + R_{R_y} \, x \, \overrightarrow{R_y} + R_{R_z} \, x \, \overrightarrow{R_z} + R_{T_1} \, x \, \overrightarrow{T_1} + R_{T_2} x \, \overrightarrow{T_2} + \, R_{T_3} \, x \, \overrightarrow{T_3} + R_{T_4} \, x \, \overrightarrow{T_4} + R_{T_5} \, x \, \overrightarrow{T_5}$$
$$+ \, R_{W_2} \, x \, \overrightarrow{W_2} + R_{W_3} \, x \, \overrightarrow{W_3} + R_{W_4} \, x \, \overrightarrow{W_4} + R_{R_f} \, x \, \overrightarrow{R_f} + R_N \, x \, \vec{N} + R_F \, x \, \vec{F} \qquad (4)$$

The design process have had several stages, in the first one was designed, built and tested one prototype for each limb. In this way, the built prototypes are displayed in the Fig. 5.

Figure 5. Trial prototypes.

Then, supported on the given consideration for the first models was made a more exhaustive design implementing the Pahl & Beitz method (Ravera,et al., 2013), generating a second conceptual design that integrate measurements for both limbs, the proposal is presented in the Fig. 6.

Figure 6. Second conceptual model.

The computational component integrates the code lines for the static model equation system solution. Then, the first models of the platform were designed, including both a graphic interface (See Fig. 7) and a database to store the patient's data and the measurements. This interface enabled delivering the results of the patient's progress in graphical-numerical format, as shown in the Fig. 8.
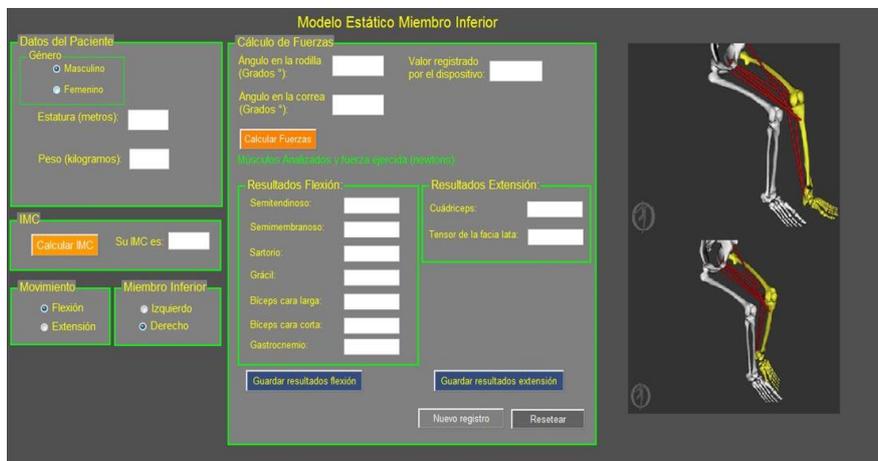

Figure 7. First model of the computer platform graphic interface.

Figure 8. Graphical-numerical results of the graphic interface trials.

4. DISCUSSION

For the first version of the device was possible to integrate the analytical model, the measurement mechanism and the platform. However, it was found, based on the physiotherapist criteria, that between the presented model, the device's configuration (electro-mechanical component) and the position adopted by the patient during the evaluation, there were inconsistencies, since for the measured movement compensations were produced with other muscle groups from those taken into account in the flexion-extension movement model.

Thus, this first version served to identify what difficulties were presented at the measurement time, difficulties that were solved in the second version proposed. Therefore, the provided results for the entered measures in the platform, finally were in typical ranges of healthy people, not greater than muscular forces without discrimination.

5. CONCLUSION

The developed biomechanical models allow to quantify the forces exerted by each muscle group in flexion and extension movements. The creation and implementation of a computer platform which solves the models, makes possible to create a database with the average force values and makes easier the interpretation and analysis of results for the clinic specialist. The new conceptual alternative design of this device was proposed according to different requirements, including increased patient comfort, easy use and optimized the data acquisition system. The design proposed allows a general assessment of forces, because not only the device but also de biomechanical models are able to sense and response to any initial angular position for the upper and lower limb of the patient.

For future improvement of this development, the use of electromyography should be implemented to identify and activate or deactivate some muscles at the biomechanical models.

6. REFERENCES

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7. RESPONSIBILITY NOTICE

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