Relationship Between the Electrical Response of a Skeletal Muscle Versus the Applied Force and the Angle of Flexion

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ABSTRACT

Studying the relationship between muscle force and some electrical parameters of muscle measured on the surface could serve as an indirect indicator of force that would be useful for various applications. In this work, it is proposed to find a possible relationship between muscle force and parameters obtained from surface electromyography (EMG), and electrical impedance myography (EIM) depending on the angle of flexion of the biceps brachii of a case of study. A machine was developed that allows fixing an angle of elbow flexion, combined with a dynamometer which allowed the recording of force simultaneously with the EMG and EIM. The maximum peak and AC power of the EMG were calculated, as well as the magnitude of the impedance for a range of angles between 0˚(full extension) and 100˚ of flexion. The magnitude of impedance vs. frequency showed 3 decreasing transitions, two small at 400Hz and 12KHz and one large at 4.59MHz. An almost linear relationship was obtained between the force and the angle of bending, and a convex nonlinear relationship with a local maximum (at 40˚ / 80Nt) between the peak values and the AC power of the EMG vs. the flexion angle and force. Polynomial models were used to fit the data by minimum squares, being better for the 3rd and 4th order. An increase in the sample is recommended as well as testing more suitable models for the analytical behavior of the data obtained.

Keywords: Muscle force, EMG, EIM, Muscle modelling

INTRODUCTION

Currently, in the field of biomedical engineering, muscle force has been measured traditionally using fixed and complicated assemblies based on dynamometers. To study muscle contraction force there are different techniques like electromyography (EMG), and Electrical Impedance Myography (EIM).

EMG is a common technique that measures the biopotentials produced by muscle contractions, transmitted through neighboring tissues to the skin surface, and EIM measures bioimpedance which is related to the dielectric composition of tissues (Ngo et al., 2022).

This research seeks to combine both techniques simultaneously to analyze muscle contraction as a function of flexion angle. This would allow the indirect measurement of muscle force from noninvasive and easy-to-measure electric parameters which are useful for a variety of applications.

OBJECTIVES

- To design and create a machine that will allow the measurements of the applied force for a fixed angle and simultaneously the electrical response of the skeletal muscle depending on the flexion angle and the applied force.
- Use electromyography and electrical impedance myography simultaneously to measure the electrical responses of the skeletal muscle depending on each flexion angle and the applied force.
- Analyze the results to determine if there is a relationship between the electrical response, the applied force, and the flexion angle.

METHODOLOGY

Recording fixture: The machine was designed in Autodesk Fusion 360(fig 1) and manufactured(fig 2) to fix the biceps flexion angle and hold a dynamometer.

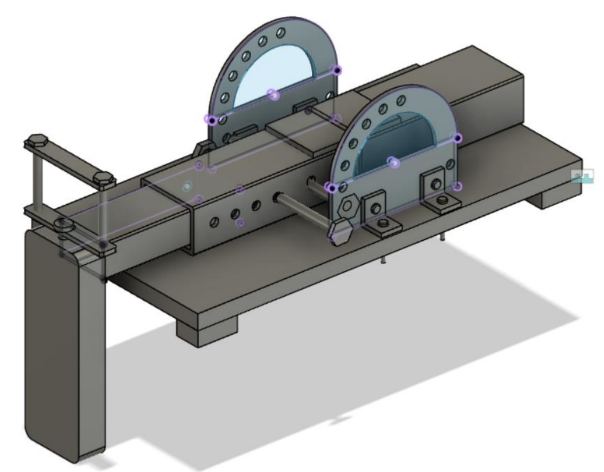

Figure 1: Machine Design in Autodesk Fusion 360

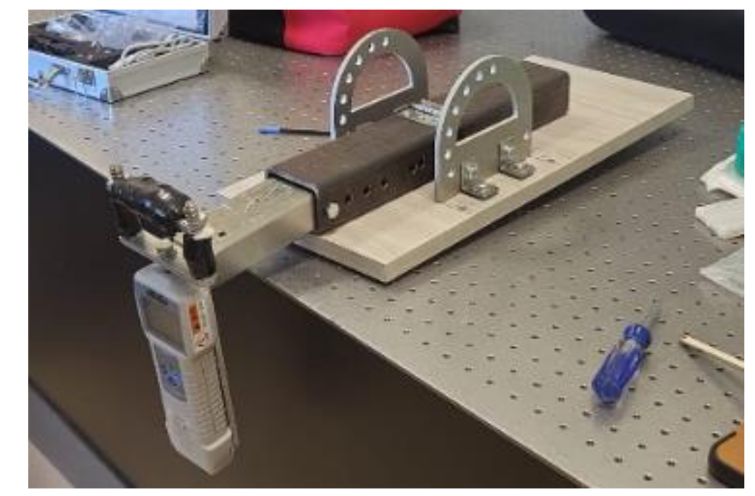

Figure 2: Finished Manufactured Machine

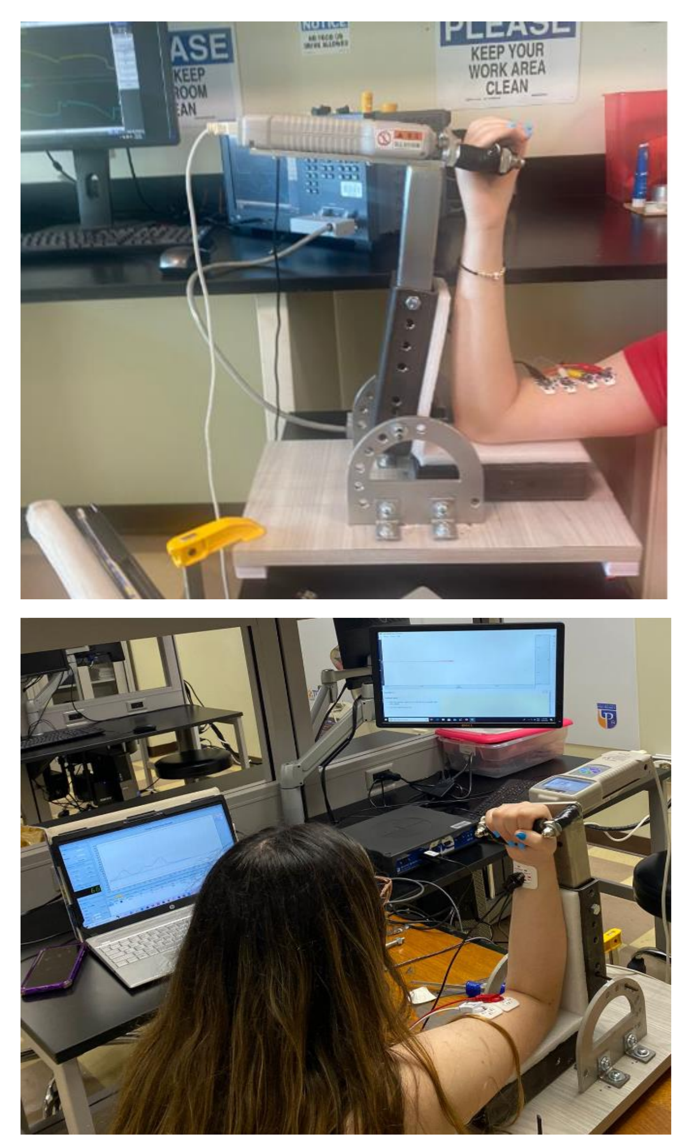

Figure 3: EIM (up) and EMG (down) Recording Process

Data gathering: For **EIM** four electrodes were placed on the biceps, between the medial acromion and the cubit fossa at 1/3 of the cubit fossa with internal electrodes at 1 cm and external electrodes at 3 cm. A current of 100 µA was induced at a frequency sweep of 20Hz-20MHz, and impedance was acquired using a Keysight E4990A Impedance Analyzer (fig 3 up), with muscle resting and contracting.

For **EMG**, a BIOPAC MP36 Data Acquisition system was used. Two electrodes were placed on the biceps between the medial acromion and the cubit fossa at 1/3 of the cubit fossa separated by 20mm. The third electrode was on the ventral part of the wrist center (Fig 3 down).

Readings for EIM and EMG were made every 20 degrees with a muscle recovery time of 8 min between measurements. This process was repeated ten times to analyze the parameters.

RESULTS & ANALYSIS

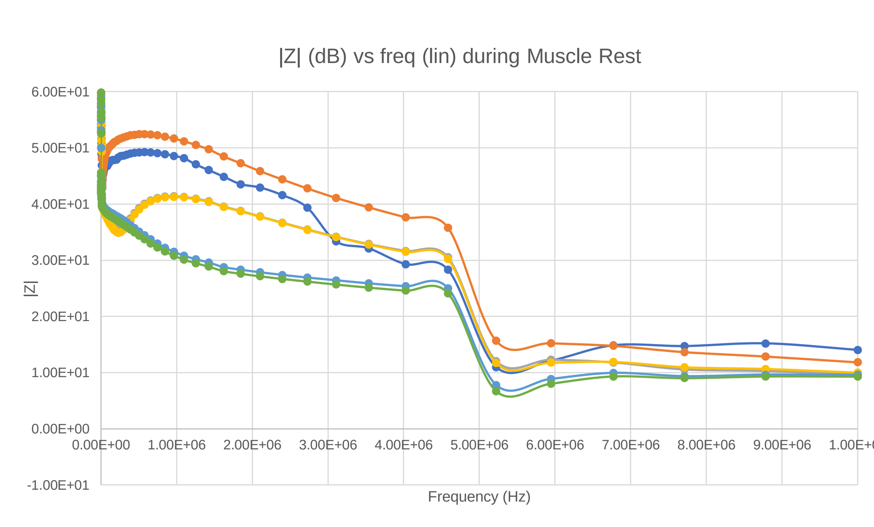

Figure 4: Impedance vs. Frequency during Muscle Rest

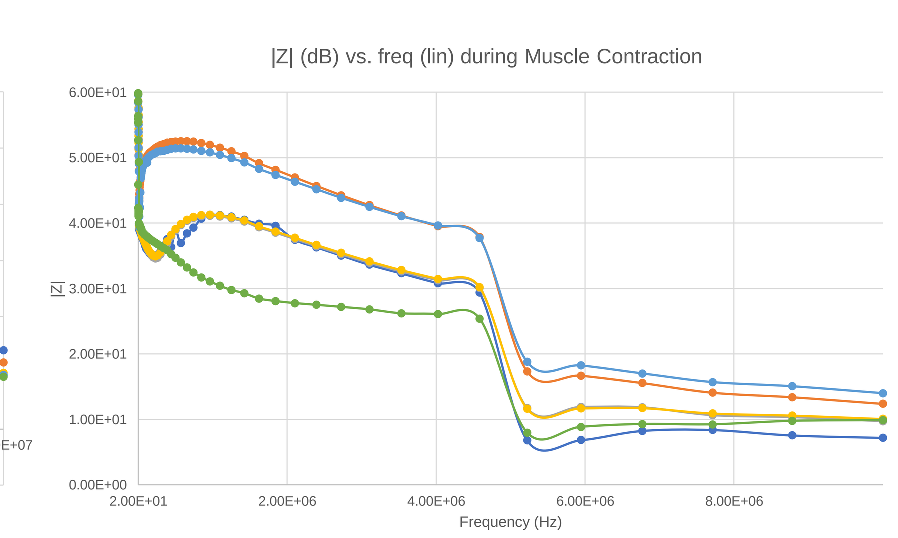

Figure 5 : Impedance vs. Frequency during Muscle Contraction

EIM: Regardless of the flexion angle and whether the muscle is exerting force or at rest it was observed that: the greater the length of the muscle (smaller angle), the greater the impedance, and decreasing transitions of the impedance modulus were observed at 400Hz, 12KHz and a big one at 4.59MHz (Figs. 4 & 5).

EMG: There is a linear relationship (Figs. 6 & 7) between force and flexion angle with R^2=0. 9956. The average maximum voltage and the AC power/variance as a function of angle and force showed a convex nonlinear relationship (explained by González et al.) with a local maximum (at 40˚/80Nt). 4-order polynomial was the best to fit those data (Figs 8 & 9), based on R^2. However, from the physiological point of view, a model with 2 or more points of the maximum or minimum value in the range of motion of the muscle is not suitable.

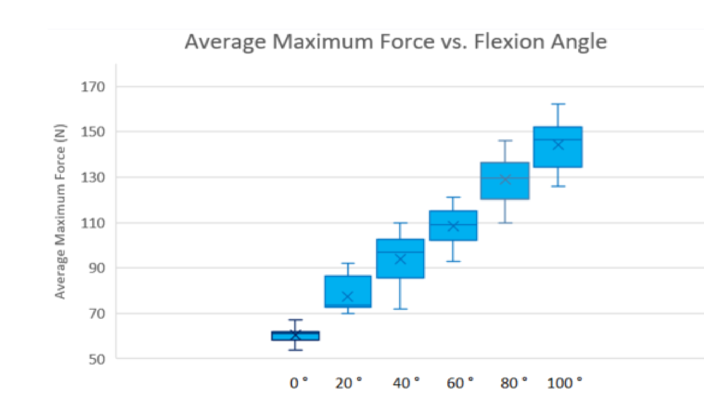

Figure 6: Avg. Max. Force vs. Flexion Angle

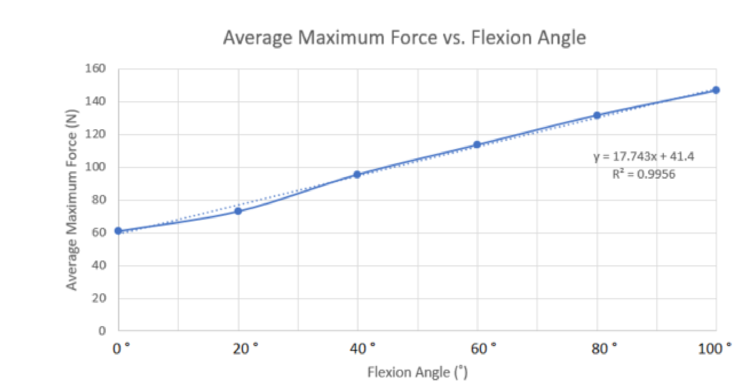

Figure 7: Avg. Max. Force vs. Flexion Angle Trendline Curve

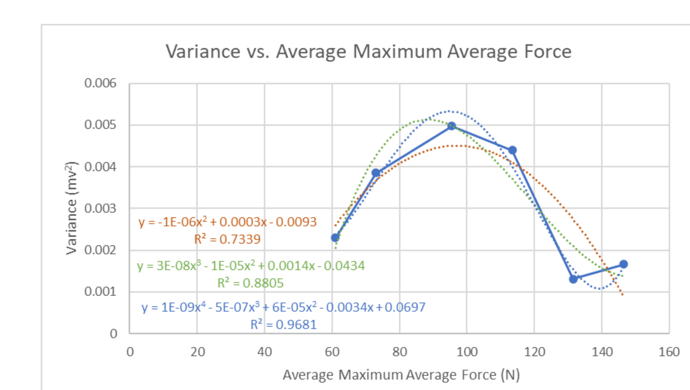

Figure 8: Variance vs. Avg. Max. Force w/Trendline Curves

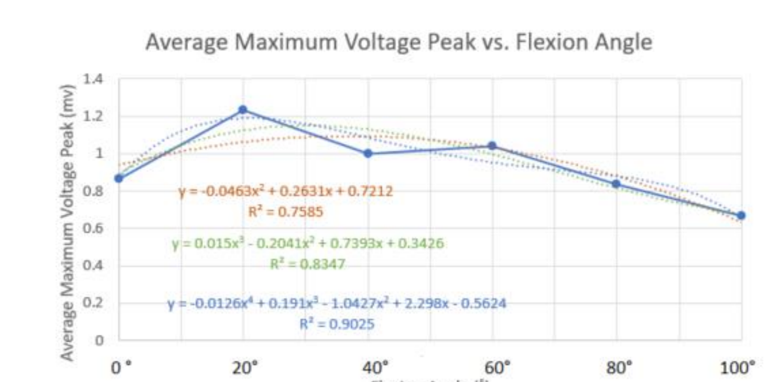

Figure 9: Avg. Max. Volt. Peak vs. Flexion Angle w/Trendline Curves

CONCLUSIONS & RECOMMENDATIONS

A relationship between force and flexion angle was found (linear), as well as between surface EMG parameters (max peak and variance) and angle/force (convex function). Despite it was best fitted by a 4th-order polynomial, it is not adequate for this physiological case, then for future work is recommended to explore other models (i.e. gamma functions), and to measure more angles of flexion in a bigger sample.

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