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Construction of fitted behavior laws from experimental data for muscle aging simulation

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1. Introduction

Developing realistic numerical model of physiological systems generated recently a rising interest from the medical community. These models should help the clinician to refine his diagnosis related, for example, to muscle aging pathologies as sarcopenia. In order to simulate muscle aging, it is mandatory to be able to set model parameters to their correct values at any age (Douania et al. 2019). However, literature data being sparse we propose to set relationship between age and parameter values. We focused on the Biceps brachii (BB) for our multiscale and multiphysics models (Carriou et al. 2016) as it is a fusiform muscle, used in many daily tasks and practical for the recording of HD-sEMG signals. Hence this study will focus of this particular muscle.

Our approach in this work is to use regression analysis to interpolate the parameter value between the ones available in the literature and be able to simulate realistic configurations at any age, but also to simulated aging of a given virtual subject. The abstract is organized as follows: a literature report of the available parameter values for each subject category (by age and sex), data sources with high standard deviation or inadequate measurement protocol were excluded, modeling the relationship between aging and parameter values using classical regression models.

The Cross-Sectional Area (CSA) of BB muscle are rarely reported in the literature. Usually the BB, Brachialis and Triceps are reported together globally. Terms like Anatomical Cross-Sectional Area (ACSA) and Physiological Cross- Sectional Area (PCSA) are also frequently used in these studies. ACSA design the muscle CSA measured in the plane perpendicular to its tendons (the longitudinal axis), at the widest point along the muscle. PCSA is the muscle CSA measured in the plane perpendicular to the muscle fibers. It is

obtained by dividing the muscle volume by its true fiber length. For the BB muscle (fusiform muscle, the PCSA do not vary which is not the case for pinnate muscles.

2. Methods

The Table 1 shows CSA values of BB muscle with the elbow positionned at 90° of flexion. We should mention that many techniques for muscles CSA measurement are reported in the literature. The most used are the computed tomography (CT), the MRI and Ultrasound Extended-Field-Of-View (UEFOV). No significant difference are noted between results using these techniques, only the time cost is a major advantage for the UEFOV method. We assumed the young group to be bellow the age of 30 and the elder one above 60 in accordance with most studies we reviewed. Studies or subjects groups with intense sports practice were excluded for this work.

Table 1: Comparison between the CSA of the biceps brachii muscle reported in the literature (YM: Young Men; EM: Elder Men).

Sub ject	Age (yr.)	CSA (cm ²)	Number of subject	Modality	Reference
YM	23.3 ±3	12.7± 2.3	20	MRI	Klein et al. 2002
	23.3 ±1.3	12.4± 1.2	8	CT	Miller et al. 1993
	28± 0.1	15.3± 2.5	8	CT	Klitgaard et al. 1990
	12~ 25	11.8± 2.7	8	MRI	McCall et al. 1996
EM	81± 13	9.1±1 .7	23	MRI	Klein et al. 2002
	68± 0.5	12.5± 3.3	8	CT	Klitgaard et al. 1990

2.2 Growth models

Four growth model, linear, exponential, logistic and Gompertz model, were fitted from experimental data and the plausibility fo the obtained relationship were assessed.

Linear growth: the relationship with age is evolution with aging can be modeled with a linear equation:

$$p(x) = a \cdot x + p_0 \quad (1)$$

Where $p(x)$ is the muscle parameter at age x , a is the growth rate, p_0 the initial parameter value.

Exponential growth: the parameter growth rate evolves with age, in proportion to the parameter values, getting larger or smaller. The general form of this model is:

$p(x) = p_0 \cdot e^{a \cdot x}$ (2) Where $p(x)$ is the muscle parameter at age x , a is the growth factor, p_0 the initial parameter value.

Logistic growth: In logistic growth, a parameter growth rate increases (or decreases) as it approaches an imposed extremum value, known as the carrying capacity. The general form of this model:

$$p(x) = \frac{k \cdot p_0}{p_0 + (k - p_0) \cdot e^{-a \cdot x}} \quad (3)$$

Where $p(x)$ is the muscle parameter at age x , a is the growth rate, k is the carrying capacity, p_0 the initial parameter value.

Gompertz-Weibull growth: It is also a sigmoid function. In contrast to the simple logistic function in which both asymptotes are approached by the curve symmetrically, here the asymptotes have different growth rates. The general form of this model is:

$$p(x) = c \cdot e^{-e^{b-a \cdot x}} \quad (4)$$

Where $p(x)$ is the muscle parameter at age x , a is the growth factor, b is the halfway point, and c is an asymptote, since $\lim_{x \rightarrow +\infty} c \cdot e^{-e^{b-a \cdot x}} = c$.

The equations 1, 2, 3, and 4 were all fitted from the selected experimental data. The model equation parameters are estimated using the Levenberg-Marquardt algorithm (non-linear least squares optimization function).

3. Results and discussion

To obtain the estimated relationship between the muscle CSA and age, we first eliminate experimental data with high standard deviation. Then we have applied a regression using growth equations of section 2.2. Four curves of CSA decline are estimated (Figure 1).

Given the high variance of the data, the simple quality of fit isn't enough to discriminate between the possible models. We use our a priori knowledge of muscle aging to guide our choice. Muscle force starts to decline around the age of 40 and can be associated with a reduction of muscle mass. The decline is constant, only its speed is modulated. Taking into account these informations we selected the Gompertz-Weibull. This model shows a plateau for younger male and then a progressive diminution of CSA with age. The other models present behavior that are unrealistic when put against our knowledge.

We will use the Gompertz-Weibull equation to obtain the muscle CSA at each age for future models. However it can only hint at possible values for a generic virtual subject.

Similar work has been performed for other morphological parameters of the muscle and for aging female subjects as well.

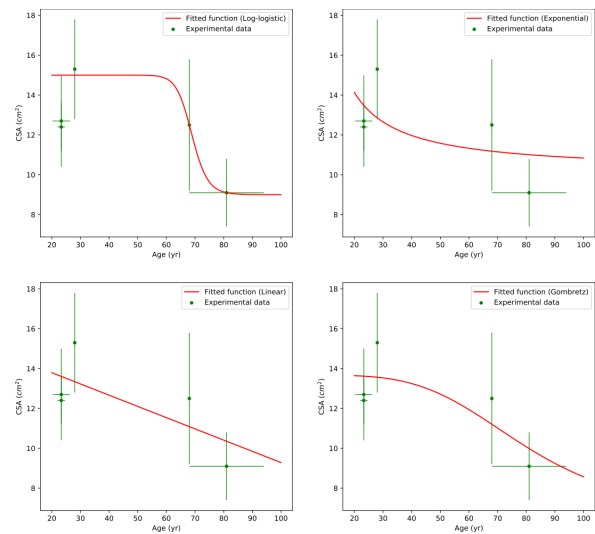


Figure 1: CSA fitted functions for male subjects.

Finally, such behavior laws are mandatory for personalizing a future neuromuscular multiscale and multiphysics model to subject age. This model aims to mimic muscle aging with a high physiological realism.

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Conflict of Interest Statement

The authors declare no conflict of interest.

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