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USING AN INVERSE METHOD TO OBTAIN THE MATERIAL PARAMETERS OF THE MOONEY-RIVLIN CONSTITUTIVE MODEL FOR PELVIC FLOOR MUSCLES

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Abstract *The group of levator ani muscles (puborectal, pubococcygeus and iliococcygeus muscles) is of the most importance in the active support of the pelvic organs and urethral closure by resisting the downward forces imposed to the organs and to the pelvic floor whenever the intra-abdominal pressure is increased. Deficient muscular contraction, which may be caused by direct neuromuscular damage can result in major defecation disorders or vesico-uterine prolapsed [1].*
For clinical, technical and ethical reasons it is not possible to obtain the properties of these soft tissues in vivo. The utilization of inverse methods is therefore required in order to obtain estimative for the mechanical properties of these structures.
In this work, an optimization algorithm was implemented in order to obtain the optimal mechanical parameters for the Mooney-Rivlin constitutive model [2]. The optimization algorithm uses the python scripting language to couple the Matlab and Abaqus software. The Powell method was used for the optimization part of the algorithm [3].

1. INTRODUCTION

The study of female pelvic floor muscles is important by the prevalence and costs of different pathologies related to these muscles [1] [3]. These have a negative impact on the daily lives of women.

The female pelvic floor is an example of a soft tissue support structure that includes fascia, ligaments and muscles of the urogenital region. It extends from the *symphysis pubis* to the coccyx, and comprises the urogenital hiatus for the passage of the urethra, vagina and anus.

The pelvic floor muscles are of the most importance in the support of the pelvic organs and urethral closure by resisting the downward forces imposed to the organs and to the pelvic floor whenever the intra-abdominal pressure is increased. Deficient contraction, which may be cause by direct neuromuscular damage, can result in major defecation disorders.

The mechanical characteristics of the pelvic female floor are relevant to explain pelvic floor dysfunction. The decreased elasticity of the tissues often causes the inability to maintain urethral position, and also leads to vaginal and rectal descend when coughing or defecating due to the increase in intra-abdominal pressure [4]. These pathologies may result from direct damage of the pelvic floor muscles or ligaments or changes in its stiffness, as well as those of the pelvic fascia, associated to menopause, pregnancy, hormonal changes [5] [6].

As the analysis *in vivo* of the mechanical properties of these tissues is not possible, biomechanical simulation is required.

The aim of this work is to obtain material parameters of the Mooney-Rivlin constitutive model hyperelastic [1] [2] through an Inverse Method, using the Powell´s method [7] [8].

2. MATERIALS AND METHODS

2.1 Acquisition of MRI

To obtain geometric information of the pelvic floor muscles in biomechanical simulation were acquired magnetic resonance imaging (MRI) (Figure 1) with the respective authorization of the Ethics Committee on Health (protocol: CES195 / 12). The subject was a woman of 30 years, nulliparous, without clinical problems suggestive of pelvic floor dysfunction. Images were acquired at rest and during the Valsalva maneuver (increased intra-abdominal pressure).

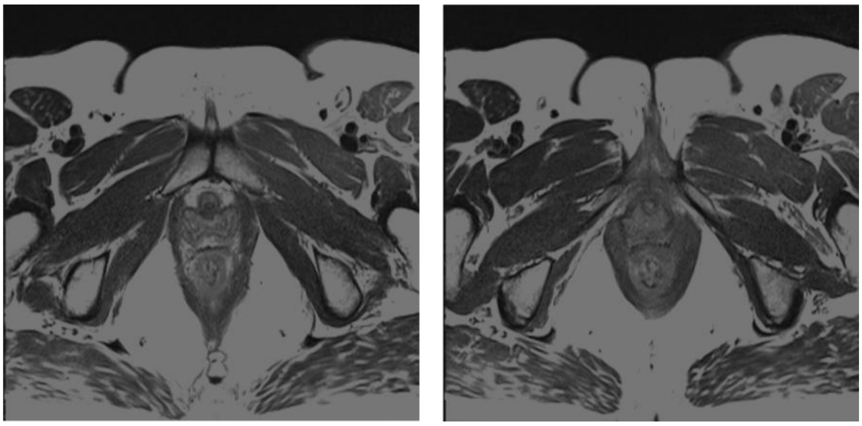

Figura 1. MR images of the pelvic floor muscles.

2.2 Processing of the magnetic Resonance Images

Order to build the 3D model (Figure 3) from the MR images was performed manual segmentation of muscles (Figure 2) using the Mimics® software v.16 (Software and Services for Biomedical Engineering, Materialise HQ, Belgium).

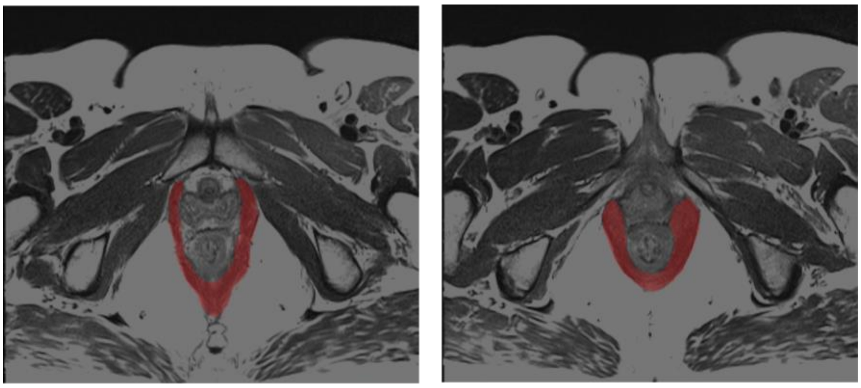

Figura 2. MRI processed in Mimics software for obtaining the Pelvic Floor Muscle.

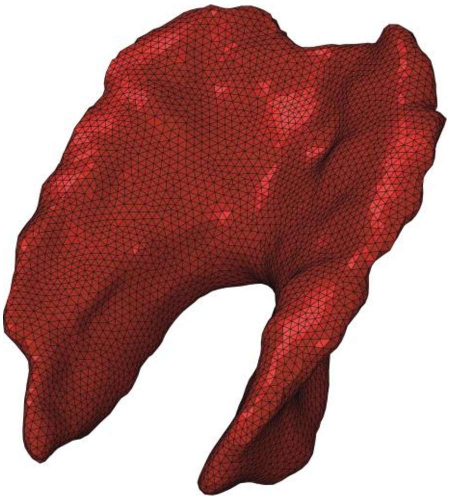

Figura 3. Finite element model of the pelvic floor muscles.

2.3 Boundary Conditions applied to the Pelvic Floor Muscles

The bony pelvis is important to define the points of attachment of the pelvic floor. The bony pelvis model was obtained by processing the MR images in the Mimics® software.

The bony pelvis helps to define the boundary conditions of the pelvic floor. The posterior part of the pelvic floor is fixed by the coccyx and the anterior part of the pelvic floor is fixed by the *symphysis pubis* (Figure 4).

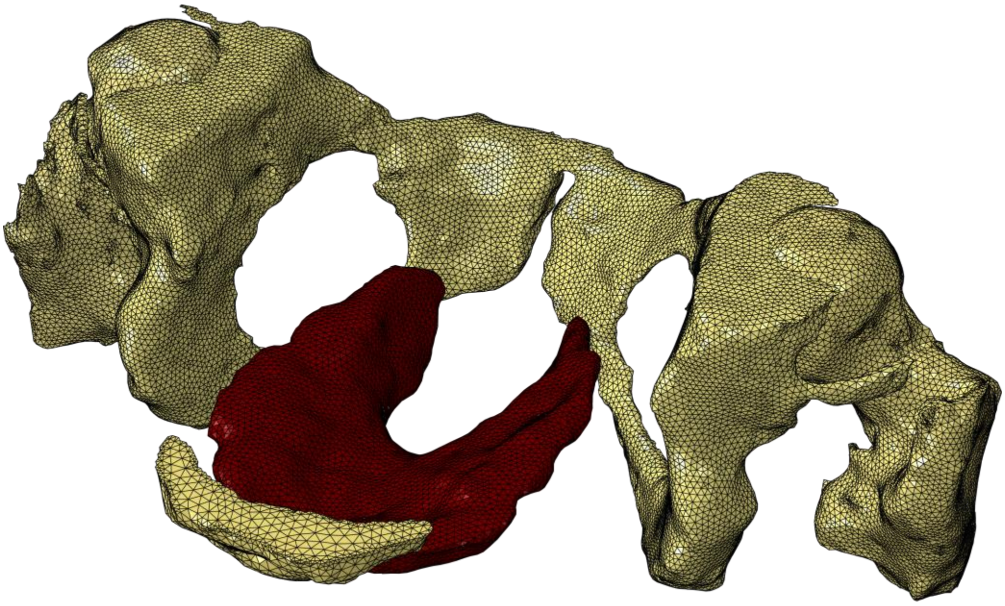

Figura 4. Finite element model of the bony pelvis and pelvic floor muscle.

2.4 Properties applied to the Finite Element Model for the Pelvic Floor Muscles

Loadings of 5E-4 MPa and 45E-4 MPa were set, as simulating the intra-abdominal pressure values for supine at rest – representative of organ load – and valsalva maneuver, respectively. The final pressure of 40E-4 MPa was applied to the inner surface of the pelvic floor muscles.

2.5 Optimization of Material Parameters of the Mooney-Rivlin Constitutive Model Hyperelastic

The constitutive model applied to the Pelvic floor finite element model was the Mooney-Rivlin.
The Mooney–Rivlin material law, commonly used in biomechanical simulations, was used in this study. This simple material law utilizes a nonlinear relationship between stress and strain to describe incompressible hyperelastic materials that exhibit near-isotropic behavior. The Mooney–Rivlin constitutive model [2] is characterized by Eq. (1).

$$W = c_{10}(I_1 - 3) + c_{20}(I_2 - 3) \tag{1}$$

Where W is the strain energy function and c_{10} and c_{20} are material parameters.

2.6 Optimization Process

The optimization algorithm searches for an optimal set of material parameters in order to minimize the objective function [7] [8]. The parameters corresponding to the computed

minimum of the objective function are assumed to represent the real tissue parameters. In this study, the objective function to be optimized is no longer an equation and becomes a simulation with finite elements.
An Inverse Method was implemented to obtain the optimal material parameters for the Mooney-Rivlin constitutive model by using the Python® scripting language to couple the Matlab® MathWorks v. R2013b (Mathematical Computing Software, Natick, Massachusetts, USA) and the Abaqus® software.

3. RESULTS

In this work the numeric simulation is included in the optimization process with the initial material parameters for the constitutive model.

3.1. Acquisition of Curves at Rest Position and Valsalva Maneuver

During the process:

- Iteratively the material parameters are changed and comparisons are made between two curves.
- This whole process is repeated until we can minimize the distance between the simulation result and the experimental data (curve on valsalva maneuver) (see Figure 5).

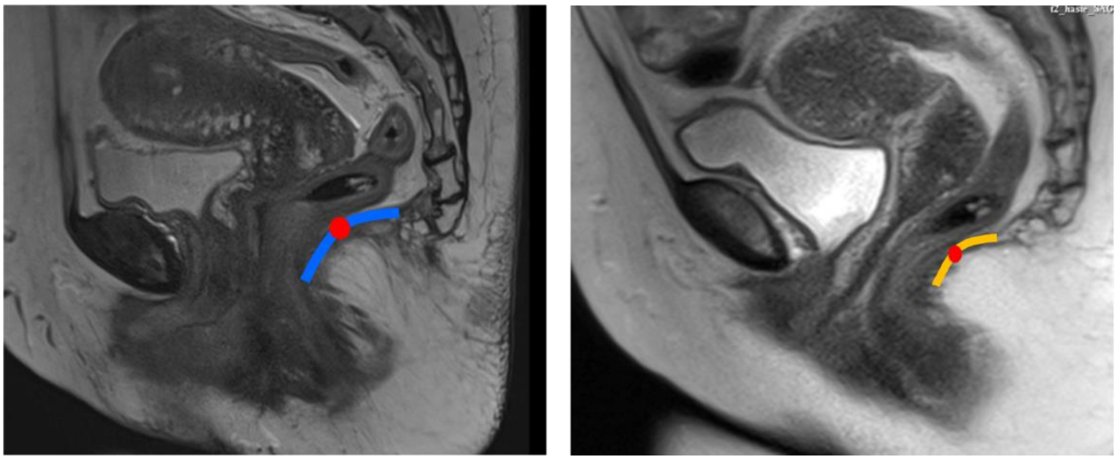

Figura 5. Curves at rest and Valsalva Position.

3.2. Comparison of the Curves during the Optimization Process

The Figure 6 displays two curves, one at rest position (blue) and another on Valsalva Position (orange). These curves represent the position of the pelvic floor muscle. These curves were obtained from Magnetic Resonance Images in the sagittal plane.

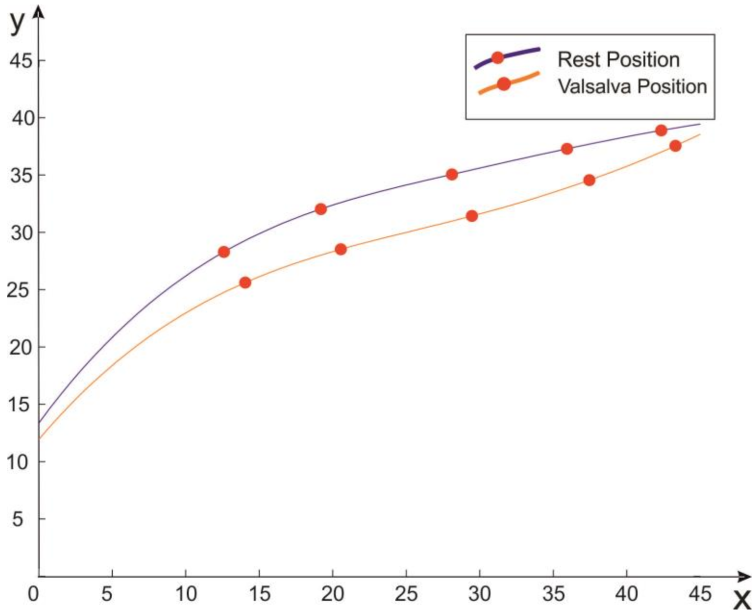

Figura 6. Representation of the rest position and valsalva maneuver, before of the application of the optimization process.

After application of the optimization process occurred an approximation of the curves as can be seen by the graph of Figure 7.

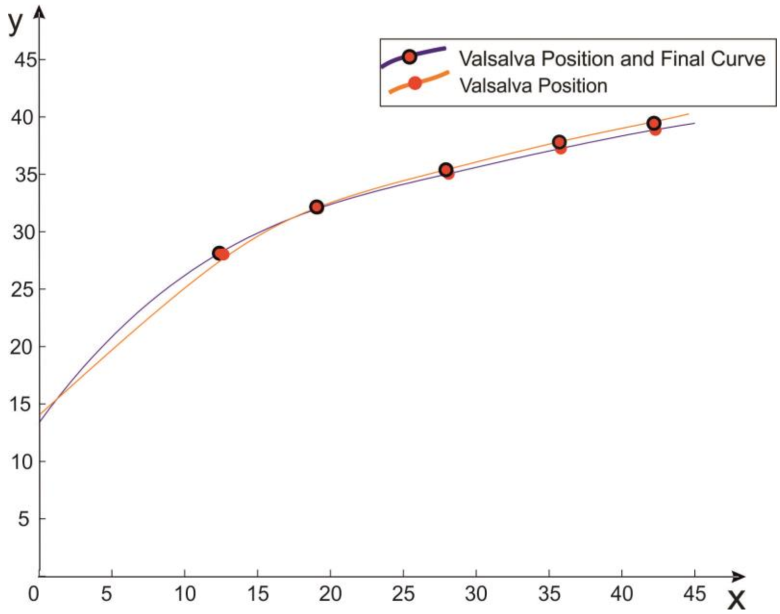

Figura 7. Representation of the rest position and valsalva maneuver, after of the application of the optimization process.

3.3. Comparison of Material Parameters

Table 1 shows the material parameters of the Mooney-Rivlin constitutive model hyperelastic (before and after the optimization process) (see Table 1). The material parameters for the pelvic floor muscles obtained in valsalva were $c_{10} = 1.50$ *MPa* and $c_{20} = 1.53$ *MPa*.

Optimization Process	C_{10}	C_{20}
Before	5.0	2.0
After	1.50	1.53

Table 1. Material parameters of the Mooney-Rivlin constitutive model hyperelastic.

4. CONCLUSIONS

Since it is not possible to directly obtain material properties from tissues *in vivo*, data from experimental tests and optimization algorithms may be used to estimate the most accurate and subject-specific constants.

The finite element model is deformed to Valsalva position. The optimization method appears correctly reproduce the muscular displacement, which allows to obtain in reverse of the material parameters for the Mooney-Rivlin constitutive model hyperelastic, which according to the values in the literature [1].

The work presented here is important since it allows obtaining the biomechanical properties of the pelvic floor muscles. It is important to determine these properties in order to understand the pelvic floor dysfunctions that affect the daily lives of many women.

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