Variation of the material parameters of the Mooney-Rivlin hyperelastic model applied to the pelvic floor muscles of two women - asymptomatic and with pelvic organ prolapse

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Variation of the material parameters of the Mooney-Rivlin hyperelastic model applied to the pelvic floor muscles of two women - asymptomatic and with pelvic organ prolapse

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Abstract

The pelvic floor is made up of a set of soft tissue structures, supported by a network of muscles, which are in turn attached to each other and to the pelvis by condensations of fascial and fibromuscular tissues [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.

Hence, in this work, an optimization scheme was used to estimate the material parameters of the pelvic floor muscles of two women, one without pathology and other with pelvic organ prolapse. For this purpose, was used the Mooney-Rivlin hyperelastic constitutive model and the inverse finite element analysis.

Subject Headings. The inverse FEA coupled with MRI allow obtaining *the* biomechanical properties of the pelvic floor muscle in a non-invasive manner.

The biomechanical properties of the female muscles are relevant when explaining pelvic dysfunctions, since these dysfunctions may result directly from disorders in those properties.

Author Keywords. Pelvic Floor Muscle, Material Parameters, Finite Element Method, Magnetic Resonance Images, Optimization Algorithm

1. Introduction

The biomechanical analysis is important to understand the pelvic floor dysfunctions (PFD) - such as stress urinary incontinence (SUI) and pelvic organ prolapse (POP) (Hendrix et al. 2002; Dietz et al. 2005; Brandão et al. 2013). This also to improve clinical outcomes, as well as the decreased elasticity of the tissues often causes inability to maintain the normal positions of the pelvic organs (Thyer et al. 2008). The PFD can result from inadequate biomechanical properties in the supportive structures - pelvic ligaments, endopelvic fascia or muscles - that can be associated with risk factors - such as hormonal changes, vaginal delivery, aging, among others (Abramowitch et al. 2009).

Radiographic evidence of lack of support to the pelvic organs and the widening of the *levator hiatus* comes mainly from evaluating muscle defects or ligament rupture through the images techniques - such as ultrasound and Magnetic Resonance (MR) images (Dietz 2004; Tunn et al. 2006).

Previous experimental *in vitro* studies have been addressed to evaluate biomechanical properties of the pelvic ligaments, vaginal tissue and *levator ani* (LA) muscle (Cosson et al. 2003; Cosson et al. 2004; Lei et al. 2007; Rubod et al. 2008; Martins 2010). To obtain these biomechanical properties, acquired tissue during surgery or from female cadaver has been tested using different techniques: uniaxial and biaxial tensile tests. However, these collected tissues are frequently afflicted in clinical environment, and consequently, the comparison to *in vivo* healthy tissues is difficult (Baah-Dwomoh et al. 2016).

In this context, the aim of this work was estimate the material parameters of the pelvic floor muscles (PFM) of two women - one without pathology and other with POP - during Valsalva maneuver.

2. Materials and Methods

For this study, two women were recruited - one with POP and other without pathology. The T2-weighted axial images were used to create 3D geometrical models through semi-automatic segmentation of consecutive slices where the contours of the PVM, obturator internal muscle (OIM), coccyx, and *symphysis pubis* were defined, via the Mimics® Innovation Suite v. 17 (Materialise, Leuven, Belgium).

The triangulated 3D surface model of the PVM was imported to the Abaqus® software v.2016 (Dassault Systemes Simulia Corp., Providence, RI, USA) to create the finite element mesh for each subject, by using hybrid linear tetrahedral elements (Abaqus C3D4H) (see Figure 1).

Boundary conditions were imposed to the model to define the insertion points of the PVM in the coccyx, obturator internal muscle and *symphysis pubis.* The pressure of 4 kPa was applied to the inner surface of the PVM to simulate the Valsalva maneuver (Noakes et al. 2008).

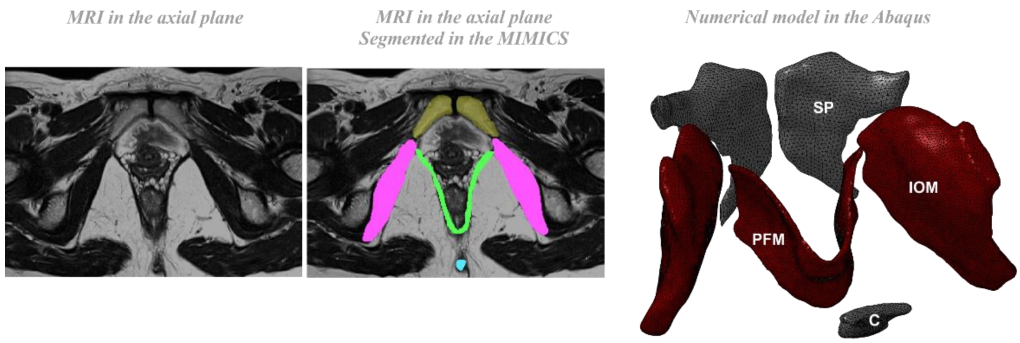

Figure 1. Magnetic Resonance images in the axial plane of a woman without pathology and finite element model. C - coccyx; IOM - internal obturator muscle; PFM - pelvic floor muscles; SP - symphysis pubis.

The Mooney-Rivlin hyperelastic constitutive model was applied to the PVM to simulate the passive behavior.

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

The optimization algorithm searches for the suited set of material parameters of the Mooney-Rivlin hyperelastic constitutive model, in order to minimize its objective function (Powell 1977; Gao et al. 2013). In this work was used an inverse FEA implemented by Silva et al. (Silva et al. 2016) to obtain the material parameters for Mooney-Rivlin hyperelastic constitutive model by using the Python scripting language to couple the MATLAB MathWorks v.R2016a (Mathematical Computing Software, Natick, Massachusetts, USA) and the Abaqus software.

3. Results

The material parameters of the Mooney-Rivlin hyperelastic constitutive model were higher for woman with POP. The difference between two women was approximately 37.5% for the c_1, 63.2% for the c_2.

variable (MPa)		asymptomatic	POP
Mooney-Rivlin	c_1	0.020	0.032
	c_2	0.007	0.019

Table 1. Material parameters of the Mooney-Rivlin hyperelastic constitutive model for the PFM obtained through inverse FEA.

4. Discussion and Conclusions

The material parameters of the Mooney-Rivlin hyperelastic constitutive model higher for the muscles of the woman with prolapse (see Table 1), hence the stiffness is higher when compared with the one of the asymptomatic woman.

The computational models coupled with inverse FEA can represent mechanical phenomena such as the Valsalva maneuver and they seem to be a promising possibility to determine the *in vivo* biomechanical properties of the PFM, leading to a relationship between for the incontinent women and women with prolapse, which may contribute to the clinic.

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