Portuguese Journal of Sport Sciences
11 (Suppl. 2), 2011

ANALYSIS OF THE CONTRACTION OF THE PUBOVISCERAL MUSCLE BASED ON A COMPUTATIONAL MODEL

Thuane da Roza[1], Maíta Poli de Araújo[2], Teresa Mascarenhas[3], Joana Loureiro[3], Marco Parente[1] and Renato Natal Jorge[1]

IDMEC- Faculty of Engineering, University of Porto, Porto, Portugal[1]
Sector of Urogynecology and Vaginal Surgery, Federal University of São Paulo, São Paulo, Brazil[2]
Faculty of Medicine, University of Porto, São João Hospital, Porto, Portugal[3]

The Pelvic Floor (PF) is a set of soft parts that close the pelvis. Its function is related with the support and suspension of the pelvic organs maintaining urinary and fecal continence. When the pelvic floor muscles (PFM) are not strengthened, pelvic dysfunctions may appear. The strengthening exercises are performed through contraction of the PF, which are the basis of physiotherapy treatment. The aim of this study is to build the pelvic floor muscle, through magnetic resonance imaging (MRI), and simulate through the finite element method the contraction in an athlete that practices synchronized swimming. The present work shows a methodology that can be applied in the pelvic floor biomechanics.

KEY WORDS: Pelvic Floor, Finite element method, Biomechanics.

INTRODUCTION: The pelvic floor consists of a group of muscles and connective tissue that extends as a sling across the base of the pelvis; it comprises two layers, the superficial perineal muscles and the deep pelvic diaphragm. It’s function is to provide support for the pelvic organs, the bladder and elements of the spine, as we can see in Figure 1 (Ashton-Miller & DeLancey, 2007). “Levator ani” is the collective term used to describe the deep PFM. The levator ani consists primarily of the striated muscles pubococcygeus (PC), puborectalis (PR) and iliococcygeus (IC) (Wall, 1993). In an healthy women at rest, the levator ani muscles are in contraction, thereby keeping the rectum, vagina, and urethra elevated and closed by pressing them anteriorly toward the pubic symphysis (DeLancey, 1993).
Pelvic floor disorders (PFD) can be identified as a wide spectrum of interrelated clinical conditions, including pelvic organ prolapse, urinary incontinence, fecal incontinence, voiding dysfunction, and defecatory dysfunction (Bump et al., 1999). Because of its high prevalence, deleterious effects on quality of life and its impact on the health care system, PFD are an important public health issue (Bump & Norton, 1998). It is estimated that one or more of these conditions affect up to one-third of adult women (Olsen et al. 1997). The origins of the Pelvic floor muscles (PFM) dysfunction are multifactorial, being a consequence of human evolution, childbirth, lifestyle, aging and the practice of high-impact exercise (Daneshgari & Moore, 2006).
The exercises of voluntary contraction of the pelvic floor are the basis of treatments of physical therapy for the Pelvic floor disorders. These treatments present many benefits, such as: improving body perception and awareness of pelvic region, increased vascularization of the pelvic region, increasing the tone and muscle strength of the floor; improvement biomechanics of the pelvic muscles and keeping the group stronger (Bump, 1991; Petricelli, 2003). The accurate assessment and measurement of symptoms relating to pelvic floor disorders is essential for clinical diagnosis and monitoring of outcome (Ghoniem et al. 2008), therefore Magnetic Resonance Imaging (MRI) has been used in the diagnostic evaluation of the pelvic floor dysfunctions. Recent advances in MRI has provided evidence of localized muscle injury in an individual, so it will be possible to better understand the relationship between injury to a specific part of the muscle and specific female pelvic floor problems (DeLancey et al. 2007). Knowing the type of injury is an important guide to proper treatment (DeLancey et al. 2007; Bo & Sherburn, 2005).

Portuguese Journal of Sport Sciences
11 (Suppl. 2), 2011

MR images allow the generation of three-dimensional (3D) solids of the pelvic floor muscles through manual segmentation. The study of the biomechanical behaviour of pelvic floor muscles contributes to analyse this complex musculature structure (Janda et al 2003). These 3D solid models are discritezed to apply the Finite Element Method (FEM) (Parente et al. 2008).
The aim of this study is to simulate the contraction of pubovisceral muscle (composed of the pubococcygeal and puborectal muscles) using the finite element method on computational meshes based on MR images.

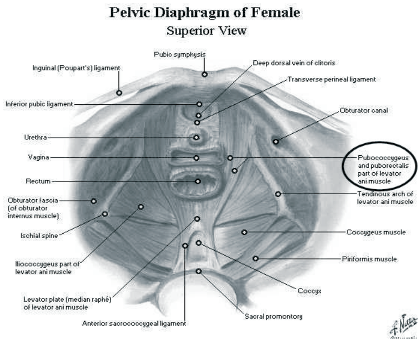


Figure 1: Pelvic floor muscles are located inside the pelvis.

METHODS: The study was performed in a 20 years old female athlete that practices synchronized swimming, and is asymptomatic and nuliparous. The MR images were acquired from the subject in a supine position, using a 3.0T system. Field view of the exam was 25×25 cm, 2mm thick with no gap. The subject was asked not to contract the pelvic floor during imaging. This study used twenty consecutive images obtained in the axial plane.
For the 3D model construction, the images acquired in format DICOM - Digital Imaging and Communications in Medicine - were converted into to jpeg format, with all dimensions of the initial image. After the preparation of images to use, one can start the construction of the model, using CAD software. Thus it is created a set of parallel plans, separated according to the value at which the MR images were obtained.
After editing the images, the process of building the model is initiated. We used a CAD (Computer Aided Design) software, to perform manual segmentation of the pubovisceral muscle (a part of levator ani muscle) in each image individually. In order to build the 3D model the images were grouped sequentially in space (this process can be seen in Figure 2).

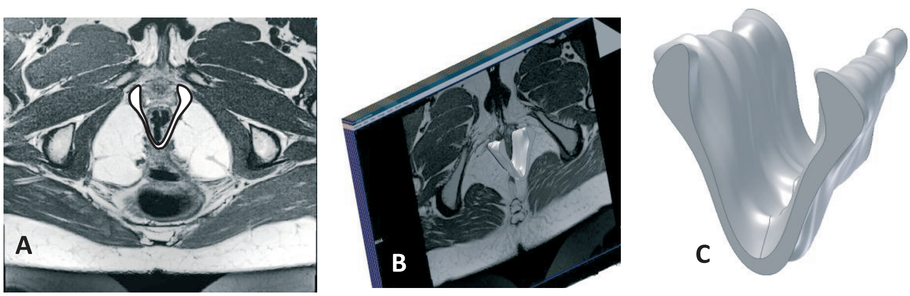


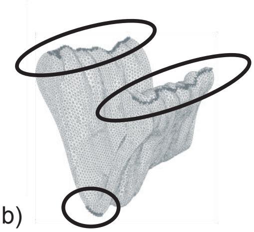
Figure 2: The construction of 3D solid models start with the drawing of the spline contour around the structure (a), then, all the images are linked (b), and finally, the 3D models are generated (c).

After the construction of the 3D solid, the model is saved in STEP – Standard for the Exchange of product model data - format and exported to the software of numerical

Portuguese Journal of Sport Sciences
11 (Suppl. 2), 2011

simulation “ABAQUS” to create the numerical model. The finite element mesh shown in Figure 3a was generated using ABAQUS finite element tool, and the analyses were made through the same software. The methodologies presented by D’Aulignac (2005) and Parente (2008) were followed.
After these procedures, the new numerical model is ready to be used in Finite Element Method simulations. For the simulation of the PF contraction the ABAQUS software was used based on a UMAT subroutine containing such formulation of the active muscle (Parente et al., 2009).
In order to simulate the intra-abdominal pressure, a distributed load of $1x10^{-1}$ MPa was applied – in ventral surface, and to try to simulate reality, the movement restrictions were applied in three regions. The first was held in the region where PF is linked to the coccyx, at the most posterior part, and the other two boundaries were applied to the upper lateral region of the muscle where PF is linked to the tendinous arch and the obturator fascia (right and left) as shown in Figure 3b. Once the bounddaries and the pressure where applied an activation of the contraction of the pubovisceral muscle, that ranged between 10%, 50% and 100%, was also applied.

a)



b)

Figure 3: In the left figure were ableto see the finite element mesh in the pubovisceral muscle, while in the right figure the circles demonstrate the boundary conditions that where applied in the coccix and the tops of laterals.

RESULTS AND DISCUSSION: In order to compute the final deformation of the pubovisceral muscle, three levels of forces were applied: 10%, 50% and 100%, been 100% the maximal contraction. The graph in Figure 4 represents the contour of the PF in the mid-sagittal plane. Furthermore we can see the displacement of the contracting process in the referred plane.

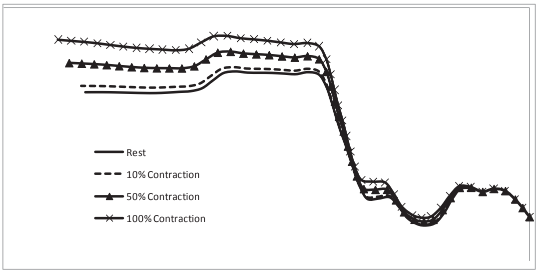


Figure 4: Simulation of contraction pelvic floor.

Note that the pubovisceral muscle manages to keep contractions at high levels as well as throughout its length. In the table below we can see the values of the displacements. These findings corroborate to the study carried out by Constantinou, who found similar values for the displacements experimental obtained in young women (3.5mm).

Table 1
Displacements average found in cranium-caudal direction in athlete women

	10% Contraction	50% Contraction	100% Contraction
Mean (SD)	0.20 (0.15)	0.93 (0.68)	1.69 (1.21)
Displacement (mm)	0.50	2.27	4.04

It is important to remember that awareness of the correct contraction of the PF is difficult to learn. The dynamic simulation models of the displacement of the pelvic floor may allow a dynamic analysis of its morphology and its relation to deformation. Thus, when a woman in physiotherapy treatment perform these contractions, theyshould be the strongest and the most consistent possible, that whay it would be possible to reach equal or similar values of displacements, like the values shown in the table above.

CONCLUSION: The present work shows a methodology that can be applied in the pelvic floor biomechanics. The constitutive law and parameters used here to compose biomechanics finite element analyses were adequate to simulate contraction in a pelvic floor in a 3D model. It may be possible to analyze the different behaviours of the contraction of the pelvic floor in distinct pathologies. Therefore the 3D models should be evaluated with the use of more models including different types of pathology and be compared with the medical findings on MRI.

REFERENCES:

Ashton-Miller J.A,. DeLancey J.O. (2007). Functional anatomy of the female pelvic floor. *Ann N Y Acad Sci,* 1101, 266–96.

BO,K. & Sherburn ,M. (2005). Evaluation of female pelvic floor muscle function and strength. *Physical Therapy*, Norway, 85; 269-82.

Bump, R. (1991). Assessment of Kegel pelvic muscle exercises performance after brief verbal instruction. *Am J Obstet Ginecol, Richmond,* 16, 322-28.

Bump R.C. & Norton P.A. (1998). Epidemiology and natural history of pelvic floor dysfunction. *Obstet Gynecol Clin North Am*, 25,723–46.

Bump R.C., Mattiasson A., Bo K., Brubaker L.P., DeLancey J.O., Klarskov P. et al (1999) The standardization of terminology of female pelvic organ prolapse and pelvic organ dysfunction. *Am J Obstet Gynecol,* 180, 299–305.

Constantinou C.E., Hvistendahl G., Ryhammer A., Nagel L.L., Djurhuus J.C., (2002). Determining the displacements of the pelvic floor and pelvic organs during voluntary contractions using magnetic resonance imaging in younger and older women, *BJU Int,* 90, 408-14.

Daneshgari F, Moore C (2006). Advancing the understanding of pathophysiological rationale for the treatment of stress urinary incontinence in women: the “trampoline theory”. *BJU Int,* 98,8–14.

DAulignac, J. Martins, Pires E., Mascarenhas T., Natal Jorge R. (2005). A shell finite element model of the pelvic floor muscles. *Comp Met Biomech and Biom Eng*, 8, 339–47.

DeLancey J.O.L. (1993) Anatomy and biomechanics of genital prolapse. *Clin Obstet Gynecol*, 36, 897

DeLancey J O L, Morgan D M, Fenner D E, Kearney R, Guire K, Miller J M, Hsu HH, Umek W, Ashton-Miller J A. (2007). Comparison of Levator Ani Muscle Defects and Function in Women With and Without Pelvic Organ Prolapse. *Obstetrics & Gynecology*, 109, 295-302.

Ghoniem G., Stanford E., Kenton K., Achtari C., Goldberg R., Mascarenhas T., Parekh M., Tamussino K., Tosson S., Lose G., Petri E. (2008). Evaluation and outcome measures in the treatment of female urinary stress incontinence: IUGA, *Int Urogynecol J Pelvic Floor Dysfunct,* 19, 5-33.

Janda, S. Vander Helm, F.C.T. Blok, S.B. (2003). Mensuring morphological parameters of the pelvic floor for finite elements modeling purpose. *J Biomech*, 36, 749-57.

Olsen, A.L. Smith,V.J. Bergstrom, J.O. et al. (1997). Epidemiology of surgically managed pelvic organ prolapse and urinary incontinence. *Obstet Gynecol,* 89, 501-06.

Parente, M.P.L. Natal Jorge, R.M. Mascarenhas, T. Fernandes, A.A. Martins, J.A.C. (2008). Deformation of the pelvic floor muscles during a vaginal delivery, *Int Urogynecology J*, 19, 65-71.

Parente M.P.L, Natal Jorge R.M., Mascarenhas T., Fernandes A.A., Martins J.A.C. (2009). The influence of the material properties on the biomechanical behavior of the pelvic floor during a vaginal delivery, *Journal of Biomechanics*, 42, 1301-1306.

Petricelli C.D.A. (2003). A importância dos exercícios perineais na saúde e sexualidade feminina, *Fisio e Terapia*, 24-25.

Wall N. (1993) The muscles of the pelvic floor. *Clin Obstet Gynaecol*; 36, 911–23.

Acknowledgement

The authors truly acknowledge the funding provided by Ministério da Ciência, Tecnologia e Ensino Superior – Fundação para a Ciência e a Tecnologia (Portugal) and by FEDER, under grant PTDC/SAU-BEB/71459/2006.