3D reconstruction of pelvic floor for numerical simulation purpose

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ABSTRACT: Female pelvic floor disorders (stress urinary incontinence, fecal incontinence, pelvic organ prolapse) affect approximately 60% of woman over 60 years old [1]. The real geometry and architecture of female pelvic floor and connective tissues are complex and difficult to visualize from two-dimensional (2D) images. To facilitate the understanding of pelvic floor geometry, in this work 3D models were building. A 3D helpful model of pelvic floor could aid the understanding of the anatomy and physiology of this complex part of the female body. These models were constructed from 2D medical images, obtained by magnetic resonance imaging (MRI).
The purpose of this study was to help the identification of pelvic disorders by using MRI scans and reconstructed 3D models. Three women were studied. Pelvic organs and their structures were manually segmented, namely: bladder, urethra, vagina, levator ani (puborectalis, iliococcygeus and coccygeus), obturator internus and pubic bone. 3D models of female pelvic floor were created from a combination between the individual organs, muscles and bones. Three 3D model created were compared and differences were noted between the pelvic floor 3D model of a woman with disorders and the 3D models without disorders.

Keywords: Women Pelvic Cavity, Numerical Simulation, Image Segmentation, 3D Reconstruction

1. INTRODUCTION

The pelvis, pelvic floor musculature and the associated structures comprise one of the most complex regions of the human anatomy.
Recent advances in magnetic resonance imaging (MRI) have allowed us to study the appearance of these regions in normal women and in the women with pelvic floor dysfunction (Fig 1).

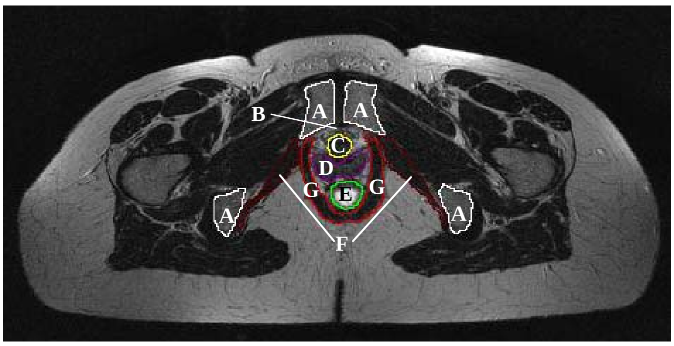

Figure 1 – Axial MR Image of the pelvic cavity.
A – bones, B – blader, C – urethra, D – vagina, E – rectrum, F – obturator internus, G – levator ani

The main objective of this work was to use a combination of axial MRI and three dimensional (3D) models to describe these differences.
Three different women were studied, two Egyptians and one Caucasian woman.
There were three steps to do this study. The purpose of the first step was to obtain familiarity with the anatomy of the levator ani subdivisions and determine characteristic features for each subdivision in each scan plan (Fig. 1). In a second step differences between the 3D models of the levator ani in obtained from the MRI scans of three women were identified. The construction of 3D model female pelvis constituted the third step.

2. MATERIALS AND METHODS

The pelvic floor 3D model construction was based on the three pairs of levator ani: the pubococygeus and the puborectalis and the iliococcygeus muscles, which described in the existing literature [4-6].
The levator ani muscles and muscular structures of the urethra comprise a system. These muscles are recruites during a cough to help prevent urine loss during stress. The coordinated action of these elements depends upon the central nervous system [2].

The pubococygeus and the puborectalis form a U shape (Fig. 2) as they originate from the inner surface of the public bone on either side of the middle and insert into the vagina. The iliococcygeus muscle forms a horizontal sheet that spans the opening in the posterior region of the pelvis between the pubococcygeus muscle, the posterior ilia and sacrum.

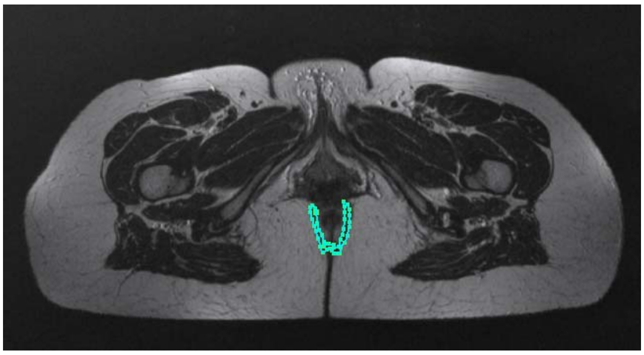

Figure 2 – pelvic floor muscles and structures

This information was used to construct five individual model muscle bans.
Two dimensional (2D) MRI has been used to assess the anatomy of the female pelvic floor.
The MRI data were manually segmented where relevant outlines of levator ani muscles were digitized from consecutive stretch (used the CAD Sofware - Autodesk Inventor 11).
The imported profiles were connected to do the render (lofted). The manual segmentation time was, approximately, 2 hours for each subject [3].
Three-dimensional surface models were generated (Fig 3) and the computer time for 3D model generation was approximately one hour per subject [3].
Three models (3D) of pelvic floor muscles was built (Fig. 3, 4, 5).
In the model of the Fig. 4 and 6 we can see an asymmetry in the levator ani.

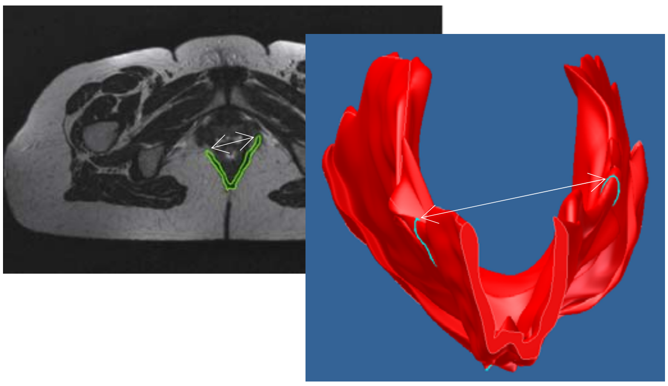

Figure 3 – 2D MRI and 3D Model of the levator ani (slices with thickness of 2 mm), asymmetry in the levator ani (Egiptian woman) – white arrow

Slice-by-slice was segment manually from each subject structures (Fig. 6 - a, b, c, d, e, f).
The MRI data of the Caucasian woman (slices with thickness of 5mm) was chooses to construct 3D surface models with levator ani muscles, obturator internus muscles, urethra, vagina, rectrum, blader and bones (Fig. 7).

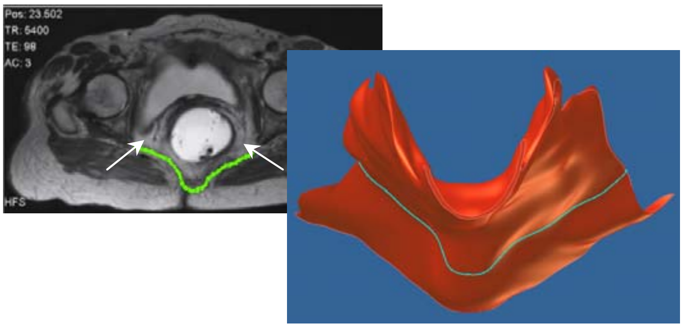

Figure 4 – 2D MRI and 3D Model of the levator ani (slices with thickness of 5 mm), asymmetry in the levator ani (Caucasian woman) – white arrows

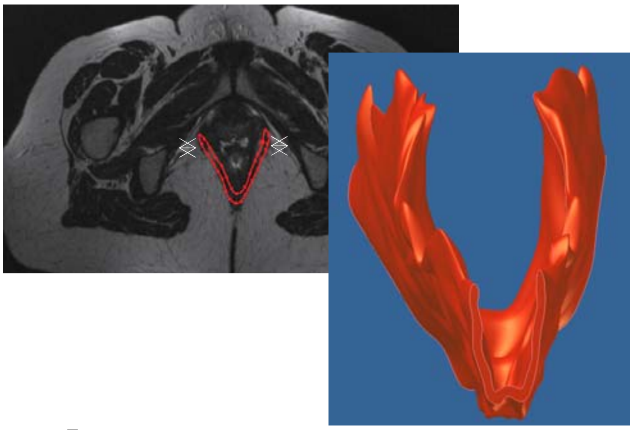

Figure 5 – 2D MRI and 3D Model of the levator ani (slices with thickness of 5mm), symmetry in the levator ani (control Egiptian woman) – white arrows

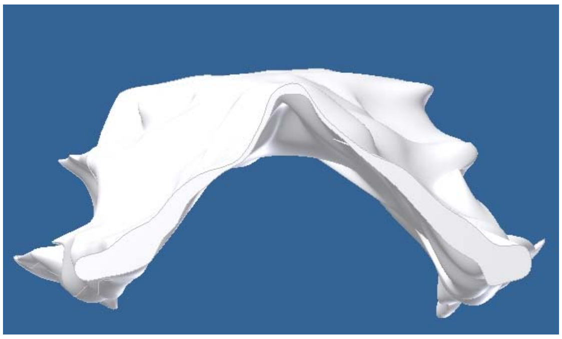

Figure 6a –Bones

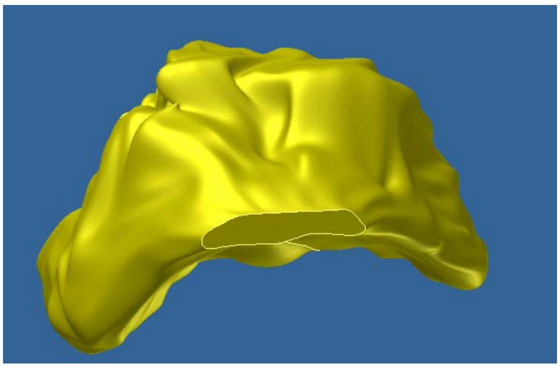

Figure 6b – Bladder

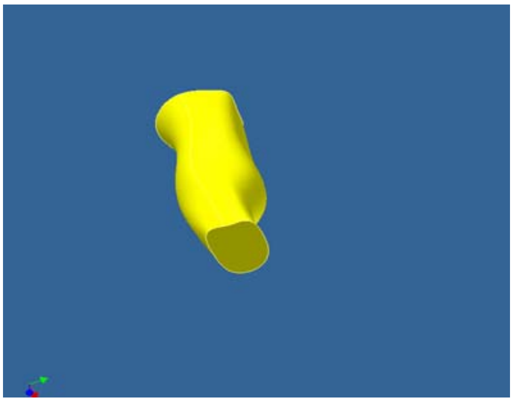

Figure 6c –Urethra

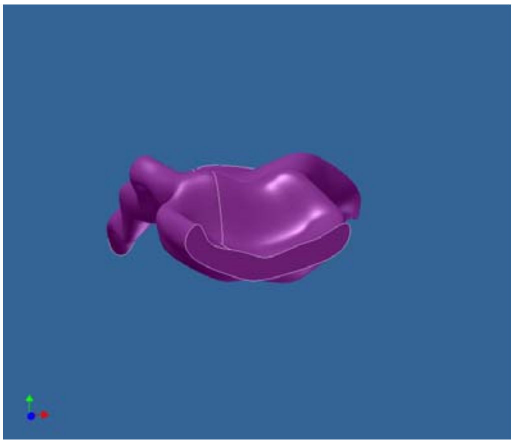

Figure 6d – Vagina

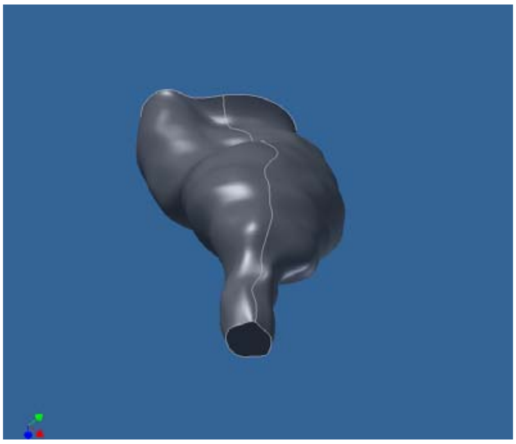

Fig 6e – Rectrum

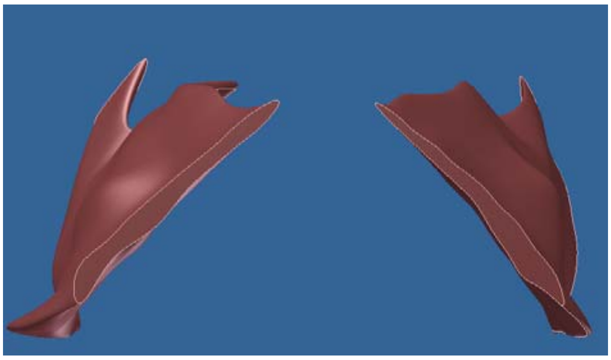

Figura 6f – Obturator internus muscles

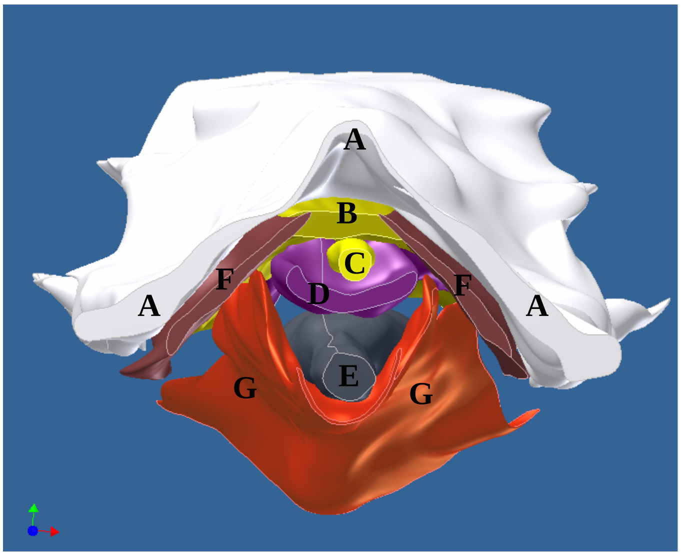

Figure 7 – Female pelvic floor 3D model. Color scheme: white=bones (A), yello (flat)=bladder (B), yello=urethra (C), purple=vagina (D), gray(dark)=rectrum (E), brown=obturator internus muscles (F), red=levator ani muscles (G)

3. RESULTS AND DISCUSSION

The 3D anatomy and geometry of healthy female pelvic floor derived from MRI images shows consistent signal intensity.

3D model reconstruction is feasible and can be used in a research setting to evaluate complex anatomy relationships which may help to identify pelvic floor dysfunction.

This methodology can also be used to evaluate levator muscle morphology and volume in a patient.

A larger study can be conducting to validate this technique and to better understanding the relationship between pelvic floor geometry and pelvic floor dysfunction.

4. FUTURE WORK

Neurophysiology of the pelvic floor is not completely understood yet. The importance of its symmetry and asymmetry of innervation has been pointed out. These facts have clinical relevance in case of pelvic floor trauma or incontinence surgery. Better reconstruction techniques of 3D model and 3D finite element models are necessary to help the specialists to confirm correlations between symptoms development and asymmetry of sphincter innervation.

It is proposed also as future case study, using the 3D reconstruction, the racial differences in pelvic morphology and geometry.

5. ACKNOWLEDGMENTS

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