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Biomechanical study on the bladder neck and urethral positions: Simulation of impairment of the pelvic ligaments

Sofia Brandão [a,*], Marco Parente [b], Teresa Mascarenhas [c], Ana Rita Gomes da Silva [c], Isabel Ramos [a], Renato Natal Jorge [c]

[a] Department of Radiology, Centro Hospitalar de São João—EPE, Faculty of Medicine, University of Porto, Alameda Prof. Hernâni Monteiro, 4200-319 Porto, Portugal
[b] IDMEC, Faculty of Engineering, University of Porto, Rua Dr Roberto Frias, s/n, 4200-465 Porto, Portugal
[c] Department of Gynecology and Obstetrics, Hospital de S. João, Faculty of Medicine, University of Porto, Alameda Prof. Hernâni Monteiro, 4200-319 Porto, Portugal

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ABSTRACT

Excessive mobility of the bladder neck and urethra are common features in stress urinary incontinence. We aimed at assessing, through computational modelling, the bladder neck position taking into account progressive impairment of the pelvic ligaments.

Magnetic resonance images of a young healthy female were used to build a computational model of the pelvic cavity. Appropriate material properties and constitutive models were defined. The impairment of the ligaments was simulated by mimicking a reduction in their stiffness.

For healthy ligaments, valsalva maneuver led to an increase in the α angle (between the bladder neck-symphysis pubis and the main of the symphysis) from 91.8° (at rest) to 105.7°, and 5.7 mm of bladder neck dislocation, which was similar to dynamic imaging of the same woman (α angle from 80° to 103.3°, and 5 mm of bladder neck movement). For 95% impairment, they enlarged to 124.28° and 12 mm. Impairment to the pubourethral ligaments had higher effect than that of vaginal support (115° vs. 108°, and 9.1 vs. 7.3 mm).

Numerical simulation could predict urethral motion during valsalva maneuver, for both healthy and impaired ligaments. Results were similar to those of continent women and women with stress urinary incontinence published in the literature. Biomechanical analysis of the pubourethral ligaments complements the biomechanical study of the pelvic cavity in urinary incontinence. It may be useful in young women presenting stress urinary incontinence without imaging evidence of urethral and muscle lesions or organ descend during valsalva, and for whom fascial damage are not expected.

1. Introduction

Stress urinary incontinence (SUI) and organ prolapse (Patel et al., 2007) have a significant negative impact on quality-of-life. The pathophysiology is multifactorial, including aging, hormonal changes from menopause, vaginal delivery and high parity, often in consequence of nerve, muscle or ligament direct injury, pelvic fascia or ligament collagen degradation (Patel et al., 2007).

As experimental work in vivo is very hard to implement, imaging evidence and biomechanical modelling (Dietz, 2004; Yip et al., 2014) have illustrated the role of striated pelvic floor muscles defects in urinary (in)continence and organ support. While they act by means of passive and active forces (Chamochumbi et al., 2012), the pelvic fascia and ligaments provide additional passive stabilization (Brandão and Ianez, 2013). Evaluating ligament biomechanics according to tissue *status* is relevant to understand SUI features.

Previous computer modelling focused on the normal pelvic mobility (Cosson et al., 2013). Also, in the context of pelvic organ prolapse, the vaginal and vesical position was evaluated considering muscle and apical support weakening and impairment (Chen et al., 2006, 2009; Yip et al., 2014). Results suggest that the extent of anterior vaginal prolapse is related to the degree of both muscle and uterosacral–cardinal support impairment. Simulating 90% and 60% of ligament and pubovisceral muscle impairment, respectively, led to a threefold increase in vaginal prolapse, which explains the vesico-urethral descent.

The role of (ab)normal apical support on vesical position is in this way modelled. However, to our knowledge, the role of pubourethral ligaments (PUL) was never included in such analysis.

Abbreviations: ATFP, arcus tendineous fasciae pelvis; IAP, intra-abdominal pressure; PUL, pubourethral ligaments; SUI, stress urinary incontinence

* Corresponding author. Tel.: +351 96 4089922.
E-mail addresses: Sofia.brand@gmail.com (S. Brandão), mparente@fe.up.pt (M. Parente), rita.mgs89@gmail.com (A.R.G. da Silva), iramos@med.up.pt (I. Ramos), rnatal@fe.up.pt (R.N. Jorge).

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The PUL are important urethral stabilizers that insert on the posterior surface of the pubic bone (El-Sayed et al., 2007; Kim et al., 2003; Petros, 1998), as shown on Fig. 1(a and b). When they suffer from injury or laxity (c–e), an increase in the retropubic space, bladder neck funneling and urethral hypermobility may occur (Pregazzi et al., 2002). As a result, "complaint of any involuntary loss of urine on effort (…)", as defined by the International Continence Society, may occur during events that result in increased intra-abdominal pressure (see Fig. 1f)—as for example, sneezing, coughing, defecating or during physical exercise. This is a common finding in patients suffering from SUI (Kim et al., 2003; Pregazzi et al., 2002).

In what concerns UI, and from a functional aspect, the PUL are critical structures, along with the paraurethral and vaginal tissue and the *levator ani* muscle. The structural degradation of the support structures such as the ligaments and fascia can be another ingredient to develop SUI, as stated by the Integral Theory (Petros and Woodman, 2008). If the mechanical properties of the ligaments induce their laxity, the backward force against the PUL and the downward force against the uterosacral and cardinal ligaments during valsalva may prevent muscles from effectively pushing the urethra against the pubic bone. On the other hand, injury models in rats such as urethrolysis or PUL transection have reproduced trauma, and results showed urethral hypermobility and long-term SUI (Kefer et al., 2008). For these reasons, by modelling the joint action of the PUL along with the apical support may add information on its contribution to (ab)normal bladder neck and urethral mobility, which are findings in young women presenting SUI, but with no evidence of organ prolapse or muscle damage.

Accordingly, the purpose of this work was to model, under a mechanical perspective, the effect of distinct levels of ligament impairment. For this purpose, we measured the bladder neck mobility and the changes in the α angle for valsalva maneuver using live subject MRI and a computational model based on the Finite element method.

2. Materials and methods

2.1. Subject and imaging

The Institutional Review Board approved this work (protocol: CES195/12).

A nulliparous 24-year female with no complains of pelvic dysfunction was the volunteer for the scanning session. A gynecologist observed her and no morphologic or functional abnormalities were found.

The volunteer was instructed on how to perform correct valsalva maneuver at two different time-points. First, a trained nurse and the gynecologist gave full instructions during clinic observation. Second, the nurse and an experienced physiotherapist on pelvic floor rehabilitation gave additional support during the scanning session. Several attempts were performed with the volunteer lying in the scanner table before the beginning of the acquisitions.

Magnetic resonance images were acquired in the supine position at rest using a 3.0 T system (Magnetom® Tim Trio, Siemens Medical Solutions, Erlangen, Germany) equipped with two (anterior and posterior) 6ch-phased-array RF coils. The woman lied in supine position with legs together in a semiflexed position.

Multiplanar pelvic high-resolution T2w fast spin-echo (FSE) images were obtained (TE/TR 96/3860 ms; 2 mm slices (no interslice gap); field-of-view 26 cm; matrix 384 × 384 and 3 NSA (number of signals averaged).

Additional dynamic images were obtained in the mid-sagittal plane, approximately every 1.6 s for 30 s using a half-Fourier acquisition single-shot turbo spin-echo (HASTE) pulse sequence (TE/TR 96/1600 ms; 6 mm slices; field-of-view 28 cm, matrix: 155 × 256 and 1 NSA).

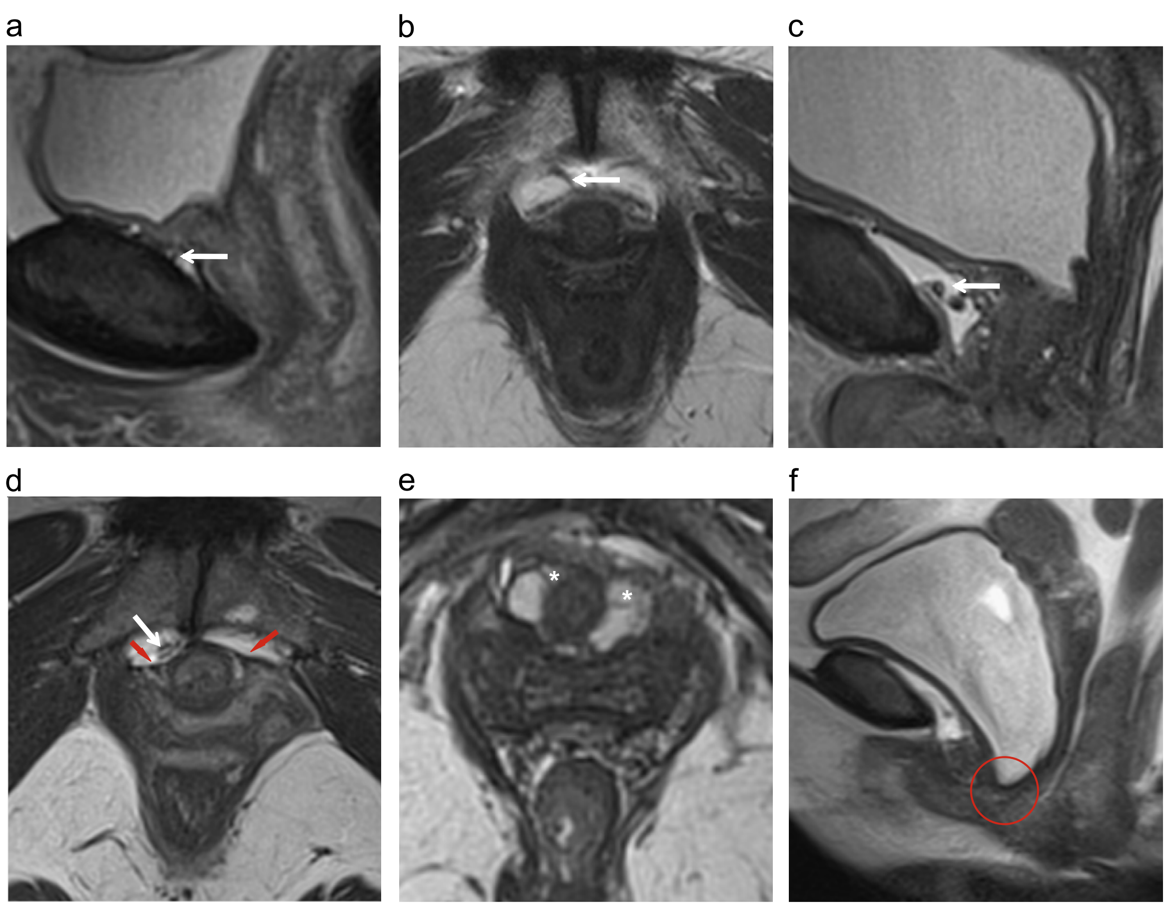

Fig. 1. Magnetic resonance imaging (MRI) of the support to the urethra and bladder. The pubourethral ligaments are thin hypointense bands that attach the bladder neck to the symphysis pubis. They can be seen in sagittal (a) and axial high-resolution images (b) (white arrow). Some women with stress urinary incontinence (SUI) show ligament distortion (c) and (d), and increased retropubic space. The position of urethra may not be maintained, as the peri- and paraurethral ligaments (red arrows on (d)) and (asterisks on (e), respectively) are not stretched tight, and urethral rotation may occur. Urethral hypermobility and bladder neck funneling (red circle on (f)) are shown during valsalva maneuver. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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