386

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THE ROLE OF PELVIC FLOOR MUSCLE (ACTIVE/PASSIVE) AND LIGAMENTS IN PREVENTION OF PELVIC ORGAN PROLAPSE: A NEW BIOMECHANICAL MODELLING

<u>Hypothesis / aims of study</u>

Female pelvic floor dysfunctions (PFDs) include a wide range of disorders like urinary incontinence, pelvic organ prolapse and fecal incontinence [1]. Biomechanical modelling conferred numerous capabilities to the researchers in finding the contributions of the tissues and the organs in quantifying clinical indices of the PFDs. Previous works strived to develop a model with further details in organ components and influencing factors, nevertheless, considered some components as rigid bodies in the finite element model [2]. Therefore, the aim of the present study is to develop a comprehensive model that considers the roles of the ligaments, passive/active components of the muscles within a parametric study of the pelvic floor. It was hypothesized that the activity of the muscles can compensate the pelvic organ prolapses (POPs) occurred due to the impairments of the members or imposed conditions to the subjects.

<u>Study design, materials and methods</u>

A finite element analysis was used to calculate the prolapse of the pelvic organs under different conditions. The model employed its geometry from the cloud point of the pelvis bone landmarks [3] for the attachments of the muscles, ligaments and organs as well. The muscles (pubococcygeus, puborectalis and deep transverse perineal) were modelled using shell membranes (non-compression) reinforced by spring elements as the muscle fibres (Figure 1).

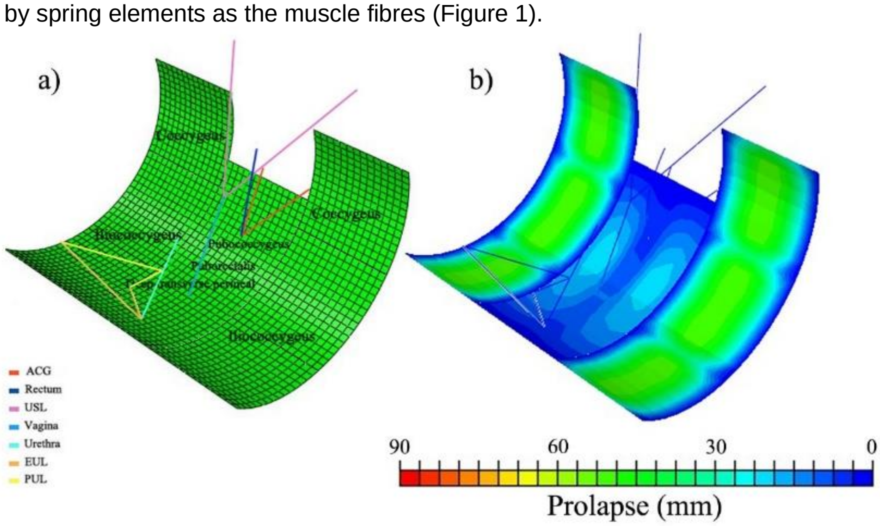

Figure 1. (a) Meshed model with Ligaments, Orifices & Muscles; (b) contour of the displacement in the model that represents the prolapse

The passive and the contractile properties of the muscles at different levels were assigned to these spring elements in the correct anatomical orientations as non-linear force-displacement data, according to

$$\sigma = \sigma_{Act.} + \sigma_{Pass.} = \sigma_{max} \,.\, \alpha \,.\, f(\dot{l}) \,.\, \sin(\pi[0.5 + \varepsilon]) + e^{-2.996 + 7.675\varepsilon}$$

where σ and ε denote the fibre stress and engineering strain values, σ_{max} is the maximum stress with magnitude of 50 N/cm^2. Also, α represents the muscular activation and $f(\dot{l})$ is the force term as a function of fibre contraction velocity force equals with the unit.

From pelvic floor ligaments only anococcygeal, uterosacral, external urethral and pubourethral were modelled with beam elements. The urogenital hiatus (urethra, vagina and rectum openings) were considered in the model by beam elements. Uniform intra-abdominal pressures (IAPs) were applied to the whole model in three levels from the normal condition of the pregnant cases. Four activation levels of the muscles (0, 30, 60, 90 %), three levels for the passive properties of the muscles (10, 50, 100 %), two impairment levels for the ligaments (0, 80 %) and three IAP levels (50, 100, 168 cm-H_2O) were taken into account to prepare total 41472 cases to be solved in an automatic series of finite element solutions (Abaqus, version 6.11) as shown in Figure 2. Displacements of the organ ducts were assumed as the POP measures.

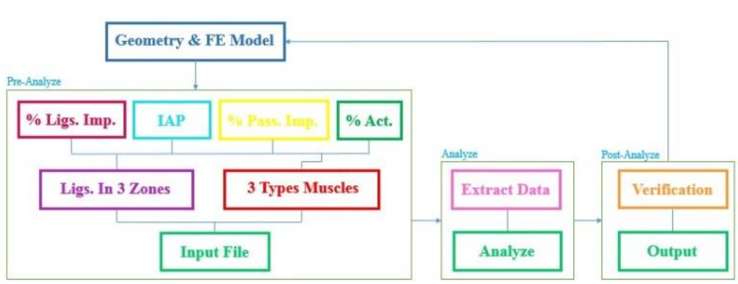

Figure 2. Flowchart of the study including automatic input data generation to be solved in Abaqus.

Statistical analyses were done using SPSS-16 software. The effects of different levels of the parameters, i.e. IAP, ligament impairment, passive properties of the muscle and voluntary contraction were evaluated using the ANOVA method regarding to the prolapses for the organ ducts of anterior, middle and posterior pelvic floor zones.

Results

Increased IAP had negative effects of pelvic floor and deteriorated POPs. Levator ani muscle (specially pubococcygeus) activation and its passive property had statically significant effects in the creation of the prolapses in all pelvic organs ($p = 0.000$). The impairments of the anococcygeal ($p = 0.000$), external urethral and pubourethral ligaments ($p = 0.000$) were also significant, but uterosacral ligament had no significant role in protection of the anterior prolapse ($p = 0.993$). For the middle zone prolapse, the impairments of the anococcygeal ($p = 0.031$), and the external urethral and pubourethral ligaments ($p = 0.000$) were also significant; however, the uterosacral ligament effect was insignificant with respect to the urethral prolapse ($p = 0.991$). The *p*-values for the posterior prolapse proposed significant effects of the anococcygeal ($p = 0.009$) and two ligaments of external urethral and pubourethral ($p = 0.001$) and non-significant effect of the uterosacral ligament ($p = 0.998$).

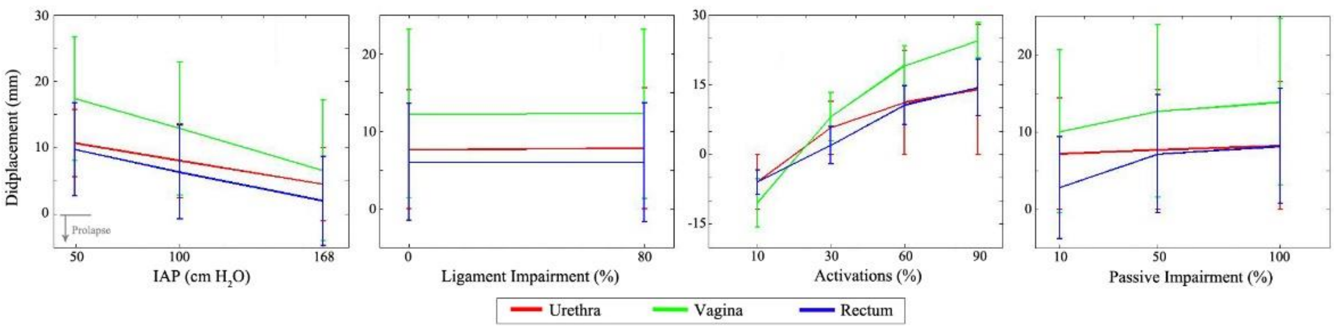

Figure 3. Plots of displacement-effective parameter in three zone of modelling.

Interpretation of results

The results of the analyses indicted that the major role to compensate the prolapse of the pelvic organs is owned to the muscular activation of the pubococcygeus muscle. Recruitment of the other two muscles was the next important factors to prohibit the POPs. The passive properties of the muscles were in similar contributions in anterior zone prolapsed, but the middle or posterior prolapses were significantly affected by the pubococcygeus muscle.

Pelvic floor ligaments' impairments played lowest role in the prevention prolapse by which is in contrast of the integral theory. On the other hand, the greater IAP magnitudes remarkably deteriorate the prolapse of the organs.

Concluding message

The IAP had remarkable effects on pelvic organ prolapses. The muscular activation can compensate the defects in passive properties of the organs or the ligaments impairments. In our knowledge this is the first study that modelled ligaments, active and passive muscles components in more than 41472 cases. Future studies will deal with developing a predictive equation to assess the effect of role-playing parameters including tendinus arc and urethral/anal sphincters and their crosslinks on the urethral, vaginal and rectal prolapses.

References

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Disclosures

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