Hyperelastic Constitutive Modelling of the Male Pelvic System to Understand the Prostate Motion, Deformation and Neoplasms Location with the Influence of MRI-TRUS Fusion Biopsy

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Abstract : Computational modeling of the human pelvis using the finite element (FE) method has become extremely important to understand the mechanics of prostate motion and deformation when transrectal ultrasound (TRUS) guided biopsy is performed. The number of reliable and validated hyperelastic constitutive FE models of the male pelvis region is limited, and given models did not precisely describe the anatomical behavior of pelvis organs, mainly of the prostate and its neoplasms location. The motion and deformation of the prostate during TRUS-guided biopsy makes it difficult to know the location of potential lesions in advance. When using this procedure, practitioners can only provide roughly estimations for the lesions locations. Consequently, multiple biopsy samples are required to target one single lesion. In this study, the whole pelvis model (comprised of the rectum, bladder, pelvic muscles, prostate transitional zone (TZ), and peripheral zone (PZ)) is used for the simulation results. An isotropic hyperelastic approach (Signorini model) was used for all the soft tissues except the vesical muscles. The vesical muscles are assumed to have a linear elastic behavior due to the lack of experimental data to determine the constants involved in hyperelastic models. The tissues and organ geometry is taken from the existing literature for 3D meshes. Then the biomechanical parameters were obtained under different testing techniques described in the literature. The acquired parametric values for uniaxial stress/strain data are used in the Signorini model to see the anatomical behavior of the pelvis model. The five mesh nodes in terms of small prostate lesions are selected prior to biopsy and each lesion's final position is targeted when TRUS probe force of 30 N is applied at the inside rectum wall. Code_Aster open-source software is used for numerical simulations. Moreover, the overall effects of pelvis organ deformation were demonstrated when TRUS–guided biopsy is induced. The deformation of the prostate and neoplasms displacement showed that the appropriate material properties to organs altered the resulting lesion's migration parametrically. As a result, the distance traveled by these lesions ranged between 3.77 and 9.42 mm. The lesion displacement and organ deformation are compared and analyzed with our previous study in which we used linear elastic properties for all pelvic organs. Furthermore, the visual comparison of axial and sagittal slices are also compared, which is taken for Magnetic Resource Imaging (MRI) and TRUS images with our preliminary study.

Keywords : code-aster, magnetic resonance imaging, neoplasms, transrectal ultrasound, TRUS-guided biopsy
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