Finite Element modelling of human pelvic organs and interactions: Analysis of prostate motion.

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Summary

Finite Element (F.E.) simulations of the pelvic organ motions and interactions have been developed, in the framework of the prostate cancer therapy. From a medical point of view, the aim of the predictive simulations of the prostate motion is the shrinking of the margins around the clinical target volume (C.T.V.) inside the gland during radiation therapy, in order to keep away the neighboring organs from any hazardous radiations.

Introduction

The external radiotherapy consists in irradiating with X-rays the affected cells in order to destroy them. Lately, the development of conformal radiotherapy allowed the delivery of larger doses to the Clinical Target Volume (CTV) without damaging the normal neighboring tissues. This advanced technique uses the same types of machines as the standard radiotherapy; the only difference is that a kind of diaphragm (beam limiter) is installed in the path of the radiation beam, so that it conforms better to the shape of the tumor.

Considering the prostate as the CTV, the problem of focusing the radiation accurately is even harder, given the uncontrollable motion of the gland. In this context, we propose a biomechanical model that simulate the pelvic anatomy and interactions and help to predict the prostate motion and location in real time (during the radiotherapy treatment).

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Method and results

The 3D Geometry of the pelvic organs is constructed using a CAD software from the set of points generated from the organ boundaries delineated on the CT images.

Experimental data related to the geometry (rectal and bladder wall thickness) and the mechanical behavior of the human pelvic soft tissues [1, 2] are reported from the literature. A large variation of properties can be noticed, hence we rather adopt an inverse method for the identification of the constitutive law of the bladder and the rectum (the prostate is considered as linear elastic with Young modulus E = 60kPa, [3]).

An hyper-elastic compressible third order constitutive Ogden model is adopted

$$\sigma = \sum_{i=1}^{3} \mu_i \left(e^{\varepsilon \alpha_i} - e^{-\frac{1}{2}\varepsilon \alpha_i} \right) \qquad (1)$$

The mechanical properties (moduli in table 1) are determined from an adjustment of simulated displacements to measurements, done in [4] on a deceased person.

Parameters	Rectum	Bladder
μ1 (MPa)	1.91e-08	4.37e-08
μ2 (MPa)	3.63e-03	1.17e-04
μ3 (MPa)	2.24e-03	4.45e-08
α1	1.36	3.77
α2	15	6.76
α3	4.16	1.12
Shell thickness	3mm	3mm

Table 1: Ogden moduli and coefficients as determined by the inverse method for the bladder and the rectum . Shell thickness is also mentioned.

Large displacements and strains are assumed. The boundary conditions are specified, specifically the distension pressures (3 kPa) for the bladder and the rectum.

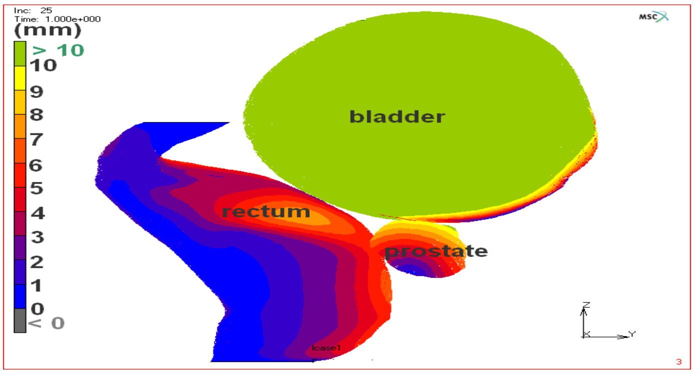

Figure 1: F.E. simulation results: isodisplacements

The current study is a new contribution of the biomechanical approach to the radiotherapy of the prostate, and the obtained results show the relevance of the Finite Element method for predicting the human pelvic organ motions and interactions. The model shows realistic trends of the prostate motion. More accurate experimental data, obtained from direct measurements, are needed to refine the simulations.

On the long term, these simulations shall be integrated into a robotic radiotherapy system, extending the existing collaboration between medical doctors, radiotherapy physicists, and mechanicals researchers.

Reference

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4 Rubod C., Boukerrou M., Mathias B. et al. (2007) : "Vers une modélisation du comportement de la cavité pelvienne" *CFM2007 Proceedings*.