

## Numerical and experimental study of the mechanics of Bladder filling process

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### ABSTRACT

The bladder is a very important organ and its main function is to store and release urine, which causes constant loading and volume change. The bladder wall is a smooth muscle reservoir that is capable of shrinking and expanding, depending on the volume of urine stored within it. Its movement has direct effect on the diagnosis and treatment of medical conditions of bladder and adjacent organs such as the prostate. It has been reported that the bladder filling have direct influence on the positioning accuracy of the prostate in a Radiotherapy or brachytherapy process. A detailed understanding of the liquid filling process within an *in vivo* condition is very important for studying their mechanics and interaction with other organs. In this work, a systematic approach has been developed based on realistic MRI subject data to study the deformation of bladder during filling. Experimental work on water filling with isolated balloon and bladder phantom has been performed and the results were used to validate a numerical finite element model. The approach was then used to simulate the deformation of the bladder within the pelvis system and the numerical results were compared to the volume–pressure curves during bladder filling *in vitro* and *in vivo*.

### INTRODUCTION

The human bladder is a typical hollow organ of thin membranes. Its main function is to continuously store the urine arriving from the kidneys (filling process) and, to completely void (micturition) [1]. It is a reservoir for accumulating urine from the kidney and it also contracts to eliminate urine, which is achieved through the shrinking and expanding of the smooth muscle in response to the volume of urine stored within it. The main functional data of a human bladder is the pressure-volume relationship, which is relevant to the daily function of the human body as well with many medical conditions such as urinary incontinence, prolapsed bladder and bladder cancer. A computational tool to simulate the filling process will also help improving the understanding of the firmness and compliance of the bladder. The filling process of bladder is directly relevant to several medical treatment process associated with the pelvic organs; one particular case is the radiotherapy treatment of prostate cancer [2]. Prostate cancer is one of the most common cancers in men with a high fatality rate among other cancer types. Three of the most common treatment methods for prostate cancer are chemotherapy [3], prostate surgery [4] and, the most common treatment method, radiotherapy [5]. One of the major challenges during radiation therapy is to minimise damage to normal cells, by delivering an adequate dose aimed and timed accurately to destroy tumour cells and spare the surrounding normal counterparts [6; 7]. However, there

are many factors that affect the position of the prostate during the course of the radiotherapy over a long period of time (over a period of about seven weeks) [8]. One of the main factors is the volume change of the bladder due to filling between the planning scan and the treatment periods [9].

### MATERIAL AND METHODS

The water filling process was tested in both isolated condition and within in a phantom of the pelvis system. The nonlinear material properties of the rubber sheet of the phantom were characterised using a novel inverse finite element (FE) modelling technique and the results were compared to micro tensile tests[10;11] The material properties predicted were then used to model water filling process of balloon mimicking the bladder filling process. A generic phantom has been developed resembling the structure of the pelvis system based on realistic three dimensional MRI images taken at the transverse, sagittal and coronal directions. The system is capable of continuously monitoring of the bladder filling processes and its effect on surrounded organs by measuring the movement of the bladder and the other organs. The validated program was then used to simulate the bladder filling process and its effect on the movement and deformation of other organs at different filling levels.

### RESULTS

A 3-D model has been developed mimicking the water filling process. The boundary conditions were assigned to

the ends of the balloon to avoid movement of the balloon in all directions during the balloon expansion after applying the pressure. A typical deformation field is shown in Fig. 1. The numerical results showed good agreement with the experimental measurements (Fig. 1(b)). Fig. 2 shows typical deformation of the bladder with two volume levels, which accurately predicted the shape change of the bladder, and the volume pressure relationship could be readily predicted. In addition, the key process and parameters such as the wall movement and pressure volume were established and showed good agreement with experimental data.

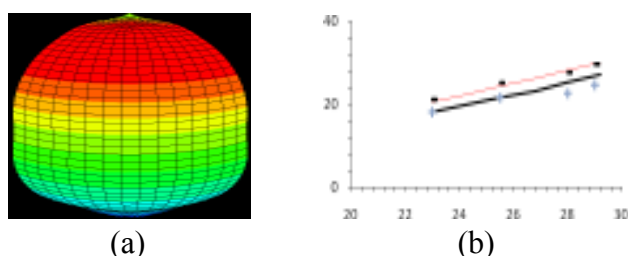


Figure: Typical deformation field during water filling process (a) and (b) Comparison of dimensional change of the water filled balloon (point) and the FE prediction (solid line).

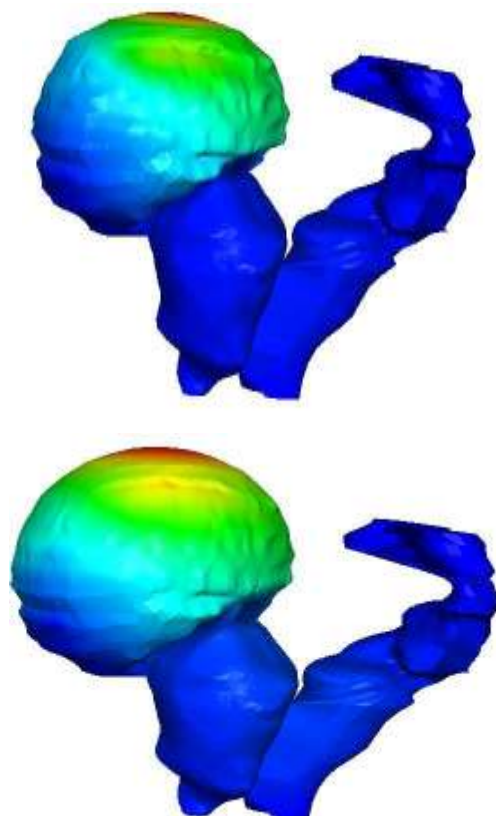


Figure 2: Deformation of the bladder during filling at different stages.

## DISCUSSION

The deformation of the bladder during filling is a complex process; a detailed understanding of this process has significant importance for many medical areas. The subject pressure-volume relationship prediction is important to establish the deformation of pelvic organs that is directly relevant to the prostate radiotherapy process. Moreover, the methodology established could also be used to study the bladder deformation in other issues relevant to the functions of human bladder in fields such as Urology, bladder cancer, ureter obstruction and bladder abnormality etc.

The two sets of data have different initial pressure value but with a similar trend for the stable filling process, which is relevant to the work to be modelled in this work. The difference in the initial pressure was probably due to the difference in subject's age, bladder shape, volume and bladder medical conditions as well in a cystometry tests. The combined experimental and numerical investigation represents a significant step forward from other published modelling works, where either used a simplified structure/geometry or loading condition.

The setup of the water filling tests of the balloon has provided important data to validate the modelling approach, which gave the confidence in the FE procedure and paved the way to use the program to simulate the bladder filling process within the pelvic system.

## CONCLUSION

In this work the filling process of bladder has been systematically studied. The testing with a phantom was validated by comparing the modelling results with experimental work. The validated program was then successfully used to predict the bladder deformation and the movement of the surrounding organs.

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