



Surface Representation of the Urinary Bladder and Bio-mechanical Analysis by Linear Dynamic Model

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Abstract. The biomechanical characterization of Urinary Bladder is essential to create new therapeutic tools as artificial tissue replacement or electrical stimulators. In this paper, we applied a linear model, the so-called viscoelastic Voigt's model to calculate the viscosity and elasticity in three regions of a bladder under the experimental condition of tensile stresses. Additionally, we acquired the tridimensional surface of urinary bladders by a cloud of points that were processed in digital format. Viscosity and elasticity are represented on the surface reconstruction. Three bovine bladders were processed with an average sample viscosity of 89.33×10^{-6} Ns/mm² and average elasticity of 1.3×10^{-3} N/mm, the isotropic condition was evaluated. The digital representation includes a cloud of points of 9×10^6 elements on average. These results are the base of a future computational simulation platform.

Keywords: Urinary bladder · Biomechanical modeling · Surface acquisition

1 Introduction

Urinary bladder (UB) is a hollow organ which stores urine (up to 400 mL), UB can keep pressure nearly constant due to the stress relaxation property of its wall [1]. The stress urinary incontinence (SUI) is a problem that affects the adult population. The involuntary loss of urine during coughing or physical activity is caused by weak pelvic floor or urethral sphincter. Developing new therapies requires the knowledge of mechanical properties of UB, for instance, the use of implantable electronic stimulators and the use of engineered tissue for substitution [2]. For this reason, it is necessary to develop methods for the calculation of biomechanical parameters of the tissue, that allows us to understand its behavior under mechanical stress condition. We propose a method to derive the biomechanical parameters of elasticity and viscosity for UB tissue under tensile conditions, considering a linear dynamic Voigt's model [3], this information is associated to the digital representation of the UB surface. The process

includes the sample preparation, the standardization of the capture routine, and the mechanical test conditions.

2 Methodology

2.1 Cloud of Points Acquisition of UB Surface

The experiments were run, using three male bovine bladders from an abattoir within less than two hours of slaughtering the animal. Bladders were frozen for transportation at $-2\text{ }^{\circ}\text{C}$. The defrosting occurred at room temperature for two hours. For each of the three experiments the bladder cleans and fills up with water up to maximum volume, then empties to distend. Connective tissue and adipose tissue were removed from the outer surface of UB. Bladder was continuously hydrated with saline solution at 0.9%. The organ is allocated over a solid three-dimensional base structure that emulates the anatomy of UB, such structure was designed and printed with Polylactic Acid (PLA). Marker points were added to the outer surface of the UB, two points on each region, separated 1 cm, to identify the part used for the tensile test. The point cloud of the bladder's surface was obtained using a 3D scanner EinScan-SE from SHINING 3D and the software EinScan-S series v2_7.0.6 installed in a Laptop with a RAM of 16 GB, i7 processor, graphic memory 4 GB NVIDIA with a spatial resolution of 0.2 mm. The cloud of points filled with a triangular mesh geometry. The mesh was configured with high resolution (0.17 mm) and sharpen texture, filled and saved as a 3D object.

2.2 Mechanical Characterization of the Tissue

We dissect the UB sample considering the methodology described in [1]. UB is divided in three parts: superior, middle and inferior, see Fig. 1a. We designed a template (Fig. 1b) to achieve size standardization of every sample cut from the UB with measures (test area of 150 mm^2 and a grip zone of 352.5 mm^2). The UB muscular tissue was dissected by placing the printed template (3D printed) over the tissue and cutting around it. Thickness of each sample is registered. The stress-strain testing involved a 200 N loads using a stress machine Univert by Cellscale TM, data acquisition occurred at a period of 1 ms. Stress-strain curves were obtained using Microsoft Excel and Mathworks Matlab a2017.

Mechanical Model and Parameter Identification. Voigt's model was used for the characterization of the UB mechanical parameters [3], with a viscosity parameter (η), parallel to an elastic component (E). The strain (ϵ) is considered the same for both elements and the total stress (σ) is the summation of independent stresses for each component Eq. (1). The transfer function of the differential equation is considered for the parametric identification Eq. (2), the data of stress and strain from the tensile test was used in the Identification System toolbox of Matlab for this purpose.

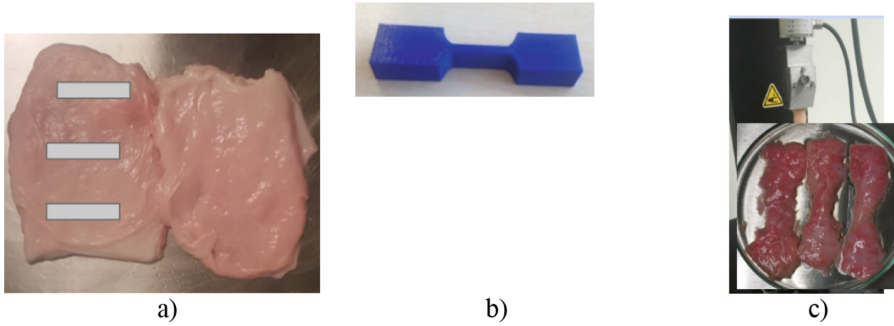


Fig. 1. (a) Dissection of the bovine bladder with a mark for each region. (b) template and obtained samples per region, (c) tensile test experimental setup.

$$\sigma = \sigma_E + \sigma_\eta = E\varepsilon + \eta \frac{d\varepsilon}{dt} \quad (1)$$

$$H(s) = \frac{\varepsilon(s)}{\sigma(s)} = \frac{1}{\eta s + E} \quad (2)$$

3 Results and Analysis

The surface reconstruction process is shown in Fig. 2. Figure 2a shows the UB before of the cleaning and distension process. The samples had an average maximum volume of 300 ml. Figure 2b shows the cleaned sample during the scanning, UB is allocated over a printed base of 200 ml capacity. Meshing the sample resulted in the reconstructed surface shown in Fig. 2c. We compare the measures from the digital representation with the real sample to assess if the reconstruction was accurate. Size of this UB resulted in $74.5 \times 126.32 \times 78.65$ mm.

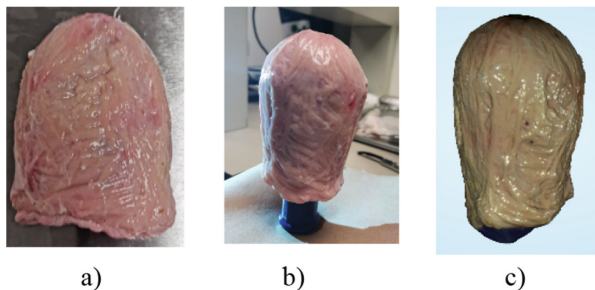


Fig. 2. (a) Sample organ cleaned and partially dissected. (b) UB allocated over a designed support. (c) Sample UB after meshing the cloud of points (6,355,097 points and 12,711,042 triangles). Marker points can be seen in the reconstruction.

After the scanning process, the samples for tensile testing were dissected as is shown in Fig. 1(a), one sample for each section of the bladder: upper, middle and the lower region are obtained, Fig. 1a. In Fig. 1b the printed template to cut the samples is showed, as well as the samples for each region. Figure 1c shows the tensile test experimental setup. To calculate the stress, the thickness is measured in order to calculate the cross-sectional area. This area has a value of 45.835 mm^2 on average. In Fig. 3 an example of the obtained stress-strain graphics is presented, as can be seen the tissue sample endured a maximum force of approximately 0.077 N/mm^2 with a displacement of 43 mm. After this point, the sample breaks, which is observed in Fig. 3 when the stress falls.

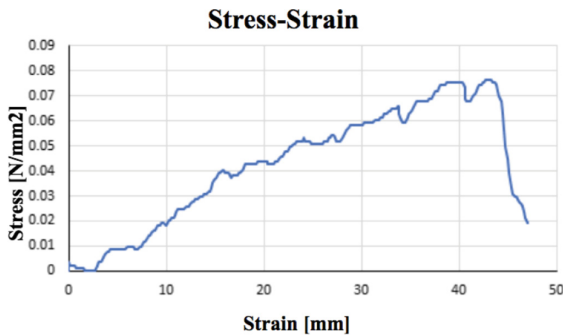


Fig. 3. Example of stress-strain graph for the tensile stress test for one of the tissue samples. After deformation of 43 mm, the stress falls, after the break point.

Stress and Strain time series were used by the system identification toolbox, we obtained elasticity (E) and the damping constant (η). We obtained that the lower region has the most elastic tissue ($1.76 \times 10^{-3} \text{ N/mm}$) of the three regions and the upper the most viscous one with $2 \times 10^{-4} \text{ Ns/mm}^2$, similar results have been found by other authors [4, 5], but with different magnitudes due to the use of porcine bladder instead of bovine. The average values of the samples resulted in $1.3 \times 10^{-3} \text{ N/mm}$ for the elastic constant and $89.33 \times 10^{-6} \text{ Ns/mm}^2$ for the viscos constant.

4 Conclusions

A cloud point of the surface bovine UB was obtained using tridimensional scanning, it was possible to reconstruct the UB surface. The viscosity and elasticity parameters were characterized for tissue samples of bladder, using a linear dynamic mechanical model; the lower region had the most elastic tissue, and the upper region the most viscous, under isotropic conditions. A current research is carried out considering the anisotropy of the tissue and, frequency response.

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