NUMERICAL MODELS OF THE URETHRAL LOWER DUCT

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1. Introduction

Most lower urinary tract pathologies, such as hyperplasia, stricture or urinary incontinence are treated using medical device that strongly interact with the urethra. Knowledge of its mechanical behaviour can improve the design of new devices and development of bioresorbable stents made of polymeric materials. Rabbit urethra tssue is similar to human urethra (histomorphometric features). In this paper male New Zealand (NZ) white rabbit urethra was investigated. The horses urethra was investigated by Natali et al [1]. Male human urethral tissues were tested and modeled in paper [2] and the rabbit tissues [3]. The present investigation entails histological, experimental and numerical results (mechanical behaviour) for a proximal and distal regions of the urethra.

2. Materials and methods

Mechanical parameters of tissues were determined for 7 urethra resected from male NZ white rabbits and all the animals were intact and clinically health. Each urethra was divided into 2 sections (proximal, distal regions of the length 8mm). Tensile tests on tubular urethra samples were performed (closed ring). Stress-strain curves were developed and regression was performed. The mechanical properties are defined by the Ogden 2 parameters isotropic hyperelastic model (homogenized mechanical properties). Compared to the other material models (Mooney-Rivlin, Neo-Hookean, Polynominal form), the Ogden option usually provides the best approximation to a solution at larger strain levels. The applicable strain level can be up to 700 percent. Non-linear least squares problem was solved and material constants were appointed (Proximal section: $\mu_1=0.0005$, $\alpha_1=6.4191$, $\mu_2=61.984$, $\alpha_2=6.421\text{x}10^{-5}$; Distal section: $\mu_1=-0.4036$, $\alpha_1=-0.0041$, $\mu_2=-0.4036$, $\alpha_2=-0.0041$). The urethra section is defined from histological image with particular regard to the lumen section. The geometrical model is imported into the finite element software ANSYS Mechanical APDL 16.2. An example of a proximal section of the intact urethra is presented in Fig.1. A two-dimensional solid model of the urethra was discretized with the use of PLANE182 element. It is defined by four nodes having two translations at each nodes. Plane stress element behaviour is assumed. Numerical analyses simulating inflation state are performed for proximal and distal urethras sections. Maximum intraluminal pressure for the rabbit urethra equals 4kPa [3].

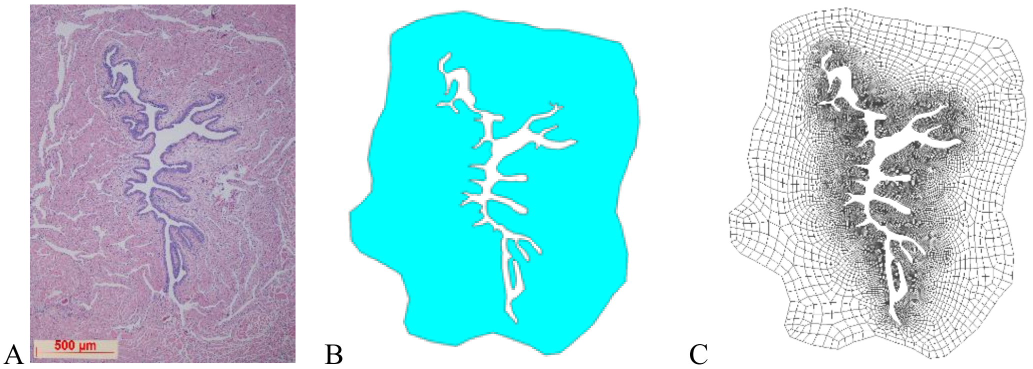

Figure 1: Rabbit proximal urethra-transverse section: (A) trichrome histological section (magnification x40), (B) geometrical model, (C) two-dimensional finite element model.

3. Numerical results

The strains field (Cauchy strain tensor) was calculated for the internal pressure in the range 0-4kPa. The numerical analysis of inflation tests allows evaluating the urethras mechanical behaviour in intraluminal state. The first Cauchy strain ε_1 is presented in Fig.2A. Tensor components versus pressure are reported in Fig.2B. Measurement of strains was made at the point marked with an arrow. For the maximum pressure the first maximum Cauchy strain equals 117%. The second Cauchy strain equals -54%.

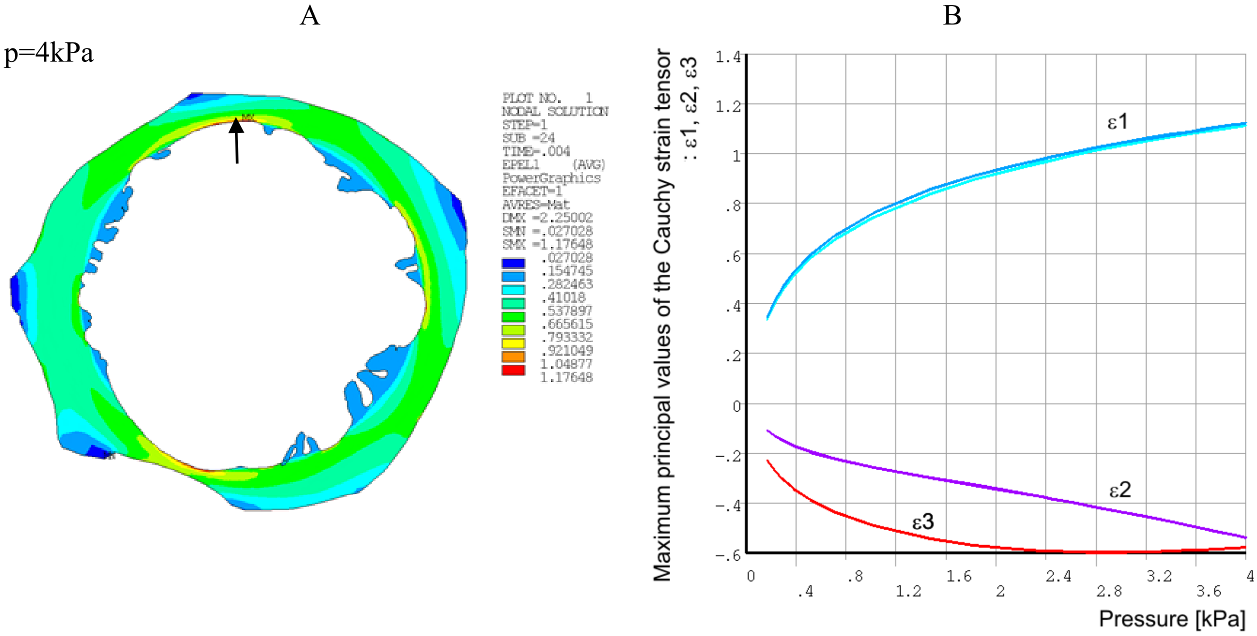

Figure 2: Numerical results of intraluminal pressure test: (A) contours strain field ε_1 for p=4kPa, (B) maximum principal values of the Cauchy strain tensor.

4. Conclusions

Evaluation of histological and mechanical properties of the urethra in animal models enables preliminary assessment of the change of deformation field values. Large strains have been identified in the tissue, which change non-linearly as a function of intraluminal pressure. The luminal cross-section area (CSA) increased several times. The interaction between the highly deformable tissue and a potential polymeric material (stent) is the goal of further works. The next steps of researches will numerical modeling of a urethra stricture and inflammation state and interaction with polymeric materials.

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