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Prototyping of a human bladder model using SLS and mold casting for in-vitro simulation of the transurethral resection of the prostate

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Abstract: This work presents a fabrication method for an elastic urinary bladder model with near-physiological mechanical and thermal properties using Rapid Prototyping. The model is part of an experimental setup for in-vitro simulation of the Transurethral Resection of the Prostate (TURP). Tensile tests of commercial silicone elastomers, together with FEM simulations were used to find a suitable material for the Bladder-model. A mold was then fabricated by selective laser sintering and the model was manually casted. The mechanical compliance of the finished model shows a reasonable agreement with the predicted behavior, with a max. discrepancy of 15% at 40 mbar.

I. Introduction

Transurethral resection of the prostate (TURP) is the gold standard for surgical relief of bladder obstruction due to benign prostatic hyperplasia (BPH) [1]. During TURP, high-frequency vaporization of the excess prostate tissue is performed layer by layer with an electrode. The energy dissipated by the electrode increases the temperature of the irrigating fluid and the surrounding tissue. This is a primary concern regarding patient safety, and cannot be easily measured *in-vivo*. At the same time, the pressure of the irrigating fluid in the bladder (saline solution) can reach 60-70 mbar, leading to typical bladder volumes of approx. 500 ml and quasi-spherical shapes [2]. Temporary occlusion of the fluid outlets at the resectoscope are common, and lead to fluctuations of the bladder volume during surgery. This in turn influences the flow patterns in the system and the heat transfer to the tissue.

The wall of the human bladder consists mainly of a smooth muscle layer with an average thermal conductivity of 0.522 W/m*K [3] and a wall thickness in men with BPH around 3.5 mm [4].

For better understanding of the thermomechanical effects during TURP, an experimental *in-vitro* model has been built at the TH-Lübeck in cooperation with Olympus Winter & Ibe GmbH. An essential improvement to the current model is the implementation of an elastic bladder with thermal and mechanical properties similar to those of real tissue. In addition, the new model should be transparent or translucent to allow for quantification of the gas accumulated in the bladder during resection. In this work, a fabrication method for a silicone bladder model is presented and the agreement with physiological parameters from the literature as well as with FEM-simulated values is evaluated experimentally.

Usually, silicone parts are manufactured by injection molding, requiring expensive and time-consuming tooling for the molds. In this work, 3D-printing was used instead, allowing for cost effective, fast and flexible realization of the mold.

II. Material and methods

The complete TURP simulation setup is shown in Fig. 1. It consists of an urinary bladder and a prostate model, immersed in a thermal bath at 37°C. Pressure and temperature sensors are installed at physiologically relevant locations. The measurements are carried out using porcine tissue inserted into a cylindrical sample holder.

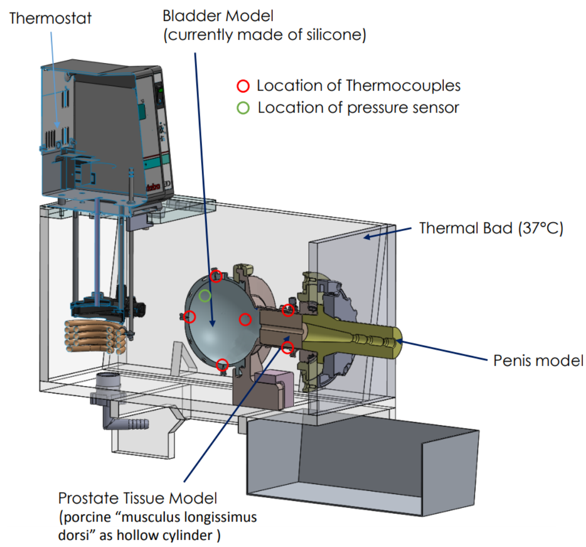

Figure 1: Simulation model for thermal analysis during TURP

Considering the information from the literature (see section 1), a hollow spherical shape out of silicone rubber, with a wall thickness of 3.5 mm and an initial volume of 250 ml was chosen for the bladder model. Since the average thermal conductivity of commercial silicone rubbers is around 0.200 W/m*K, higher temperatures than

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during real surgery may be expected while using the *in-vitro* model. Besides, heat transfer to the surroundings is also affected by the temperature and the forced convection in the thermal bath. A validation of the experimental setup on an animal model is thus needed, and will be carried out in the near future.

The mechanical properties of seven commercial 2K silicone rubbers (RTV-2) with Shore A hardness from 0 to 45 were tested according to DIN 53504. The deformation of the bladder model expected during TURP-measurements is within the linear elastic range for all considered silicones. Therefore, the stress-strain curves were used to obtain the corresponding modulus of elasticity, and mechanical FEM-simulations were then carried out using an isotropic, linear-elastic material model. As a result, a Zhermack's silicone ZA8 was chosen for the new bladder model. This silicone rubber is translucent, has a modulus of elasticity of 0.06 MPa and lead to a simulated mechanical compliance within reported physiological values (see Fig. 3).

The CAD model of the bladder was used to create a 3-part casting mold for a single hemisphere. The mold was manufactured by SLS printing of PA12. The internal surfaces of the mold were grinded (grit 600 and 1200) and polished to increase the final transparency of the model. Vaseline was used as a release agent, as well as to close remaining pores of the material. Two identical silicone hemispheres were casted with the mold and cured for 4 hours at 50°C. After demolding, the two halves were bonded together with Wacker E43 silicone adhesive.

The compliance of the model was measured by evaluating the fluid volume as a function of the static pressure by varying the relative height of a water-filled container connected to the model with a flexible hose. The volume change of the hose itself can be neglected.

III. Results and discussion

The proposed method successfully produced an elastic urinary bladder made of silicone (Fig.2).

Figure 2: Urinary bladder model made of silicone with connections for thermocouples and venting on the surface.

Fig. 3 shows the pressure-volume curves from the actual compliance measurements, compared to those of the FEM-simulations and the physiological values from the literature [5,6]. The behavior of a human bladder varies considerable from patient to patient and depends on age and clinical picture. During TURP, only the model response at medium and high pressures between 30 and 70 mbar is relevant. In this range, the largest discrepancy between simulated and measured volumes is 15 % at 40 cmH_20, which is smaller than the variability observed in physiological data.

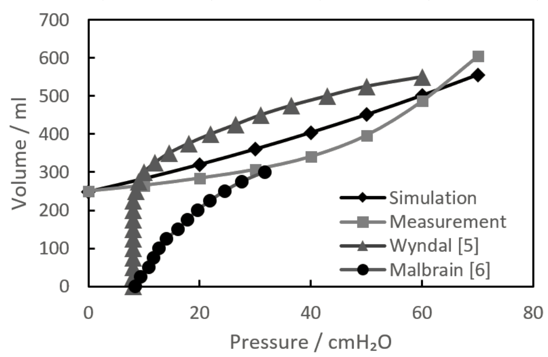

Figure 3: Urinary bladder volume as a function of pressure. Simulation / Measurement (Zhermack ZA8) and Literature [5,6]

A better agreement between simulated and measured values could be obtained by using a non-linear material model for the FEM simulations - such as Neo-Hook or Mooney-Rivlin - together with experimental measurements of the biaxial stress-strain behavior.

The next steps are the thermomechanical characterization of the complete *in-vitro* model and its clinical validation in an animal trial.

IV. Conclusion

Rapid Prototyping enabled a cost-effective and flexible fabrication of an elastic silicone bladder model with realistic physiological behavior, which can be used to simulate the thermomechanical conditions during transurethral resection of the prostate.

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AUTHOR'S STATEMENT

Authors state no conflict of interest

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