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Indirectly additive manufactured deformable bladder model for a pelvic radiotherapy phantom

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Abstract: The increasing variance in imaging radiotherapy demands the use of deformable phantoms for validation or quality assurance as well as for general training. This paper describes the development and manufacturing of a deformable urinary bladder model that can be implemented in a radiotherapy pelvic phantom. The advantages of additive manufacturing (AM) are used to produce an anatomically realistic mold, as well as a dissolvable core. The casted silicon bladder has different wall thicknesses which show realistic deformation behavior compared to a human bladder.

I. Introduction

Prostate carcinomas are the most common malignant tumor diseases in men. In addition to surgical forms of treatment, the tumor can be treated with radiotherapy. In this case, the whole prostate is irradiated uniformly in several sessions. Special care must be taken to ensure that neighboring organs at risk, such as urinary bladder and rectum, receive as little radiation dose as possible. In recent years, targeted radiation of the tumor within the prostate has been increasingly investigated [1]. Due to the smaller and optimized target volume compared to conventional treatment, the continuous determination of the tumor position during irradiation is all the more important. However, daily volume variations of bladder and rectum cause changes in position of the prostate, which can be monitored using different imaging modalities. Therefore, a deformable pelvic prostate phantom can enable comprehensive quality assurance of the entire radiotherapy procedure.

The developed pelvic phantom includes various organs, such as bone, urinary bladder, rectum, prostate as well as surrounding tissue [2]. The materials used are chosen to allow multimodal imaging of the phantom with computer tomography (CT), magnetic resonance imaging (MRI), and ultrasound. The phantom needs to be constructed in such a way that when the urinary bladder and rectum are filled, the position of the prostate changes. For this purpose, the urinary bladder should be able to expand up to twice its volume. A prerequisite is therefore an anatomically correct form and expansion which can be achieved using additive manufacturing (AM). The development, manufacturing and simulation of an anatomical bladder model with realistic deformation for a pelvic phantom is the purpose of this work and will be described in the following.

II. Development of a bladder model

There are two manufacturing options for producing models or phantoms using additive manufacturing [3]. On the one hand, the desired model or part of the model can be produced directly with AM, and, on the other hand, indirect production can take place via a mold construction (see Fig. 1). The latter is used when a mold or mold inserts of the phantom are manufactured using AM. Material requirements for imaging only have an influence in direct manufacturing, whereas they play no role in the indirect manufacturing of a mold. In order to manufacture a bladder in a shape which has the same anatomical deformation as a human bladder, an indirect manufactured is chosen in this work.

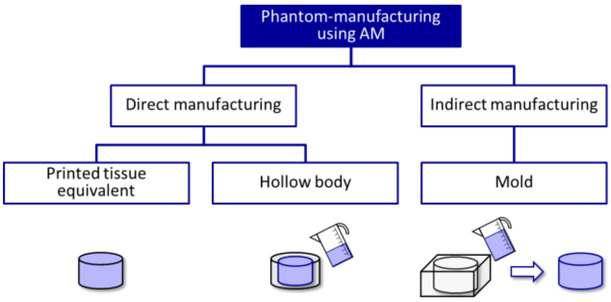

Figure 1: Types of phantom manufacturing using AM (based on [2])

To generate an anatomical bladder, medical CT scans of a prostate cancer patient were collected and segmented. The STL model of the bladder is then equipped with three perforated straps, each of which has two holes, and are

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placed along the symmetry axes of the bladder. The holes will be used for the attachment of the bladder to the positioning system inside the phantom, which allows to reproduce specific bladder positions. Before the bladder model is then placed in a CAD mold as a negative mold, the wall thickness and the realistic deformation are determined using a simulation.

Anatomic bladder deformation is simulated in *Autodesk Inventor*, where boundary conditions and internal pressure were applied to the 3D model. In addition to the compressive stress, two fixed bearing conditions were added to the outer surfaces of the lateral connectors. Only the inner surface was adjusted to mimic the anatomical behavior, whereas the outward geometry was kept constant. The procedure is iterated until satisfactory deformations with an appropriate bladder shape could be simulated and compared to literature results [4]. The resulting wall thickness is shown in Fig. 2.

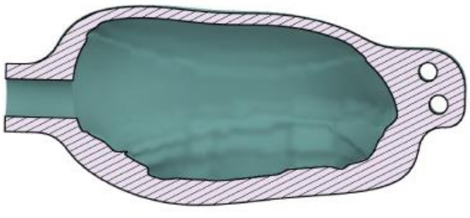

Figure 2: Sagittal section of the final bladder model.

The outer mold for manufacturing the bladder wall consists of two parts which can be joined together and contain the negative mold of the urinary bladder, as shown in Fig. 2. The outer mold is fabricated using a stereolithography process (SLA), which allows one to produce the models layer by layer from a liquid synthetic resin that hardens under UV light. In this work, the SLA printer Form3 by Formlabs, Somerville, USA with a clear resin was chosen.

Since a hollow bladder with a wall thickness of 2-3 mm (cf. Fig. 2) is to be produced, a core that can be dissolved is also required. Wax, gelatin, chocolate or washable high-impact polystyrene (HIPS) as well as polyvinyl alcohol (PVA) can be used for the core. However, melting or washing out can leave residues that are difficult to remove. It makes sense to use a material that can be additively manufactured without having to use an intermediate positive mold to form the negative. Due to the higher dissolution rate of PVA, this filament was chosen for the core. The core was then manufactured in two parts, that were joined after printing, with a fused deposition modeling (FDM) process, by using the I3 Mega S printer by Anycubic, Shenzhen, China. A gyroid structure is placed in the core interior to promote washout. The core is assembled after printing and fixed via a plane in the outer mold halves. In a next step, the mold was closed and secured with the help of screws (cf. Fig. 3). For producing the bladder wall, a two-component silicon (RTV2 Shore hardness 33 by Silikonfabrik.de, Germany) that crosslinks at room temperature was then used. To ensure that the flow is clearly visible during casting in the transparent mold, the silicone was colored with blue pigment. After the silicon was cured, the mold was disassembled. The PVA core was finally dissolved using warm water which was injected into the interior of the core. The resulting urinary bladder can be seen in Fig. 3.

Figure 3: Assembled bladder mold (left) and silicon model of bladder wall (right).

III. Results and discussion

The bladder model was integrated in the pelvic phantom and, through the opening, could be filled with different water volumes. Using CT scans of each filling and overlapping each bladder, the deformation could then be analyzed. Overall, the silicone bladder shows the stretching behavior that was predicted in the simulation, with a larger extension in the cranial than in the caudal direction.

IV. Conclusions

AM has great potential for the construction of anatomical models and phantoms for medical use. In this paper, AM is used to manufacture a urinary bladder with realistic expansion. Different AM processes (SLA and FDM) are used for the mold and dissolvable core. The designed bladder model consists of silicon with different wall thicknesses and mimics anatomic deformation. The successful implementation of the bladder, filled with different water volumes, in a pelvic radiotherapy phantom could be evaluated via CT imaging.

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AUTHOR'S STATEMENT

Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study.

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