Three-Dimensional Models and Simulation Tools Enabling Interaction and Immersion in Medical Education

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Abstract. The article proposes the creation of a library of clinical cases generated from images of minimally invasive procedures, which will enable students to experience immersive way of performing procedures enabling the implementation of a Biodesign Lab in Medicine, which will bring real cases (initially in the domain of obstetrics and cardiology) as a premise, to the virtual world, hands-on learning and experimentation of advanced technologies based on a multidisciplinary and active participation of physicians and computing engineers, experiencing and sharing experiences.

Keywords: Virtual reality · 3D modeling · Visual simulation · Minimally invasive surgery · Noninvasive diagnostic methods

1 Introduction

New forms of interaction and access to technologies previously available only to large technology centers are increasingly close to the everyday reality of the common user. Technological development has altered several practices in healthcare, covering activities such as diagnosis, treatment, management and education, and requiring the development of new skills by professionals.

Rare diseases or invasive procedures are critical in medicine because trial is limited to the number of cases, often incurs risk of life, and little training material is available. Considering the long learning curve in medical education, it is undeniable the contribution of three-dimensional models and simulation tools enabling interaction

A. Marcus (Ed.): DUXU 2015, Part III, LNCS 9188, pp. 662–671, 2015.
DOI: 10.1007/978-3-319-20889-3_61

and immersion closer to reality. Knowledge is constructed seeking information and exploring data as it existed. The minimally invasive treatment of heart disease, for example, is a lengthy process and it is very difficult to achieve the ideal positioning of medical devices such as stents. This is because the visualization process to be 2D, using fluoroscopy, while the procedure is in real 3D. Simulation of these procedures will aid the physicians when implementing this training activity.

In this context, the article proposes the creation of a library of clinical cases gene - rated from images of minimally invasive procedures, which will enable students to experience immersive way of performing procedures enabling the implementation of a Biodesign (http://www.ccbs.puc-rio.br/index.php/pesquisa/laboratorio-biodesign) Lab in Medicine, which will bring real cases (initially in the domain of obstetrics and cardiology) as a premise, to the virtual world, hands-on learning and experimentation of advanced technologies based on a multidisciplinary and active participation of doctors and computing engineers, experiencing and sharing experiences.

In cardiology, 3D physical model of the thoracic aorta and the transcatheter aortic valve implantation was chosen as a clinical case. The use of physical models in fetal research, an area in which there are few studies on digital modeling also has introduced. The result suggest a new possibility in the interaction between parents and fetus during prenatal care, physically recreating the uterus during pregnancy, showing the actual size of the fetus, as well as its anatomy. In the next sections these clinical cases are described.

2 Clinical Cases in Cardiology

The first experiments were conducted in order to understand the difficulties found during the endovascular procedure and how to produce physical 3D models could be useful in educational terms and, ultimately, for the purpose diagnostic. After performing the Computerized Tomography (CT) angiography of the aorta, and an images segmentation process, the 3D model was built by the physical rapid prototyping technique [1, 2] and a virtual simulation of the route taken by catheter into the aorta was done. This is a non- surgical alternative for aortic valve replacement in patients with aortic stenosis - taught considered unsuitable for surgery. The self-expanding transcatheter valve bioprosthetic, CoreValve has been widely used from the worldwide.

2.1 3D Physical Model - Thoracic Aorta Prototype

In order to demonstrate the possibilities provided by three-dimensional technologies, images of the thoracic region of a patient using multi-slice CT were obtained. Initially we selected the case of an aneurysm of the abdominal aorta patient, classified as complex due to anatomical reasons. The aortic aneurysm is a dilation of a segment of blood vessel. These images were handled to select only the region of interest, obtaining a three-dimensional digital model of thoraco-abdominal and thoracic aorta (Fig. 1). Thereafter, a physical model was made using additive manufacturing.

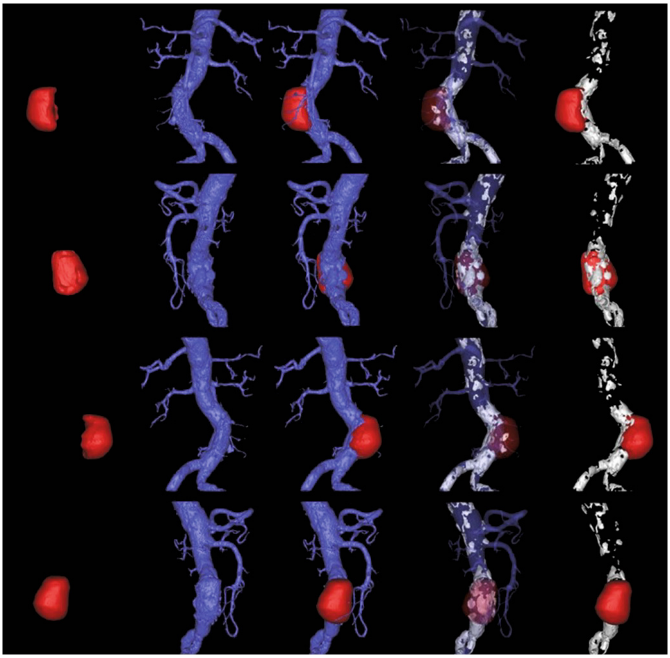

Fig. 1. A sequence of 3D software protocol was developed to target the aneurysm with high fidelity and to create a flexible aortic 3D prototype.

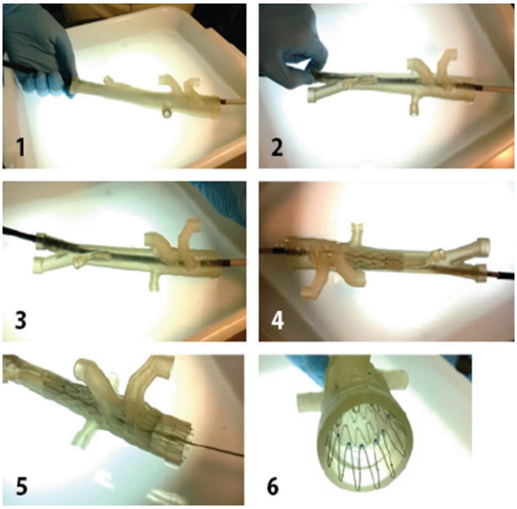

Fig. 2. Endovascular Procedure

The assay was made in order to understand the difficulties encountered during the endovascular procedure and how 3D physical model could be useful in training and, ultimately, for diagnostic purposes.

To test the viability of the aorta prototype (Fig. 2), we simulated the endovascular procedure, positioned the guide wire (Fig. 2 – number 1, 2 and 3) and insert the stent up to the desired level for their release. (Figure 2 – number 4 and 5) After the withdrawal of the guide wire, the prosthesis had been completely deployed and well positioned (Fig 2 – number 6). The procedure was a success.

2.2 A Virtual Simulation of the Route Taken by Catheter into the Aorta

In cardiology, the transcatheter aortic valve replacement – TARV, was chosen as a case study. Once a particular exam was selected, a written informed consent from the patient was obtained. The present study was registered at the National Council for Ethics in Research (CONEP), from the Brazilian Ministry of Health.

The TARV procedure has a long learning curve. Tridimensional tools, like physical models and virtual simulations may, in the near future, perform an important role in this learning process [3, 4].

An angiography-CT of the aorta was performed by Somatom Sensation 64 × 0.6 mm CT scanner (Siemens Inc., Germany). The DICOM images were transferred to the software Mimics® (Materialise, Belgium) and the aortic lumen was selected. An image segmentation process was performed as show in Fig. 3.

A physical 3D model was built by the rapid prototyping technique, using the Stratasys uPrint equipment (Stratasys, USA) with ABS plus material. This includes physical modeling of the aortic root, coronary arteries, ascending aorta, aortic arch and descending aorta.

A virtual simulation of the route taken by catheter into the aorta was implemented using the software 3ds max 2014 (Autodesk, Inc., USA). The physical and virtual model represents the patient-specific anatomy. Figure 4 shows the start of the virtual navigation process in a segment of the abdominal aorta. Figure 5 represents the lumen of aortic arch. At the top right of the image is shown the catheter in the lumen of the aorta.

After validation and reproducibility analysis, this process can be presented as a pre-step procedure to add accuracy and safety to the real transcatheter aortic valve replacement. Probably, using this procedure, it may be possible to detection of aortic diseases, like aneurysm, marked tortuosity and atheroma plaque. Thus with the VR, the doctor can navigate along the route taken by catheter into the aorta, made possible a close analysis of reality making the surgical planning or decision-making more effective.

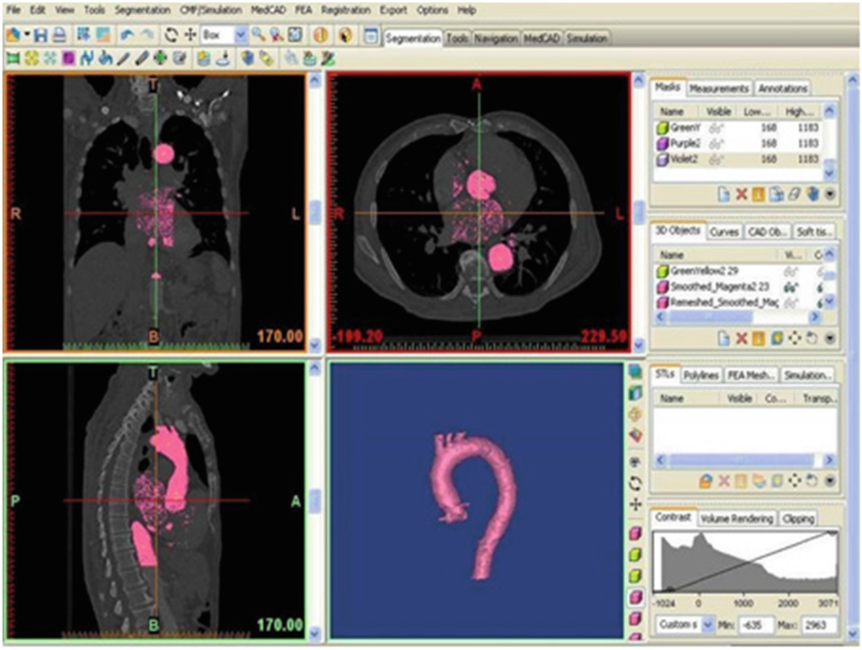

Fig. 3. Segmentation process performed in Mimics® (Materialise, Belgium)

Fig. 4. Navigation process performed in abdominal aorta

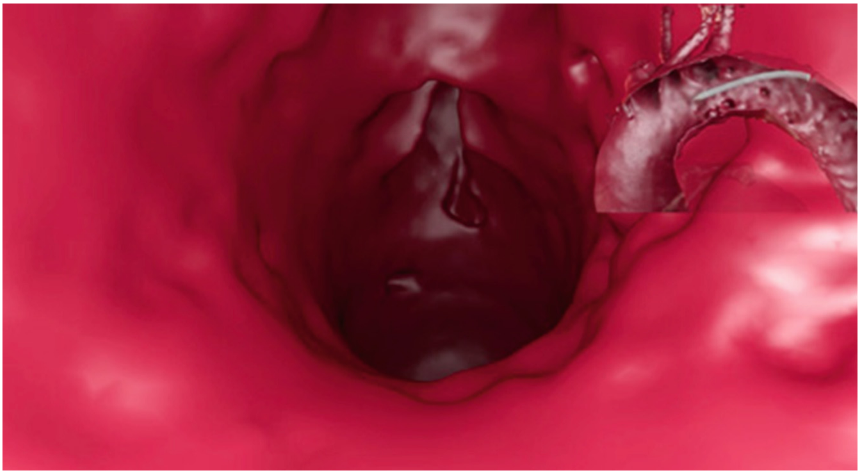

Fig. 5. Navigation process performed in the lumen of the aortic arch

3 Clinical Cases in Obstetrics

3.1 Virtual Bronchoscopy for Evaluating Cervical Tumors of the Fetus [5]

The objective was to investigate the use of magnetic resonance imaging (MRI) with virtual bronchoscopy (VB) to evaluate fetal airway patency in four fetuses with a cervical tumor (three lymphangiomas and one teratoma).

Cervical tumors (Fig. 6), although uncommon, create unique circumstances for the management of pregnant women, and are a serious medical dilemma. Although the incidence of congenital tumors is low, ultrasound (US) is effective for identifying fetal tumors [6]. Estimation of the degree of tracheal compression or distortion allows multidisciplinary planning for delivery and neonatal resuscitation [7]. Magnetic resonance imaging (MRI) with virtual bronchoscopy (VB) can provide information about the fetal airway [8].

The aim of this case was to investigate the use of MRI with VB for evaluating fetal airway patency in four fetuses with a cervical tumor.

The examinations were performed between 26 and 37 weeks gestation. All 4 fetuses were examined by ultrasound and MRI on the same day. No other fetal abnormalities were detected. MRI was performed using a 1.5-T scanner (Siemens, Erlangen, Germany). A 3D file of the airway was created by overlapping layers generated by MRI. The 3D files were converted into an OBJ extension using the 3D modeling software MAYA (Autodesk, USA). This allowed the virtual positioning of observation cameras while working with multiple windows. Using the indoor and outdoor lighting features, 3D simulation movies were generated for analysis of a virtual path.

The main outcome was the creation of 3D virtual airway paths (Fig. 7) on all fetuses and VB was successfully carried out on each case. In all 4 fetuses there was absence of invasion, compression or distortion of the trachea. Thus the MRI with VB could become a useful tool for studying fetal airway patency in cases of cervical tumor.

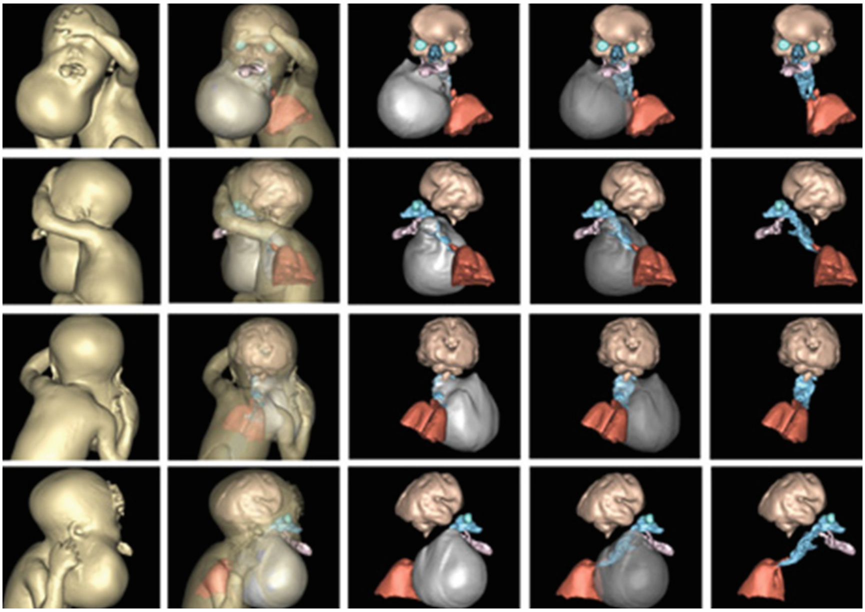

Fig. 6. Cervical teratoma, 33 weeks. 3D view of the fetus and tumor

3.2 Additive Manufacturing Models of Fetuses Built from 3D Ultrasound (3D US), Magnetic Resonance (MR) Imaging and Computed Tomography (CT) Scan Data [6]

In this study the main outcomes presented were the possibility to create 3D virtual models from 3D US, MR or CT both separately and also in various combinations. Additive manufacturing systems allow the conversion of a 3D virtual model to a physical model in a fast, easy and dimensionally accurate process [9, 10]. Additive manufacturing (AM) is the automatic, layer-by-layer construction of physical models using solid freeform fabrication.

A key concern of this study was obtaining high-quality images that could be manipulated with 3D software without loss of accuracy [11]. Fetal movements during image acquisition are one of the principal difficulties. This is less of a problem with ultrasound as the real time image can be frozen during a movement unlike MR imaging. However the lower contrast resolution with 3D US can cause difficulties at gray scale boundaries. Image quality is directly associated with the precision of the final virtual 3D mathematical data that will be used to generate the prototype. Images from medical scans are acquired by "slicing" the physical body. Superimposition of the captured slices from 3D US, MR or CT results in construction of a virtual 3D CAD (computer-aided design) model. The additive process begins when the virtual 3D CAD model is sliced in layers that are used to guide the deposition of materials, layer by layer, to generate a physical 3D model [11, 12].

The construction process transfers a 3D data file that specifies surfaces and solid internal structures to AM equipment that builds physical models through the superimposition of thin layers of raw materials 14. This study introduced the use of additive manufacturing models into fetal research, an area where studies on digital 3D modeling have been scarce. The results suggest a new possibility for interaction between parents and their unborn child during pregnancy, by physically recreating the interior of the womb during gestation, including physical appearance, actual size and malformations in some cases.

The techniques described in this study can be applied at different stages of pregnancy and constitute an innovative contribution to research on fetal abnormalities. We believe that physical models will help in the tactile and interactive study of complex abnormalities in multiple disciplines. It may also be useful for prospective parents by recreating a 3D physical model with the characteristics of the fetus that allows a more direct emotional connection to the unborn child [13, 14].

Physical models have been used in fetal medicine for teaching purposes, but to the best of our knowledge, no examples are known that apply contemporary physical modeling technology to their production [15, 16]. Combining the different image modalities of 3D US, MR and CT may result in an increase in the interaction of both medical doctors and parents with the growing fetus, for educational and even future diagnostic purposes.

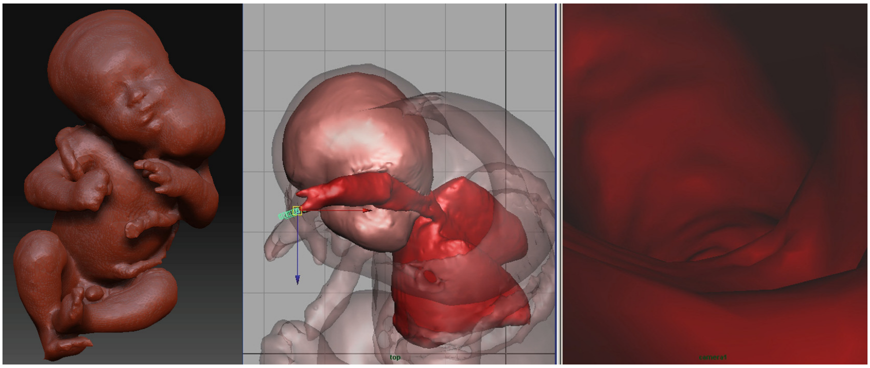

Fig. 7. Virtual bronchoscopy, 34 week fetus with cervical teratoma.

4 Conclusion

The visualization of internal anatomical structures provides substantial advances in the medical field through diagnostic imaging, reducing the subjectivity of diagnosis and taking the right treatment. These models generated in the described clinical cases help plan minimally invasive interventions and provides a great knowledge of the anatomical dimensions, facilitating the learning of health professionals. These features, when combined with additive manufacturing, creates new opportunities for scientific research and new teaching techniques in health care. The models used in cardiovascular area, for example, for in vitro test new devices and procedures generally consist on prototypes of animal origin or craft, which do not represent true human anatomy.

The increasing technological development in obtaining and viewing images trough non-invasive technologies has brought great advances in medicine, especially in viewing the fetus.

Based on our results, we believed that physical models would help in the tactile and interactive study of many medical disciplines. These techniques may be useful for prospective parents, especially visually disabled parents, as they recreate a 3D model with the physical characteristics of the fetus, as allowing a more direct emotional connection with the unborn baby.

The Virtual Reality (VR), which offers advanced interfaces capable of providing the user immersion in environments with which you can interact and explore, has permeated the area of health, bringing new possibilities for three-dimensional modeling and simulation. The feasibility of reproducing real situations without risk to patients, cost savings due to reduced use of physical objects and the ability to model, simulate and visualize impossible actions to be perceived in the real world are reasons for that VR applied to health constitutes an area of increasing interest.

If on one hand this scenario is enabling the emergence of innovative applications and new modes of interaction, on the other hand the use of 3D modeling in Medicine is still nascent. There is still relatively little knowledge about the best techniques to implement and evaluate the use of these environments, as well as how this form of interaction can benefit different application domains that are still limited by conventional interaction techniques based on the type WIMP interfaces (Windows, Icons, Menus and Pointing device), but the first step to create the clinical cases library was performed.

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