3D vessel modeling for diagnosis and training

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***Abstract*—Patient specific knowledge of hepatic segmental anatomy is essential to liver therapy and surgical planning. Contrast enhanced computed tomography (CT) is the predominant 3D imaging modality for non-invasive analysis due to its ability to highlight the intra-hepatic vascular network, and distinguish tumor from normal parenchyma. In this clinical context, computer-aided tools can assist diagnostic and therapeutic planning for liver diseases. This leads to a simple three-dimensional visualization of the organ, its vascular system, and the tumor position. The surgeon uses this information during the pre-operative phase to plan the operation. The purpose of this work is to pose the basics for the development of a semi-automated system for the realization of low-cost, deformable, patient-related organs (or part of them) to be used for pre-operative planning and surgical training.**

I. INTRODUCTION

A specific planning procedure for tumor resection is a real challenge in oncological liver surgery due to the enormous individual anatomical variability [1]. The liver has a complex internal anatomy consisting of three different vessel systems and the biliary ducts. This intricate three-dimensional configuration makes liver resections a challenging operation. A transection of any of these structures leaves a part of the liver without supply or drainage causing, in the worst case, the death of the patient. However, as introduced by Couinaud in [2], the liver is built on individual anatomical segments, which allow the surgeon to resect specific parts of the liver while maintaining intact its functionalities [3]. This schematic classification divides the liver into eight different segments according to the branching structure of the portal and the hepatic vein. It is a useful tool for surgeons since it allows a better understanding of the intervention environment.

Currently, in addition to the anatomical knowledge, various tools are available for planning a surgical operation. Surgeons can use 3D volumetric rendering (e.g. coming from CT) of the specific area or its physical realistic model that can be bought from synthetic organ manufacturer. The former is a promising tool since it allows a more direct comprehension of the organ's anatomy and so have a more clear planning ability. Despite this, commercially available synthetic organs do not always correctly represent the patient-specific anatomy. To improve surgeon's planning capability a more precise tool has to be produced.

In the following, the different stages for the realization of a low-cost patient-based 3D physical deformable models of the liver's vessel are presented. Figure 1 is depicted a schematic view of the process used. This model is a first step toward the realization of a full organ that can be used for diagnosis and training. The importance of these results can be identified in the reproducibility of the cast anatomical structures (also without the need for expensive 3D printers) and the possibility of having a more realistic surgical mock ups.

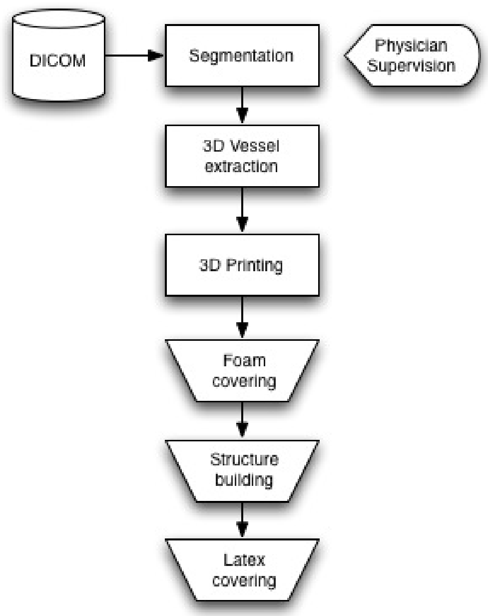

Fig. 1. A schematic view of the realization process. The rectangle shape indicate unsupervised automated action, while trapezoid ones are executed manually by a human operator.

II. MATERIALS AND METHODS

For simplicity, we considered a non-pathological liver CT data from which we are interested to extract the vessel' structure. We performed a segmentation by applying a set custom-designed MeVisLab [4] block-functions. The first step consist in the identification of the vascular system (made both by vessels and arteries) with its branches. This was done manually by identifying some seed points for the region growing like algorithm. An experienced physician gives as input the few parameters that control the algorithm evolution and acts as a supervisor of the system (i.e. he/she validates the output of this phase). Figure 2 shows the results of the output of this phase.

The result is then used to create a virtual representations

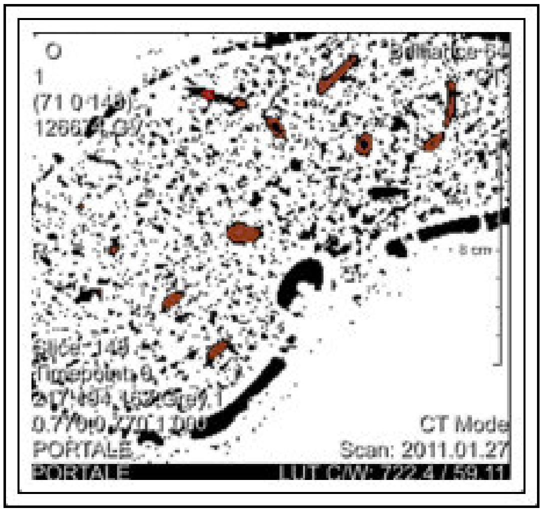

Fig. 2. Output of the region growing segmentation. In the figure the dark area is the liver profile, the red area identifies the vessels segmentation. The white is identify as image background and it is not taken into consideration during the analysis.

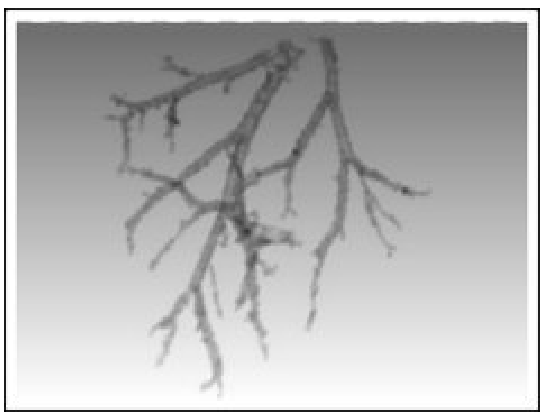

Fig. 3. The 3D visualization of the segmented vessels.

of patient anatomy (Fig. 3). It can be used to provide to the surgeon a immediate visualization of the liver's vessel structure. It can be further processed and can be directly used as input for any standard stereo-lithographic printer. This allow to obtain a patient-specific physical rigid model that can be used for planning the surgery. However, due to their stiff structure they can not be used during training. In fact, to effectively support training, the models have to reproduce the physical behavior of real vessels, and deform under the application of external forces given by surgical tools. Thus the synthetic organs should be built with soft materials.

The idea is to retrieve a modular structure from the rigid model previously made and then cover each section with foam rubber. This step allows to obtain a semi-rigid structure that can be placed in shape, with an adequate support system (e.g. metal wires placed within the structure), and permit a easier extraction once the covering material is dry. It is important to chose the most suitable material that will be used to obtain the final model. Among the available ones, we used Prochima's

Fig. 4. The casted model. A 3D latex model.

natural pre-vulcanized latex [5]. Due to the complexity of the structure of the liver's vessel tree (it branches along different planes), to prove the concept, we used a simplified version of it that includes only few branches.

III. Results

The results of the segmentation and 3D model extraction are encouraging. They have been validated by an expert radiologist and thus confirming the correctness of the process. The model obtained by following the presented procedure, although its simplicity, has given promising results. In figure 4 is presented a prototype of the simplified vascular system. The method used to cast the model and the material used have been demonstrated to be suitable to reproduce the structure of the vessels and to ensure their vascularity. Different physicians have considered useful having such model to be used in pre-operative phase, unlike this further analysis related to their usage have not yet been done.

IV. Conclusion and Future Works

Traditional surgical planning uses volumetric information stored in a stack of intensity-based images coming from computerized tomography (CT) or similar imaging methods. The surgeon then uses specific software that displays 2D slices of the volume leaving the surgeons in charges to build its own mental 3D model. This is a difficult task even for experienced surgeons. To help their mental process and to allow them to exhaustively explore the operational area, physical 3D patient-based model can be useful. In addition to this, the models can be used to train surgeons on peculiar situation.

In this paper we proposed a technique for fast prototyping of low-cost, patient-based 3D soft model that can be used during training and pre-operative planning. Starting from CT data, we segment and reconstruct a 3D volumetric model of the liver's vessel system. From that we build a modular structure and then produce a simplified deformable model.

As future work we are interested in considering the realization of the more complex model, i.e. the full liver's vessels tree. In order to archive this goal a (semi-)automatic method, that identify the branches of the vessel, is needed. Its output will help us in the realization process and allow us to produce a more realistic anatomic model.

Acknowledgment

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