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SYNAPSE 3D USER'S VOICE 03
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Smart surgery using Synapse 3D for pre-operative planning

Peyman Sardari Nia, MD, PhD
Department of Cardiothoracic Surgery
Maastricht University Medical Center, the Netherlands

Introduction

Surgical procedures are comprised of many technical steps and their outcomes are dependent on the skills of individual surgeons and the anatomy of the individual patients. This is reflected by a plethora of studies showing an association between surgical volume and outcomes across all the surgical sub-specialties.
The surgical volume is in fact a surrogate marker of surgical skills and cumulated experience to address the variability in the individual anatomy of patients subjected to the same surgical procedure. Indeed even experienced surgeons acknowledge that the most routine surgical procedure can exhibit variable difficulties based on the individual anatomy of the patients. Surgical discipline has been in balance between art and science. As in art it is the craftsmanship and uniqueness of the individual surgeons that has a profound effect on quality of the work. The art is characterized by uniqueness and the craftsmanship whereas in science we aim at reproducibility. In surgical discipline we cannot reproduce even the exact same operation in the same patients but we try to reproduce the same results. To move from this craftsmanship toward smarter surgery, we need to improve the quality of care for as many patients as possible. Additionally, surgical procedures have become more technical and more diverse with the advancement of minimally invasive procedures. There is also a paradigm-shift in medicine moving from pathology-based treatment to Personalized Medicine. In Personalized Medicine we do not ask which treatment is more superior but which patients are more suitable for which treatment. For surgical procedures this means whether a patient is anatomically suitable for the procedure in question.
To move from craftsmanship to smart surgery and to apply the concept of Personalized Medicine in surgical discipline many new tools can be used, such as:

- Three-dimensional (3D) reconstruction of patient's anatomy
- Rapid prototyping (3D printing)
- Simulation
- Intra-operative guidance

Fujifilm has one of the most comprehensive packages that allow the implementations of these new tools in daily practice. The aim of this manuscript is to provide a comprehensive depiction of these tools in clinical practice by Synapse® 3D software package.

3D-reconstruction

During the surgical procedures we go through the individual anatomy of the patients layer by layer and perform our interventions. Although two-dimensional views through a CT-scan provides valuable information regarding the anatomy and pathologies by radiologists, for surgeons the three-dimensional relationships between structures in surgical field are vital for execution and planning of any intervention. With 3D reconstruction one creates a three-dimensional view of operative field. These new images are not meant to trace pathology or to make additional diagnosis, which is the field of a radiologist, but to create the operative anatomy to help a surgeon. As the applicability of the 3D reconstruction is apparent for practicing surgeons, its use in clinical practice will be dependent on following factors:

- Evidence provided in literature that the use of these new tools is associated with superior clinical outcomes.
- Evidence provided in literature that the 3D reconstructions correspond to the actual anatomy of the patients.
- The user-friendliness in terms of time to reconstruct and time one needed to go through the reconstruction.

With regard to the first two factors, although the technology is new, the evidence is compiling regarding the clinical usefulness of the 3D reconstruction. With regard to third factor, the Synapse 3D provides a very rapid (minutes) reconstruction based on the CT-scan and one can learn quickly to apply the tools within the software to use the reconstruction. The 3D reconstruction based on CT-scan provides a platform for a surgeon to go through the patient's anatomy layer by layer before any intervention is done. The Synapse 3D can be used on the Desktop computer or even on a notebook.
The 3D reconstruction in pre-operative planning can be applied for following reasons:

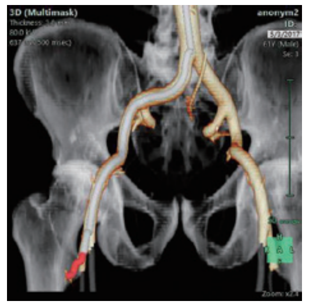
- Evaluation of anatomic suitability for a certain procedure, mostly minimally invasive procedure
- Planning an operation and detecting anatomical variabilities
- Simulation
- 3D printing
- Intra-operatively as guidance

Within Synapse 3D, one can simulate the size of different cannulas for performing a transcatheter cannulation in the groin. In Figure 7, we can see three different patients with simulated cannulation pre-operatively. In patient 1 (Figure 7A) a cannule of 19 Fr can be used without any problem. In patient 2 (Figure 7B) a 19 Fr cannula insertion would not be possible. In patient 3, (Figure 7c) although 19 Fr cannula can be used, the extreme tortuosity can create a problem if the cannula is advanced to far into the iliac vessel.

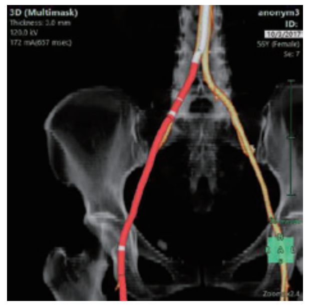
3D printing

In the early 1980s, the concept of 3D printing was introduced (i.e. three-dimensional (3D)-printing) and was originally developed for the industrial field of work. As 3D printing is becoming more available and more cost-effective, it can be a viable tool in surgical planning. 3D printing could provide an additional tool for physicians to more clearly understand spatial relationships of designated anatomical structures by physically modeling them.
One of the features of Synapse 3D is that the user can convert the anatomical reconstructions into the STL files that can be processed further or directly be printed in 3D. In Figure 8, we have a case of a tumor in the left upper lobe invading the chest wall. In panel A, we can appreciate 3D reconstruction of this tumor, in panel B, C and D the 3D reconstructed STL-files and in panel E the 3D-printed lung with all the structures.
These 3D-models can be used for planning of a complex operation, training of young physicians, discussing complex cases in tumor boards and discussing the operation with the patient.

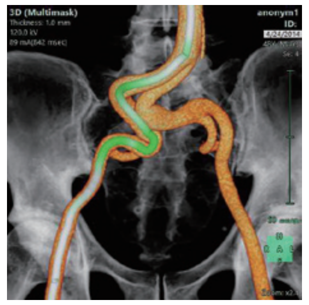
◆ Figure 7A



◆ Figure 7B



◆ Figure 7C

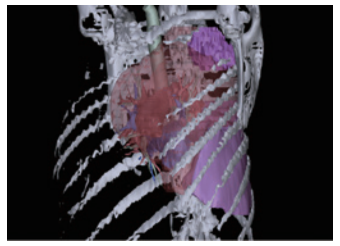


Three different patients with simulated cannulation pre-operatively. In patient 1 (Figure 7A) a cannule of 19 Fr can be used without any problem. In patient 2 (Figure 7B) a 19 Fr cannula insertion would not be possible. In patient 3 (Figure 7c) although 19 Fr cannula can be used, the extreme tortuosity (green color) can create a problem if the cannula is advanced too far into iliac vessel.

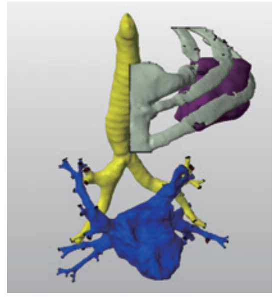
Intra-operative guidance

Although 3D reconstruction is valuable for operative planning, the intra-operative use of these reconstructions for guidance of a procedure can also be valuable. Within Synapse 3D there are various modalities to export the 3D models and use them intra-operatively as guidance during a procedures. In Figure 9 we can appreciate the use of double monitor for VATS with 3D vision whereby one can use the 3D reconstructed models in interactive PDF-file for guidance during the resection.
In future, we should be able to overlap the 3D reconstructed models with intra-operative live-images to have more precise intra-operative navigation.

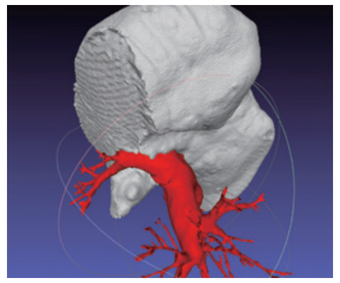
◆ Figure 8A



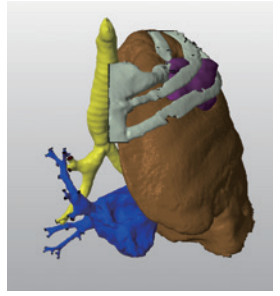
◆ Figure 8B



◆ Figure 8C



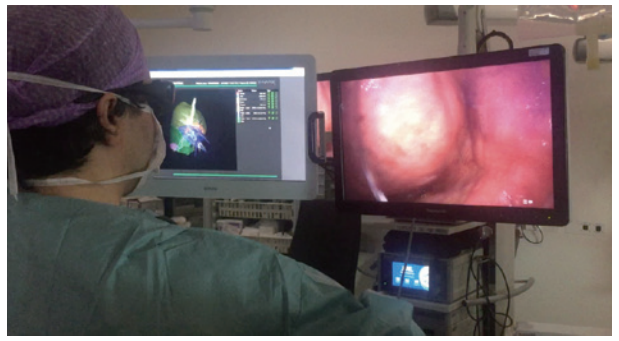
◆ Figure 8D



◆ Figure 8E

Tumor of left upper lobe invading the chest wall. In panel A we can appreciate 3D reconstruction of this tumor with surrounding structures, in panel B, C and D the 3D reconstructed separate STL-files and in panel E 3D-printed lung with all the structures.

◆ Figure 9

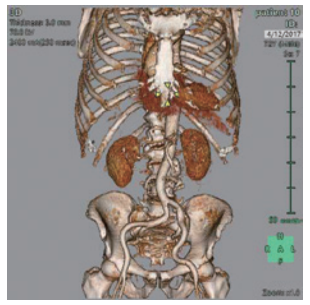


Double monitor is used for VATS with 3D vision whereby one can use the 3D reconstructed models in interactive PDF-file on one of the monitor for guidance during the resection.

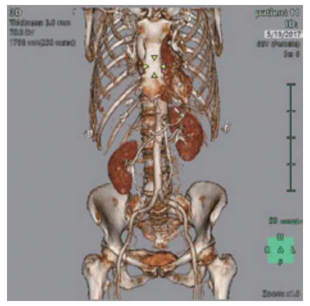
Evaluation of anatomic suitability

Conventionally, most cardiac procedures are done through median sternotomy and use a heart-lung machine centrally. With advent of minimal-access procedures in last two decades, new techniques are developed whereby we perform the same procedures through smaller incisions (partial sternotomy or mini-thoracotomy) with connection of heart-lung machine peripherally (through the groin) with transcatheter cannulation. The procedures are mostly done for aortic valve and mitral valve surgery.
For aortic valve replacement through minimal-access, an upper mini-sternotomy up to intercostal three is done. With 3D reconstruction using Synapse 3D, one can reconstruct the surgical anatomy and evaluate the suitability for this procedure. For example in Figure 1, we can compare the surgical anatomy of two different patients evaluated for minimal-access aortic valve replacement. In patient one (Figure 1A), the position of the aortic root is at the level of xyphoid whereby with an upper mini-sternotomy one cannot reach the aortic root and expose the aortic valve for a replacement. However in patient two (Figure 1B), the aortic root is at mid-level of sternum and minimal access procedure is feasible. The determination of aortic root using Synapse 3D in 3D reconstructed surgical anatomy provides the spatial relationship between the location of the aortic valve in relation to sternum.
For endoscopic mitral valve surgery (mini-thoracotomy combined with peripheral perfusion through the groin), the size of groin vessels, and the tortuosity and calcifications have an impact on groin cannulation. For example in Figure 2, we have three different patients evaluated for endoscopic mitral valve surgery. Patient 1 (Figure 2A) has normal diameters of groin vessels (in relationship with size of normal cannula used), no significant tortuosity and no significant calcification. Patient 2 (Figure 2B) has very small groin vessels whereby no desired cannula size can be used. Patient three (Figure 2C) has extreme tortuosity at the iliac level whereby a blind use of guide-wire for transcatheter cannulation could be problematic. These anatomical characteristics of the vessels are quickly visible through automatic segmentation within Synapse 3D.

◆ Figure 1A



◆ Figure 1B



In patient one (Figure 1A) the position of the aortic root is at the level of xyphoid (curser) and in patient two (Figure 1B) the aortic root is at mid-level of sternum (Curser).

◆ Figure 2A

◆ Figure 2B

◆ Figure 2C

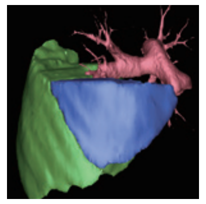
Three different patients are evaluated for endoscopic mitral valve surgery. Patient 1 (Figure 2A) has normal diameters of groin vessel (in relationship with size of normal cannula used), no significant tortuosity and no significant calcification. Patient 2 (Figure 2B) has very small groin vessels whereby no desired cannula size can be used. Patient three (Figure 2C) has extreme tortuosity at iliac level whereby a blind use of guide-wire for transcatheter cannulation could be problematic.

Planning an operation and detecting anatomical variability's

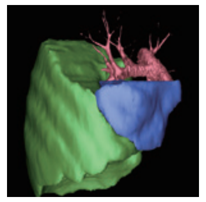
Early-stage lung cancer is preferably treated by lobectomy or anatomic sub-lobar resections (anatomic segmentectomies). Whether these procedures are done with VATS (Video-assisted Thoracic Surgery) or thoracotomy, pulmonary anatomy is of paramount importance for these anatomic resections. With Synapse 3D, one can make a 3D reconstruction of pulmonary anatomy in minutes for planning the operation and detect any anatomical variability's. In Figure 3, we can see three different patients referred for right upper-lobe lobectomy. Patient 1 (Figure 3A) has a normal anatomy, patient 2 (Figure 3B) has early branching of truncus anterior and patient three (Figure 3C) has multiple aberrant pulmonary branches to right upper lobe. Knowing these individual anatomical variations helps a surgeon intra-operatively with performing the procedure, especially if the operation is done through VATS.
For endoscopic mitral valve surgery the size of groin vessels, the tortuosity and calcifications have an impact on groin cannulation, but also anatomical variabilities.

◆ Figure 3A

◆ Figure 3B

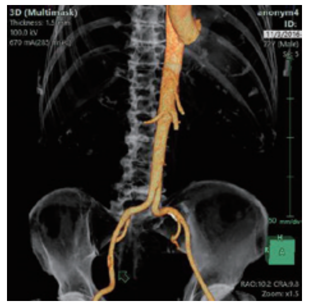


◆ Figure 3C



Three different patients referred for right upper-lobe lobectomy. Patient 1 (Figure 3A) has a normal anatomy, patient 2 (Figure 3B) has early branching of truncus anterior and patient three (Figure 3C) has multiple aberrant pulmonary branches to right upper lobe.

◆ Figure 4A



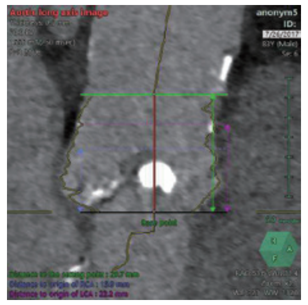
◆ Figure 4B

We can see that right iliac vessel has a short dissection (Arrow) (Figure 4A and 4B) and therefore cannulation in right groin could create a retrograde dissection.

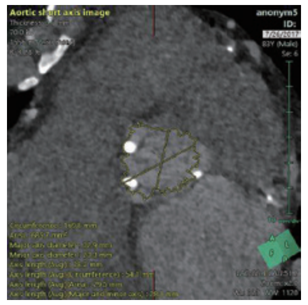
In Figure 4, we can see that right iliac vessel has a short dissection (Figure 4A and 4B) and therefore cannulation in right groin could create a retrograde dissection with disastrous consequences for the patient. In this patient we can safely use the left groin, as the left iliac vessel is not dissected.

Accurate assessment of aortic dimension is important to decide on the correct transcatheter heart valve (THV) size for patients undergoing transcatheter aortic valve replacement (TAVR). Also, the access for TAVR is important, as in transfemoral approach the groin vessels should have adequate diameters.
Given the inherent motion of the aortic root, an ECG-gated multidetector CT acquisition is necessary to achieve the best image quality with minimal motion artifacts. The aortic annulus is measured in the systolic phase, during which it has the largest diameter.
The aortic annulus is generally elliptic but assumed a more round shape in systole, thereby increasing the minimum diameter but without a significant change in perimeter. On the basis of these, ECG-triggered scanning of the aortic root with systolic measurements is recommended.
The mean annular diameter (preferably on the basis of systolic images) can be obtained based on annular cross-sectional long-axis and short-axis diameters (Figure 5A, 5B). The annular perimeter is automatically tracked using a planimetry tool on a workstation. Finally, the mean annular diameter is calculated based on these measurements. All these measurement are obtained automatically in Synapse 3D and also can be adjusted manually. One can also simulate the virtual placement of the valve in the reconstruction (Figure 5C, 5D). Also, there is a possibility to track the catheter insertion and track for transapical approach automatically (Figure 5E, 5F). In this example a transapical Edwards Sapien 3 29mm was successfully placed.

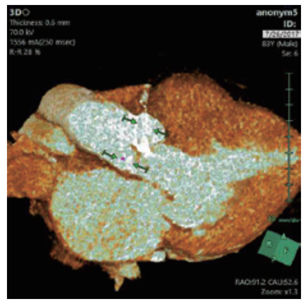
◆ Figure 5A



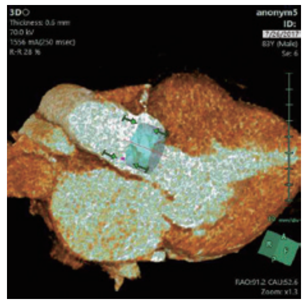
◆ Figure 5B



◆ Figure 5C



◆ Figure 5D



Simulation

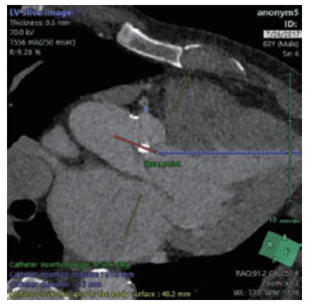
Anatomic sub-lobar resections (anatomic segmentectomies) are technically more challenging because of its anatomical complexity, high variability of vascular and bronchial structures and the technical difficulty in obtaining an adequate surgical margin. However, patients with some early-stage lung cancer may benefit because of lung-sparing resection.
With Synapse 3D, one can virtually simulate anatomical segmentectomies pre-operatively. In addition to 3D reconstruction of a patient's individual anatomy with Synapse 3D, a surgeon can identify the segmental bronchi based on the location of the tumor and perform a segmentectomy. With this virtual segmentectomy modality one can determine:

- Sites of resection of the pulmonary vessels, bronchi and inter-segmental veins
- Calculate the extent of the surgical margin
- Visualize the segmentectomy surface

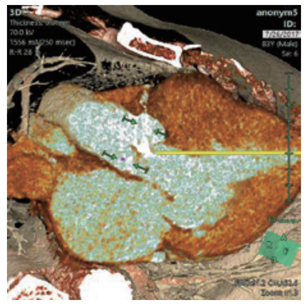
In Figure 6 (6A and 6B), we can appreciate a case of virtual segmentectomy of posterior segment of right upper lobe.

For endoscopic mitral valve surgery, as indicated above, the size of groin vessels is important for groin cannulation.

◆ Figure 5E

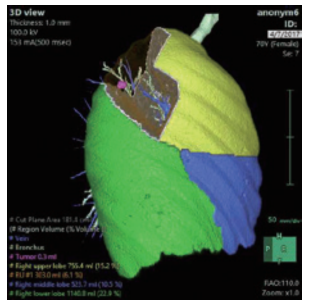


◆ Figure 5F

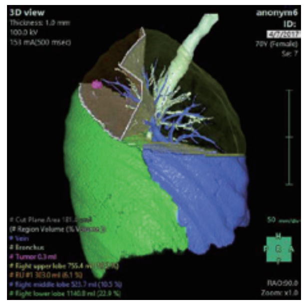


For TAVI measurements, mean annular diameter is obtained based on annular cross-sectional long-axis and short-axis diameters. The annular perimeter is automatically tracked using a planimetry tool on a workstation (Figure 5A, 5B). One can also simulate the virtual placement of the valve in the reconstruction (Figure 5C, 5D). There is also a possibility to track the catheter insertion and track for transapical approach automatically (Figure 5E, 5F).

◆ Figure 6A



◆ Figure 6B



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