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 procedure. 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 an 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.

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 skill and cumulative 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 an 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 allows 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.
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 transcatheater 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 one (Figure 2A) has normal diameters of groin vessels (in relationship with size of normal cannula used), no significant tortuosity and no significant calcification. Patient two (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.

Planning an operation and detecting anatomical variations

Early-stage lung cancer is preferably treated by lobectomy or anatomic sub-lobe 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. In Figure 3, we can see three different patients referred for right upper-lobe lobectomy. Patient one (Figure 3A) has a normal anatomy, patient two (Figure 3B) has early branching of trunks 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 variations.

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 planimeter tool on a workstation. Finally, the mean annular diameter is calculated based on these measurements. All these measurements 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 transluminal approach automatically (Figure 5E, 5F). In this example a transapical Edwards Sapien 3 29mm was successfully placed.

Simulation

Anatomic sub-lobe 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 anatomic segmentectomies pre-operatively. In addition to 3D reconstructions 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 segmentectomies 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.

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