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Multi-organ segmentation for 3D visualisation of abdominal structure to enhance learning experience in medical education and pre-surgical planning of abdominal abnormalities

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RESEARCH

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ABSTRACT

Background

Medical image segmentation plays an important role in assisting clinical diagnosis, as well as medical education to enhance learning anatomy and pathology. A 3D anatomical model which can be either visualized as 3D reconstruction or virtual reality views or 3D printed models adds valuable information to standard 2D visualizations for assessing the depth of the abdominal region structures and abnormalities and enhancing the learning experience.

Aim

This study aims to explore the methodology and efficiency for 3D segmentation of abdominal organs comparing the abdominal region of both normal and abnormal intestinal cases using an open source software 3D Slicer.

Methods

Two CT scans of anonymised images with normal and intestinal enteritis were selected to be segmented, analysed, and converted into 3D virtual anatomical models. The models were used in comparison to assess limited areas that could not be assessed via 2D visualisation and depict differences from the soft tissue organs.

Results

The majority of the organs were able to be image processed and converted into 3D visualisation. Evidently, the gastrointestinal system poses varying challenges due to irregular pathway and difficulties to distinguish density value towards adjacent organs. Despite the challenge, 3D segmentation of the small and large intestines were visualised and differentiated.

Conclusion

This study demonstrates the feasibility of utilising 3D Slicer for multi-organ segmentations, although it still poses many challenges and limits to soft tissue components. Further development of automatic segmentation is necessary to make the image processing and segmentation approach more practical for routine applications.

Key Words

3D printing, segmentation, gastrointestinal organs.

What this study adds:

1. What is known about this subject?

3D image segmentation and reconstruction has been widely used in the medical industry that provide benefits to present unreachable regions that cannot be accessed in 2D, prepare practical discussions and aid in learning education.

2. What new information is offered in this study?

This study focuses on the gastrointestinal system including the stomach, large colon and small intestine which are made up of soft tissue and often challenging to distinguish in CT scans. Therefore, new findings can be retained and contribute to existing studies.

3. What are the implications for research, policy, or practice?

3D visualisation through reconstruction of image processing could serve as a useful pre-surgical planning tool in gastrointestinal abnormalities by enhancing understanding of complex anatomical structures. Additionally, the 3D virtual anatomical model when 3D printed or created as virtual reality views can be used for medical training.

Background

Medical Imaging is a process that utilises various techniques to observe the human anatomy structure, to diagnose and manage patients with existing or unknown medical abnormalities[1]. The imaging procedure is currently the most valuable approach to collect a patient's visual scan data of their anatomical structure for analysis. There are many types of imaging techniques used in the medical industry, and each one serves its own particular purpose. The most commonly used imaging modalities in clinical practice are Computed Tomography (CT), Magnetic Resonance Imaging (MRI), and ultrasound. For image segmentation and 3D reconstructions, CT and MRI are most commonly used given the acquisition of volume data which comprises an essential component for 3D reconstructions[2-4].

Whilst 2D and 3D rendering of medical images allow the unveiling of the anatomical structure of region in the human body, there is still a constant restraint to the extent which 2D visualisation can display. Furthermore, the depth of the images is not determined with respect to the number of slices of images provided. This leads to difficulties in evaluating the essential information and position of the organs with respect to the dataset. Hence, the images do not clearly define the 3D perspective of possible abnormalities resulting in difficulties to analysis or create interventions. Additionally, the difficulties of producing a high-resolution visualisation of segmented areas in the abdominal region are due to the complex orientation and position layout within the body frame. Therefore, the medical industry is in search for an efficient method to visualise the human anatomical structure in 3D visualisations whilst being able to diagnose specific areas which cannot be defined in a 2D perspective.

3D printing technology is rapidly evolving with capability of creating patient-specific or personalised models by replicating anatomy and pathology with high accuracy[5-9]. 3D printed models are shown to be useful in many areas from medical education to pre-surgical planning and simulation of complex procedures and enhancing doctor-patient communication. Virtual Reality (VR), a well-developed technology provides an innovative approach to monitor patients through the capabilities of overviewing the human structure in an immersive environment. This concept utilises simulation of the real-world time which grants users to directly interact with the virtual aspect from one end to another. Hence, an object can be defined through assessing the different views from its orientation it portrays to researchers. With the increase of productivity in VR, it has earned an important spot into today's society within clinical practises and medical facilities throughout its use in providing comprehensive surgical plan procedures as well as enhancing, the learning experience for educational purposes.

There are many limitations with respect to the exploration of the depth with the human anatomical composition involving the locations of organs from inaccessible areas, leading researchers to rely on their imagination to allocate the position in the human structure. Hence, there is a loss of information when viewing in a 2D aspect compared to 3D which consequently results in difficulties to discover what lies beyond the unreachable region.

From the current limitation, researchers and clinicians have undertaken a series of assessments, to establish a solution that will aid with the visualization of the anatomical structure. At this stage, physical models and 2D reconstructions are heavily used in the medical industry as well as 3D reconstruction for solid tissue structures. Within this project, the intention is to implement a 3D visualization premise that uses anonymized CT dataset of the human body for image segmentation of various types of organs. Subsequently, the abdominal area of the human anatomy will be the primary focus due to the large area of accessible soft tissue to be examined. Another objective of this study is to utilise an open source software 3D Slicer for image segmentation and test its feasibility in segmenting these multiple organs.

Materials and Methods

CT data acquisition

Two anonymised cases with one being normal and another diagnosed with enteritis were selected, reviewed and analysed. CT images were acquired in a 128-slice multi-slice CT scanner (Siemens Definition Flash, Siemens Healthcare, Germany) with slice thickness of 1.0 mm and reconstruction interval of 0.7 mm. Contrast-enhancement in arterial and venous phases was performed in these two cases to allow visualisation of multiple organs, in particular, liver, pancreas, kidneys, abdominal aorta and its arterial branches, as well as inferior vena cava. This also ensures high quality of original source CT images for the subsequent image processing and segmentation of various organs and structures.

Image post-processing and segmentation

The datasets which were in Digital Imaging and Communications in Medicine (DICOM) format were imported into 3D Slicer (Brigham and Women's Hospital (BWH), Boston, MA, USA), an open-source program that contains various features for image processing and segmentation (Figure 1). Various organs including the bone structures, liver, pancreas, spleen, kidneys, aorta and blood vessels were segmented in an instant from an extension 'Segmentation extra effect' that enable the organs to be segmented efficiently. Regarding the soft tissue organs, especially including small and large intestines, each slice had to be manually marked due to difficulties in recognition of each vital soft tissue organ against adjacent solid tissue organs. Furthermore, due to the complexity of the density value varying along each slice, the masking tool couldn't not be utilised to separate the walls of the small intestine form each other. The time taken for segmentation of all the various gastrointestinal organ and cardiovascular organ (heart and major blood vessels) were recorded to showcase of segmentation of normal versus intestinal enteritis (Table 1).

Results

3D Slicer was able to comprehend most of the image processing of the abdominal region. The list of organs that were successfully segmented and exported to Standard Tessellation Language (STL) files ready for 3D printing include: the bone structures, the two kidneys, spleen, stomach, liver, gallbladder, pancreas, heart, aorta, blood vessels and large colon (Figure 2). The advantage of using 3D slicer is its flexibility to display the anatomical differentiation of different organs. With the removal of the complex small and large intestines, the relationship of he cardiovascular system with the larger gastrointestinal organ including liver, stomach, pancreas, and spleen can be clearly differentiated (Figure 3). These structures are relatively easier to segment compared to the small and large intestines as denoted by the time taken to undertake segmentation of each organ (Table 1). The 3D reconstruction of the small and large intestines clearly display anatomical relationship between the ascending, transverse and descending colon (Figure 4). The ascending and descending colon are retroperitoneal and transverse colon is intraperitoneal. The 3D segmentation also clearly depicts the colon ascending superiorly from caecum and meeting the right liver lobe (Figure 5). Figure 5 also clearly depicts the transverse colon extending from right to meet the spleen where it turns a 90 degree to descend inferiorly, and when colon begins to turn medially, it becomes the sigmoid colon.

As shown in Table 1, there is a significant variation between the time taken to segment these solid organs and bowel structures with the longest duration on segmenting small and large intestines.

Discussion

Slicer 3D was found to be a useful tool for the segmentation and visualisation of the images. The software can output the DICOM dataset onto the screen, displaying in axial, coronal, and sagittal views. 3D Slicer provides a semi-automatic feature tool that allows pre-existing segment marking to be over layed onto the top of the current dataset if the system detects similarities from the pre-set function. However, due to the case containing abnormalities, this tool only partially works on specific large segments such as the liver and kidneys. Thus, more time was invested in the process of manually marking out the remaining unmarked segments. The 3D anatomical model could enhance the teaching and training for abdominal surgical trainees. Sampogna, et al. States that further studies are necessary before mandating these new techniques into surgical training programs; however, the benefits of adapting these technological advances into abdominal surgical training are worth the extra time, cost and effort[10]. They also suggest that VR offers an eco-sustainable method of learning about interventional procedures that may solve some of the medico-legal and ethical issues of medical education[10].

Song et al. found that 3D printed models scored higher than conventional CT imaging when it came to educating patients about pancreatic tumour resections and what the surgery would entail[9]. 3D printed models are also reported in many studies showing advantages over traditional approaches in learning anatomy and pathology, as well as assisting with preoperative planning of tumour resection[11-16]. Recent systematic reviews such as Perica and Sun16 and Rossi et al. discuss the value of 3D printed models in liver tumours [17,18]. For example, Perica and Sun suggest 3D printed models can assist with preoperative planning and may be used in the simulation of malignant hepatic tumour resection. Rossi et al. suggests that further research could be conducted to investigated the relationship between patient-specific 3D printed models and patients' intra- and postoperative outcomes.

VR simulation has also been shown as a useful tool in improving surgery or surgical outcomes by allowing users to immerse in a virtual environment[19-21]. VR and more advanced technology, Mixed Reality (MR) are reported to offer superior advantages over the traditional 2D views in surgical planning and simulation of cardiac anatomy and pathology as reported by some recent studies[22-24]. However, there is a lack of similar reviews on the clinical value of both 3D printing and virtual reality in surgical planning of abdominal organs, and also research on investigation of how the 3D reconstructions or visualisations to enhance learning anatomy and pathology of abdominal organs is lacking. Our early experience with segmentation of these organs in this study lays a good foundation for further research to determine both educational and clinical value of 3D reconstructions in understanding complex abdominal organs.

There were several limitations in this study. This report presents our early experience of using 3D Slicer for multi-organ segmentation despite promising results presented, manual segmentation was used to segment small and large intestines showing very time consuming. Further research should focus on fully automatic segmentation of these organs, and with use of Artificial Intelligence (AI) tools to further improve the segmentation process. Some recent studies have reported the potential and possibility of segmenting anything in medical images[25-27].

Small sample size is another limitation. Future studies with inclusion of more datasets such as various abdominal diseases are needed. Further, we only tested the CT cases. Inclusion of cases acquired with different imaging modalities such as MRI, ultrasound or other imaging techniques are needed. This could include common pathologies and rare diseases in these abdominal organs or structures so that the value of 3D reconstructions could be further validated[28].

Conclusion

This study proves the feasibility of multi-organ segmentation using an open-source software tool for interactive 3D visualization. The visualization process will offer researchers new information in regards of performing surgical planning for future references. Further research ideally would include a better bowel preparation to produce a higher quality of data to segment. Thus, more potential diseases can be prevented, or quick interventions can be developed to patient's medical conditions. An exploration of fully automatic segmentation within 3D Slicer is being studied with the aim of speeding up the segmentation process with high accuracy.

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CONFLICTS OF INTEREST

Authors declare that they have no competing interests.

Tables & Figures

Table 1: The relative time taken to segment each organ in the two CT cases.

Organs	Time taken (mins/ hour)	Comments
Liver	1 hour	Large organ, relatively smooth and easily distinguishable from other adjacent organs. More time can be invested to smoothen the edges and segment the blood vessels inside the liver.
Stomach	2 hours	The stomach is curved slightly towards the back due to the inflammation of the small intestine. The stomach is made up of air walls which also contain (residue) within the organ.
Bone structures	30 minutes	Easily segmented utilising density value to isolate then from adjacent organs.
Gallbladder	20 minutes	Relatively small, located near the liver.
Spleen	45 minutes	Well defined and easy to segment
Pancreas	50 minutes	Relatively easy to segment with defined blood vessels
Kidneys	45 minutes	Well defined and easy to segment. More time can be invested to segment out the blood vessels.
Heart	1 hour	Relatively easy to segment due to contrast enhancement
Blood vessels/branches	1.5 hours	Easy to segment due to contrast enhancement
Small intestine	In progress	Difficulty due to overlay of structures
Large intestine including rectum	6 hours	Some incomplete areas

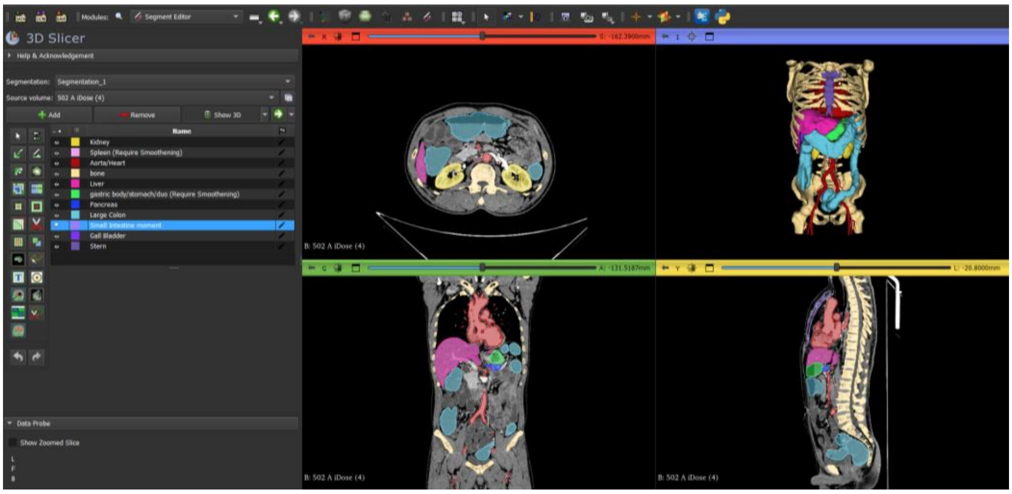

Figure 1: Comparative view of the CT scan in axial, coronal and sagittal planes vs the 3D visualisation of the abdominal organs and aortic arteries following multi-organ segmentation of CT data using the 3D slicer software. Artificially coloured organs facilitate the view of the different anatomical location and presentation.

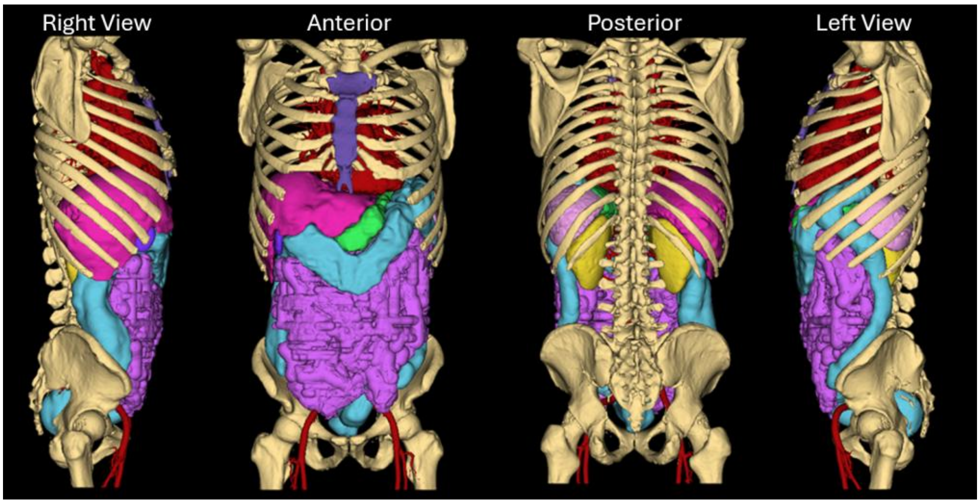

Figure 2: Multi-organ segmentation of CT data using the 3D slicer software transforms 2D view of CT scans into interactive 3D visualisation of the abdominal organs and aortic arteries. Each organ is artificially coloured to show the different anatomical location and presentation.

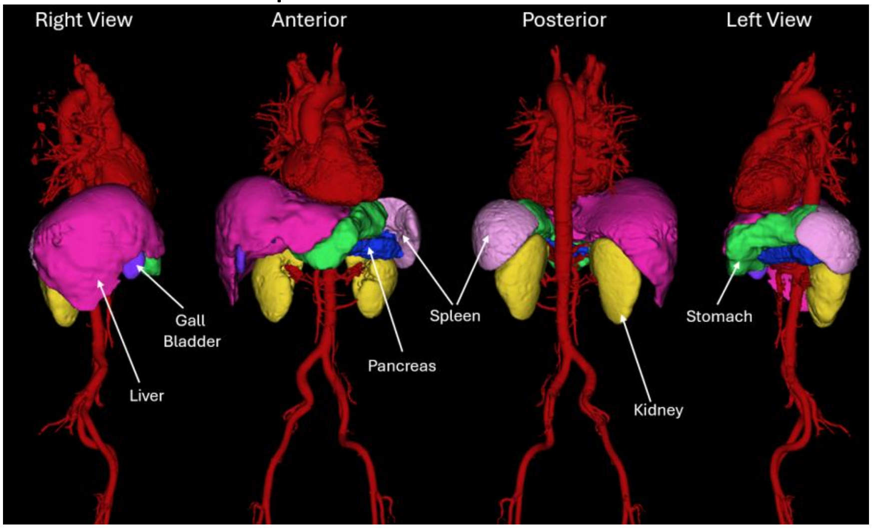

Figure 3: The cardiovascular system, liver, stomach, spleen, pancreas and kidneys with well-defined structure and shape were easier to segment into 3D visualisation and interactive images. Each organ can be artificially removed to display the view of full organ. Bony structures and soft tissues were moved in the 3D visualisations.

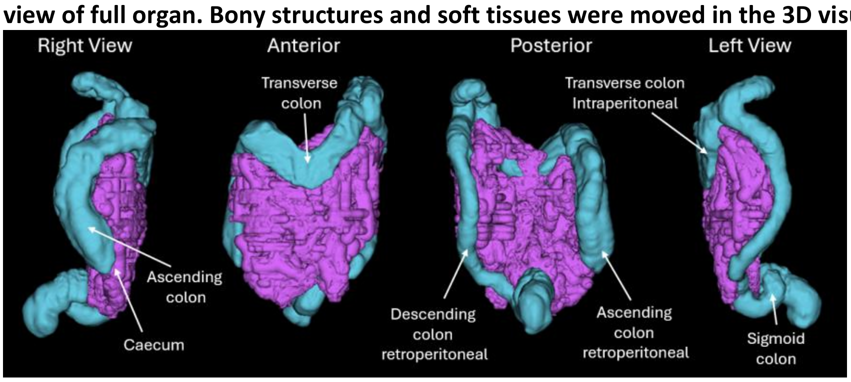

Figure 4: The small and large intestines (colon) were the most challenging organs to segment. This took extensive amount of time to create the 3D structure as shown in these views.

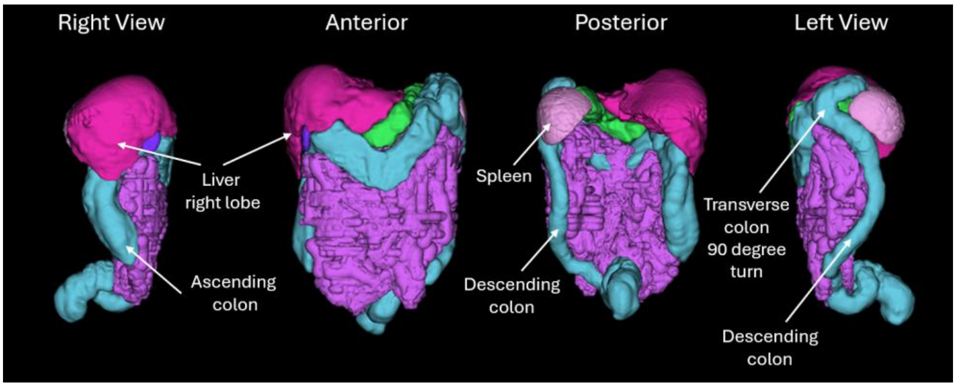

Figure 5: The 3D segmentation also clearly depicts the colon ascending superiorly from caecum and meeting the right liver lobe. It also clearly depicts the transverse colon extending from right to meet the spleen where it turns a 90 degree to descend inferiorly, and when colon begins to turn medially, it becomes the sigmoid colon.

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