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Research Article

An Easy to Use Workflow of 3D Medical Reconstruction for Preoperative Planning and Surgical Education

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Abstract

Background: 3D imaging and 3D printing have been widely adopted and profoundly impacted our healthcare. The use of 3D technology has a great potential to facilitate pre-operative planning and clinical education, allowing versatile view and measure of landmarks from a patient's model pre- and during operation. However, the current clinical practice is still dominated by computed tomography in conjunction with x-rays. Therefore, this project aimed to develop an easy to use, low cost, and accurate workflow of generating medical 3D models. The workflow will help improving the medical education and career training of surgeons.

Methods: This study proposed an uncomplicated, rapid, and open-sourced process of converting 2D image datasets into 3D models using Drishti software. We used thirteen orthopaedic patients' datasets. Each dataset was imported into the software to segment 3D bone surfaces from surrounding soft tissues.

Results: Utilising Drishti software, we developed a simple workflow of converting patient computed tomography data to 3D models, and demonstrated using a pelvic fracture case. Using this workflow, we converted six pelvic fracture cases and six different bone regions into high quality anatomical replicas suitable for 3D printing.

Conclusion: The workflow has a good potential to be incorporated into the routine training of surgeons, which may largely improve the pre-operative planning and anatomical education through a single site de-novo setup. The workflow based on the easy to use and open-sourced software package is simple to reconstruct 3D medical models from 2D datasets.

Introduction

During the past decades, 3D imaging and 3D printing have infiltrated into our healthcare system and produced profound impact. The applications ranged from CT converted 3D models, virtual reality, to 3D printing surgical aid, surgical guide, and customized implant [1-4]. 3D reconstruction of bone or organ models in virtual space can serve as templates for surgeons to perform pre-operative planning and design patient-specific surgical instrument or implant [5]. The usefulness of 3D models has been proved to benefit intra-operative navigation and surgical training [6]. This is especially important for tumour and comminuted fracture cases that required accurate reproduction of the diseased region using virtual 3D models or 3D printed objects [7,8]. The use of 3D technology has a great potential to facilitate clinical training, allowing versatile view and measure of key landmarks from actual patient model pre- or intra-operatively [9,10]. As such, implant sizing and orientation can be better prepared, and surgery procedure can be planned with higher confidence [11,12]. Surgeries will take advantage of these features by reducing time consumption, blood loss, risk of incidences, and complications [13].

While the cost of 3D assisted surgery is foreseeably reducing due to the technological advances, clear provision of surgeries upgrading from 2D to 3D system becomes more widely adopted [14,15]. Although 3D imaging and segmentation tools and processes have been investigated [16], the technology is yet to be accepted as a standard clinical practice for a majority of surgeons. Meanwhile, the commercial available medical software is usually expensive and inaccessible to those who need [17]. In addition, a well-trained biomedical engineer collaborates with surgeons is necessary to assist with 3D related surgeries [18,19]. As the 3D surgery has been coming to clinical practice, the creation of an easy to use, low cost, and accurate workflow of generating medical 3D models will help medical students and clinicians to quickly adapt the 3D surgery. This study uses orthopaedic models as an application example, with the aim to establish an uncomplicated, rapid, and open-sourced process of converting 2D image datasets into 3D models. The 3D model construct procedure can be incorporated into the professional training of medical students and surgeons. The outcome will imperatively improve health care through anatomical education and pre-operative planning.

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Materials and Methods

Image acquisition

Following ethics approval from the Australian National University (ANU) and the ACT Health Human Research Ethics Committee (ETHLR.17.160), we collected thirteen de-identified patient CT image datasets from the Trauma and Orthopaedic Research Unit, ACT, in which seven datasets were different pelvic fractures and the other six were different bones including spine and pelvis, skull, tibia, spine and shoulder, shoulder joint, and knee.

Generating 3d bone model

Optimization for the conversion of CT images to 3D bone model using the Drishti suite v2.7 (https://github.com/nci/drishti) was performed. To reconstruct a medical 3D model from 2D images, we used two modules of the Drishti software suite: Drishti Import and Drishti Paint. Drishti Import loaded the CT image directories and transferred the dataset to a Drishti readable data processing file for further segmentation. The data processing file was then imported to Drishti Paint for bone segmentation and 3D reconstruction by modules such as thresholding, gating, and tagging. We detailed the bone reconstruction procedure as below for training purposes.

Drishti import

3D reconstruction tools usually establish voxel data from CT images to generate point-cloud. Drishti Import takes the responsibility to convert CT files into .plv.nc format for further processing using Drishti Paint.

Upon opening Drishitiimport.exe, we drag the folder containing the CT image stack into the software window to preview the dataset. Then the data were saved as .plv.nc file at a designated location for further process. We defaulted the setting during the process.

Drishti paint

Within the Drishti suit, Drishti Paint is the software to operate 3D reconstructions. It has several segmentation modules to assist the process of separating skins, soft tissues, and bones. It also meshes segmented point-cloud to 3D models in .ply format, which is similar to .stl 3D printing format but contains colour information.

After we acquired .plv.nc file from Drishti Import, we dragged the file into the Drishti Paint window and defaulted the sub sampling level. Then Drishti Paint provided an instant 3D rendering view of current segmentation, along with the CT image view. Using the segmentation tools such as thresholding, region growing, and gating, we isolated the area of interests (different bones in this study). The outcome of each operation was displayed instantly in the 3D view and highlighted in the CT image view. When we were satisfied with the rendered 3D model, we selected the "Mesh Tagged Region" in the File menu to export the 3D model as .ply file.

Results

In this study, we proposed an optimised workflow for the conversion of a patient's CT Images to a virtual 3D model (Figure 1). Drishti Import easily converted the CT image stack to point cloud for further processing using Drishti Paint. Using Drishti Paint, we further performed 3D segmentation of the area of interest of our study. This process is relatively simple and easy to learn. Comparing to the commercial software platforms that perform similar functions, Drishti is free of charge and can be re-developed to suit other studies. These inbuilt features such as thresholding, gating and tagging are demonstrated in Figure 1. These modules are easy to use and essential for medical applications. The meshed 3D model (Figure 1g) in .ply file is compatible with most of the 3D printing platforms, and its colour information is easy to remove to become the standard .stl 3D model for 3D printing purpose.

Using the same workflow, we processed all thirteen CT datasets; the results are shown in Figure 1-3. Depending on the different datasets, the workflow generated fractured bone models (Figures 1 and 2) and different bone regions (Figure 3) at a reasonable quality. These 3D models help orthopadeic surgeons to better understand fracture line morphology inpatient's anatomy.

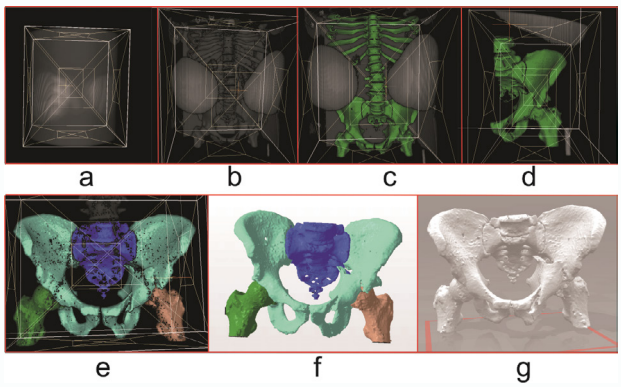

Figure 1: Examples of image-processing using Drishti Paint v2.7. The panels show the appearance of a rendered 3D model of a comminuted pelvic fracture after performing different segmentation techniques using real time volume rendering.

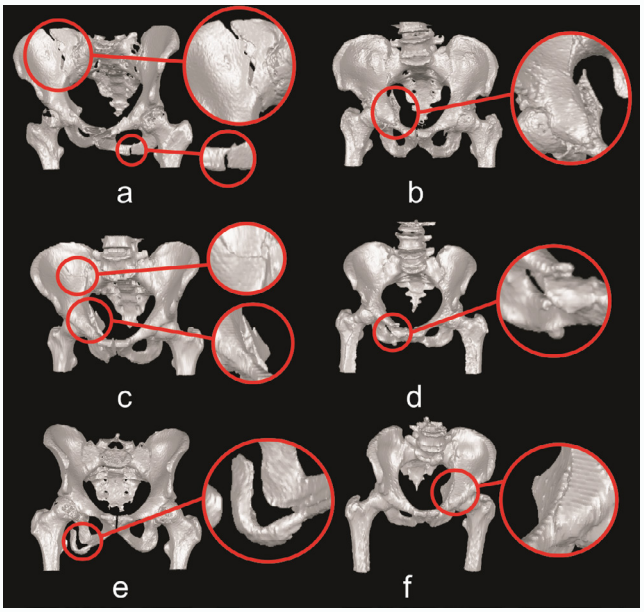

Figure 2: Different pelvic fractures allowing for the comparison of fracture cases.

Discussion

The 2D to 3D workflow

This study has proposed a 3D medical reconstruction workflow that is easy and free to use for orthopaedic surgeons. Medical students,

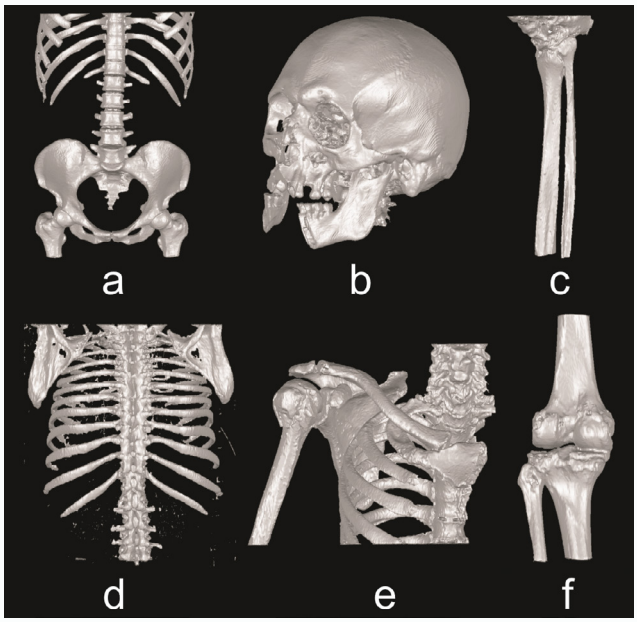

Figure 3: Different bones converted by the software.

trainees, and surgeons can access this tool and establish their own 3D medical models for medical training, pre-operative planning, and customized implant design.

A better 3D model quality can be achieved using a finer slicing interval of CT image to acquire a better surface morphology at the slicing direction. However, patient would suffer higher radiation exposure for more CT scans. On the other hand, the 3D reconstruction algorithm distinguishes soft tissue and bone by their grayscale contrast. A CT image at a higher contrast level is preferred for an easy segmentation. The reconstruction quality also depends on the amount of surrounding soft tissues. Regions such as skull (Figure 3b) and knee (Figure 3f) that have less soft tissue can generate relatively cleaner 3D models, and those have more soft tissue (such as thorax in Figure 3d) contains more spikes and noise elements that require further cleaning.

The paid or open-sourced image processing techniques have been well described by other researchers [18,19,21-23]. The image reconstruction workflow using Drishti contains favourable features for medical purpose, such as the built-in real time 3D rendering view along with the CT thresholding view, and simplified procedures to acquire a medical 3D model. Comparing to the other open-sourced 3D reconstruction software such as 3D Slicer, Drishti is less "engineering" and thus provides less advanced processing modules such as logical operation and voxel-level processing, which make it more suitable for clinicians. Although the exported 3D models are at similar resolutions, the 3D rendering view in Drishti sacrifices voxel level resolution but improves the fluency of the real-time rendering process for urgent needs. Thus, it requires less hardware support that is more accessible for developing countries. On the other hand, further quantified 3D measurement and customized implant design cannot be realized within Drishti frame. A third-party reverse engineering tool such as Meshlab (ISTI-CNR, Italy) or Geomagic (Materialise HQ, Belgium) will be required. This study lacks comparison with commercial platform such as Materialise MIMICS (Materialise HQ, Leuven, Belgium) due to inaccessibility [24].

This paper has highlighted some of the technical issues faced in producing 3D models and working in virtual space. Image processing is time consuming and further automated processes would enhance accessibility of the technology [25]. Hardware limitations are also germane and the process inevitably will be further enhanced by maximising the available computing power with a dedicated workstation appropriately specified for the role.

3D medical model for surgical planning

3D medical models greatly facilitate the understanding of the size, geometry, and spatial relationship of actual anatomy [26]. As demonstrated in Figures 2 and 3, the 3D reconstruction of a patient's CT images allows visualizing and manipulating bone from different angles and different scales provides the full surface information of a diseased or fractured region. With the assist of 3D engineering software. The sizing and land marking of the anatomy can be measured at greater ease with higher accuracy. When performing pre-operative planning, surgeons can highlight the surface features of a patient's 3D model at their preferred view. The pre-operative understanding of the actual bone surface greatly increases surgeons' confidence of performing the surgery, especially when these 3D anatomy features can be 3D printed and brought to an operating theatre to assist surgery. This study demonstrates that the cost of 3D reconstruction-either software cost or labour investment - is low. The conversion of CT images to a 3D model is a fast and easy process, can be quickly learned, and performed as a routine clinical practice.

3D medical models for anatomy training

The reconstructed 3D model can also be used as education aids for anatomical training. The 3D reconstruction workflow is relatively easy to learn, and facilitates learner's understanding of the region of interests from a patient. The inbuilt features such as rotation, zooming, and labelling provides a hands-on experience and can be changed to suit the individual learner.

This study has tested the feasibility of 3D rendering different pelvic fracture cases with a reasonable quality for learning and comparison purposes (Figure 2). The software processes bones at different regions and sizes and exhibits a favourable resolution for clinical use (Figure 3). The outcome means that different education needs and CT sources could mostly be accommodated using the technique. However, a limitation of this study is its potential application to orthopaedics. The 3D reconstruction of soft tissue such as skin and organs are theoretically feasible but needs to be further validated.

In addition, the traditional segmentation usually starts with a global thresholding technique, which defines the upper limit and lower limit of the grey scale and isolates the areas in between. Depending on the different CT qualities, the grayscale differences between bone and surrounding soft tissue might be low. A minor change at the threshold selection might result in a largely different outcome. Drishti developed an open-sourced gradient thresholding technique that substitutes the global thresholding tool for largely ease of the thresholding process and improves the repeatability between operators. However, further exploration of this technique will be required.

Take home message

This study has developed a detailed procedure to produce a 3D medical model using the free Drishti software. This is a potential processing tool for accurate, rapid and inexpensive generation of 3D anatomical models by orthopaedic surgeons. We propose that the routine training and clinical practice of orthopaedic surgeons incorporate the procedure and 3D model.

Conflicts of Interest and Source of Funding

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