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CASE REPORT

Cost-effective anatomical modelling in robot-assisted partial nephrectomy – a case study

RJ Urry

Netcare Waterfall City Hospital, South Africa

Corresponding author, email: james.urry@urologycare.co.za

Patient-specific preparation before minimally invasive partial nephrectomy is necessary to understand the tumour's relationship with the hilar and vascular structures of the kidney. Virtual and physical three-dimensional (3D) models of the kidney were constructed for a 56-year-old patient undergoing robot-assisted partial nephrectomy for a small hilar renal mass using open-source software and 3D-printed at minimal cost. The model improved preoperative planning, aided navigation to the tumour, and allowed safe identification of the vascular structures. With open-source software and the improved availability of lower-cost 3D printers, 3D modelling can be achieved with minimal financial, administrative, and time costs.

Keywords: cost-effective anatomical modelling, robot-assisted partial nephrectomy

Introduction

A surgeon's preparation for surgery can be divided into knowledge- and technique-based preparation. The latter can be divided into general, procedure-, and patient-specific preparation.[1] Patient-specific preparation requires patient-specific data per procedure and is thus not offered by most models and simulations. Surgeons performing minimally invasive partial nephrectomy benefit from patient-specific preparation due to the complex patient and tumour characteristics, which require consideration before surgery, particularly the tumour's relationship with the hilar and vascular structures.[2]

Traditionally, patient-specific surgical preparation for partial nephrectomy involved examination of cross-sectional computed tomography (CT) imaging in axial, coronal, and sagittal planes. Volume-rendered imaging does not allow for an adequate differentiation between the tumour, normal parenchyma, vessels, and collecting system, as there is insufficient contrast between these structures to differentiate them.[2]

Software has been developed to differentiate medical images into anatomical structures, a process known as segmentation. This process involves identifying and delineating specific anatomical structures or regions of interest (ROI) within medical images. In manual segmentation, the user manually draws ROI on individual slices of the image using drawing tools like paintbrushes, polygons, and region-filling tools. In semi-automatic segmentation, the user places "seeds" within the ROI. An active contour algorithm is used to delineate structures based on intensity and gradients, followed by user correction of the segmentation. Once segmented, three-dimensional (3D)reconstructions of the anatomy can be created.

ITK-SNAP (http://www.itksnap.org) is one example of this software. It is an open-source, multi-platform application that can generate 3D models from Digital Imaging and Communications in Medicine (DICOM) images and can be downloaded for free.[3]

Case presentation

A 56-year-old male patient was found to have a 1.8 × 2.6 cm small renal mass adjacent to the hilum of the right kidney and a contralateral uncomplicated pelvic ectopic kidney on CT imaging

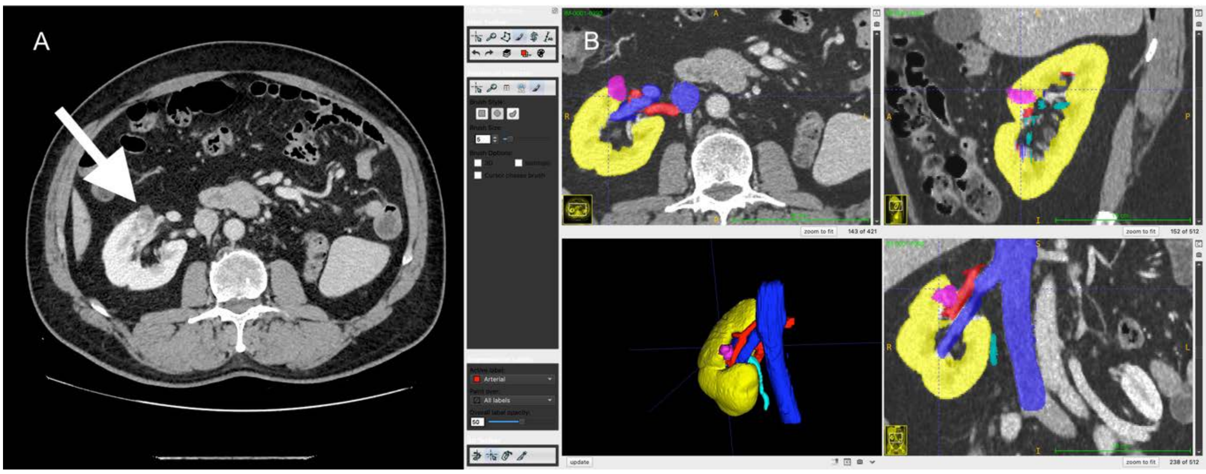

Figure 1: A – axial CT scan of the abdomen showing the renal tumour (white arrow), B – screenshot of axial, coronal, and sagittal images of the same CT scan imported into ITK-SNAP with the segmentation of the anatomy (yellow – kidney, red – arteries, blue – veins, light blue – collecting system, pink – tumour)

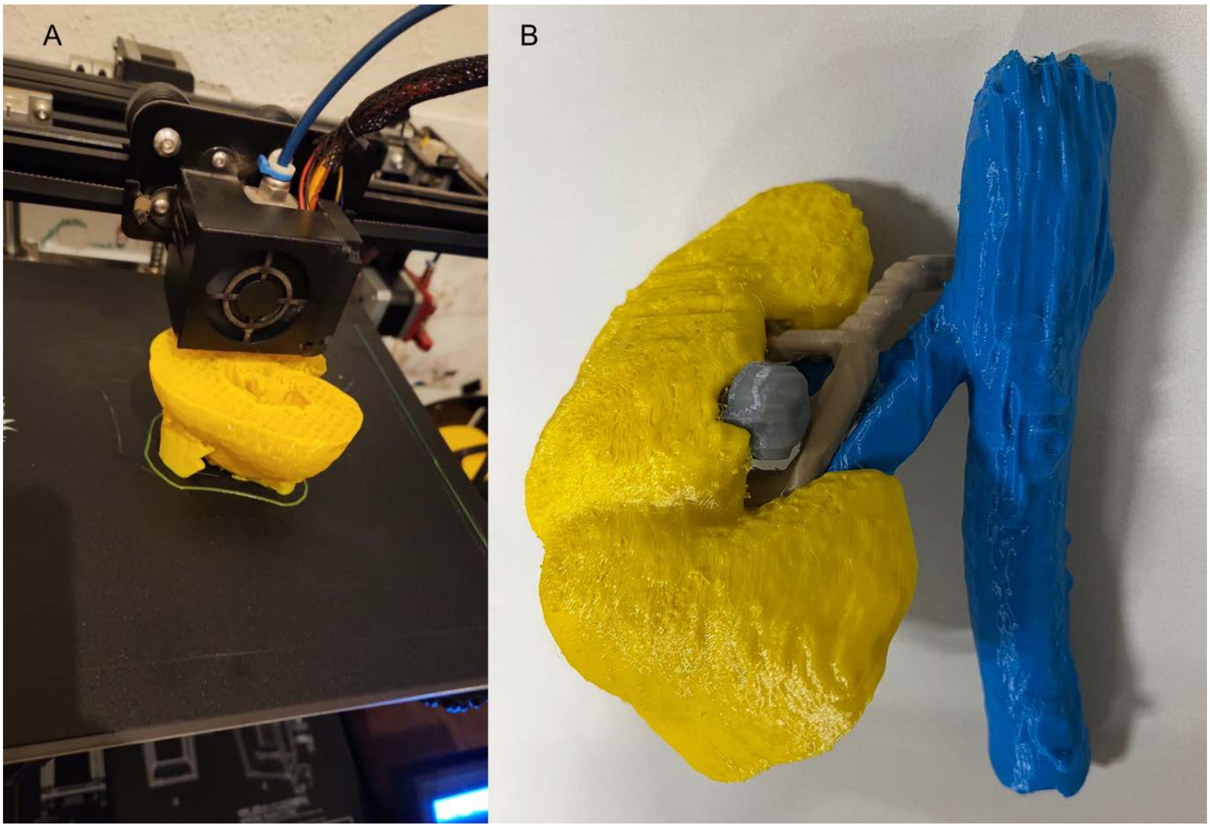

Figure 2: A – 3D printing of the model, B – the final 3D printed model

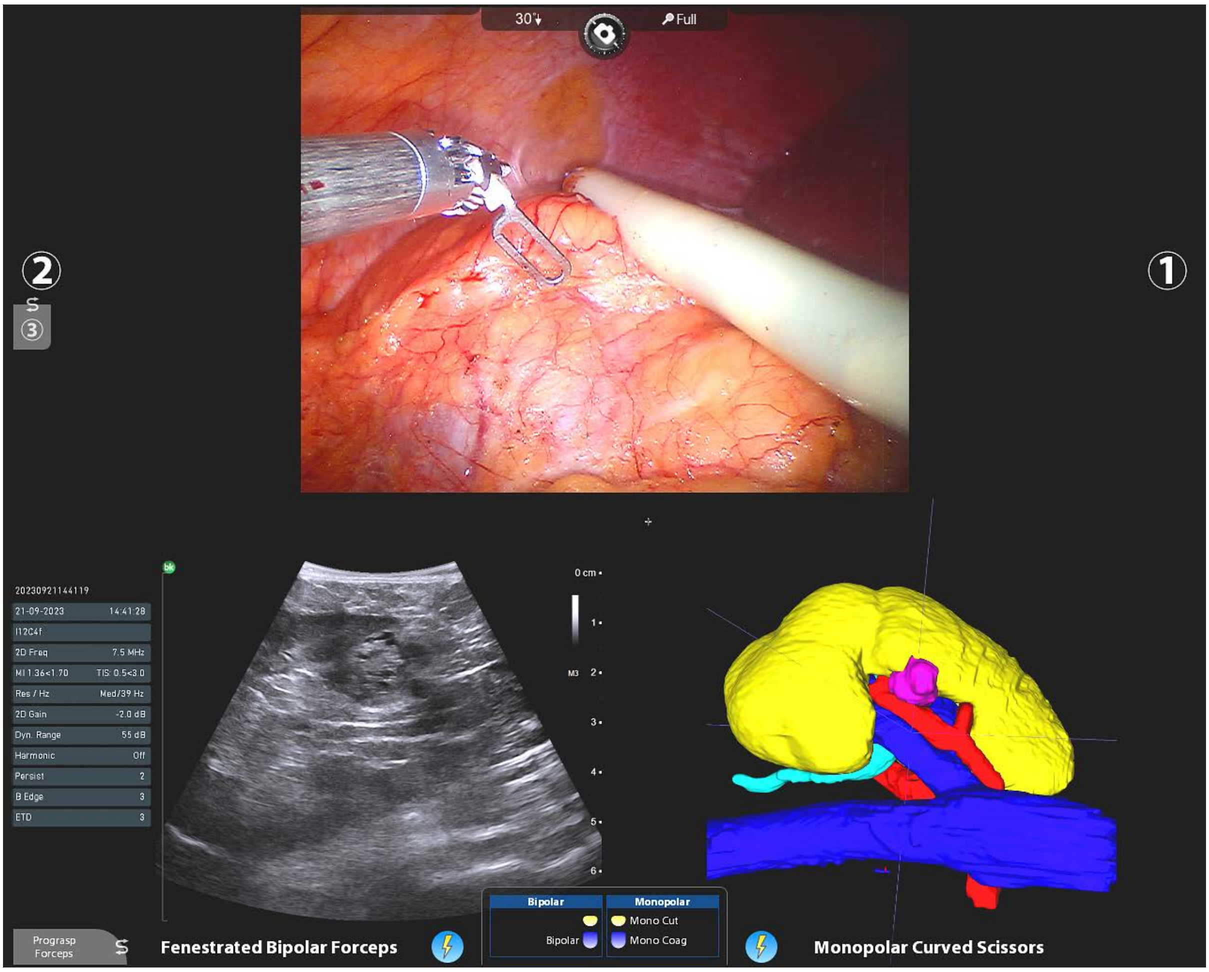

Figure 3: Intraoperative console view showing the surgical view, intraoperative ultrasound, and 3D virtual model as “picture-in-picture” views using the TilePro function of the da Vinci Si Surgical System

performed for non-specific abdominal pain. An ultrasound-guided renal biopsy was performed but was inconclusive. Because of his young age and the predicted 83% risk of renal cell carcinoma, he selected surgical management rather than active surveillance.[4] The patient was referred for radical nephrectomy because the tumour was considered too close to the renal vessels to perform a partial nephrectomy safely.

A 3D model was constructed to better understand the relationship between the renal vessels, collecting system, and tumour. Using ITK-SNAP, the DICOM CT images were imported and segmented. A 3D virtual model was created (Figure 1) in ITK-SNAP using semi-automatic segmentation, exported to a 3D printer file format, and printed (Figure 2). The construction of the 3D model took approximately four hours (including learning to use the software for the first time), and the 3D printing cost was approximately USD 25.00.

A robot-assisted partial nephrectomy was undertaken. The 3D model was displayed within the robotic console view as a "picture-in-picture" using the TilePro function of the da Vinci Si Surgical System (Intuitive Surgical, United States) alongside imaging from the intraoperative ultrasound obtained using a Flex Focus 800 ultrasound machine (BK Medical, Denmark) with a 4-way laparoscopic transducer (Figure 3).[5] There was no registration of the virtual model to the anatomy, and it was manually manipulated by the surgeon using the computer mouse to align the anatomy cognitively.

The tumour was found between the superior and inferior branches of the renal artery and vein adjacent to the renal sinus. No cooling of the kidney was performed, and mannitol was not given during the procedure to mitigate potential ischaemic injury to the kidney. After exposure of the renal vasculature and the tumour, an intraoperative decision was made to proceed without clamping the hilar vessels. The exposure was adequate, the tumour was small, and the surgeon felt there was a good chance of successful enucleation and renorrhaphy off-clamp without significant blood loss.

The tumour was successfully enucleated after using the third arm of the da Vinci Si Surgical System to gently and bluntly retract the inferior branches of the renal vessels. As the tumour did not involve the collecting system or any main or segmental vessels of the kidney, a single-layer renorrhaphy was performed. The surgery was completed off-clamp, with zero ischaemia and minimal blood loss, in a console time of 44 minutes and 10 seconds, without placement of a drain, and with a one-night hospital stay.

The surgeon subjectively felt that the virtual and physical models aided surgical planning and intraoperative navigation. The histopathology showed an International Society of Urological Pathology (ISUP) grade 2 clear-cell renal-cell carcinoma, which was completely excised.

Discussion

3D modelling before surgery is no longer a novel technology, with requisite open-source software available since 2006.[3] Nonetheless, this form of patient-specific preoperative preparation is not used routinely in patients undergoing partial nephrectomy. This may be due to several factors.[2] Firstly, the administrative, financial, and time costs of constructing accurate and clinically useful models may be prohibitive. Secondly, the usefulness of such models is debatable.

Several commercial systems are available to perform segmentation and 3D anatomical modelling. Examples of these include Vincent (FUJIFILM Healthcare Americas Corporation, United States), DICOM to Print (Oqton, United States), Hyper Accuracy 3D (Medics 3D, Italy), and Materialise Mimics (Materialise NV, Belgium). These companies do not publish the cost of their software licences.

A study of the costs of producing 3D printed models focused on the cost of the 3D printing but did not comment on the cost of the commercial segmentation and modelling software employed.[6] A study documenting the cost of setting up a 3D medical modelling department at the University of Cincinnati documented an average total cost of USD 2 737 per model.[7] Such prices are not viable in developing countries, hence the attractiveness of free, open-source applications like ITK-SNAP. Another open-source application that offers similar functionality is 3D Slicer (https://www.slicer.org).[8]

An early report on using a virtual image-guided 3D modelling system in robotic partial nephrectomy showed no negative impact on surgical workflow and offered the surgeon a subjectively improved appreciation of the hilar anatomy.[9] Another report showed that accurate 3D modelling of the kidney before partial nephrectomy assisted in choosing vessels for selective vascular clamping and avoiding global ischaemia of the kidney.[10]

A recent meta-analysis has provided the most insight into the clinical usefulness of 3D models in minimally invasive partial nephrectomy.[11] The study concluded that 3D guidance is associated with less non-tumour renal parenchyma excision and ischaemia, less frequent opening of the collecting system, and lower blood loss and transfusion rates. However, there were no significant improvements in operative time, renal function outcomes, oncological outcomes, conversion rates to radical nephrectomy, or complication rates.

With this case, the physical and virtual 3D models subjectively improved preoperative planning in choosing partial nephrectomy, aided navigation to the tumour, thereby minimising surgical time, allowed for the safe identification of the vascular structures, and allowed for the tumour to be excised off-clamp with minimal blood loss and zero ischaemia. The availability of free, open-source segmentation software and increasing access to lower-cost 3D printers made this possible with low financial, administrative, and time costs. With the advent of artificial intelligence (AI) in medicine, we can look forward to faster and more accurate segmentation with less human input and even progression to augmented reality surgery with AI registration of the 3D model to the surgical field.[12]

Conclusion

Constructing virtual and physical 3D models of renal anatomy before undertaking minimally invasive partial nephrectomy for renal tumours potentially improves surgical planning, intraoperative navigation, vascular control, and ischaemia time, with minimal impact on the surgical workflow. With open-source software and improved availability of lower-cost 3D printers, these models can be constructed with minimal financial, administrative, and time costs.

Conflict of interest

The author declares no conflict of interest.

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ORCID

RJ Urry https://orcid.org/0000-0003-3214-532X

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