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Case Report

3-dimensional model rendering and printing: enhanced visualisation for complex multi-compartment cases

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ABSTRACT

Complex surgical oncology demands meticulous preoperative planning, particularly in multi-specialty surgeries. Aligning surgical objectives, considering factors such as surgical intent, approach feasibility and minimization of trauma, is crucial. While traditional imaging modalities like MRI and CT are invaluable for planning, the integration of 3D modelling can provide enhanced visualisation of patient-specific anatomy and pathology. A 3D model was generated from MRI scans using 3DSlicer® software for segmentation and MeshLab® for refinement. Structures such as the bladder, rectum and prostate were manually contoured. The model was printed using a Bambu® Lab A1 3D printer with PLA filament. The printed model informed surgical planning for a multidisciplinary team managing a 60-year-old man with advanced bladder cancer invading the rectum. The 3D model provided detailed spatial understanding of anatomical relationships, improving preoperative planning and intraoperative execution. The surgical procedure, including cystoprostatectomy and Hartmann's procedure, was successful, with the 3D model providing guidance in the approach and enhancing collaboration among team members. The model's contribution extended beyond visualisation. It optimized surgical strategy by aiding in delineation of the tumour and enhancing interdisciplinary communication. Its educational utility helped trainees & students grasp pelvic anatomy and surgical techniques. Limitations included time-intensive manual segmentation and reliance on high-resolution imaging. Future advancements, such as automated segmentation and augmented reality, could improve efficiency and intraoperative applicability. 3D modelling and printing proved valuable in managing a rare, complex surgical case, fostering interdisciplinary collaboration and improved patient care. Further research and development could broaden its adoption and impact in surgical practice.

Keywords: Printing, Three-dimensional, Colorectal surgery, Urology

INTRODUCTION

Complex surgical oncology requires a great degree of preoperative planning; this becomes even more paramount when there is dual or multiple specialty involvement. A key element in combined surgeries is ensuring that the objectives of the surgical team are aligned. The important considerations include intent of surgery, whether this be curative versus palliative and symptom control, or debulking surgery to facilitate adjuvant therapies. Certain aspects of complex surgery, including feasibility of minimally invasive surgery, reducing surgical time and trauma, are factors that surgeons would like to improve. Traditional imaging modalities including Computerized Tomography (CT) and Magnetic Resonance Imaging (MRI) are invaluable tools in determining the extent of disease and by extension, planning of the operative approach for the patient, especially in rectal surgery. As such, there is an ongoing push towards the development and use of technology that provides more comprehensive information on the patient's anatomy and pathology to aid in surgical forward planning. Over the past decade, there has been increasing interest in the use of Three-Dimensional (3D) modelling in surgery. These models use advanced image processing derived from existing diagnostic imaging such as CT and MRI scans to create a 3D render of an individual patient's anatomy and pathology.[1] These models carry a variety of applications including in surgical planning, trainee and student education, as well as in pre-operative patient counselling.[2,3]

3D models have also been used to create 3D printed anatomical replicas of the patient's anatomy, which carry similar advantages to virtual 3D models.[3,4] However, there is currently no evidence that 3D printing or modelling leads to any improvement in patient outcomes, and there have been no studies comparing the benefits of virtually rendered 3D models to printed ones.[4] To date, 3D modelling technology has predominantly been applied to the field of Orthopaedics and Maxillofacial Surgery.[2,5] More recently, additional specialties, including Cardiothoracics, Neurosurgery, and Paediatric Surgery have begun to explore its applications.[6-8] General and Colorectal surgery as specialties, have been reasonably slow to adopt 3D modelling technology. This may be secondary to difficulties in creating 3D renders of Parenchymatous viscera such as the spleen or pancreas, compared with structures offering clear visibility and contrast, such as bone or clearly defined structures, such as vasculature.[9,10] In the abdomen, the literature has primarily focused on the application of 3D modelling to liver and kidney surgery with limited colorectal applications.[3,4,11] There are currently no published studies evaluating the use of 3D modelling in complex combined urological and colorectal surgical cases.

The aim was to demonstrate an innovative approach using 3D modelling and printing, a form of enhanced visualisation, to aid a complex surgical resection. The case used to demonstrate this is an advanced urothelial bladder cancer with rectal invasion. The unique challenges posed by this case, in terms of the rarity of the pathology and the intricate anatomy of the pelvis, provide an opportunity for an innovative approach to surgical planning.

CASE REPORT

A 60-year-old man presented to a regional Australian hospital with a long-standing history of haematuria and obstructive uropathy. Initial imaging showed a large, advanced bladder tumour with signs of locoregional invasion without systemic disease. Cystoscopy confirmed this to be a high-grade urothelial carcinoma with focal sarcomatoid and squamoid features. His background includes severe perianal scarring secondary to subcutaneous infections, initially thought to be due to Crohn's disease but later confirmed to be hidradenitis suppurativa. A laparoscopic loop ileostomy was fashioned for him to aid symptom reduction 10 years ago.

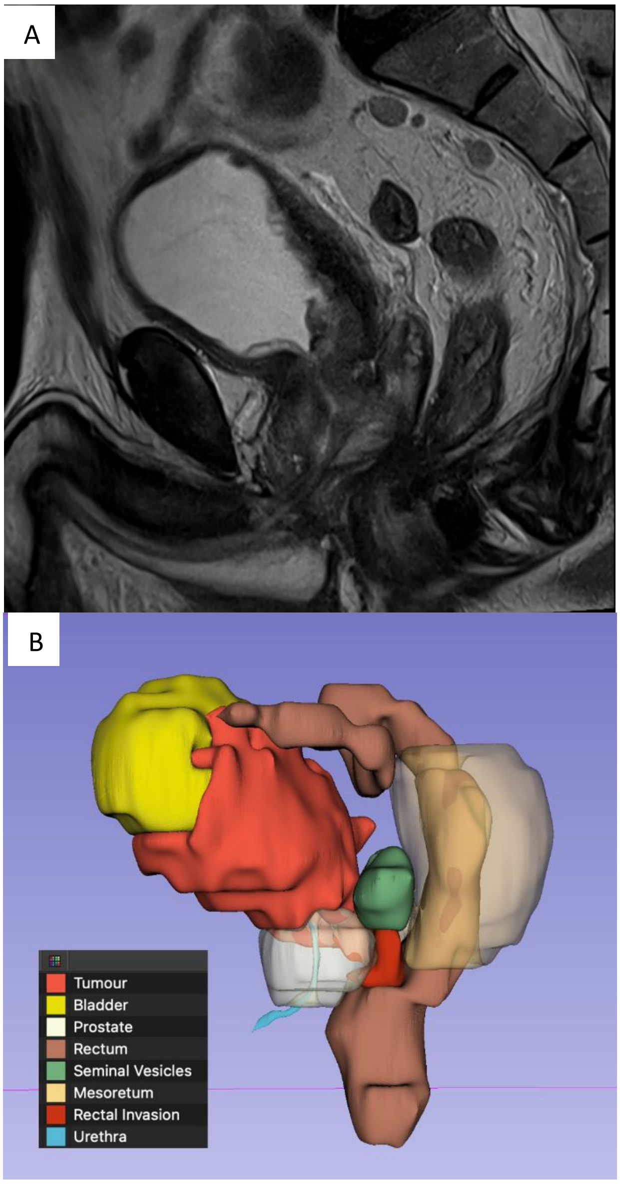

Figure 1: (A) Sagittal pelvic MRI (left) and (B) 3D model (right).

An MRI pelvis was performed pre-operatively which showed evidence of the tumour on the right side of the bladder with invasion into the perivesical tissue. This involved the right vesicoureteric junction leading to hydroureter and obstructive uropathy. A subtle tethering of the rectum to the prostatic tumour invasion suggested involvement of the rectum 4 cm from the anal verge. His case was discussed at a Urology Multidisciplinary Meeting (MDM). The option of neoadjuvant therapy was considered. However, surgery was determined to be the most feasible approach upfront, given the absence of systemic disease. The 3D-model approach was approved under clinical governance processes and contributed to unique management of an uncommon case. We used the CARE checklist when writing the report.

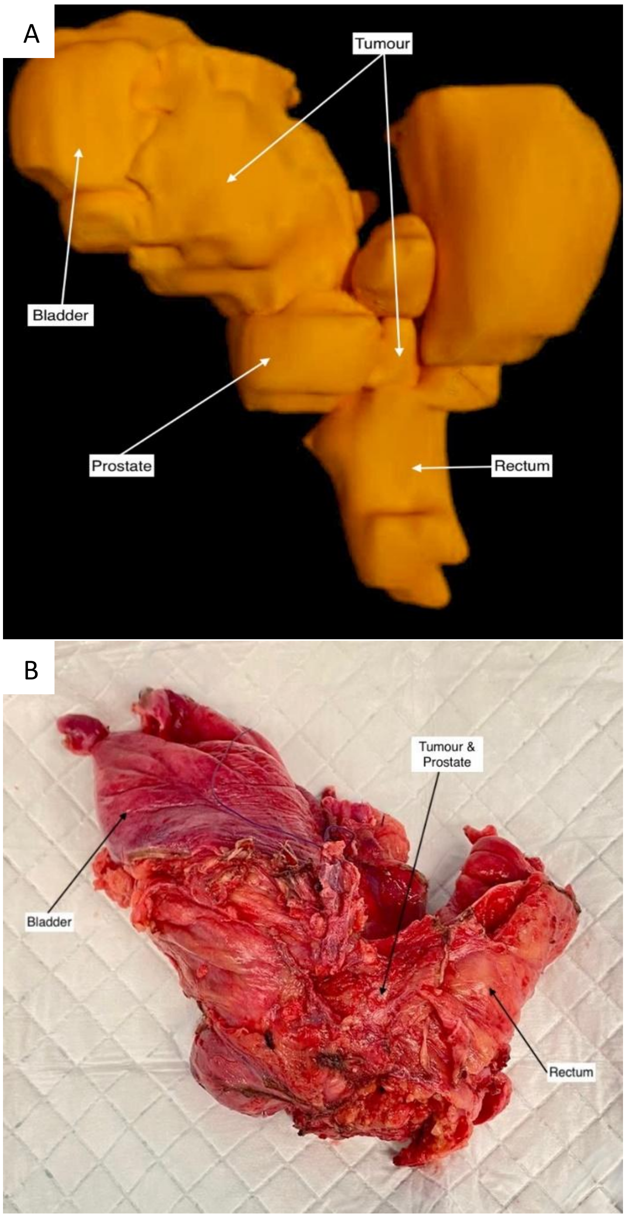

Figure 2: (A) 3D printed model (left) and (B) resected specimen (right).

MRI technique

Machine: 1.5 Tesla MAGNETOM Sola magnetic resonance imaging machine by Siemens Healthineers® (Erlangen, Germany). 16 channel total body coil. The patient was in supine position. Standard pelvic protocol was used. The T1 axial, T2 axial, coronal and sagittal sequence parameters are listed in Table 1.

3D modelling

The DICOM images were imported into 3DSlicer® version 5.6.2. TI Axial imaging was used for segmentation, with the crosshair visibility function used to check structures across the T2 planes. First, the bladder tumour was traced manually by a Colorectal Surgeon. This was depicted in dark red. Following this, the structures were contoured as follows - Bladder (yellow), Rectum (brown), Seminal vesicles (green), Urethra (blue) and Prostate (white). The model was then exported as a Standard Tessellation Language (STL) format and imported into MeshLab 2023.12 software. MeshLab allowed for the next stage of model creation, smoothing of the edges and mitigation of faults between layers or the stairs effect.

3D printing

The 3D model was printed using a Bambu Lab® (Shenzhen, China) A1 3D printer which offers a build volume of 256×256×256 mm, providing ample space for this model (72×140×152 mm). A matte, orange-coloured basic Polylactic Acid (PLA) filament was selected for its ease of use and suitability for medical modelling applications.

The slicing process was conducted using Bambu Studio® software, with the following settings (Table 2). The printing process completed successfully in 4 hours and 56 minutes without any technical issues. Post-processing involved the careful removal of support structures to preserve the model's intricate details.

Operative plan using 3D printed model

The 3D model was able to show us in a 1:1 fashion, the anatomy of the key resection structures. The initial plan was discussed at a case conference leading up to the planned procedure date. The printed and 3D rendered imaging was used to inform an efficient operative approach. The final operation would be a total cystoprostatectomy and ultralow Hartmann's procedure. This would include converting his existing loop ileostomy to an end colostomy and facilitating the natural position of an ileal conduit. The colorectal team advised that a perineal wound sustained from an abdominal perineal approach (whether intersphincteric or not) would have a high risk of failure due to the patient's perineal scarring from his hidradenitis suppurativa.

The colorectal team would begin by taking down the loop ileostomy, placing an Alexis capped port and performing a laparoscopy. They would then proceed to rectal mobilisation posteriorly down to the pelvic floor. The upper rectum would then be divided using a laparoscopic stapler, leaving the involved anterior aspect to be resected en-bloc. The colorectal team would then place a transanal access port in a TATME-like approach to suture the rectum closed proximal to the site of tumour invasion.

The TME plane created posteriorly would then be entered and extended circumferentially to divide the lower rectum completely before the prostate. The Urology team would then perform an open cystoprostatectomy, ureteric dissection and division, before proceeding to extraperitoneal dissection of the bladder and control of the Dorsal Venous Complex (DVC) and pedicles. The colorectal team would then guide the urology team's extraperitoneal dissection into the space created in the TATME plane, further dividing the lateral peritoneal attachment of the rectum and removing en-bloc, the involved rectum, prostate and prostatic urethra, seminal vesicles and intact denonvilliers fascial plane. The rectum was oversewn with interrupted 2.0 PDS in a double layer technique. The ileal conduit was then created, bowel continuity restored, and end colostomy and ileostomy matured.

Final operative outcome

The operative plan was successfully carried out as above. An unexpected finding of an appendiceal mucocele required that an ileocolic resection also be performed to manage the incidental finding whilst also re-establishing gastrointestinal continuity. This finding did not significantly impact our operative approach and on retrospective analysis, was seen to be visible on staging CT scans prior.

Table 1: Sequence parameters of utilized MRI scans.

Sequence parameters	Sequences			
	T1 axial	T2 axial	T2 coronal	T2 sagittal
Matrix	320, 210	288, 230	272, 218	272, 226
Repetition time (ms)	430	6810	7010	6850
echo time (ms)	9.9	99	98	98
Layer thickness (mm)	5	3.5	3.5	3.5
Spacing (mm)	6	3.5	3.5	3.5
Number of averages	1	2	2	2

Table 2: Slicing process settings.

Parameter	Setting/detail
Layer height	0.2 mm
Infill density and pattern	Sparse infill at 0.45 mm, internal solid infill at 0.42 mm
Support structures	0.42 mm
Print orientation	Oriented flat on the build plate

DISCUSSION

This paper demonstrates a novel model for preoperative planning; by utilizing 3D modelling and printing technology in the surgical management of bladder cancer with rectal invasion. This technique improved preoperative planning, interdisciplinary collaboration, and care for a complex patient with a significant burden of disease. 3D modelling transforms standard imaging into detailed, patient-specific, anatomical maps. In this case, the model informed a greater understanding of the tumour's anatomical location and its relationship to the prostate, rectum and mesorectum.

This was used as part of a pre-operative multidisciplinary case conference between the colorectal and urology teams to plan the steps of dissection and anticipate potential challenges in a collaborative manner to ensure the best operative approach for the patient. Previous studies have similarly recognised the value of 3D modelling in improving spatial understanding in the pre-operative setting, which has been shown to reduce intraoperative uncertainty.[12-16] Collaboration between surgical units for complex cases is often infrequent, which can result in poorly coordinated efforts. Such inadequate collaboration may lead to interdepartmental conflict, discord during operative management, and potential compromises in patient outcomes. To mitigate these risks, preoperative case discussions should be considered a mandatory step in all combined surgical cases. In the centre, the 3D model used was found to be a useful tool in facilitating this collaboration through illustrating the various ways in which the resection could be approached. This is particularly valuable in cases such as this, which involve high grade malignancy in a complex location (pelvis).[17] The ability to analyse the physical model which was created in a 1:1 fashion allowed for greater understanding of the specimen needed to be excised.

The primary use of the 3D model in this case was for operative planning. However, it also offered significant educational value for trainee surgeons and medical students. An experienced surgeon can pair traditional imaging techniques to intraoperative anatomy, a skill that is gained over time; we believe this technique aids in this process, allowing increased understanding and engagement from team members. Unlike traditional 2D learning resources, 3D modelling offers an interactive and spatially enhanced modality that fosters a deeper understanding of anatomy.[18] Studies within colorectal surgery have highlighted the educational advantages of 3D modelling, demonstrating its superiority in promoting anatomical comprehension compared to textbook-based learning.[19] Notably, 3D-printed models outperformed MRI visualisations in anatomy identification assessments, with participants showing a clear preference for 3D models over 2D alternatives.[20] These findings highlight the potential of 3D modelling to aid medical education by offering an engaging and effective tool for anatomical learning.

In the present case, the 3D model was also used when counselling the patient in the preoperative setting. In describing the procedure, the model was used as a visual aid for the patient, to better conceptualise the location of their pathology, as well as the proposed operation. This improved the patient's understanding of their condition and provided the opportunity to ask targeted questions pertaining to their diagnosis and surgical management plan, which aided in the consent process. This is in line with the advantages of 3D modelling recognised in the literature.[21,22] This case was performed at a regional Australian centre, which posed significant challenges in ensuring a favourable patient outcome.

While the urological and colorectal teams are composed of highly experienced surgeons, numerous studies suggest that higher volume centres are safer for these complex cases in terms of reducing short term complications.[23] However, Auerbach et al argue that the volume of cases may not be a determining factor; rather, adherence to quality measures (such as case conferences and multidisciplinary meetings), plays a more critical role in patient outcomes.[24] In this case, the surgical team's proactive approach and commitment to quality improvement led to the development of a 3D model for preoperative planning. This tool served as a valuable adjunct to increasing our quality measures and from our perspective, the uncertainty of the complex surgery was certainly minimized.

There were several challenges encountered in the development of the 3D model for this case. The MRI scans were completed using 3.5 mm slices which limited the resolution and detail of the render. In future, standardised imaging protocols dedicated to the development of 3D renders may be used. This would include the use of thinner slices and consistent voxel dimensions that maximize the detail of the render. The process of segmentation is also subject to variability between surgeons and radiologists.

For this case, the segmentation process took approximately 90 minutes and at this time, must be performed manually. Although not significant for an individual case, when extrapolated to multiple cases over time, this adds a greater burden to the already significant workload of the surgeon. Automated segmentation offers a potential means of improving this. Recent literature looking at automated segmentation of abdomen-pelvic MRIs has shown the process to take seconds or minutes, depending on the application and organs segmented its adoption in surgical planning could streamline workflows and enhance reproducibility of the modelling.[25,26] Accessibility is another important consideration. Whilst open-source software such as 3D slicer is freely available, not all institutions have access to the required imaging modalities and 3D printing technology. This is currently a barrier to widespread adoption of 3D modelling in surgery. It is suggested that future work should explore cost effective methods towards introducing 3D modelling across more regional and rural centres.

Regarding future directions, integration of AR into surgical workflows can aid preoperative planning and intraoperative guidance. During the preoperative phase, AR in conjunction with virtual surgical planning, enables the generation of detailed, patient-specific 3D anatomical models. These models allow surgeons to simulate operative strategies in a controlled virtual environment while enhancing the understanding of complex anatomical relationships, therefore reducing operative time and improving accuracy.[27,28] The intraoperative application of AR builds upon these preoperative advancements, providing real-time, interactive guidance by projecting 3D models into the operative field. This enables surgeons to visualize critical anatomical structure in real time, reducing navigational error and increasing navigational speed.[29] However, further research is required to identify and address the potential limitations of their implementation, as well as to rigorously evaluate their accuracy, safety, and overall clinical efficacy.

CONCLUSION

This innovative approach demonstrated the value of 3D modelling and printing in the pre-operative and intra-operative management of a complex patient with high grade bladder cancer with rectal invasion requiring multi-disciplinary care. It fostered collaboration and a shared understanding of the operative approach between surgical disciplines and positively influenced the care of the patient. This technology shows great promise and should continue to be developed and applied in surgical settings to unlock its full potential.

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