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Clinical application of three-dimensional printed models in preoperative planning of pancoast tumour resection

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Brief Report

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ABSTRACT

Background
The resection of pancoast tumours is a highly challenging procedure for cardiothoracic surgeons. A patient-specific 3D printed model of the tumour may be useful as an adjunct to standard preoperative planning procedures.

Aims
This study aims to assess the clinical value of a 3D printed pancoast tumour model as a preoperative planning tool.

Methods
Two anonymised cases of pancoast tumours were obtained and one was chosen to be 3D printed. The model was presented to two cardiothoracic surgeons with more than 10 years of experience. Interview and questionnaire sessions were conducted to sought expert opinions about the clinical value of the model as a preoperative planning tool.

Results
The participants agreed that the 3D printed model provides an accurate representation of the exact location of the tumour in relation to surrounding structures. The hand-held model also offers a tactile approach to preoperative planning, facilitating the planning of ports placement. The model is also potentially useful in team communication and patient education, leading to improved surgical outcomes.

Conclusion
This study has demonstrated the clinical value of a patient-specific 3D printed model of pancoast tumour in preoperative planning. Apart from enhancing the surgeons' understanding of the anatomical location of the tumour, the model is also easily manipulated. Future research could investigate the impact of 3D printed model on short to mid-term clinical outcomes.

Key words:
3D printing, model, education, surgery, lung cancer

Implications for Practice:

1. What is known about this subject?
The application of 3D printing in preoperative planning has been demonstrated in the resection of various tumours including pulmonary nodules. However, there is still limited evidence about its application in lung cancer, particularly pancoast tumours.

2. What new information is offered in this review?
This study demonstrated the clinical potential of 3D printing as a preoperative planning tool in pancoast tumour resection.

3. What are the implications for research, policy, or practice?
With further advancement of technology, the limitations of 3D printing may be overcome. This would allow further research to be conducted in this field, with the ultimate goal of improving patient outcomes.

Background

In recent years, three-dimensional (3D) printing technology has emerged as an exciting field, continuously gaining recognition across the medical field with applications in a variety of domains: education of medical students and healthcare professionals, preoperative planning, training and simulation of surgical procedures, and improvement of doctor-patient communication.[1,2] Its application in preoperative planning has been particularly proven to be valuable in the resection of cardiac tumours[3], osteochondroma[4], liver tumours[5], and renal tumours[6]. Recent studies also demonstrated the accuracy of 3D printing localization techniques for the treatment of pulmonary nodules in preoperative and intraoperative settings, which yielded positive results.[7,8] Despite the advancement, there is still very limited evidence about the application of 3D printed models in lung cancer. This study endeavours to assess the clinical value of a 3D printed pancoast tumour model as a preoperative planning tool.

Pancoast tumours are also known as superior sulcus tumours due to their location in the lung apex.[9] The resection of pancoast tumours remains a highly challenging procedure because they often invade into surrounding structures such as the nerves, blood vessels, ribs, vertebrae and muscles.[10] Therefore, the use of a patient-specific 3D printed model of the tumour may be useful as an adjunct to standard preoperative planning procedures.

Methods

Two anonymized cases of pancoast tumours were obtained from a public hospital, with one case being an operable pancoast tumour and the other being inoperable. The operable case, who was a 66-year-old male patient was chosen to be 3D printed for the assessment of its clinical usefulness.

Computed tomography (CT) scan of the selected case was performed on a 64-slice CT scanner (GE Healthcare Optima CT660) with detector collimation of 64x0.625mm, gantry rotation of 630ms, 120kVp and 149mAs and a slice thickness of 1.25mm. The dataset in Digital Imaging and Communications in Medicine (DICOM) format was first imported into a commercially available biomedical imaging software Analyse 12.0 (AnalyzeDirect, Inc., Lexana, KS, USA) for image post processing and segmentation. The bones were first segmented using an automatic approach to allow separation from the structures. The tumour was segmented manually due to its close location to the adjacent anatomical structures, slice by slice, with special attention due to being of similar density to the surrounding soft tissues. After that, the segmented structures were assembled via 3D rendering to allow visualization of the intended final object. The segmented volume data was then converted into Standard Tessellation Language (STL), which enabled being printed by the 3D printer.

In order to assess the model's clinical value, the model was presented to two cardiothoracic surgeons with more than 10 years of experience. Two interviews and questionnaire sessions were conducted over a two-months period. One of the focuses of the questions was to evaluate the accuracy of the printed model, as compared to visualising the CT images on a computer screen. Further, usefulness of the model as a preoperative tool was also explored. Some questions were also designed to explore the clinical value of the model in other areas such as medical education and patient education. The participants were also asked to provide opinions regarding the possible limitations and areas of future improvement for the model.

Results

The bones and tumour were printed separately using different materials and colours to provide a better visual representation of the anatomical details and facilitate understanding of the spatial relationship between structures. The bones were printed using polylactic acid (PLA), and included the upper ribs, vertebrae, sternum and the clavicles (Figure 1). A magnet is attached to the second rib to allow the attachment of the tumour, in order to demonstrate the most accurate spatial relationship between them (Figure 1B).

On the other hand, the pancoast tumour was printed using the relatively soft and elastic thermoplastic polyurethane (TPU) to achieve tissue-like quality. A magnet is also incorporated on the top of the tumour to allow accurate attachment to the second rib (Figure 2). The final model shows the precise location of the tumour in relation to the ribs and vertebrae (Figure 3).

Overall, the participants agreed that the 3D printed model of the pancoast tumour provides a better representation of the exact location of the tumour in relation to the bones, as compared to viewing the CT images on a two-dimensional (2D) computer screen. The participants mentioned that the tumour appears to be more inferior than expected (Figure 3b), which explains with the lack of clinical findings suggesting brachial plexus involvement.

The hand-held model also offers a tactile approach to preoperative planning. The participants appreciated the opportunity to freely manipulate the model, which could potentially assist in planning the placement of ports during the operation. Apart from that, the model could also facilitate communication between the surgical team members, to ensure consistent understanding of the operation. It may also be extremely useful in patient education, enhancing the patient's understanding of the nature of their disease and the operative plan. Overall, the 3D model is thought to have the potential to improve overall surgical outcomes.

Discussion

The utilization of 3D printing as a preoperative localization tool was demonstrated by Fu et al.[7] Compared to CT-guided localization technique, 3D printing technique allows accurate localization of small pulmonary nodules, it is less time consuming, easier to operate, pain-free and resource-conserving. In terms of intraoperative use, Chen et al. has demonstrated the potential of 3D printing to reduce surgical approach and method conversion rates, operative time and intraoperative blood loss.[8] Unlike the previous studies, this study focuses on the use of a 3D model as a preoperative planning tool for the resection of a primary pancoast tumour, with secondary interests of its use in medical and patient education.

The greatest benefit of this 3D model would be the accurate and realistic representation of the location of the tumour, which would contribute to the assessment of resectability preoperatively. In terms of clinical decision-making, it is important to consider a lot of other factors such as patient's physical condition; hence the model may not play an important role in choosing the best treatment approach or surgical equipment.

In a study conducted by Yoon et al, patient satisfaction scores were higher when 3D models were used when obtaining informed consent for surgical resection of stage I lung cancer.[11] Although not explored extensively, the participants agreed that the model could be of significant benefits in patient education, with the potential to enhance patient comprehension and surgeon-patient rapport.

In terms of limitations, the segmentation process was challenging because the tumour was of similar density and within close proximity to the surrounding tissues, which may have compromised the accuracy of the actual extent of the tumour on the model. It would also be ideal to include more structures on the model, especially the muscles as invasion is highly likely according to the participants. If the model was printed in life-size with the inclusion of more structures, it could potentially be used as a surgical training tool, allowing mock surgeries to be performed.

According to the radiology report, the tumour was reported to measure approximately 66mm. Measurement of the printed tumour was made to assess the accuracy of the tumour size. In Figure 4, the printed tumour was measured to be approximately 59mm in length. This demonstrated slight discrepancy between the identified tumour size on CT images as compared to the printed tumour. The difference was most likely caused by the measurement error that was introduced during image post-processing and segmentation. This needs to be addressed in future studies with inclusion of more cases and assistance of automatic or semi-automatic segmentation tools.

Conclusion

In conclusion, the 3D printed pancoast tumour model provides the surgeons with a better understanding and an accurate representation of the anatomical location of the tumour. The model offers the advantage to be easily manipulated, with the potential to improve the ultimate surgical outcomes. Therefore, a 3D printed model could be a useful addition to the preoperative planning process. With further advancement of technology, the limitations of 3D printing may be overcome. Further research would be ideal to provide additional insight into the clinical values of 3D models in improvement of treat outcomes based on short to mid-term follow-ups.

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PEER REVIEW

Peer reviewed.

CONFLICTS OF INTEREST

The authors declare that they have no competing interests.

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No

ETHICS COMMITTEE APPROVAL

Ethical approval was obtained from Curtin University Human Research Ethics Committee.

Figure 1: 3D printed bones

A B

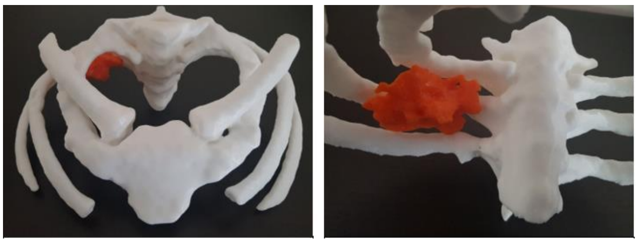
(A) Front view (B) Bottom view with magnet (circled)

Figure 2: 3D printed tumour

A B

(A) Top view with magnet (B) Bottom view

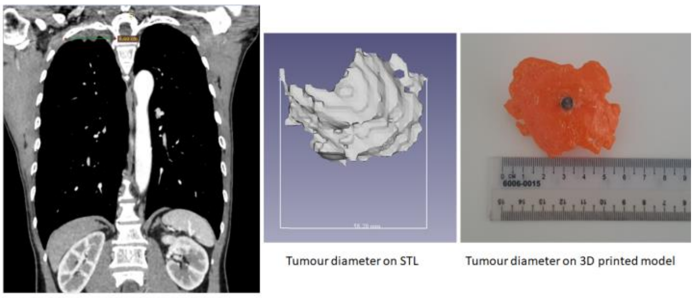
Figure 3: The complete model



A B

(A) Front view (B) The exact location of the tumour in relation to the bones

Figure 4: The tumour diameter measured on original CT, STL and 3D printed model



Tumour diameter on STL

Tumour diameter on 3D printed model

Tumour diameter on coronal CT image

The maximal transverse diameter of the tumour was measured 66mm, 58.2mm and 59mm on original CT image, STL (Standard Tessellation Language) and 3D printed model, respectively.