3D-Printed Tumour Models

Subjects: Oncology
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Three-dimensional (3D) printing technology has revolutionized our perception of how advanced technologies contribute to medical education and clinical practice by augmenting the current visualization tools or standard diagnostic or planning approaches used in the different fields of medicine. 3D printed personalized models serve as a valuable tool in improving understanding of complex anatomy and pathology, in particular, when assessing tumours, since 3D printed physical models provide direct visualization of the tumour in relation to surrounding structures.

3D printing cost heart cardiovascular disease model medicine

1. Introduction

Three-dimensional (3D) printing technology has revolutionized our perception of how advanced technologies contribute to medical education and clinical practice by augmenting the current visualization tools or standard diagnostic or planning approaches used in the different fields of medicine. Patient-specific or personized 3D-printed models derived from medical imaging datasets such as computed tomography (CT), magnetic resonance imaging (MRI) or ultrasound have been increasingly used for medical applications, with research findings proving its value in different aspects [1][2][3][4][5][6][7][8][9][10][11][12][13][14][15][16][17][18][19][20].

Use of 3D-printed models has been well explored in the maxillofacial and orthopaedics areas and its value in cardiovascular disease and other areas is showing great promise [10][11][12][13][14][15][16][21][22][23][24][25][26][27]. Although promising results are available in the literature, one of the main obstacles to implementing 3D-printing technology on a large scale is due to the relatively high cost and limited access to the 3D-printing facilities [28][29][30]. This includes the software tools used for image processing and segmentation, 3D printers, printing materials, and the process of post 3D printing (such as model cleaning, etc.). The cost per model varies widely ranging from less than USD 100 to more than USD 1000, depending on the purpose of using these models for medical applications (whether they are used for medical education or clinical communication or simulation of surgical procedures or surgical planning) [29][30][31][32].

2. 3D-Printed Tumour Models

Personalized 3D-printed models are shown to play an important role in enhancing a viewer's understanding of the complex anatomy and spatial relationship between tumours and surrounding anatomical structures, with studies reporting its clinical value in surgical training and planning, and the operative simulation of various tumours [6][7][8][9]

[19][20][33][34]. Researchers have printed several models of different types of tumours from CT and MRI datasets, with the aim of exploring the usefulness of 3D-printed tumour models in preoperative planning when compared to the current approaches based on image visualizations.

2.1. 3D-Printed Breast Cancer Model

Researchers developed a patient-specific 3D-printed breast model from a normal breast MRI scan and identified suitable materials simulating MR imaging features of adipose and fibroglandular tissues [35][36]. First, researchers used 3D-printing technology to create the hollow skin and fibroglandular region shells using tissue-mimicking materials. Then, researchers tested five materials (agarose gel, silicone rubber with/without fish oil, silicone oil, and peanut oil) and measured their T1 relaxation times on a 3T MRI scanner. The results showed that silicone oil's T1 relaxation time was similar to that of fibroglandular tissue, while peanut oil's T1 relaxation time was similar to that of adipose tissue. Hence, silicone oil and peanut oil were injected into the 3D-printed fibroglandular model and skill shell model, respectively. Furthermore, researchers scanned the 3D-printed model with six different MR sequences including fat- and non-fat suppressed sequences to perform quantitative measurements of breast volume, fibroglandular tissue volume and the percentage of breast density between these two different scanning sequence groups [35]. Quantitative measurements of breast fibroglandular tissue volume and the percentage of breast density on fat-suppressed sequences were significantly higher than those measured on non-fat suppressed sequences ($p < 0.05$), although there was no significant difference in breast volume measurement ($p = 0.529$) [36].

There are only a few studies available in the literature regarding the development of 3D-printed breast models for use in the medical imaging area [37][38][39], while research on the assessment of breast density with the use of a realistic 3D-printed model is lacking. The 3D-printed breast model can be used to identify optimal breast MR scanning parameters for the quantitative analysis of breast density.

2.2. 3D-Printed Lung Cancer Model

Researchers printed a lung cancer model based on CT images of a patient diagnosed with a Pancoast tumour, which is located in the lung apex. Surgical resection of Pancoast tumours could be very challenging because of their invasion into surrounding structures such as ribs, vertebrae, blood vessels and muscles [40]. Researchers reviewed two cases of Pancoast tumours and chose an operable case with bones and the tumour printed using different materials. The models were presented to two cardiothoracic surgeons with more than 10 years of experience for the evaluation of the usefulness of 3D-printed models as a preoperative tool. Participants agreed that the 3D-printed model offered a better representation of the exact tumour location relative to bones when compared to standard CT images. The model was considered to have potential value in assisting operation and facilitate communication between team members. It was also found to be extremely useful in medical education [41]. Studies reported the clinical value of using 3D-printed models in improving surgical safety and patient's understanding of surgical resection of lung cancer [42][43], but at the cost of USD 1000 printing per model [42].

2.3. 3D-Printed Renal Cell Carcinoma Model

3D-printing technology is increasingly used in printing kidney models for renal disease with research findings showing its clinical value in the preoperative planning and simulation of renal disease, education of junior surgeons, enhancement of operative skills for senior surgeons, as well as the facilitation of interdisciplinary communication and decision making in terms of the management of patients with renal cell carcinoma (RCC) [6][7][44][45][46]. Researchers chose a case with low-grade renal cell carcinoma on the inferior pole of right kidney and printed the model with TPU. Measurements of dimensional accuracy at different anatomical locations did not show significant differences between the 3D-printed model, original CT images and STL file. The 3D-printed model was presented to five urologists with 5–20 years of experience in the surgical treatment of RCC. All participants agreed that the 3D-printed model could facilitate preoperative planning, and believed that it could reduce intra-operative complications. They also agreed that a 3D-printed model could be used for the training of inexperienced surgeons and for patient education and patient–clinician communication [47]. The developed low-cost model is suitable for medical education and patient communication, while for clinical applications such as the pre-surgical planning of RCC resection, 3D models printed with multi-colour materials are preferable, as shown by a recent systematic review [48], despite the relatively high cost (between USD 400 and 1000).

2.4. 3D-Printed Pancreatic Cancer Model

The use of 3D printing in pancreaticobiliary disease is only reported in a few case studies with results showing that 3D-printed models improve the outcome of pancreaticobiliary surgeries by enhancing the understanding of the operation process and serving as a training tool [5][20][49][50]. Researchers printed a pancreatic cancer model along with abdominal aorta and main arterial branches and also created VR views for comparison with 3D-printed models with regard to their value in the preoperative planning of pancreatic tumours. Researchers invited six participants (four pancreatic surgeons, one surgical resident and one gastroenterologist) to provide their opinions on the clinical value of both 3D-printed models and VR in the preoperative planning of pancreatic tumour resection. All participants agreed that both the 3D-printed model and VR offered better spatial awareness between the pancreas and surrounding vessels, and helped the planning of complex surgery when compared to the original CT images. Five out of six participants considered that VR was more useful than the 3D-printed model in the preoperative planning of pancreatic tumour resection. Further studies with the inclusion of more participants, especially novice surgeons, are needed to validate the clinical value of 3D-printed pancreatic models in preoperative planning or skill improvement. The preliminary findings are consistent with others [49][50], although future studies should include more cases and participants to allow robust conclusions to be drawn.

2.5. 3D-Printed Biliary Cyst Model

Application of 3D-printing technology in biliary disease is limited as most of the current reports are focused on hepatic disease such as hepatocellular carcinoma or liver transplant [2][8][9]. Researchers generated a 3D-printed model from a case with a rare and huge biliary cyst in the common bile duct [51]. Right and left hepatic ducts, and common bile duct including the cyst, were printed with 3D-printed model scanned on a 64-slice CT scanner. CT images of the 3D-printed model were used to measure dimensions of these biliary trees for comparison with an STL file and 3D-printed model. The results showed the high accuracy of the 3D-printed biliary model in replicating anatomical structures of the biliary system with significant differences in measurement between the STL file and 3D-printed model. The significant discrepancy in measurements could be due to inconsistencies among the orientation and location of anatomical landmarks between post-processed data (STL file) and 3D-printed physical models and this needs to be considered in future studies [51]. The large discrepancy was also reported by Bati et al., with significant differences in dimensional measurements between 3D STL images and the original images/images of the 3D-printed model [49]. A 3D-printed model of the biliary system can be used for education and training, as well as the treatment of complex biliary disease [52][53].

2.6. 3D-Printed Chest Models

Researchers printed a chest phantom comprising lungs, trachea, ribs and thoracic vertebrae to provide a realistic anatomical environment to host 3D-printed models such as heart, coronary artery and pulmonary artery models. This is especially important for studying optimal CT scanning protocols, with a reduction in radiation dose, with 3D-printed models placed in a thoracic cavity with anatomical structures surrounding them. The previous studies showed the feasibility of using 3D-printed aorta, coronary and pulmonary artery models to determine appropriate CT protocols with lower radiation doses but acceptable image quality. However, these phantoms were placed in a simple plastic or acrylic container without having anatomical thoracic or abdominal structures available [54][55][56][57][58]. The developed 3D-printed chest model could further advance the previous research with robust findings generated, as all of the anatomical structures are simulated in the 3D-printed models.

2.7. 3D-Printed Models of Abdominal and Pelvic Organs

Researchers encountered a case of situs ambiguus which is a rare congenital anomaly with multiple abdominal or pelvic organs abnormally positioned [59]. Both CT and MRI images were used to segment abdominal organs including the liver, spleen, stomach, kidneys, aorta and its main arterial branches, bladder, and uterus [60]. These organs were 3D-printed for a demonstration of the abnormal position of some organs within the abdominal and pelvic regions. The 3D-printed models can be used for educational purpose for medical students, family members of the patient and also between clinical colleagues. Personalized 3D-printed models of these abdominal and pelvic organs are shown in a range of applications, from medical education to training and the simulation of surgical procedures to residents and surgical teams, with an improvement in surgery outcomes [61][62][63][64].

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