

Modeling and Personalized 3D Printing of Pancreatic Tumors: New Tools for the Pre-Operative Work-Up: A Scoping Article and Case Study

Benjamin Malavallon^{1*}, Anne-Lise Hachulla², Antonio Nastasi¹, Stephane Hertig¹, Carmen Gonelle-Gispert⁴, Bernhard Egger³, Sylvain Terraz² and Leo Bühler⁴

¹Department of Surgery, University Hospitals of Geneva, Geneva, Switzerland

²Division of Radiology, University Hospitals of Geneva, Geneva, Switzerland

³Department of Surgery, Hospital Fribourg, Villars-sur-Glâne, Fribourg, Switzerland

⁴Faculty of Science and Medicine, University of Fribourg, Fribourg, Switzerland

Received March 13, 2020; Accepted March 19, 2020; Published August 10, 2020

ABSTRACT

Background: Pancreatic adenocarcinomas are aggressive and mostly diagnosed at an advanced stage. Precise radiological assessment remains challenging and small tumors can be difficult to localize during surgery, necessitating large resections. An innovative approach for the pre-operative work-up of borderline or small tumors is the three-dimensional (3D) printed pancreas model.

Objective: We conducted a scoping review of research on the use of 3D printing in pancreatic tumor surgery to review current status and future perspectives of this approach and its advantages and disadvantages. We examined the feasibility of implementing it in our unit with a case study.

Design: Online databases were used to identify all papers published, including conference abstracts, primary research and expert consensus. We selected 8 publications that discussed the utility of 3D modelling and printing in pancreatic tumour surgery.

Results: Two case studies, 2 cases series, 1 expert consensus, 1 review, and 2 randomized trials reported on advantages and disadvantages on 3D printing in pancreatic surgery, three of which were conference abstracts. There was no homogeneity in the reported outcomes.

Our case study was a 48 years old patient with a neuro-endocrine tumor of the pancreatic head managed with exploratory laparotomy and subsequent cephalic duodeno-pancreatectomy.

Retrospective evaluation of a 3D printed model of his pancreas indicates that the exploratory laparotomy could have been avoided if such model was available at the time.

Conclusion: The quality of current literature is low, and further research is required to establish concrete benefits of this technique. Early reports show benefit in the preoperative diagnosis and evaluation of the resectability, vascular invasiveness, and relative position of the tumor to abutting structures. Main disadvantages are time requirements, cost and availability of expert radiologists.

Implementation of 3D printing is accessible to our hospital and not considered a major technical challenge, but a new method of using available resources.

Keywords: Imaging, Three-Dimensional Printing, Three-Dimensional 3D printing, Pancreas, Pancreatic Neoplasms, Pancreatic tumors

Corresponding author: Benjamin Malavallon, University Hospitals of Geneva, Switzerland, E-mail: leo.buhler@unifr.ch

Citation: Malavallon B, Hachulla AL, Nastasi A, Hertig S, Gispert CG, et al. (2020) Modelling and Personalized 3D Printing of Pancreatic Tumors: New Tools for the Pre-Operative Work-Up: A Scoping Article and Case Study. BioMed Res J, 4(2): 235-244.

Copyright: ©2020 Malavallon B, Hachulla AL, Nastasi A, Hertig S, Gispert CG, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

INTRODUCTION

Current diagnostic methods for pancreatic tumors

Pancreatic adenocarcinoma is associated with high mortality and short life expectancy despite recent advances in our comprehension of its pathophysiology. A confounding factor is that, due to its central location in the abdomen, symptoms and clinical signs are discreet and late to be recognised. The main curative treatment consists of surgical excision followed by adjuvant chemotherapy. To determine whether the patient is eligible for surgery, it is necessary to establish the stage of the tumor, the presence or absence of distant metastases and the extension of the tumor to surrounding structures, in particular the arterial vessels (celiac artery, common hepatic artery, splenic artery, superior mesenteric artery) and veins (portal vein, splenic vein, superior mesenteric vein).

Establishing the stage and extension of pancreatic tumors can be achieved through various radiological methods, with relatively similar performances. Abdominal Computer Tomography (CT) scanning remains the key reference for evaluating pancreatic tumors and, depending on the location of the tumor, other radiological examinations such as pancreatic MRI, endoscopic ultrasound or PET-CT can also be useful. Several staging systems exist today to establish the resectability of these tumors. The most widely used system on an international basis is the 'MD Anderson Varadhachary/Katz' staging system for adenocarcinoma of the pancreatic head and uncinate process [1].

This staging system is relatively simple and useful for clearly resectable and non-resectable tumors. However, given the heterogeneity of pancreatic tumors, establishing the relationship between the tumor and the vascular structures represents a major challenge, especially as this precise relationship constitutes the main cornerstone impacting medical decision. Therefore, a less clear intermediate zone exists for borderline tumor that remains a radiological challenge to this day. One technique to assist in visualization and interpretation of pancreatic CT or MRI images is the use of three dimensional (3D) radiological reconstructions, a common practice in several areas of medicine, such as angiology, oncology, surgery and anatomy [2].

Although it allows for a better representation than two dimensional imaging (2D), it still relies on subjective interpretation due to the radiological heterogeneity of pathological human tissue. In order to increase the precision of tumor representation with regard to neighboring structures, the method of segmentation and 3D printing has been recently tested by a small number of medical centers, especially in Asia [3].

This technique proposes a selection of pancreas tissue, tumor and blood vessels based on CT-scan slices, from which a 3D model is created with specialized software. The location,

sizes and congruity ratios between other anatomical structures and the tumor are highlighted on the 3D model with different colors and volumes. The model is saved as a readable file in STL format (stereo lithography) that can be sent to a 3D printer. The result is a physical 1:1 scale model, which can be used "hands-on" to evaluate the extent of the parenchymal tumor, its vascular relationships and location.

Applications of 3D printing in the medical field

Yao et al. [4] summarized various applications for 3D printing in medicine. They reported that it already plays a prominent role in some areas of surgery, such as neurosurgery, plastic surgery, oral and maxillofacial surgery, orthopaedics and cardio-vascular surgery, including anatomical training for medical students. Among the benefits of this technique, the authors mention improved pre-operative planning, reduced surgical time and rates of complications as surgeons are able to prepare before the surgery, for example to ascertain more precise tumor location.

A recent systematic review by Martelli et al. [5] identified various advantages and disadvantages of the use of 3D printing in surgery. The review included 158 studies dating between 2005 and 2015, the majority from China, Germany, the US and Japan. The main scope of application was the production of anatomical models, surgical aids and "hands-on" operative models, with maxillofacial surgery and orthopedics being predominately featured among the included studies.

Other innovative applications included the use of sterilized models placed on the surgical field allowing for more precise surgical gestures (the surgeon being able to keep both the model and important anatomical markers in the operative field in direct sight), and the construction of implants specifically adapted to the patient's anatomy.

The authors highlighted that 3D printing offered a better understanding of anatomical characteristics, a heightened visualization of potential difficulties to surmount and the study of the patient's standard vascular variations. Beyond the improved standard pre-operative planning, some surgeons were also able to run through surgical simulations, thus establishing better approaches and improved surgical procedures. Operative times and patient morbidity-mortality rates were reduced due to fewer risks and post-operative complications (shorter anesthesia leading to reduced risk of wound infection, reduced blood loss). In certain cases, the availability of 3D printed models reduced radiological exposure of the patients and medical staff.

However, there are certain limitations and disadvantages in the use of 3D printing. The segmentation time required by the radiologist and the production time of the 3D model from radiology images is the most important factor preventing the use of 3D printing in the field of emergency medicine [4, 5].

The additional costs resulting from the purchase of effective computer hardware, segmentation software (although free software can be found) and of 3D printers assuring accurate and useful rendering for the surgeons, are also a major disadvantage. This limitation raises the question of reimbursement possibilities of these new techniques. Finally, the quality of purchased material can impose resolution limitations which could affect precision of the printed model and, therefore, its validity.

The potential benefits of 3D printing in pancreatic surgery are obvious. Aspects of patient management that can be impacted by this technique include indication for surgery, surgical preparation and intra-operative anatomical guidance, resulting in reduction of operative times and better resection margins. Ideally, this innovative process could allow for improved evaluation of the operability of tumors with borderline indications, thus reducing the need for unnecessary surgery, as well as establishing adequate margins during the surgical removal of these tumors, therefore limiting the progression of the cancer. However, the extend of the evidence supporting these claims is unclear.

Study Aim

There seems to be limited literature on the use of 3D printing for pancreatic tumors, even though rapid evolution is expected over the coming years. The aim of this scoping review was to ascertain the current application of this technique on pancreatic tumors, its advantages and disadvantages and to prepare a study protocol for a prospective clinical pilot study. The objective was to inform readers on the current techniques of 3D modelling and printing in the field of pancreatic cancer surgery and demonstrate the potential benefits by presenting how the availability of a printed model would have affected the management of a retrospective case at Geneva University Hospitals (HUG).

MATERIALS & METHODS

Scoping review

A protocol for the scoping review was prepared internally and agreed by the authors in advance but has not been published or submitted for registration to local or national databases. The local institutional review board (IRB) approved the review and the case study. The review was not funded by any specific organisation. Following the guidelines of our IRB (based at the « Centre Hospitalier Universitaire Vaudois - CHUV), we neither need an approval for a single retrospective case analysis, nor for the informed consent of the patient. Consultants (radiologists, surgeons, 3D printing specialists) are co-authors of this study and have given their written consent for this publication.

SEARCH STRATEGY

Both PubMed and Embase were searched electronically on the 2nd February 2019 with the following search terms: (3D printing) AND pancreas; (3D printing) AND (pancreatic tumour); (3D printing) AND (pancreatic surgery). No date or study type limits were set. The exact search for Pubmed can be found in additional file 1.

Articles selection and data extraction

After removing the duplicates, we performed title and abstract screening followed by full text screening, to identify articles that met the following inclusion criteria: articles written in French, English or Chinese language (since they could be translated by staff); all types of studies, including expert opinion; articles discussing the utility of 3D modelling and printing in pancreatic tumor surgery in humans. One author (BM) extracted the following data, where available, from the included studies on an excel sheet:

- Favorable outcomes: operative time, rate of complications, approach, number of infections, blood loss, feasibility, length of hospitalization.
- Non-favorable: cost, model production time.

Case Selection

There are over 60 pancreatic surgeries performed per year in our institution. We chose to evaluate a recent challenging case of a patient with neuro-endocrine pancreatic tumor that, ultimately, required cephalic duodeno-pancreatectomy. For the purposes of the case study, all details were collected retrospectively and with confidentiality. We selected this case to report that our standard management for a neuroendocrine tumor lead to the impossibility for its localization during the first surgery, which finally led to a second laparotomy and a large duodeno-pancreatic resection. We think that the availability of a 3D printed model of the pancreatic head might have allowed an enucleation or at least would have avoided the second laparotomy.

RESULTS

The initial search for each term (3D printing) AND pancreas; (3D printing) AND (pancreatic tumor); (3D printing) AND (pancreatic surgery)) resulted in 27, 11 and 26 hits in PubMed, and 63, 25 and 39 hits in Embase respectively. Title and abstract screening identified 9 articles, 1 of which was excluded because it was in Japanese. A total of 5 articles and 3 supplements (conference abstracts) were included after full text screening (Figure 1 and Table 1). The majority of evidence levels were case reports/series or expert advice. There was great heterogeneity among the articles, and the variables were rarely quantifiable. Therefore, we were unable to apply any form of systematic grouping to them or compare results, and a narrative synthesis was performed. The most pertinent information from each study is listed in Table 1. We note that 3D

visualization and printing are two closely-related subjects, and various authors often broach both subjects simultaneously. None of the 3 conference abstracts mention

funding information, and one study and one expert review received public sponsorship. The other three studies were non-sponsored.

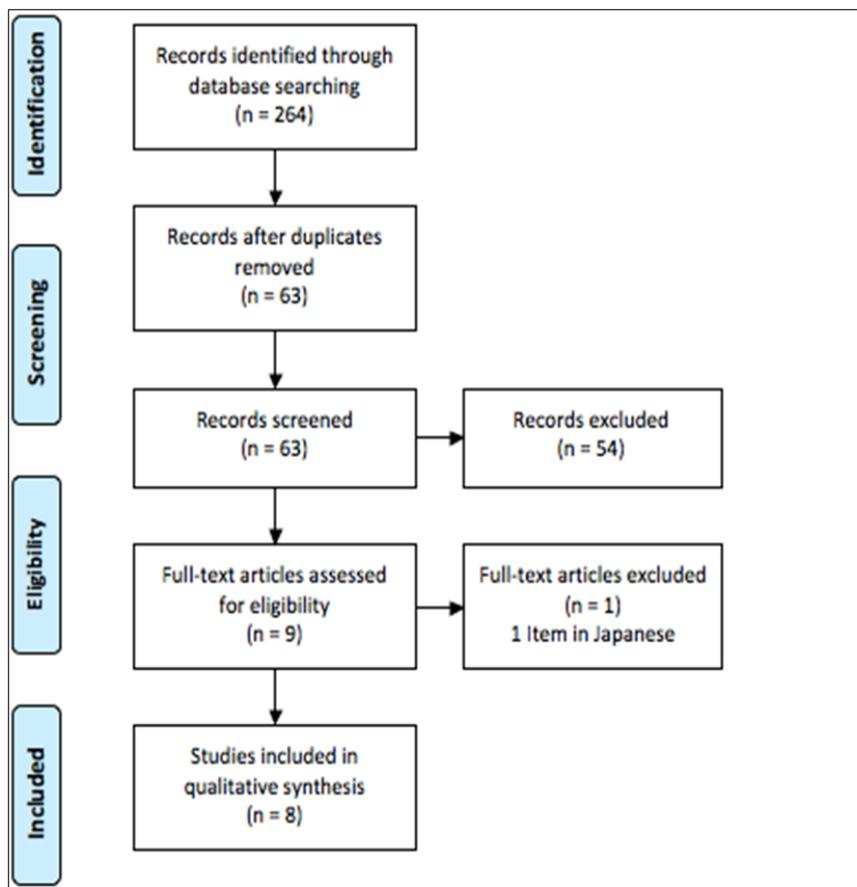


Figure 1. Preferred reporting items for systematic reviews and meta-analyses for scoping reviews flow diagram of the search and study selection process.

Table 1. Summary of the findings of the included studies.

Study	Focus	Study type and cases	Use of 3D printed model	Advantages	Disadvantages
Andolfi et al. (2016)	3D Visualization and printing	Case study, 1 pancreatic head adenocarcinoma	1. Didactic purposes 2. Discuss with the patient	1. Didactic purposes 2. Discuss with the patient	1. Costs 2. Time for producing the model
Endo et al. (2011)*	3D Visualization and printing	Case study, 1 healthy pancreas	Feasibility of anatomical demonstration	1. Surgical training 2. Visualisation of anatomy	
Marconi et al. (2017)	3D Visualization and printing	Randomised study, 15 minimally invasive abdominal procedures (1 robotic distal pancreatectomy for pancreatic tumour)	1. Evaluation of comprehension of anatomy 2. Comparison between conventional contrast CT scans, virtual 3D reconstruction	1. Surgical planning 2. Spatial orientation 3. Anatomy	1. Performant computerised support 2. Segmentation time, availability of radiologist 3. Adjustment of daily operative scheduling

			s, and 3D-printed models		
Seyama et al. (2016)*	3D Visualization and printing	Case series, 8 laparoscopic distal pancreatectomies and duodeno-pancreatectomies	Pre-operative planning and intraoperative navigation	1. Surgical planning 2. Precision of surgical gestures	
Study Group of Pancreatic Surgery in Chinese Society of Surgery (2017)	3D Visualization and printing	Expert consensus		1. Surgical planning : localisation, shape and invasion of the pancreatic tumour, evaluation of the resectability, customisation 2. Anatomy, vascular markers 3. Surgical training 4. Reduced hospitalisation time 5. Pre-operative Diagnostic help	
Yang and Huang (2017)	3D printing	Review		1. Surgical planning 2. Reduced operating time 3. Anatomy 4. Surgical training 5. Discuss with the patient	
Yasunaga et al. (2018)*	3D Visualization and printing	Case series, 24 laparoscopic distal pancreatectomies for pancreatic tumour	Pre-operative planning and intraoperative navigation	Surgical planning : reduced surgery time, blood loss and hospitalisation time	
Zheng et al. (2016)	3D Visualization and printing	Randomised study, 3 pancreatic tumors	1. Evaluation of the quality of the surgical plan 2. Comparison between 3D-rendered images and 3D-printed models	1. Surgical planning 2. Surgical training	

*conference abstracts

DISCUSSION

Expert consensus on the optimal use of 3D visualization in pancreatic surgery: An essential prerequisite for 3D printing

There is consensus among Asian experts regarding the management of patients with tumors of the pancreas head, that 3D visualization provides benefits in terms of determining the tumor location, its form and its invasiveness [3].

The vascular structures (celiac artery, superior mesenteric artery, portal vein and superior mesenteric vein) are represented simultaneously and their invasiveness is better measurable. The same applies to the location of the Wirsung or Santorini ducts. 3D visualization and printing offer the added-value of being able to manipulate structures under different viewpoints before and during surgery.

The image resolution required must allow for differentiation between the structures with millimeter precision in order to then obtain three phases of CT-scan images: native, arterial and venous [3]. Other authors recommend the use of biphasic injection CT-scan with what is called “pancreatic injection time” [6]. This “time” occurs between 40 and 70 seconds after the injection of the contrast. Another group of Japanese researchers proposes an imaging method enabling the detection of early-stage pancreas cancers [7]. Their respective studies conclude that the change in mitigation between the pancreatic parenchyma and a locally advanced tumor is more important during the arterial phase. For early-stage tumors, mitigation is more pronounced during the pancreatic and venous phases.

Following image acquisition by the CT-scan, segmentation is necessary where anatomical and pathological structures are selected along different slices and then combined to obtain a three-dimensional object. This technique also facilitates efficient localization of the tumor and its abutment as well as a map of the patient’s blood vessels. The latter can present normal and pathological structural variations. A key point brought out by the authors of the consensus [3] is the great diversity of anatomical variations in hepatic blood vessels found in the general population. Exact visualization of these variations must be obtained in order to anticipate reconstructive surgery or vascular excision. This risk is high in cases of borderline tumors. The consensus of experts recommends a high-quality visualization of the following blood vessels: superior mesenteric artery, portal vein, superior mesenteric vein, splenic vein, middle colic vein and gastro-colic venous trunk.

Benefits of 3D-printed models in pancreatic surgery

Yang and Huang [8] reported on the current status of 3D printing for pancreas surgery. In the cases of tumours of the pancreas head, surgery is highly complex and requires an in-depth understanding of location, size and the relationship of

the tumour with the vessels and organs surrounding it. In a best-case scenario, this will allow for conservative surgery (enucleation). Having access to a “hands-on” model makes it possible to remedy spatial gaps. Yang and Huang [8] highlight the advantages with regard to surgical planning and the possibility of visualising the required surgical steps. During the operation, healthy margins are easier to find, and this reduces operating time. In addition, the authors also note the advantage of having 3D models when explaining surgery to the patient beforehand.

Zheng et al. [9] report on the benefit of 3D printing in pre-operative planning in comparison to 3D visualization. They compared two groups of trainee surgeons evaluating cases of pancreatic cancer: the first group on the basis of 3D-imaging and the second based on printed 3D models. Following the evaluation, the participants undertook a subjective test to examine the quality of the surgical plan (QSP) to assess knowledge of patient anatomy and pathophysiological features, the operative plan (surgical steps, safe approach, protection of vital structures) and preparation for unexpected events. The test was prepared by experts in the field of pancreatic medicine. Findings indicated the superiority of 3D printing for surgical planning, where evaluation of the 3D-printed models resulted in significantly higher QSP scores compared to the 3D-rendered models. The key advantages were the input of touch with added sensation of textures and forms as well as the mental link between tactile and visual perception of the patient’s anatomy.

Endo et al. [10] conducted a feasibility study within their hospital to test the possibilities of segmenting and 3D printing a healthy pancreas. They concluded that the virtual model was more useful in simulating surgical gestures, whereas the physical model led to improved detection of sizes and abutment between anatomical structures.

Seyama et al. [11] examined the feasibility of using 3D printed pancreas models for pre-operative planning and navigation in 8 patients undergoing pancreatic surgery. In all cases, the planned pancreatic resections were successful, showing that 3D visualisation and printing can be useful in pancreatic surgery. The authors believe the use of 3D-models led to better pre-surgical approaches and increased accuracy in their anatomical markers during the operation.

Yasunaga et al. [12] undertook a study on the added-value of visualization and 3D-printing on a series of patients requiring laparoscopic pancreatectomy for benign or malignant low-grade tumors. As with the other authors, they studied CT-scans and then produced segmentations and 3D impressions detailing the different structures by colour. They reported that there is a true gain in term of blood-loss, operating time, and length of hospitalisation. They concluded that effective pre-surgical preparation of gestures and sequences to be completed, linked to optimal intra-operative navigation, is essential to surgical success.

Marconi et al. [13] compared conventional contrast CT scans, virtual 3D reconstructions, and 3D-printed models in their effectiveness in demonstrating the relevant anatomy of 15 patients requiring abdominal surgery (splenectomies, nephrectomies and one pancreatectomy). After randomly evaluating each method of visualisation, ten medical students, ten surgeons and ten radiologists undertook a multiple-choice test. The goal of the exercise was to be able to recognise certain anatomical structures, with their surrounding abutments, as an indication of being able to prepare a pre-operative plan. Ultimately, the 3D reconstruction and printed model led to a better comprehension of the anatomy in comparison to the visual survey of a simple 2D cut. The advantage of 3D virtual images was attributed to the fact that they can be rotated in three dimensions, thus giving an impression of depth and improving spatial orientation, although it was difficult to interpret the distances between anatomical structures. The authors conclusion was that a surgical plan could, therefore, be easily produced.

Disadvantages and limitations of 3D printing

One of the limitations of 3D-printing is that the expertise of a radiologist is required to complete segmentation of the CT-2D images, which, in turn, allows the 3D model to be printed [13]. Costs of the technique is also a concern in general [4, 5] and specifically to pancreatic imaging [14]. Furthermore, the time required for creation of each model varies depending on anatomical complexity, image quality and printer involved. In one study, the segmentation process was standardised and completed in six hours, and the printing process varied between eight and thirty hours [13]. In one case using industry-grade high quality printer, the printing took 64 hours [14]. In a healthy pancreas [10], which is undoubtedly less complex to interpret, a virtual model may require 3 hours and the 3D-printed model another 5 hours. This implies that organisation of the surgical plan has to be adjusted. Visualization and 3D printing do present an advantage in terms of comprehension of anatomy, spatial orientation and pre-operative planning but, in order to maintain efficiency and speed, they also involve the creation of specific protocols to speed the process of creating the models.

Virtual reality as an alternative to printing

Andolfi et al. [14] presented a case-report highlighting the benefits of 3D visualization and virtual reality in determining the resectability of a pancreatic head tumour. The case concerned a 56 year-old patient with an adenocarcinoma of the pancreas head, for which a CT-Scan showed a borderline tumour in close contact to the gastroduodenal artery but uncertain contact with the hepatic artery. Following 3D reconstruction of the CT sections and viewing the 3D virtual model in the ImmersiveTouch™ virtual reality platform (ImmersiveTouch, Chicago, IL, USA), the surgical team was able to determine that the tumor had invaded the hepatic artery and offer the patient pre-op neoadjuvant chemotherapy. The surgeons were also able to train prior to the real operation on the same virtual reality ImmersiveTouch™ platform.

Although the application of 3D printing for surgical preparation was not the focus of the study by Andolfi et al. [14], the authors inform how useful it was in offering explanations to the patient and their family members before surgery, and for didactic purposes. Furthermore, they indicate the substantial disadvantages of 3D printing in matters of time consumption and the cost of acquiring and producing professional material. Despite the apparent benefits of this competitive technique compared to 3D printing, virtual reality will likely never completely replace the use of physical models for surgical preparation.

PRACTICAL CASE STUDY

In order to test the feasibility of using 3D printing in our unit, we brought together a group of experts comprised of visceral surgeons, radiologists and 3D printing specialists. We initiated a 3D printing exercise from a retrospective analysis of a patient with pancreatic tumor. A 48 years old patient was diagnosed with a one centimeter hypervascular lesion of the pancreas head. This lesion exhibited all the characteristics of a neuro-endocrine tumor by CT-scan (**Figure 2**). The patient underwent an initial exploratory laparotomy to review the pancreas.

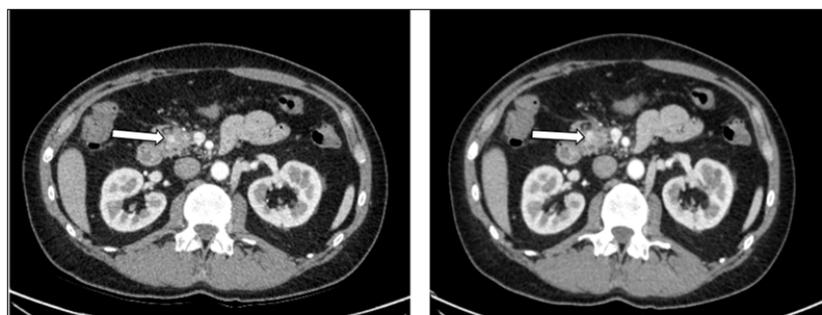


Figure 2. Abdominal CT-scan images of the patient with a neuro-endocrine tumor. The hyper vascular lesion (white arrow) is located in the head of the pancreas.

According to the pre-operative radiology work-up, the nodule was close to the pancreatic head (**Figure 2**) and an enucleation was envisaged. The intra-operative manual palpation did not indicate any location of the tumor and the intra-operative ultrasound located the tumor within the central part of the pancreas head without providing further precision. The possibility of a cephalic duodeno-pancreatectomy was raised, but this procedure was not performed at that stage because it was considered too disabling. Trans-duodenal biopsies were performed with the final diagnosis of a stage G1 (WHO classification) neuroendocrine pancreatic tumor and resection of the pancreas head was finally proposed.

Cephalic duodeno-pancreatectomy was performed at a later stage, which was complicated by epigastric pain associated with hemorrhagic shock accompanied by melena and haematochezia 3 weeks post-procedure. A pseudo aneurysm of the stump of the gastroduodenal artery that had ruptured and fistulized in a digestive loop was diagnosed and treated by placing a stent through interventional radiology into the hepatic artery, with favorable outcome. The CT images were reconstructed using a standard iterative reconstruction algorithm with the following parameters: slice thickness, 1.0 mm; slice interval, 1.0 mm; matrix size, 512x512; and medium smooth tissue convolution kernel (I26f). The neuroendocrine tumor was segmented from the abdominal CT scan images, using a dedicated software (VitreA®, Vital Images, Inc., Minnesota USA) by a radiologist with expertise in cardiothoracic and vascular imaging. The 3D model (**Figure 3**) was created in less than three hours in our radiology service and printed (**Figure 4**) using a Stratasys J750 3D printer.

The opinion of our group of experts is that availability of the 3D images and model could have changed the management, such as avoiding the first exploratory laparotomy. It is unclear if enucleating the tumor would have been possible, a procedure which may have avoided the cephalic duodeno-pancreatectomy but the probability with the help of the 3D images and the model was probably higher. We therefore see a particular interest of this new diagnostic approach and direct attention to its utility during the treatment of benign and malignant pancreatic tumors. Given the retrospective aspect of the case study, we are unable to form any further opinions other than concluding to a significantly different care when using this new instrument.

LIMITATIONS OF THE SCOPING REVIEW AND CASE STUDY

The main limitation of this scoping review is the narrow keyword search with respect to alternative spellings and types of pancreatic tumors and languages. However, the review is sufficient for the purpose of using the findings to test the feasibility of 3D printing in our unit with a case study. The low number of identified articles indicated that

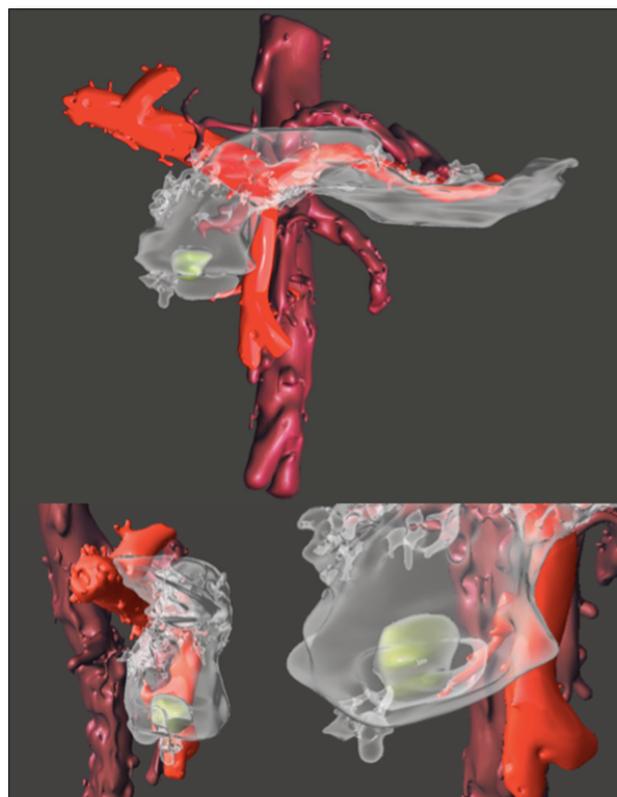


Figure 3. 3D model of the pancreas and surrounding structures. The neuroendocrine tumor (yellow) is seen in the head of the pancreas. The pancreas (white), portal trunk (red) and aorta and celiac trunk (Bordeaux) are also visible.

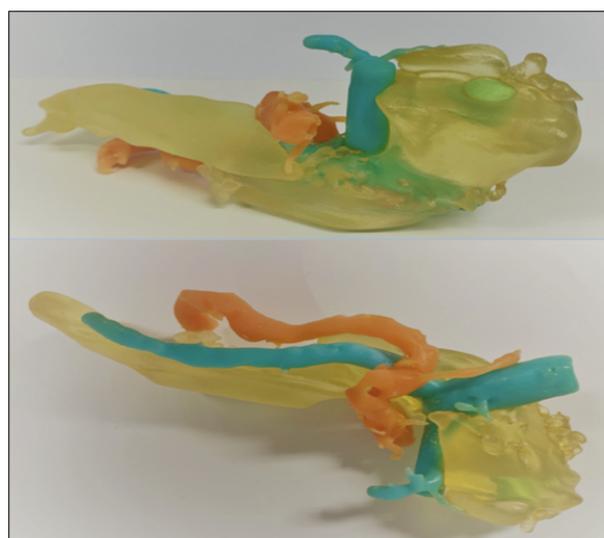


Figure 4. 3D-printed model of the pancreas and surrounding structures. The neuroendocrine tumor (green) is located in the head of pancreas. The pancreas (yellow), portal trunk (blue) and celiac trunk (orange) are also printed.

a systematic review on the subject can include more search terms and databases without major additional effort. We did not conduct any quality assessment or risk of bias in the studies we found and this is something that can be addressed with a systematic review.

Also, we are unable to form any further opinions about the use of 3D printing in our unit other than concluding to a significantly different care when using this new instrument in one patient only, due to the retrospective aspect of the case study.

CONCLUSION

Three-dimensional modelling and printing offer a new development in the management of patients with pancreatic tumors. The limited number of articles currently available offer some indication that it helps surgeons and radiologists in the preoperative diagnosis and enhances the evaluation of the resectability of pancreatic tumors, vascular invasiveness and the position of the tumor with regards to the rest of the abutting structures. There is a general consensus that the improvement of the pre-operative surgical planning process is demonstrated in reduction of risks, complications, length of hospital stay and operating time. Also, improvement in the intra-operative spatial orientation allows for better localization of the tumor and precision of the surgical gestures. Moreover, the studies indicate possibilities for surgical training and aid when discussing with patients. The main disadvantages often quoted in the literature are the time needed for segmentation and printing, the cost of purchasing the necessary equipment and, finally, the need for an efficient computer system combined with the availability and expertise of a radiologist.

In conclusion, although 3D printing has a clear potential in the field of management of patients with pancreatic tumors, clinical use of this application is still in its early stages except in certain high-volume Asian institutions. Based on our study, 3D printing is accessible to our hospital and is not considered a major technical challenge, but rather a new method of using available resources. Since both the hardware and software already exist and is used by other medical specialties, we propose that this technique should be tested in controlled studies for the management of patients with pancreatic tumors.

REFERENCES

1. Varadhachary GR, Tamm EP, Abbruzzese JL, Xiong HQ, Crane CH, et al. (2006) Borderline resectable pancreatic cancer: Definitions, management and role of preoperative therapy. *Ann Surg Oncol* 13: 1035-1046.
2. Duran AH, Duran MN, Masood I, Maciolek LM, Hussain H (2019). The additional diagnostic value of the three-dimensional volume rendering imaging in routine radiology practice. *Cureus* 11: e5579.
3. Study Group of Pancreatic Surgery in Chinese Society of Surgery of Chinese Medical Association, Pancreatic Committee of Chinese Research Hospital Association, Digital Medicine Branch of Chinese Medical Association, Digital Medicine Committee of Chinese Research Hospital Association (2017) *Zhonghua Wai Ke Za Zhi* 55: 881-886.
4. Yao R, Xu G, Mao SS, Yang HY, Sang XT, et al. (2016) Three-dimensional printing: Review of application in medicine and hepatic surgery. *Cancer Biol Med* 13: 443-451.
5. Martelli N, Serrano C, Brink H, Pineau J, Prognon P, et al. (2016) Advantages and disadvantages of 3-dimensional printing in surgery: A systematic review. *Surgery* 159: 1485-500.
6. Takeshita K, Kutomi K, Haruyama T, Watanabe A, Furui S, et al. (2010) Imaging of early pancreatic cancer on multidetector row helical computed tomography. *Br J Radiol* 83: 823-830.
7. Egorov VI, Yashina NI, Fedorov AV, Karmazanovsky GG, Vishnevsky VA, et al. (2010) Celiaco-mesenterial arterial aberrations in patients undergoing extended pancreatic resections: Correlation of CT angiography with findings at surgery. *JOP* 11: 348-357.
8. Yang YY, Huang HG (2017) Development status of three-dimensional printing technology in pancreatic surgery. *Zhonghua Wai Ke Za Zhi* 1 oct 55: 795-797.
9. Zheng Y, Yu D, Zhao J, Wu Y, Zheng B (2016) 3D Printout Models vs. 3D-Rendered Images: Which is better for preoperative planning? *J Surg Educ* 73: 518-523.
10. Endo K, Sata N, Kaneda Y, Koizumi M, Lefor A, et al. (2011) Three-dimensional (3D) model of the pancreas using routine CT data and a 3D printer: A feasibility study. *Pancreas* 40: 1321-1321.
11. Seyama Y, Kanomata H, Kudo H, Umekita N (2016) Simulation and navigation using a 3D printed pancreas model in pancreatic surgery. *Pancreatol* 16: S58.
12. Yasunaga M, Kojima S, Mikagi K, Kawahara R, Sakai H, et al. (2018) Laparoscopic distal pancreatectomy using intraoperative navigation system. *HPB* 20: S586.
13. Marconi S, Pugliese L, Botti M, Peri A, Cavazzi E, et al. (2017) Value of 3D printing for the comprehension of surgical anatomy. *Surg Endosc* 31: 4102-4110.
14. Andolfi C, Plana A, Kania P, Banerjee PP, Small S (2016) Usefulness of three-dimensional modeling in surgical planning, resident training and patient education. *J Laparoendosc Adv Surg Tech A* 27: 512-515.

ADDITIONAL FILE 1:

Pubmed Search Strategy (Literature Search performed: February 02, 2019):

(3D printing) AND pancreas:

("printing, three-dimensional"[MeSH Terms] OR ("printing"[All Fields] AND "three-dimensional"[All Fields]) OR "three-dimensional printing"[All Fields] OR ("3d"[All Fields] AND "printing"[All Fields]) OR "3d printing"[All Fields]) AND ("pancreas"[MeSH Terms] OR "pancreas"[All Fields])

(3D printing) AND (pancreatic tumour):

("printing, three-dimensional"[MeSH Terms] OR ("printing"[All Fields] AND "three-dimensional"[All Fields]) OR "three-dimensional printing"[All Fields] OR ("3d"[All Fields] AND "printing"[All Fields]) OR "3d printing"[All Fields]) AND ("pancreatic neoplasms"[MeSH Terms] OR ("pancreatic"[All Fields] AND "neoplasms"[All Fields]) OR "pancreatic neoplasms"[All Fields] OR ("pancreatic"[All Fields] AND "tumour"[All Fields]) OR "pancreatic tumour"[All Fields])

(3D printing) AND (pancreatic surgery):

("printing, three-dimensional"[MeSH Terms] OR ("printing"[All Fields] AND "three-dimensional"[All Fields]) OR "three-dimensional printing"[All Fields] OR ("3d"[All Fields] AND "printing"[All Fields]) OR "3d printing"[All Fields]) AND (("pancreas"[MeSH Terms] OR "pancreas"[All Fields] OR "pancreatic"[All Fields]) AND ("surgery"[Subheading] OR "surgery"[All Fields] OR "surgical procedures, operative"[MeSH Terms] OR ("surgical"[All Fields] AND "procedures"[All Fields] AND "operative"[All Fields]) OR "operative surgical procedures"[All Fields] OR "surgery"[All Fields] OR "general surgery"[MeSH Terms] OR ("general"[All Fields] AND "surgery"[All Fields]) OR "general surgery"[All Fields]))