Annals of Medicine and Surgery 10 (2016) 1–7

Contents lists available at ScienceDirect

Annals of Medicine and Surgery

journal homepage: www.annalsjournal.com

Review

3D haptic modelling for preoperative planning of hepatic resection: A systematic review

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HIGHLIGHTS

- 3D printing allows a fast, accurate and inexpensive production of a 3D liver model.
- A 3D printed model is excellent for education of junior staff as it offers insight to a patient's unique anatomy.
- 3D printed models could also aid in patient education and facilitate surgery by obtaining informed consent.

ARTICLE INFO

Article history:
Received 19 February 2016
Received in revised form
30 June 2016
Accepted 2 July 2016

Keywords:
3D Printing
General surgery
3D Haptic model
3D Printing liver

ABSTRACT

Introduction and background: Three dimensional (3D) printing has gained popularity in the medical field because of increased research in the field of haptic 3D modeling. We review the role of 3D printing with specific reference to liver directed applications.
Methods: A literature search was performed using the scientific databases Medline and PubMed. We performed this in-line with the PRISMA [20] statement. We only included articles in English, available in full text, published about adults, about liver surgery and published between 2005 and 2015. The 3D model of a patient's liver venous vasculature and metastasis was prepared from a CT scan using Osirix software (Pixmeo, Gineva, Switzerland) and printed using our 3D printer (MakerBot Replicator Z18, US). To validate the model, measurements from the inferior vena cava (IVC) were compared between the CT scan and the 3D printed model.
Results: A total of six studies were retrieved on 3D printing directly related to a liver application. While stereolithography (STL) remains the gold standard in medical additive manufacturing, Fused Filament Fabrication (FFF), is cheaper and may be more applicable. We found our liver 3D model made by FFF had a 0.1 ± 0.06 mm margin of error (mean ± standard deviation) compared with the CT scans.
Conclusion: 3D printing in general surgery is yet to be thoroughly exploited. The most relevant feature of interest with regard to liver surgery is the ability to view the 3D dimensional relationship of the various hepatic and portal veins with respect to tumor deposits when planning hepatic resection.
Systematic review registration number: researchregistry1348.

Contents

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http://dx.doi.org/10.1016/j.amsu.2016.07.002

1. Introduction

Three dimensional (3D) printing has gained popularity in medicine since the 1980s. As 3D printers have become more affordable, the real strength of this technique has been recognized; its ability to deliver anatomical models based on the unique characteristics of individual patients. Surgeries in fields as diverse as orthopedics [3,5,6,11], neurosurgery [23], maxilla-facial [1,2,4,8–10] and especially plastic and reconstructive [13–15] have published reports of examples of 3D printing being used in their fields. However, this technology has only slowly been adopted in general surgery.

3D printing should be of great advantage in liver surgery. Functional hepatic anatomy is separated into 8 segments known as Couinaud segments, labeled I to VIII, and defined in part by the course of the hepatic and portal veins [22]. Currently identification of these structures and delineation of hepatic segments relies on pre-operative imaging and intra-operative ultrasound. Resection of these various segments is mainly carried out for malignancies (metastatic and primary lesions) although various benign diseases may also be treated surgically.

The hepatocellular carcinoma (HCC) is the most common primary liver tumor with a prevalence in adults of 4.9 per 100,000 making it the 5th most commonly diagnosed gastrointestinal malignancy in adults [7]. HCC most commonly presents in patients with cirrhosis who have a reduced physiological reserve to withstand major liver resection. This makes preoperative planning critical to minimize removal of liver volume and avoiding post-operative liver failure. More commonly, hepatic resection is performed for colorectal liver metastases (CRLM), that have a cumulative risk of 16% of distance metastasis spreading from the primary tumor within 5 years [17]. In appropriate patients, repeat hepatectomy following recurrence of CRLM may be feasible, and for this population preoperative planning and preservation of hepatic venous structures is of even greater clinical importance. This is also true for living-donor liver transplantation (LDLT) where the venous inflow and outflow to both the recipient and donor component livers must be maintained and therefore characterized with certainty, both pre- and intraoperatively. Currently, preoperative imaging with contrast-enhanced CT or MRI remains the most important planning tool for surgery [25]. Computer based 3D CT scans have been developed for pre-operative planning, however interpretation on a 2D computer screen is inherently limited. We believe a 3D printed model will provide tactile (haptic) feedback to the user and facilitate spatial recognition of important structures.

Here, we report a systematic review of the literature and describe the use of a low cost 3D printer to create a liver model for a patient undergoing liver resection.

2. Materials and methods

2.1. Systematic literature review

The PRISMA [20] statement was used to guide the systematic literature review. A checklist is available and attached. Ovid Medline (2006-present) and pubmed (2006-present) databases were searched using the following terms and keywords alone or in combination: 3D printing, liver, Upper GI, general surgery. Inclusion criteria for studies to be included: published in English, available full text, about adults, about liver surgery and published between 2005 and 2015. Two independent reviewers decided the criterion in a standardized manner. Any disagreements were solved with consensus (Please refer to appendix for search strategy). Ultimately, six studies were found to be directly related to liver surgery and 3D printing that satisfies the inclusion criteria. The date last searched was on the 14th of June 2016. The data were extracted based on the Cochrane effective practice and organization of care, data collection form. Main information that was extracted involved what type of liver model was made, what type of 3D printer used and how it affected peri-operative outcome. In order to access risk of bias, we looked at variability of outcome in the studies as well as analyzed whether there were any possible external funding.

2.2. Printed 3D model

We used a 3D printer to create a model of a liver's venous vasculature and metastases for a patient undergoing liver resection to test the feasibility of using a low cost 3D printer for pre-operative planning. The conversion of 2D scan into 3D printing instructions are described in detail elsewhere [14]. Briefly, a 70-year-old man presented with liver metastases from a colorectal primary in Couinaud segments 4a and 4b, segment 6 and outer segment 7. Thin, axial view slices (<1 mm) of his pre-operative CT scan were examined using Osirix software (Version 4.1, Pixmeo, Geneva, Switzerland). The Region of Interest (ROI) function was used to map the hepatic and portal veins and map the metastases. The ROI areas were projected as 3D structures to produce a surface area mesh and instruction for the 3D printer. The resultant model was then printed using a 3D printer (MakerBot Replicator Z18, US) with polylactic acid (PLA) filament. The print time was 32 h and materials cost AUD