3D Printed Model of Extrahepatic Biliary Ducts for Stent Prototype Testing

Robyn Guru[1], Leia Troop[1] & Joanna Thomas[1]
[1]Biomedical Engineering Department, Mercer University School of Engineering, Macon, GA, USA

Introduction

Bile is produced in the liver and drains through the bile ducts into the small intestine where it aids in digestion (see Fig. 1A). Several inflammatory conditions of the bile ducts, including primary sclerosing cholangitis, cause strictures that prevent drainage of bile. Treatments for inflamed or clogged ducts include plastic or self-expanding metal stents (SEMs) that are inserted in the bile ducts to re-establish bile flow (Fig 1B).

The focus of this study was identifying 3D printers with the capacity to reliably fabricate models of the extrahepatic bile ducts (EHBD). 3D printing is a relatively inexpensive and timely means to fabricate parts and models. A 3D printed model of the bile ducts will enable rapid evaluation of custom biliary stent designs for patients with anatomic anomalies or extensive strictures.

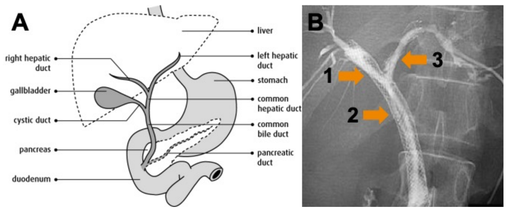

Figure 1. Bile Duct Anatomy. (A) Bile duct location in the gastrointestinal tract[1] **(B)** Cholangiogram **1**- right hepatic duct, **2–** common bile duct, **3**- left hepatic duct[2]

Methods

Anatomically accurate models of the extrahepatic bile ducts (EHBD) were generated with Autodesk Fusion 360 and exported as STL files. The STL files were then imported into the appropriate slicing software for the intended printer: PrusaSlicer→ Prusa, Cura → Moai, PhotonWorkshop → PhotonS, and preForm → Form2. Alternatively, EHBD are isolated based on density from anonymized patient magnetic resonance cholangio-pancreatography (MRCP) DICOM files using OsiriX/3D Slicer software (see Fig 2). The isolated EHBD are surface rendered and converted to a STL file. Meshmixer software is used to repair the surface rendered model as needed. Cura to generate a Gcode file for printing a Peopoly Moai printer. In the slicing software print parameters were selected including, laser power or exposure duration, brim dimensions to improve adhesion to the build plate and laser speed or Z-lift speed (see Table 1).

Table 1: Print parameters of different printers.

	Layer Thickness	Laser Power or Exposure Duration	Number of Brim Layers	Z Speed	Brim Width
Prusa	0.2 mm	Nozzle temp: 235-238°C	25% fill density	3 mm /s	5 mm
Moai	0.06 mm	61	5	100 mm/s	20 mm
Photon	0.05 mm	Bottom layer: 150s Normal layer: 15s	10	Lift speed: 0.5 mm/s Return speed: 20 mm/s	50 mm
Form 2	0.1 mm	Not user set	25	Not user set	Auto generated

Methods

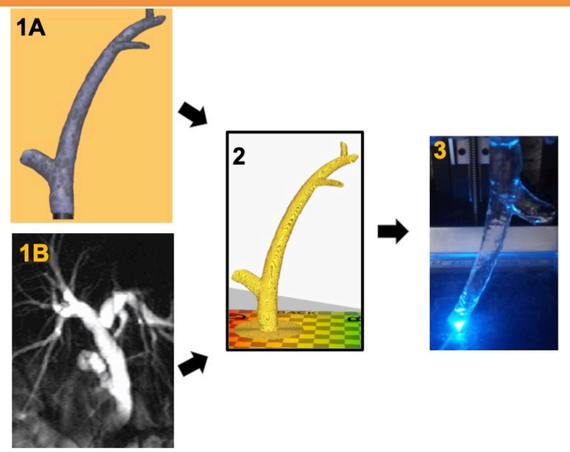

Figure 2: 3D Printing of CAD generated or patient MRCP derived bile ducts. 1A) CAD bile duct model, 1B) Patient MRCP, 2) STL file in Cura, 3) Bile duct model printing on a Peopoly Moai.

Step 1A: Anatomically accurate model of the biliary tree generated with 3D Computer Aided Design software**.**

Step 1B: Bile ducts are isolated from an MRCP with contrast based on density using image processing software.

Step 2: Appropriate print parameters selected including but not limited to the addition of a brim to improve adhesion to the build plate. STL file is then sliced to create the 3D printer file.

Step 3: 3D printer file transferred or uploaded to printer and model is printed. Following printing excess resin was removed with IPA and the model was cured with UV lights for 30 minutes.

Results

- **Prusa FDM printer:** when we printed an EHBD model with polycaprolactone filament on the Prusa FDM printer, the filament melted together across the ducts (see Fig 3A). None of the ducts were formed correctly with the Prusa so no further attempts were made.
- **Moai SLA printer:** when we printed with Formlabs Elastic Resin but it failed twice to successfully print the distal ducts (see Fig 3B). The failure of the resin to drain in the distal ends lead to the inability to take these measurements in Table 2.
- **PhotonS SLA printer:** when the EHBD model was printed on the PhotonS with Colorado Photopolymer Solutions SM442 resin, the distal ends formed as modeled (see Fig 3C), but the CAD file had an assembly flaw that caused a solid juncture at the split to the cystic duct.
- **Form2 SLA printer:** when the EHBD model was printed with the Form2 with Formlabs Elastic Resin it printed successfully. We have found, qualitatively, that the UV cure time affects the characteristics of prints.

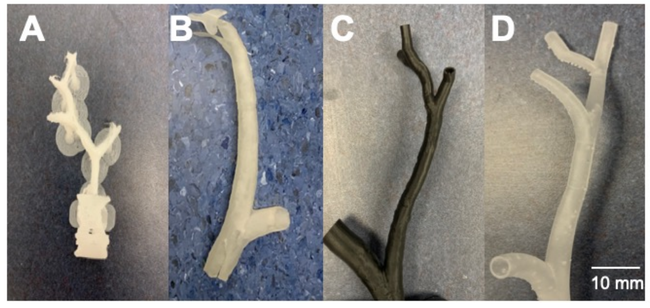

Figure 3: 3D Printed bile ducts. A) EHBD model printed on the Prusa FDM printer, B) EHBD model printed on the Moai SLA printer, C) EHBD model printed on the PhotonS SLA printer. D) EHBD model printed on the Form2 SLA printer.

Results

Table 2: Bile Duct Dimensions. The expected dimensions of the common bile duct, cystic duct, left/right hepatic ducts and the dimensions once the ducts were printed on the Prusa[1], Moai[2], PhotonS[3], and Form2[4] Printers.

	Anatomic Dimensions	EHBD Model Dimensions
Common Bile Duct	Length: 70-110 mm Wall Thickness: 1-1.5 mm Inner Diameter: 5-10 mm	Length: 16.33 mm[1], 82.66mm[2], 74.91 mm[3], 67.19 mm[4] Wall Thickness: N/A[1], 1.23 mm[2], 0.99 mm[3], 0.85 mm[4] Inner Diameter: N/A[1], 9.97 mm[2], 7.02 mm[3], 8.19 mm[4]
Cystic Duct	Length: 20-40 mm Wall Thickness: 1-1.5 mm Inner Diameter: 3 mm	Length: 10.65 mm[1], 22.83mm[2], 20.19 mm[3], 30.91mm[4] Wall Thickness: N/A[1], N/A[2], 0.97 mm[3], 0.40 mm[4] Inner Diameter: N/A[1], N/A[2], 3.7 mm[3], 3.1 mm[4]
Left Hepatic Duct	Length: 10-20 mm Wall Thickness: 1-1.5mm Inner Diameter: 3 mm	Length: 7.62 mm[1], N/A[2], 10.64 mm[3], 20.32 mm[4] Wall Thickness: N/A[1], N/A[2], 1.14 mm[3], 1.12 mm[4] Inner Diameter: N/A[1], N/A[2], 1.85 mm[3], 2.86 mm[4]
Right Hepatic Duct	Length: 10 mm Wall Thickness: 1-1.5 mm Inner Diameter: 2 – 3 mm	Length: 5.72 mm[1], N/A[2], 12.04 mm[3], 28.89 mm[4] Wall Thickness: N/A[1], N/A[2], 0.95 mm[3], 0.63 mm[4] Inner Diameter: N/A[1], N/A[2], 2.56 mm[3], 2.94 mm[4]

Conclusions

- FDM is not suitable to fabricate EHBD models. It currently can not achieve the resolution necessary with appropriate materials.
- SLA printers, both LCD and laser based, are capable of the resolution needed for an anatomically accurate EHBD model.
- Print outcomes are more reliable with the Formlabs Form2; however, material options are limited.
- Many resins and blends are available for use with open source printers; however, we found optimizing print parameters for each resin or resin blend was very time consuming.
- When we receive IRB approval we will proceed with generating models from patient MRCPs

Acknowledgements

•We would like to thank Dr. Joel Judah from Navicent Health for his feedback on his ERCP procedures.

References

1. Canadian Cancer Society (2019). Location of the bile ducts. *Canadian Cancer Society.* Retrieved from www.cancer.ca
2. Madhusudhan, K., Gamangatti, S., Gupta, A. (2015). Imaging and interventions in hilar cholangiocarcinoma: A review. *World Journal of Radiology, 7*, 2 http://doi.org/10.4329/wjr.v7.i2.28