Additive Manufacturing Technology Modeling Portal and Hepatic Veins for Embolization

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Introduction

The purpose of this research is to look at modeling portal and hepatic veins and how they are used for embolization.

Embolization is a medical procedure that restricts blood flow to a specific area of the body by blocking a blood vessel. It is minimally invasive and offers temporary relief by blocking vessels that are potentially feeding tumors and stopping excessive bleeding [1].

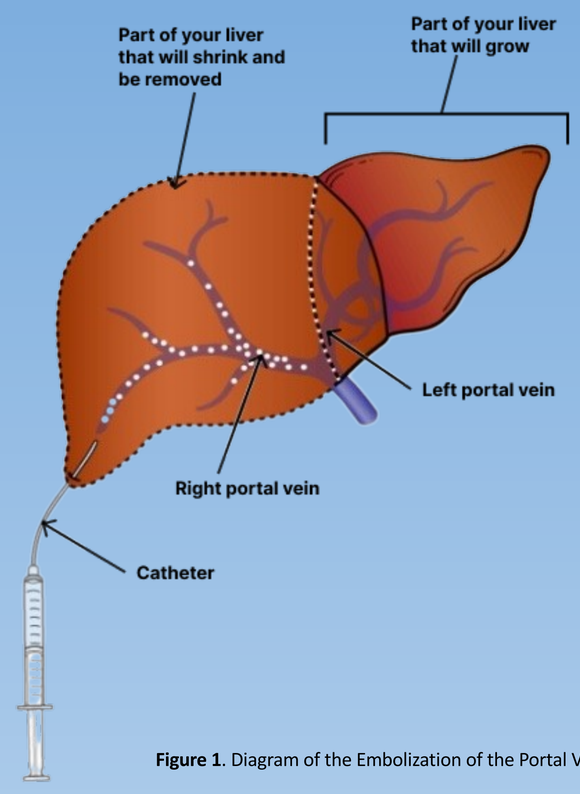

Figure 1. Diagram of the Embolization of the Portal Vein [5]

When it comes to modeling portal and hepatic veins, additive manufacturing will be used. Additive manufacturing technology has the potential to manufacture unique and accurate tubular-shaped medical devices in a layer-by-layer fashion [2]. Additive manufacturing allows for the ability to digitally configure custom composite devices that allow for the accelerated design of biological prototypes [2].

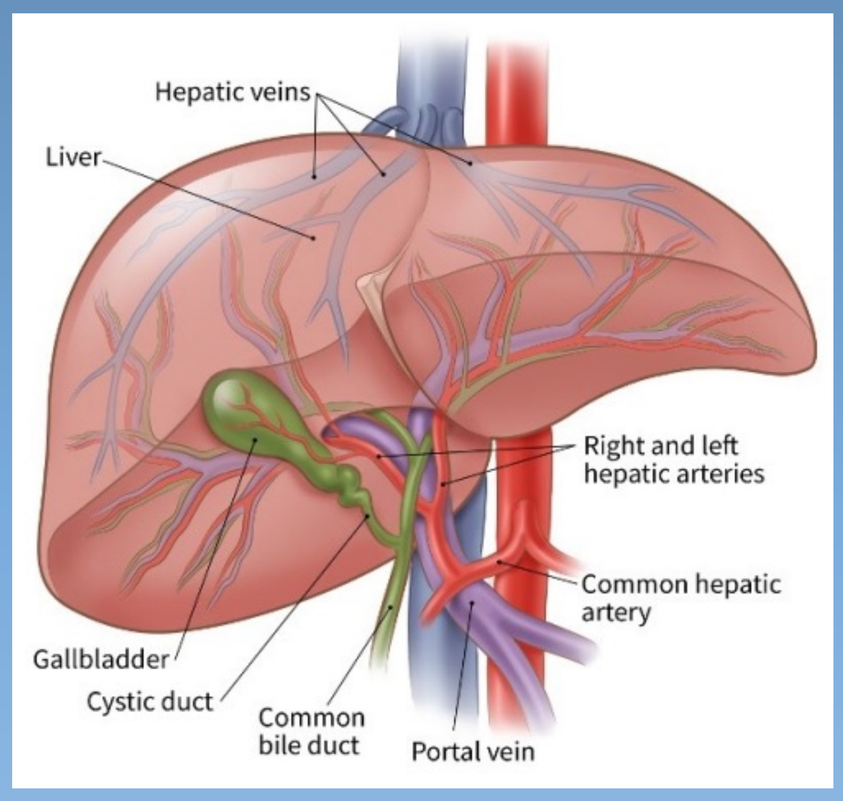

Figure 2. Labeled Diagram of a Human Liver [6]

Results – Diameter Lengths

When developing test models and devices that could replicate embolization of the hepatic and portal vein, it is important to note the age and gender of the vein trying to be replicated. While gender has a greater effect on vein diameters than age does, it is still critical to know all possible information about a test subject or patient. In multiple studies done with a variety of ages, the average portal vein diameter for males is 9.7±1.02mm and 9.10±.94mm for females. The average right, middle, and left hepatic vein diameter for males is 8.75±.92 mm, 8.63±.92 mm, and 8.5±.88 mm and 8.46±.90 mm, 8.27±.77 mm, and 8.19±.8 mm for females [4].

Results – Compliance & Elastic Modulus

The goal of a study done at the Institute of Basic Medical Sciences and the People's Hospital, Yunyang Medical College in Shiyan, China, aimed to explore the properties of the HPV in humans and pigs for liver xenotransplantation [3]. The results from the study concluded that the biomechanical properties of an HPV in a 6-month-old pig were like those of an adult human [3]. This specific research at UCD does not aim to find a suitable transplant for portal veins but it is still important to learn about the portal vein properties and those comparable to it.

In the study, the body weight, liver weight and volume, elastic modulus, and compliance of HPVs were tested in 6 humans (4 male and 2 female) and 6 pigs (aged 1-6 months). The table shows the results of the experiment. Overall, it was determined that no or very little difference in mechanical characteristics was seen in 6-month-old pigs and adult humans [3].

Table 1. Individual Body Weight and Weight and Volume of the Livers (n = 6; Means ± SD)

Groups	Body Weight (kg)	Liver Weight (g)	Liver Volume (mL)
Pigs aged 1 month	9.98 ± 0.81*	206.72 ± 24.89*	195.76 ± 10.75*
Pigs aged 2 months	18.27 ± 2.89*	375.12 ± 27.24*	355.23 ± 46.96*
Pigs aged 3 months	27.66 ± 1.53*	789.17 ± 57.16*	747.34 ± 58.28*
Pigs aged 4 months	40.83 ± 4.71*	1249.76 ± 38.37*	1183.52 ± 63.17*
Pigs aged 5 months	58.41 ± 9.09	1613.84 ± 60.83*	1528.30 ± 66.12*
Pigs aged 6 months	72.16 ± 8.29†	2020.49 ± 65.44*	1913.53 ± 53.17*
Humans aged 18–35 years	63.298 ± 5.89	1093.94 ± 84.96	1035.96 ± 13.88

Table 2. Comparison of Geometric Morphological Indices of HPVs Between Humans and Pigs of Various Ages (n = 6; Means ± SD)

Groups	Length (mm)	Wall Thickness (mm)	Diameter (mm)
Pigs aged 1 month	29.93 ± 1.74*	0.32 ± 0.03*	6.61 ± 0.06†
Pigs aged 2 months	31.40 ± 2.89*	0.37 ± 0.08*	7.63 ± 0.05†
Pigs aged 3 months	40.13 ± 4.30*	0.41 ± 0.12*	10.52 ± 0.01†
Pigs aged 4 months	52.16 ± 3.02*	0.51 ± 0.05†	10.98 ± 0.04†
Pigs aged 5 months	55.91 ± 4.78*	0.53 ± 0.04†	11.61 ± 0.05†
Pigs aged 6 months	66.28 ± 3.37‡	0.58 ± 0.05‡	12.47 ± 0.03‡
Humans aged 18–35 years	68.72 ± 5.61	0.61 ± 0.06	12.96 ± 0.24

Table 3. E_{inc} of HPVs of Humans and Pigs of Various Ages (n = 6; Means ± SD; × 10^4Pa)

Groups	Pressure (kPa) 1.2	2.4	3.6	4.8	6.0	7.2	8.4	10.0
Pigs aged 1 month	2.55 ± 0.57*	4.29 ± 1.27*	10.05 ± 2.78*	18.25 ± 4.2*	17.67 ± 3.10*	17.73 ± 0.88*	19.18 ± 3.52*	18.77 ± 3.41*
Pigs aged 2 months	6.64 ± 1.89*	10.37 ± 4.47*	16.04 ± 5.15*	21.15 ± 7.02*	23.41 ± 7.16*	22.69 ± 7.29*	23.26 ± 7.09*	23.50 ± 7.08*
Pigs aged 3 months	9.37 ± 2.67†	14.78 ± 3.11†	21.42 ± 5.72†	26.77 ± 6.38†	28.94 ± 8.53†	32.33 ± 10.19†	32.89 ± 9.48†	34.77 ± 10.01†
Pigs aged 4 months	7.82 ± 1.29†	11.96 ± 2.51†	18.03 ± 2.91†	23.32 ± 1.69†	24.17 ± 2.79†	27.14 ± 2.73†	27.12 ± 2.95†	28.97 ± 1.89†
Pigs aged 5 months	9.34 ± 1.35‡	12.94 ± 1.35‡	19.33 ± 2.01‡	24.99 ± 3.30‡	26.06 ± 3.35‡	28.33 ± 2.59‡	28.86 ± 2.75‡	31.04 ± 4.01‡
Pigs aged 6 months	9.83 ± 0.84‡	13.54 ± 1.20‡	19.78 ± 1.51‡	25.56 ± 2.04‡	26.59 ± 2.09‡	28.42 ± 2.10‡	29.02 ± 2.20‡	30.68 ± 2.03‡
Humans aged 18–35 years	10.01 ± 1.54	13.72 ± 2.80	20.33 ± 3.66	25.18 ± 4.23	26.13 ± 4.46	29.21 ± 5.64	30.29 ± 5.88	32.04 ± 5.65

Table 4. Compliance of HPVs of Humans and Pigs of Various Ages (n = 6; Means ± SD; × 10^2 mm^2 · kPa^{-1})

Groups	Pressure (kPa) 1.2	2.4	3.6	4.8	6.0	7.2	8.4	10.0
Pigs aged 1 month	2.40 ± 0.51*	1.75 ± 0.24*	1.17 ± 0.13*	0.91 ± 0.07*	0.88 ± 0.06*	0.82 ± 0.14*	0.79 ± 0.14*	0.74 ± 0.13*
Pigs aged 2 months	2.15 ± 0.43*	1.44 ± 0.19*	0.99 ± 0.06*	0.77 ± 0.03*	0.74 ± 0.04*	0.68 ± 0.03*	0.67 ± 0.03*	0.63 ± 0.03*
Pigs aged 3 months	2.01 ± 0.27*	1.34 ± 0.11†	0.90 ± 0.19*	0.70 ± 0.12*	0.67 ± 0.16*	0.61 ± 0.04*	0.60 ± 0.05*	0.56 ± 0.03*
Pigs aged 4 months	1.99 ± 0.08*	1.31 ± 0.27†	0.89 ± 0.12*	0.69 ± 0.06*	0.66 ± 0.03*	0.57 ± 0.05*	0.57 ± 0.06*	0.54 ± 0.04*
Pigs aged 5 months	1.89 ± 0.47†	1.29 ± 0.17†	0.83 ± 0.09*	0.65 ± 0.07*	0.62 ± 0.06*	0.54 ± 0.11*	0.54 ± 0.12*	0.51 ± 0.10*
Pigs aged 6 months	1.77 ± 0.26‡	1.18 ± 0.10‡	0.55 ± 0.05‡	0.35 ± 0.03‡	0.32 ± 0.04‡	0.33 ± 0.05‡	0.31 ± 0.05‡	0.30 ± 0.04‡
Humans aged 18–35 years	1.74 ± 0.28	1.16 ± 0.28	0.46 ± 0.23	0.31 ± 0.17	0.29 ± 0.17	0.28 ± 0.05	0.27 ± 0.04	0.26 ± 0.05

Tables 1-4. (1) Pig and Human Body Weight and Liver Weight and Volume, (2) Indices of Pig and Human HPVs, (3) Elastic Modulus of Pig and Human HPV, and (4) Pig and Human HPV Compliance Values [3]

Methodology

In order to fully model the portal veins, it is crucial to understand and evaluate all their biomechanical properties and characteristics. The methods used in this research were to gather as much information on past experiments done with portal and hepatic veins. Using both the mechanical properties and diameters found, it will be possible to model the veins as accurately as possible with a goal of eventually 3D printing the prototypes.

Conclusion

Additive manufacturing accurately models arteries and veins to fabricate the unique mechanical properties of natural vessels, such as nonlinear compliance .

Before printing the biological vessels, FEA analysis is needed to stimulate the model in different environments and to test design parameters. Using the parametric visual design software Grasshopper3D, modeling the synthetic vessels is done in 3 layers. The inner tube has a low-stiffness matrix to imitate elastin in natural [2]. The next layer is a fiber reinforcement layer that is made up of a series of sine waves with customizable parameters. The final layer is the encapsulation layer which ensures the layers expand and contract together under loading [2].

While the portal and hepatic veins have not been modeled yet, using the research done studying the mechanical properties of the veins, they can be properly printed with similar characteristics to natural blood vessels.

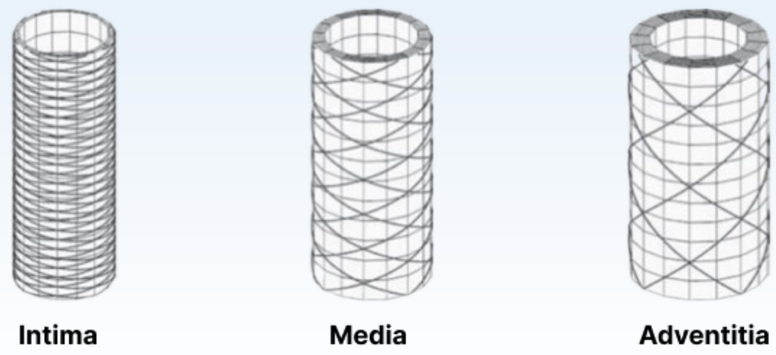

Figure 3. The three main layers of a blood vessel: Tunica Intima, Tunica Media, and Tunica Adventitia [2]

References

[1] "Embolization Procedure: Definition, Purpose Types," Cleveland Clinic, Cleveland, OH, accessed April 25, 2023, https://my.clevelandclinic.org/health/treatments/23512-embolization-procedure
[2] Byrne, O., 2021, "Additive Manufacture of Compliant Cylindrically-Based Composite Structures for Medical Device Applications," Master's thesis, University College Dublin, Dublin, Ireland.
[3] Wang, P., Li, W., Xi, G., Wang, H., Zhang, Z., Yao, B., Tang, W., Deng, Z., and Zhang, X., 2009, "BiomechanicalStudy of Hepatic Portal Vein in Humans and Pigs and Its Value in Liver Transplantation," Transplantation Proceedings,41(5), pp. 1906–1910
[4] Vasconcelos-Filho, JO.M., Pereira, A.H., Pitta, G.B.B. et al. Measurements between the hepatic veins
and portal venous system, in human cirrhotic liver: a cast study. Surg Radiol Anat 40, 395–400 (2018). https://doi.org/10.1007/s00276-017-1909-9
[5] "About Your Portal Vein Embolization." *Memorial Sloan Kettering Cancer Center*, 1 Jan. 1970, https://www.mskcc.org/cancer-care/patient-education/portal-vein-embolization.
[6] "Embolization Therapy for Liver Cancer." *American Cancer Society*, https://www.cancer.org/cancer/liver-cancer/treating/embolization-therapy.html.

Acknowledgements

I would like to thank Dr. Eoin O'Caerbhail and his lab for advising me this past semester in my research, Dr. Kevin Nolan's guidance along the way, and University College Dublin for giving me the chance to conduct research while studying abroad.