BIOMECHANICAL PROPERTIES OF 3D PRINTABLE MATERIAL USABLE FOR SYNTHETIC PERSONALIZED HEALTHY HUMAN AORTA

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Introduction

Existing applications of cardiovascular field mainly focused on the shape of the aorta or any artery (Kim *et al.*, 2019; Santoro *et al.*, 2021), but not of the biomechanical properties. As far as we know, very few studies have explored the use of soft materials in printing arteries (Biglino *et al.*, 2013; Kurenov *et al.*, 2015; Vukicevic *et al.*, 2016; Wang *et al.*, 2016). These studies are about the pulmonary artery, mitral valve, and cerebral vessels. The reported stiffness value in these studies is lower than that of the human aorta (Sherifova and Holzapfel, 2019). The objective of our work was to look forward to printable materials that can represent the human aorta.

Methods

A fresh healthy human aorta was obtained from an autopsy from the department of pathology, University Hospital of Dijon, Dijon, France (Figure 1). The patient was 16 years old and died following pulmonary embolism with no underlying health condition.

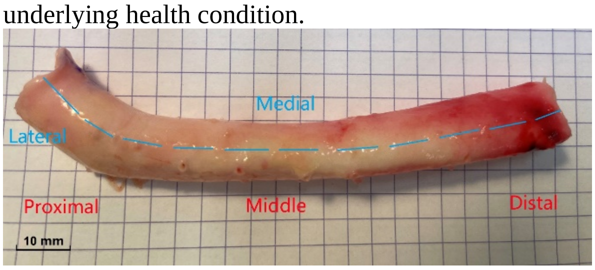

Figure 1. Photography of the healthy aortic sample taken during the autopsy. The orientation of the aorta (medial and lateral in blue – proximal, middle and distal in red) is mentioned on the image.

Multiple thermoplastic polyurethane (NinjaFlex (Fenner Inc., Manheim, USA) and Filastic™ (Filastic Inc., Jardim Paulistano, Brazil) and rubber-like (RGD450+TangoPlus (RTP), Stratasys Ltd.©, Rehovot, Israel) materials were tested to search for 3D-printable materials which can represent the similar biomechanical properties of the human aorta. The biomechanical experiments were carried out by a biaxial tensile test machine (LM1 Planar Biaxial, TA Instruments, the United States). Maximum value of Young's modulus (MYM) was calculated for the evaluation of the sample stiffness. The printed material was studied according to three parameters: failure stress, and the maximum value of Young's modulus.

Results and discussion

There was a difference between the expected printed thickness and the experimental measuring thickness, as well as MYM.

The aortic wall had a thickness of 1.49 mm ± 0.34 mm. The mean failure stress and MYM were 0.48 ± 0.09 MPa and 0.91 ± 0.23 MPa respectively.

With the thickness increases, failure stress showed a rough increasing trend in the NinjaFlex material. The stiffness (ranging from 8.24 to 11.90 MPa) did not display a steady increasing trend depending on thickness. It can be caused by non-uniformity in the printing process. Failure stress and MYM of Filastic materials did not increase with the thickness. It displayed a highly heterogeneous behavior. For the material with 0.65 mm in thickness, failure stress and MYM reached the highest values simultaneously, 2.64 MPa and 23.16 MPa, respectively.

RTP was printed in different shore hardness (SH, Table 1) and two printed directions (direction A and direction B).

Shore degree	Thickness (mm)	Failure stress (MPa)		Maximum elastic modulus (MPa)	
		Direction A	Direction B	Direction A	Direction B
70 SH	2	0.92	0.82	3.71	3.82
60 SH	2	0.48	0.57	2.91	2.64
50 SH	2	0.31	0.26	1.04	1.06
	2.5	0.22	0.20	1.25	1.11
	3	0.21	0.16	1.13	1.09
	3.5	0.22	0.22	1.06	1.06
40 SH	2.5	0.18	0.15	1.05	0.99
	3	0.16	0.14	0.82	0.95
	3.5	0.17	0.17	0.75	0.70
	4	0.20	0.18	0.74	0.76

Table 1. Biomechanical properties of RTP materials according to the different thickness and SH.

Discussion

The aortic wall is normally considered as anisotropy and nonlinear. All of the three printed materials showed a nonlinear behavior. In the biomechanical properties of the human aorta study, the range of the failure stress is between 0.54 MPa and 2.18 MPa *(Sherifova et al., 2019*). In our study on the healthy aorta, the mean failure stress value was 0.48 MPa with MYM of 0.91 MPa. Among three printed materials, RTP had the closest biomechanical properties to the healthy aortic wall available for 3D printing equivalent (0.28 MPa in stress and 1.05 MPa in Young's modulus), to create credible phantoms of the aorta.

Acknowledgements

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