Master Thesis 0044
12.08.2019

Development and validation of an artificial venous circulatory system for blood draw prototype testing

Universität Stuttgart

J. Mayer[1], J. Liu[1], P.P. Pott[1]
[1]Institut für Medizingerätetechnik, Universität Stuttgart, Germany

Institut für Medizingerätetechnik

Background

- Drawing blood is a frequent yet invasive medical routine and current research aims to improve the procedure by assistive devices. Some patients, e.g. elderly and children, are prone to venous collapse during blood draw, often requiring another puncture site to be opened. To be able to test future devices that could prevent venous collapse, a realistic model of human veins is needed.
- The overall pressure exerted on the walls of blood vessels is referred to as transmural pressure. It results from the blood distending the vessel, and tissue and muscles compressing it. Veins collapse if transmural pressure is too low to keep the thin-walled vessels in circular shape.

Artificial Veins

- Suitable tubes had to be identified that could adequately model the collapsing behavior of human veins.
- Method In many existing blood circulation models, artificial veins are made from latex. Therefore, latex tubes were manufactured in different dimensions (see Table 1) by dipping a cylindrical mold in latex milk and drying while rotating.
- The bending modulus c can be used to quantify and compare the ability to collapse of tubular structures when mimicking human veins by artificial vein-modeling tubes.

$$c = \frac{1}{12} E_t h^3$$

E_t transversal elastic modulus
h wall thickness

- Bending modulus reference values at several transmural pressures were obtained from published elastic modulus and wall thickness measurements of the jugular vein [1]. For the self-made latex veins and further comparative tubes, the Shore A hardness was measured and the compression elastic modulus derived as proposed by [2]:

$$E = \frac{1-\mu^2}{2RC_3} \cdot \frac{C_1 + C_2 Sh_A}{100 - Sh_A} \cdot (2.6 - 0.02\, Sh_A)$$

E elastic modulus
Sh_A Shore A hardness
$R, \mu, C_1 - C_3$ constant values, see [2]

- The wall thickness of the tubes was determined from microscopy images.
- Results The resulting bending moduli of human and artificial veins are listed in Figure 1. In addition, the bending modulus of a typical arm vein was estimated by extrapolation from its wall thickness and the jugular vein elastic modulus, marked by X in Figure 1.
- Discussion The bending moduli of the artificial tubes are at least 10^2 larger than in the jugular vein at comparably low transmural pressure. However, the estimated bending modulus of an arm vein is higher ($1 \cdot 10^{-7}$ Nm) and thereby close to the bending moduli of the Penrose drain and the 0.1 mm wall thickness self-made tube (senior vein, $3 \cdot 10^{-7}$ Nm). Based on the mechanical data on human veins that were at hand, these two artificial veins are therefore likely to adequately model arm veins in terms of collapsibility.

Bending modulus comparison

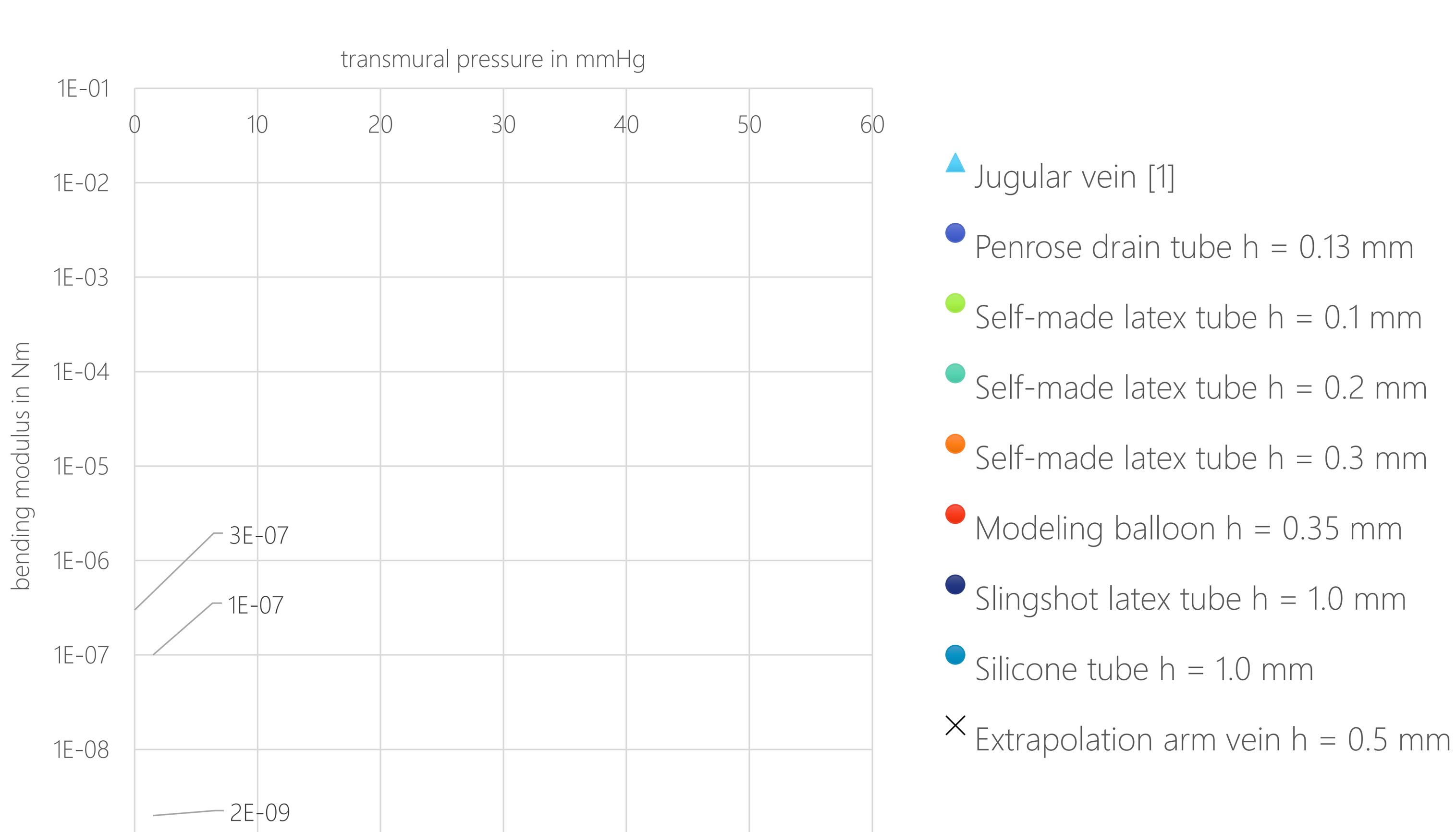

Figure 1: Bending moduli of artificial tubes at zero transmural pressure and jugular vein at different transmural pressure levels

Artificial veins sizes

Table 1: Dimensions of artificial veins used in the circulatory system

	Dimensions manufactured
Adult vein	d = 5 mm, h = 0.3 mm
Senior vein	d = 5 mm, h = 0.1 mm
Child vein	d = 3 mm, h = 0.2 mm

System Setup

- In order to reflect the variety of vein geometries throughout ageing, all three types of self-made artificial vessels (see Table 1) were incorporated into the puncture site. The veins are both supported and covered by a solidified gelatin solution as simple artificial tissue. As blood mimicking fluid, both colored water and silicone oil (dynamic viscosity 4.6 mPas, similar to blood) can be filled into the fluid container.
- The fluid is moved through the puncture site by a pressure-controlled membrane pump. Transmural pressure and flow rate are shown on a display together with the adjustable setpoints of heart rate (if required) and transmural pressure. The system can be run both at physiological venous pressure levels and at high pressure corresponding to the use of a tourniquet during venipuncture.

Artificial venous circulatory system setup

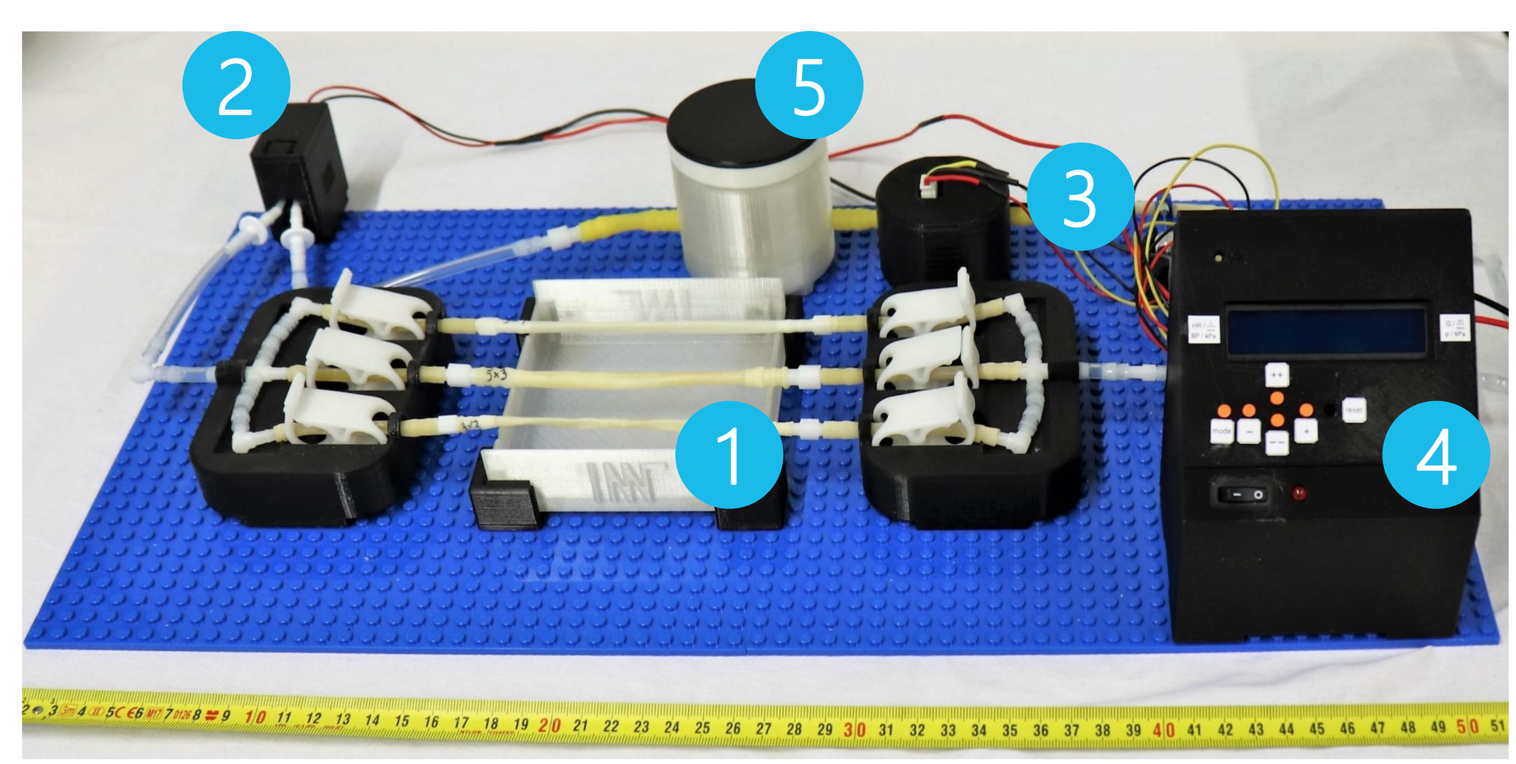

Figure 2: Venous circulatory system with puncture site (1), pump (2), sensors (3), interface (4) and fluid container (5)

Evaluation

- Six medical professionals performed venipunctures on the system. The diversity of vein geometries as well as the feeling of the latex tubes during puncture was appreciated.
- During 18 punctures, the child vein had collapsed most frequently (9 x) compared to the senior (4 x) and adult vein (1 x). This indicates that the model is suitable to mimic the increased susceptibility to venous collapse that can be observed in children and elderly.
- Some participants were able to continue blood draw even during venous collapse which does not yet reflect the challenges in human venipuncture adequately.

Outlook

- Incorporating venous valves and anastomoses (several open vessels in parallel) that are both found in human arm veins might improve the collapsing behavior during venipuncture further.
- The artificial tissue is refined for a wider range of testing to be conducted on the system.
- Retrieving precise values for geometry and elastic modulus of common puncture veins might be the key to further adjusting the mechanical properties of the self-made artificial veins.

Literature

1. Attinger EO. Wall Properties of Veins. IEEE Transactions on Biomedical Engineering. 1969;BME-16(4):253–261.
2. Kunz J, Studer M. Bauteilauslegung: Druck-Elastizitätsmodul über Shore-A-Härte ermitteln: Component Design: Determining the Modulus of Elasticity in Compression via the Shore A Hardness. Kunststoffe. 2006;(06):92–94.