3P1-7

Proceedings of Symposium on Ultrasonic Electronics, Vol. 34 (2013) pp. 425-426
20-22 November, 2013

Elasticity estimation of viscoelastic tube mimicking blood vessels by 1D theoretical model

1D 理論モデルを用いた血管模擬粘弾性チューブの弾性推定

Shohei NISHI[1†], Mami MATSUKAWA[1], Pierre-Yves LAGREE[2] ([1]Doshisha Univ.; [2]Université Pierre et Marie Curie)
西　翔平 [1†]，松川　真美 [1]，ピエール-イヴ・ラグレー[2] ([1] 同志社大学, [2] ピエール・マリー・キュリー大学)

1. Introduction

The increasing cardiovascular disease (CVD) is becoming a serious problem [1]. Two major causes of CVD are hypertension and coronary artery disease resulting from the development of arteriosclerosis. Therefore, early detection of arteriosclerosis is very important [2]. Nowadays there are various methods to diagnose the arteriosclerosis. Ultrasonography and pulse wave velocity (PWV) tests are the main diagnostic approaches used to assess the degree of arteriosclerosis [3,4]. For the purpose of early screening, we have proposed a 1D theoretical model for estimating elasticity of blood vessel. [5]

In this study, we estimate the Young's modulus of artificial vessel by 3 different methods, 1D model, LDV and tensile test and discussed the applicability of 1D model for elasticity evaluation.

2. Viscoelastic tube

2.1. Creating viscoelastic tube

Two tubes (A and B) with different Young's moduli were fabricated by polyurethane gel (Asker-C 5 and 15, Exseal Corp). The diameter and thickness were set as 8 mm and 2 mm, respectively.

2.2. Elastic evaluation of the viscoelastic tube

According to the stress-strain curve which was measured by the tensile test (Shimadzu, Ez-test), Young's modulus of tube A was estimated in the range of 160–230 kPa with the average value of 200 kPa. In case of tube B, Young's modulus was estimated in the range of 70–90 kPa with the average value of 80 kPa. The Young's modulus of an aged aorta ranges from 60 to 140 kPa [2]. Thus, the Young's moduli of tube A and tube B are considered to be similar with very rigid and normal blood vessels, respectively.

3. 1D model

A numerical calculation of the pressure wave propagation in the viscoelastic tube is performed using the 1D model [5]. The governing equations are;

Conservation of mass

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=0 \tag{1}$$

Momentum equation

$$\frac{\partial Q}{\partial t}+\frac{4}{3}\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right)=-\frac{A}{\rho}\frac{\partial P}{\partial x}-\frac{8\nu Q}{R^2} \tag{2}$$

where Q is average flux over the cross section A. ρ and ν are fluid density and dynamic coefficient of viscosity, respectively. P is the inner pressure. Young's modulus of distensile tube is estimated as

$$K=\frac{Eh}{(1-\sigma^2)R_0{}^2} \tag{3}$$

where K is the bulk modulus of the tube, E is Young's modulus, h is thickness, σ is Poisson's ratio, R_0 is unperturbed radius.

From a pressure perturbation law, we have

$$P=K\left((R-R_0)+\varepsilon_p(R-R_0)^2\right)+\eta\frac{\partial R}{\partial t} \tag{4}$$

where ε_p is coefficient of the nonlinear stress strain characteristics, η is viscosity of the arterial wall, R is the radius of tube [5].

4. Measurement of inner pressure and surface displacement of the tube

As shown in **Fig. 1**, water was discharged into a polyurethane tube by a pump (TOMITA Engineering) which mimicked the heart. The flow patterns were a half or one period of sine wave. The inner pressure was measured by a pressure sensor (Keyence, AP-10S). There were two conditions at the terminal of the tube, (1) perfect reflection by the inserted rod and (2) water tank.

Vibration velocity of the tube surface (tube wall) was measured by a Laser Doppler Vibrometer (Polytec, NLV-2500). Displacement was estimated by integrating the measured velocity.

---

mmatsuka@mail.doshisha.ac.jp

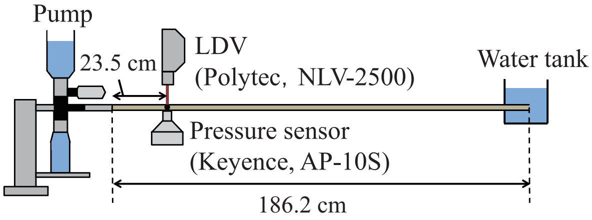

Fig. 1 Measurement system.

5. Experimental results and discussion

First, we estimated the Young's modulus of the tube by the 1D model. Pressure changes in the rigid tube are shown in **Fig. 2**. The estimation of 1D model was in good agreement with the data. From the comparison between the model and the data, we estimated the most suitable Young's moduli E for soft and rigid tubes, 65 kPa and 178 kPa.

Next, we estimated the Young's modulus from the pressure perturbation law. The inner pressure and the surface displacement were measured by the pressure sensor and LDV. The measured waveform of inner pressure and the surface displacement of rigid tube are shown in **Fig. 3**. The relation between the displacement and pressure is shown in **Fig. 4**. Parameters in Eq. (4) were selected to fit the measured data. However, the effects of ε_p and η were negligible. In the displacement from 0.00 to 0.05 mm, we obtained the values of K= 30 MPa/m which results in the Young's modulus E of approximately 190 kPa. In the displacement from -0.05 to 0.00 mm, Young's modulus was estimated as 200 kPa. In case of soft tube, Young's modulus was approximately 70 kPa. All data are summarized in **Table 1**. These Young's moduli were similar with the estimated values by the 1D model.

6. Conclusion

In this study, Young's moduli of vessel mimicking tubes were estimated by the 1D model. It was then compared with the results of two other methods. The estimated data were in good agreement. Young's modulus of blood vessel can be estimated using the 1D theoretical model.

Table 1 Measurement results.

	1D model	LDV		Tensile test
		-0.05~ 0.00	0.00~ 0.05	
Soft tube	65 kPa	70 kPa	70 kPa	80 kPa
Rigid tube	178 kPa	200 kPa	190 kPa	200 kPa

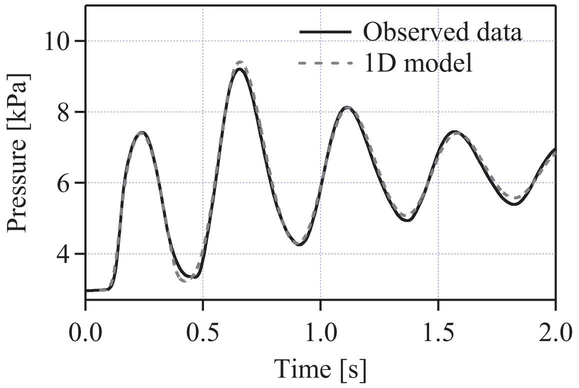

Fig. 2 Comparison between measurement and 1D model simulation.

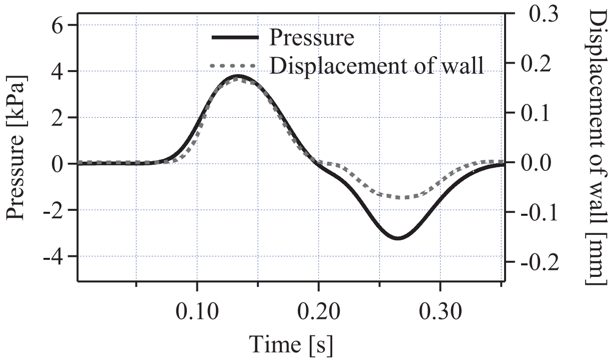

Fig. 3 Measurement data of pressure and displacement of wall.

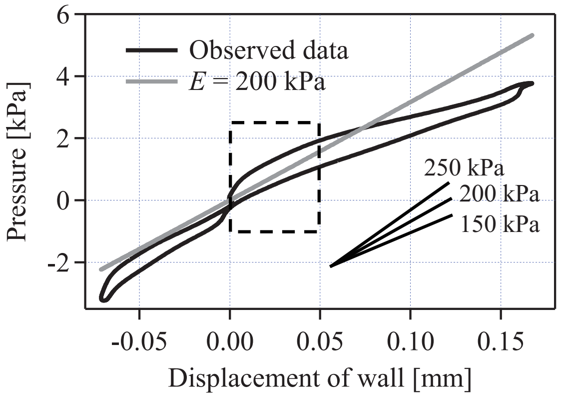

Fig. 4 Relationship between the pressure and the displacement.

References

[1] S.Mendis, P. Puska, and B. Norrving, World Health Organization, 2011.

[2] W. W. Nichols and M. F. O' rouke, *McDonald's Boold Flow in Arteries*, 5th ed, London, UK Hodder Arnold, 2005.

[3] H. Hasegawa and H. Kanai, IEEE TUFFC, Vol. 53, no. 11, 2006.

[4] M. Saito et al., IEEE TUFFC, Vol. 59, pp. 2411-2419, 2012.

[5] M. Saito et al., J. Biomec. Eng, Vol.133, pp. 121005-1-9, 2011.