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Static Analysis of Artery Expansion by the Balloon

Gwo-Chung Tsai, Sun-Jeng Chou
Department of Mechanical and Electro-Mechanical Engineering
National Ilan University

***Abstract*—In this research, ANSYS/Structure is used to do static analysis of artery expansion by the balloon. The pressure of 6MPa, 7MPa, and 8MPa are applied on the inside balloon. The deformation of balloon and plague and the force on the artery and plague are obtained. The thickness of the balloon effect on the artery and plague are also studied.**

***Index Terms*—balloon, plague, artery, static analysis.**

I. INTRODUCTION

In recent years, people work stress and lack of moderate exercise lifestyle, making cardiovascular disease rises to 101 years in Taiwan has been the second leading cause of death [1] , and the age of patients has declined. The main cause of heart disease is because of ischemic cardiomyopathy disease (IHD), also known as coronary heart disease (Coronary Artery Heart Disease, CAHD, CHD). Its main cause is due to occur around the main surface of the heart to provide oxygen and nutrients of coronary heart (Coronary Arteries), hardening or narrowing due to obstruction caused by insufficient blood supply leads to cardiac dysfunction. Atherosclerosis (Atherosclerosis) as hardening or narrowing is the most common types of obstruction. Since the deposition of fat, connective tissue and thus the formation of thrombus or regional plaque (Plaque) prominent phenomenon, when accumulated over 70% of the vessel diameter, it will trigger such as chest tightness, angina, myocardial infarction, and other symptoms.

Currently there are three treatments for coronary heart disease that included drug therapy, surgery, cardiac catheterization. With the advances in medical technology in recent years, there has been a revolutionary treatment model changes. According to the European Society of Cardiology (European Society of Cardiology, ESC) statistics, from the 1980s to receive cardiac catheterization methods increased from 27% to 54% in the 1990s. In the twenty-first century underwent cardiac catheter interventional treatment ratio has exceeded 60%. Cardiac catheterization interventional therapy, also known as transcatheter interventional therapy (Interventional Therapy) is a newly developed treatment, which is applied as a way of percutaneous peripheral arterial (shares or radial artery, etc.) along the radial direction of the arteries feeding intervention treatment equipment to coronary artery lesions. For expansion of the stenosis and a heart catheterization techniques dredge, mainly in the lumen remodeling or removal of plaque as mechanism purpose, also referred to as percutaneous coronary intervention (Percutaneous Transluminal Coronary Intervention, PCI).

Important medical measures Percutaneous Transluminal Coronary Angioplasty (PTCA) or called balloon angioplasty (Balloon Angioplasty), as interventional cardiac catheterization treatment used in the clinical treatment of clogged arteries one. System using a set can be expanded with the end of the balloon catheter into the aorta through a peripheral artery, and then into the narrowed or blocked coronary arteries to reach the site, and finally the end of the catheter balloon inflated to distraction narrow focus. Surgical benefits of this approach compared to thoracotomy was performed without, but simply carried out under local anesthesia.

This technique was applied in 1977 by Andreas Gruntzig [1] for the first time in the heart of the implementation. Improved use of a balloon catheter is in a 37-year-old male patient, the implementation of the first case of percutaneous transluminal coronary angioplasty in the world. After three years, a total of 169 cases of patients for the same operation, there are still 90% survival rate after ten years experiences. Since percutaneous transluminal coronary angioplasty technique is simple, small postoperative wound, complications machine is low (0.4%) and the cost is cheap, so gradually the medical community and the public today adopted.

II. STUDY METHOD

The study simulated balloon dilation of the blood vessels in the process, it must establish a balloon, blood vessels and plaques simulation model.

A. Balloon shape

Balloon shape is shown in Fig. 1, after expansion of the intermediate portion squeezed plaques.

Fig. 1 Balloon shape

B. Balloon material properties

Balloon catheter is usually polyamide (Polyamide) by injection or blow molding and subsequent processing is made with low compliance and enhanced features of the lumen. The

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polyamide is present in the crude use of raw caprolactam monomer (Laurolactam) through polycondensation (Polycondensation) is made, and the EMS company's Grilamid series of polyamide products currently are on the market with the lowest water absorption and the lightest materials. The balloon catheter molding materials (Grilamid L25) properties are listed in Table 1 [2] .

Table 1 balloon catheter molding materials (Grilamid L25) properties

General properties		Mechanical properties	
Density (g/cm3)	1.01	Tensile E-Modulus (MPa)	1100
Water absorption (%)	1.5	Stress at yield (MPa)	35
Moisture absorption (%)	0.7	Strain at yield (%)	6
Thermal properties		Stress at break (MPa)	80
Melting point (℃)	178	Strain at break (%)	850
Melt volume rate (℃)	20	Tear resistance (N/mm)	20
Barrier properties		Elmendorf tear resistance (N)	10
O2 transmission rate (cm^3 /m^2 24hr bar)	350	Gelboflex test (Holes/cm^2)	1300
Moisture vapour transmission rate (cm^3 /m^2 24hr bar)	8	Notched impact strength (kJ/m^2)	10

Fig. 2 [2] is for the molding material (Grilamid L25) of the stress – strain curve. The results shown in the next figure to produce the same strain (over 100%) results, which shall be greater than the vertical stress is the stress level of about 5 ~ 10 MPa.

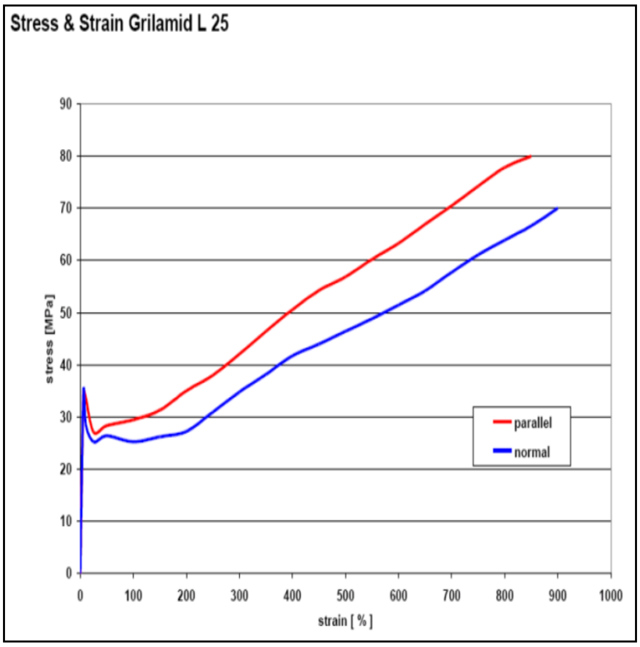

Fig. 2 Stress-strain curve of Grilamid L25

Fig. 3 [4] presents the molding material (Grilamid L25) of the shear viscosity (Shear Vsicosity) and the shear rate (Shear Rate) relationship. It can be applied at all temperatures and show greater shear viscosity shear rate smaller trends.

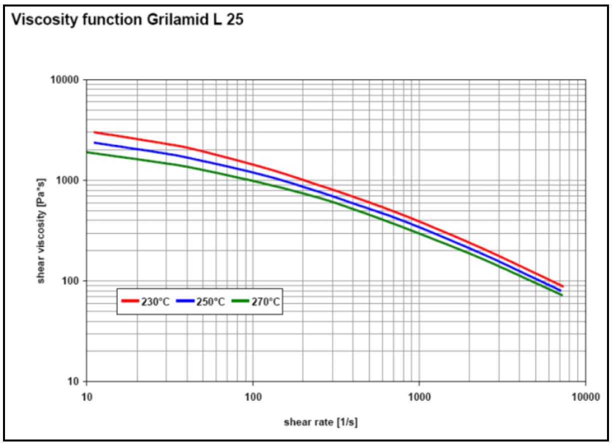

Fig. 3 Shear viscosity curves for Grilamid L25

C. Vascular and plaque material properties

Vascular and plaque are assumed to be the same material properties that listed in ANSYS v14.0, and the Young's modulus is 200MPa, the Poisson's ratio is 0.49.

Table 2 Vascular and plaque material properties

Young's modulus (MPa)	Poisson's ratio	Bulk modulus (Pa)	Shear modulus (Pa)
200	0.49	3.3333E+09	6.7114E+07

III. SIMULATION ANALYSIS

A. Model

Model is divided into three parts, contains vascular, plaque and balloons. Solid model of vascular is plotted in Fig. 4, solid model of balloon is shown in Fig. 5, and solid model of plaque is plotted in Fig. 6. The full model included these three parts is shown in Fig. 7.

Table 3 Model conditions

Vascular	Plaque	Balloon thickness
Diameter 3 mm	The maximum cross-sectional area accounted for 75% vascular	0.02mm 0.03mm 0.04mm

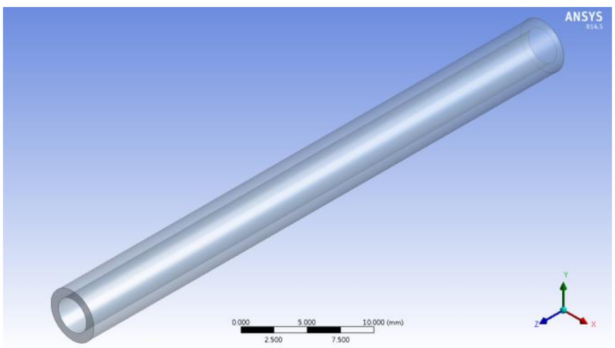

Fig. 4 Solid model of vascular

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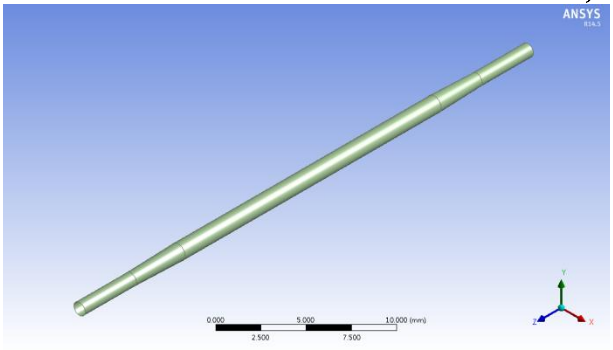

Fig. 5 Solid model of balloon

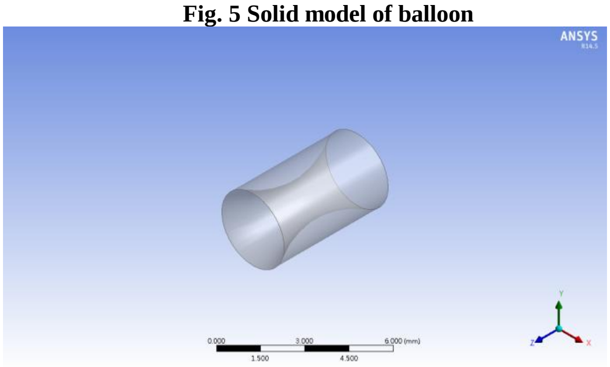

Fig. 6 Solid model of plague

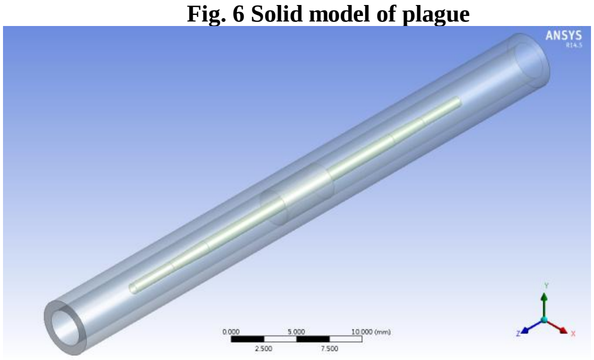

Fig. 7 full model

B. Finite element mesh

To save computing time the hexahedral elements, a total of 40,387 nodes and 8345 elements are used. Fig. 8 is a mesh as a whole cross section.

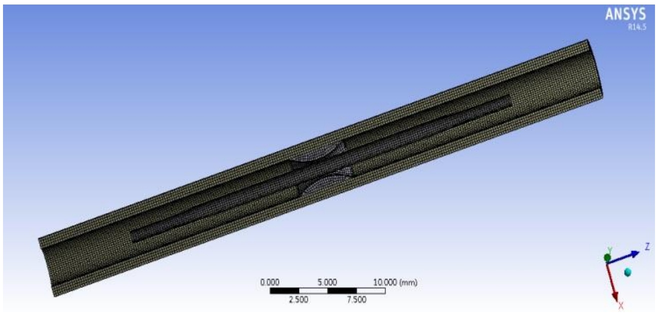

Fig. 8 Mesh as a whole cross section

C. Boundary conditions

1) Support

In order not to move the blood vessel of the vascular section added frictionless support position are shown in Figs. 9-11. Figs. 9-11 are a 1/8 model of full model.

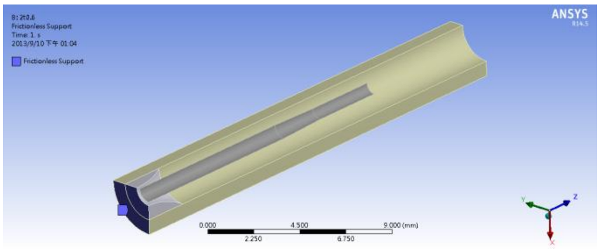

Fig. 9 Intermediate vessels joined frictionless support

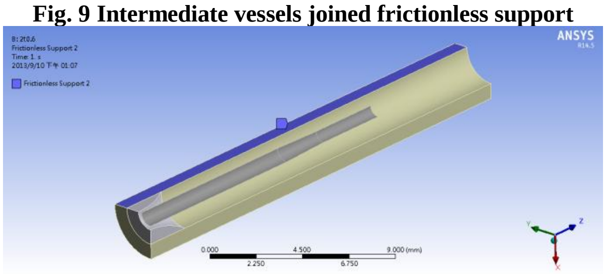

Fig. 10 Vessels on the side of the join frictionless support

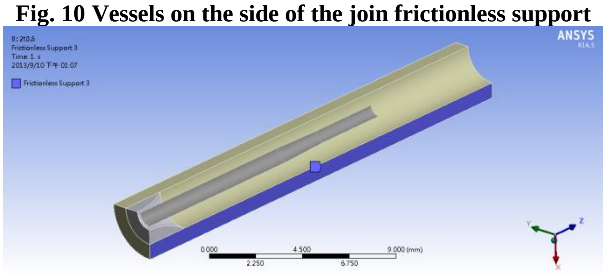

Fig. 11 Vascular underside added frictionless support

2) Displacement

In order to limit the outward expansion of the balloon, the proper displacement direction of the balloon is shown in Figs. 12-15.

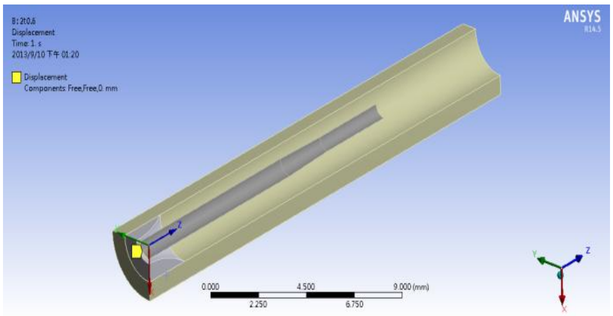

Fig. 12 Not to limit the balloon twists, intermediate Z-direction displacement is 0

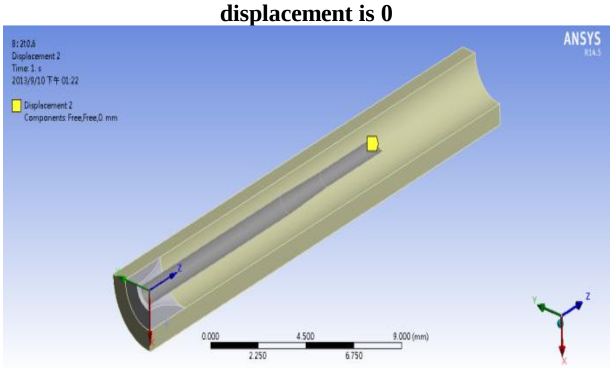

Fig. 13 The balloon cannot elongate or shorten, the balloon end of the Z-direction displacement is 0

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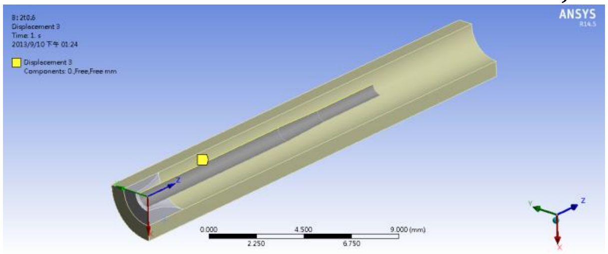

Fig. 14 Not to limit the torsional deformation of the balloon, balloon displacement in direction X side is 0

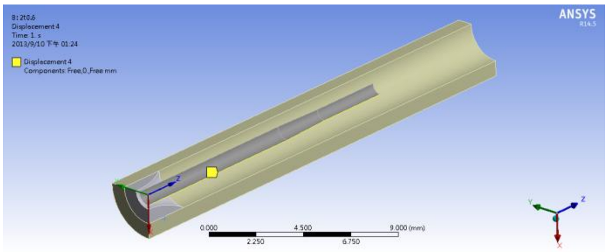

Fig. 15 Not to limit the torsional deformation of the balloon, balloon displacement in direction Y side is 0

D. Analysis settings

In order to solve successfully the initial step size is set to 1/20 seconds, the minimum step size of 1/20 seconds, the maximum step size of 1/5000 seconds.

IV. Results and Discussion

Fig. 16 is a deformed shape after balloon dilation, the figure showed the greatest deformation at the junction of plaque with the balloon, and a result is likely to cause lacerations in the area. The deformation and the stress distribution are similar in plaque shown in Figs. 17-18. Stress distribution in vascular and plaque is shown in Fig. 18. Most of the stress concentration is in the plaque, it represents the balloon effectively squeezing plaque. The results are consolidated in Tables 4-6.

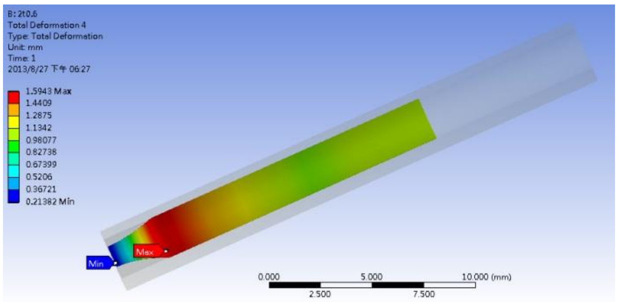

Fig. 16 Deformation of the balloon

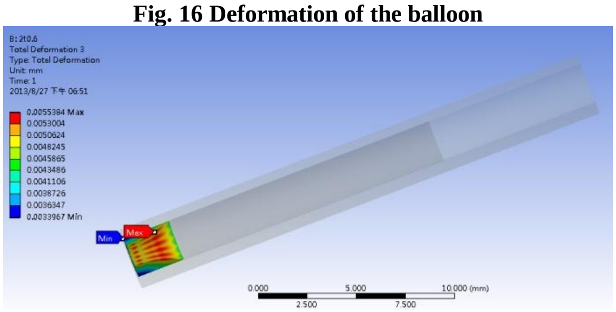

Fig. 17 Deformation of the plague

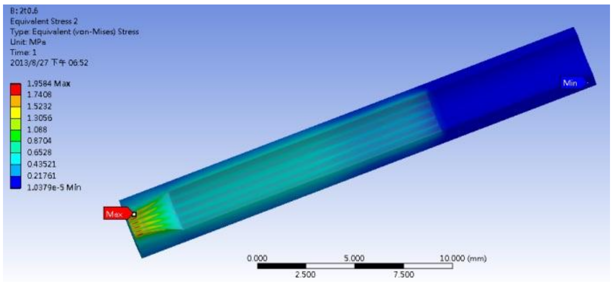

Fig. 18 Stress in plague and vascular

Table 4 Results from 0.6MPa pressure

Put 0.6 MPa			
Thickness (mm)	Balloon deformation (%)	plague deformation (%)	Vascular strain (MPa)
0.02	144.9	0.7385	1.9584
0.03	69.71	0.2375	0.65203
0.04	33.07	0.02195	0.053198

Table 5 Results from 0.7MPa pressure

Put 0.7 MPa			
Thickness (mm)	Balloon deformation (%)	plague deformation (%)	Vascular strain (MPa)
0.02	160.8	1.005	2.954
0.03	108.2	0.5832	1.4873
0.04	46.16	0.1344	0.37802

Table 6 Results from 0.8MPa pressure

Put 0.8 MPa			
Thickness (mm)	Balloon deformation (%)	plague deformation (%)	Vascular strain (MPa)
0.02	172.8	1.283	3.7601
0.03	129.8	0.8562	2.2838
0.04	69.69	0.3173	0.83352

V. CONCLUSIONS

Balloon, plague, and vescular deformation and stress increases as the pressure increases, but also decreases with increasing thickness of the balloon shown in Figs. 19-22.

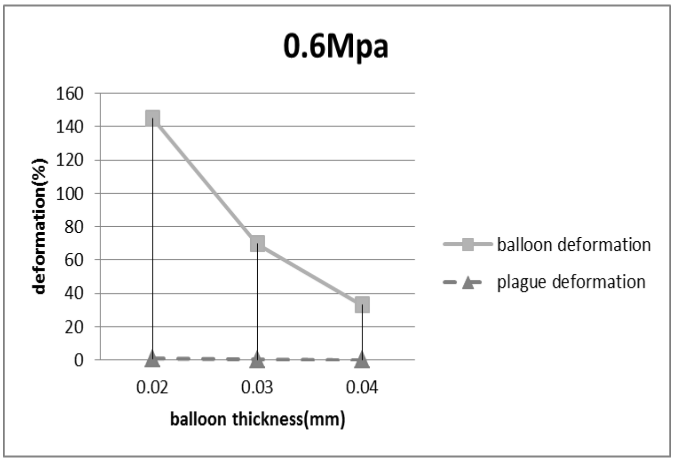

Fig. 19 Results from 0.6MPa pressure

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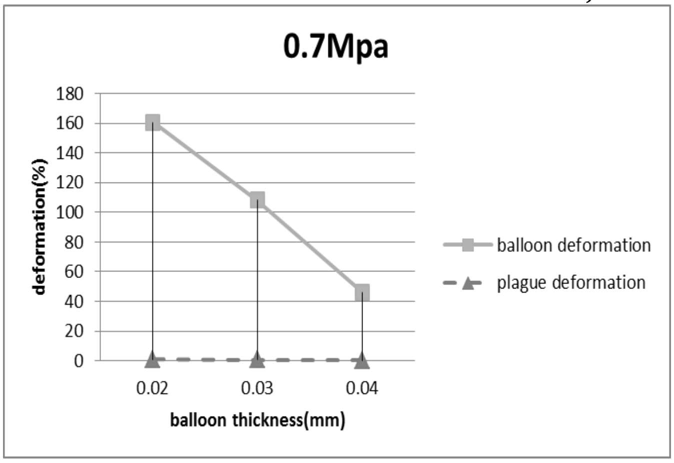

Fig. 20 Results from 0.7MPa pressure

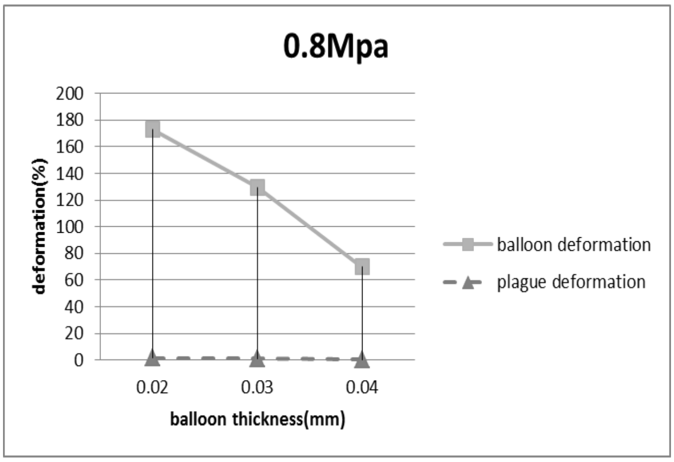

Fig. 21 Results from 0.8MPa pressure

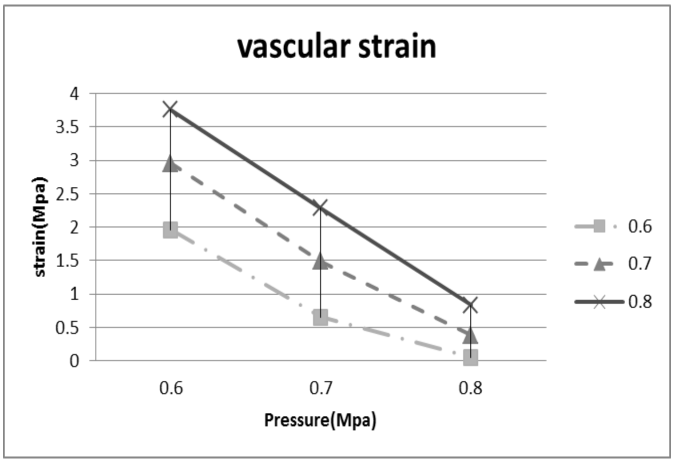

Fig. 22 Results from three different pressures

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[2] J. Theodore Dodge Jr., B. Greg Brown, Edward L. Bolson & Harold T. Dodge, "Lumen Diameter of Normal Human Coronary Arteries Influence of Age, Sex, Anatomic Variation, and Left Ventricular Hypertrophy or Dilation", Circulation, Journal the American Heart Association, P232-246, 1992.