Aorta Modeling for Heart Valve

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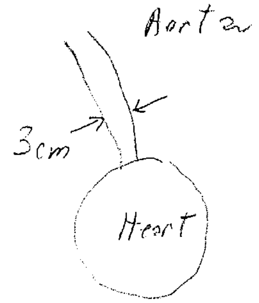


Data

$\Delta P_{max} = 300 \text{ mm Hg} = 30 \text{ cm Hg}$

$Q = 5 L/min = 5000 \text{ cm}^3/\text{min}$

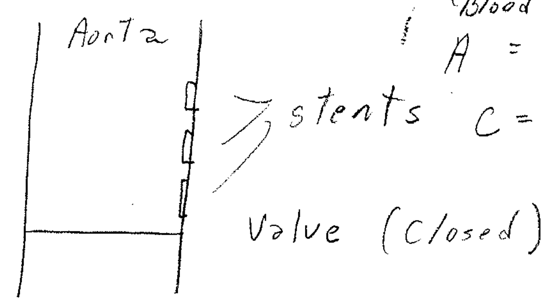
$D = 3 \text{ cm}$, $R = 1.5 \text{ cm}$

$\sigma_r \geq 1200 \text{ mm Hg}$ (Rupture stress)

$\eta_{Blood} = 1 cP = 0.01 P = 0.01 \frac{g}{cm \cdot s}$

$A = \pi \frac{D^2}{4} = \pi \frac{3^2}{4} = 7.1 \text{ cm}^2$

$C = 2\pi R = 2\pi 1.5 = 9.4 \text{ cm}$



Treat the Aorta as a rigid capillary and blood as a homogeneous liquid with viscosity of 1 cP.

Some important quantities:

Shear stress at wall, τ_w

$$\tau_w = \frac{R \Delta P}{2L}$$ shear stress at wall, L = Length

$$\bar{V} = \frac{Q}{\pi R^2}$$ mean velocity

$$\dot{\gamma} = \frac{4Q}{\pi R^3}$$ shear rate at wall

$$\tau_w = \frac{1.5 \text{ cm} \cdot 30 \text{ cm Hg}}{2 \ (1 \text{ cm})} = 22.5 \text{ cm Hg}$$

$$\bar{V} \ \frac{5000 \text{ cm}^3/\text{min}}{\pi (1.5)^2 \text{cm}^2} \ \frac{1 \text{min}}{60 \text{ secs}} = 12 \frac{cm}{s}$$

$$\dot{\gamma} = \frac{4 (5000 \text{ cm}^3/\text{min}) \frac{1 \text{min}}{60 s}}{} = 30 \text{ s}^{-1}$$

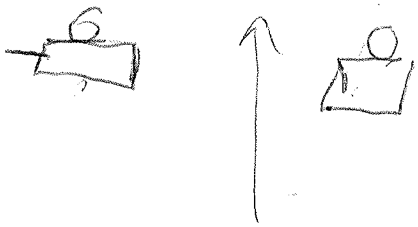
$$Re = \frac{D \bar{V} \rho}{\mu}$$

$$= \frac{3 \text{cm} \ 12 \frac{cm}{s} \ 1 \frac{g}{cm^3}}{0.01 \frac{g}{cm \cdot s}}$$

$= 3600$

for blood, $\eta \approx 3 cp$

$Re \approx 1200$



The max. stress on the ceramic when the valve is closed is

$$F_{max} = \Delta P \cdot A = 30.0\ cm\ Hg \cdot 7.1\ cm^2 \cong 200.0\ cm\ Hg\ cm$$

To keep the rupture stress below 1200 mm Hg (120.0 cm Hg), we require a certain amount of stent-aorta interface area.

$$F_{max} = \sigma_r \cdot A_{stent}$$

If specify that $\sigma_r \approx 300$ mm Hg, then we need

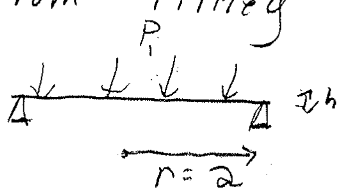
$$200.0\ cm\ Hg \cdot cm^2 = 300\ mm\ Hg \cdot A_{stent}$$

$$\therefore A_{stent} = 7.1\ cm^2$$

Convert P = 300 mm Hg to MPa

$$300\ mm\ Hg \times \frac{1.01 \times 10^5\ Pa}{760\ mm\ Hg} \times \frac{1\ MPa}{10^6\ Pa} = 0.04\ MPa$$

From Pilkey TA 407.2 .P55 1994



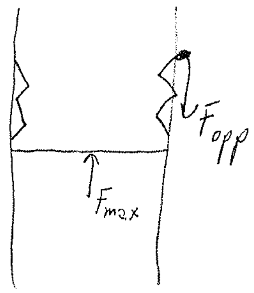
uniform load, simply supported

W_o = max. defl.

$$\frac{P_1 a^4}{E h^4} = \frac{1.016}{1-\nu} \frac{W_o}{h} + 0.376 \left(\frac{W_o}{h}\right)^3$$

$$\sigma_{rp} = \frac{E h^2}{a^2} \left[\frac{1.238}{1-\nu^2} \frac{W_o}{h} + 0.294 \left(\frac{W_o}{h}\right)^2 \right]$$

From Excel Spreadsheet "Heart"



When valve is closed, the max. force is given by $F_{max} = \Delta P \cdot A$. How is this force transmitted?

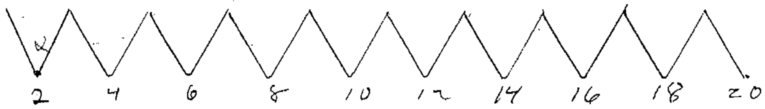
I. This stress must be opposed by a stress arising from aorta-stent interaction.

$F_{opp} = -F_{max} = \sigma_r A_{stent}$

Since we know the Aorta can withstand 30.0 cm Hg hydrostatic pressure (which is less than 120.0 cm Hg rupture strength), we will use σ_r = 30.0 cm Hg and

Thus $A_{stent} = 7.1$ cm^2

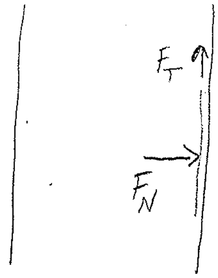
For stents of 1mm width, 10 mm high, and $\alpha = 60°C$,



∴ 20 × 0.1 cm × 1 cm = 2 cm^2

∴ need 4 stents

II. Friction must hold the stent in place



$$COF = \frac{F_T}{F_N}$$

$$F_T = F_{max} = \Delta P \cdot A = 30 \text{ cm Hg} \cdot 7.1 \text{ cm}^2 \approx 200 \text{ cm Hg cm}^2$$

The normal force exerted by the stent (which is opposed by the arterial wall) is

$$F_N = \frac{F_T}{COF} = \frac{\sigma_r \cdot A_{stent}}{COF}$$

∴ For the stent not to move, the normal force must exceed $\frac{F_T}{COF}$

$$F_N \geq \frac{F_T}{COF} > \frac{\sigma_r A_{stent}}{COF} = \frac{200 \text{ cm Hg cm}^2}{0.20}$$

∴ If $COF > 0.20$,

$$F_N = 1000 \text{ cm Hg cm}^2$$

$$\sigma_N = \frac{F_N}{A_{stent}} = \frac{1000 \text{ cm Hg cm}^2}{7.1 \text{ cm}^2} = 140 \text{ cm Hg}$$

∴ This is close to $\sigma_{rupture} \cong 120$ cm Hg

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