The Hydraulic Consequences of Vein Graft Taper

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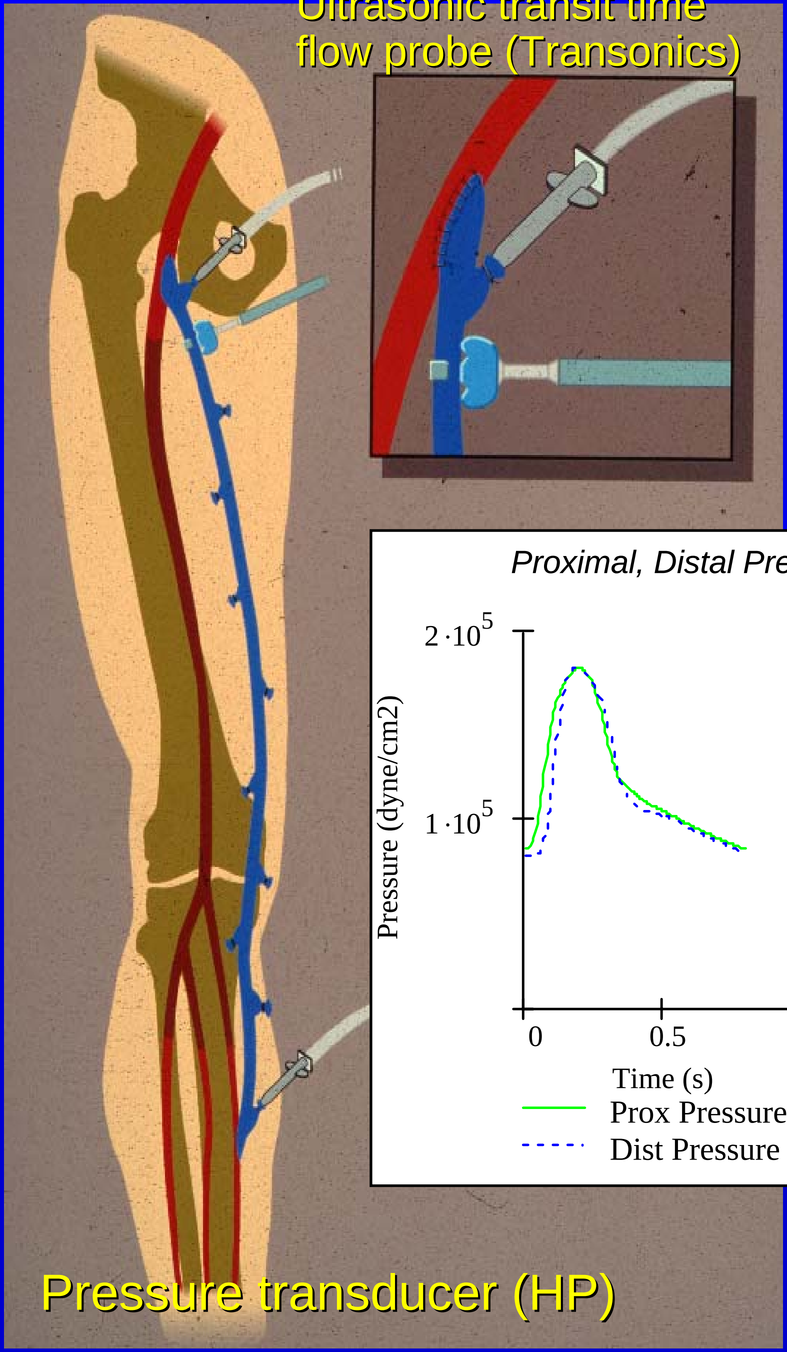
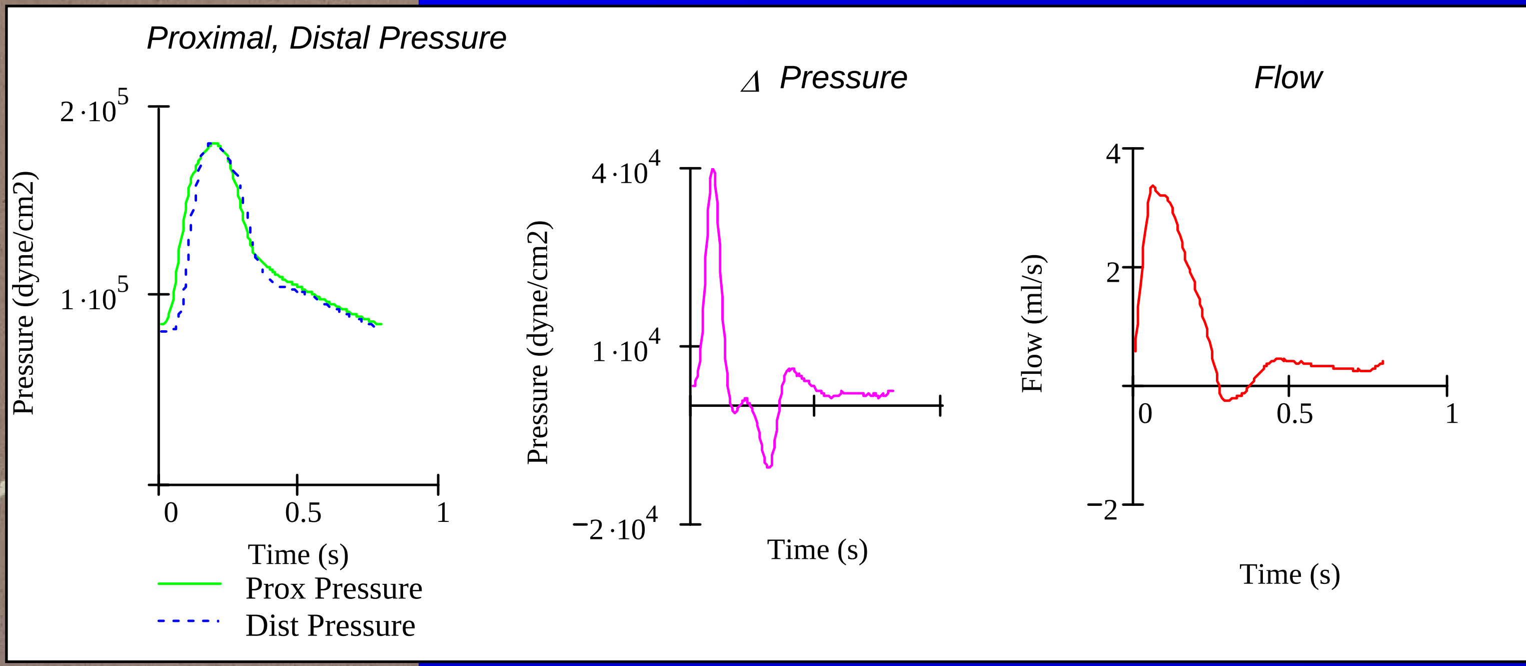
Introduction

- Internal diameter is a strong predictor of vein graft patency
- However, most vein grafts are tapered and thus the diameters varies along the length of the vessel

Purpose: To examine the hydraulic consequences of vein graft taper using longitudinal impedance

Intraoperative hemodynamic assessment of infrainguinal vein grafts

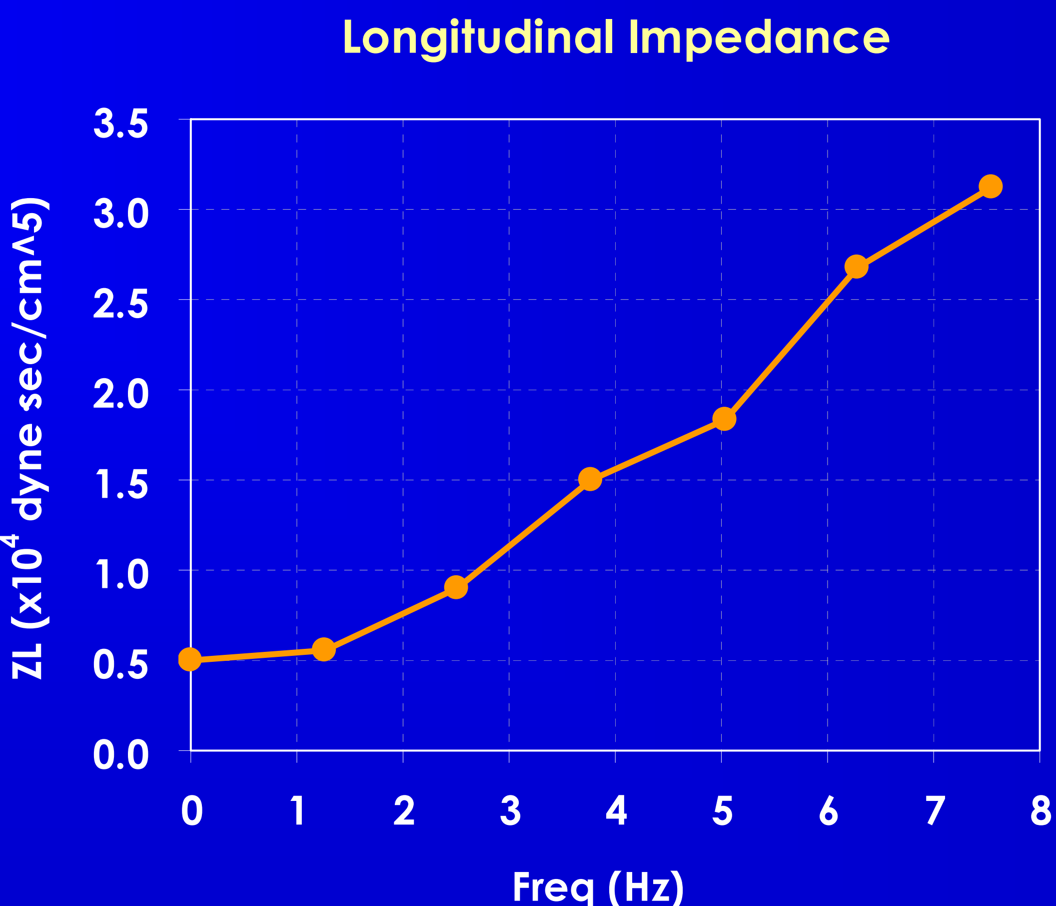




Composite waveforms of 10 heart beats

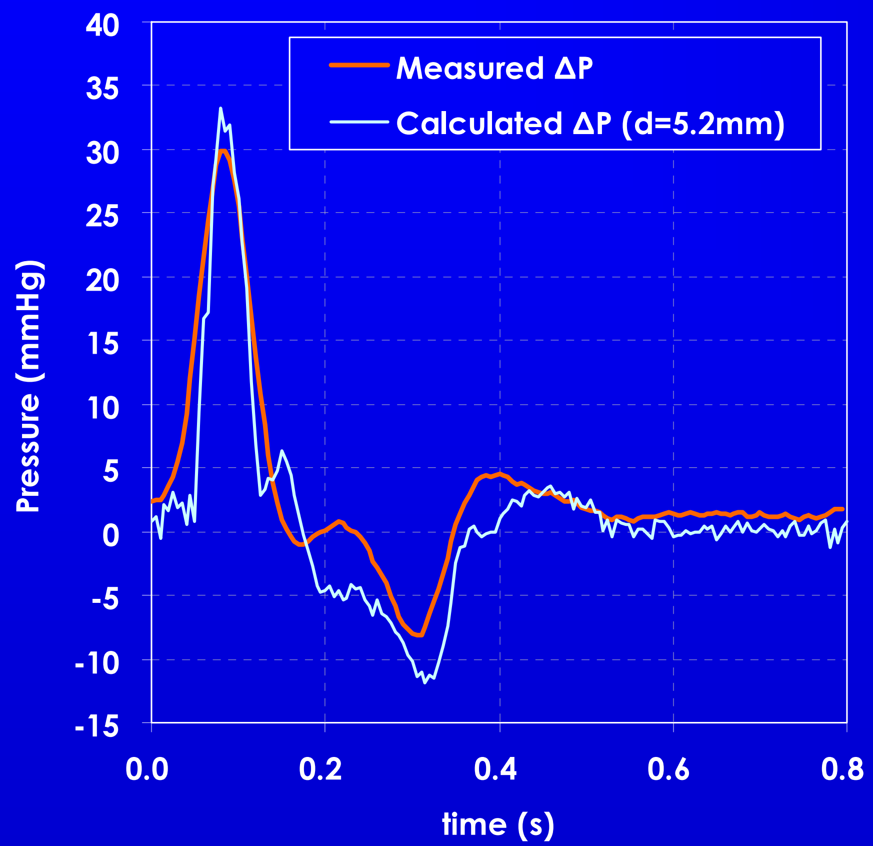
Longitudinal Impedance

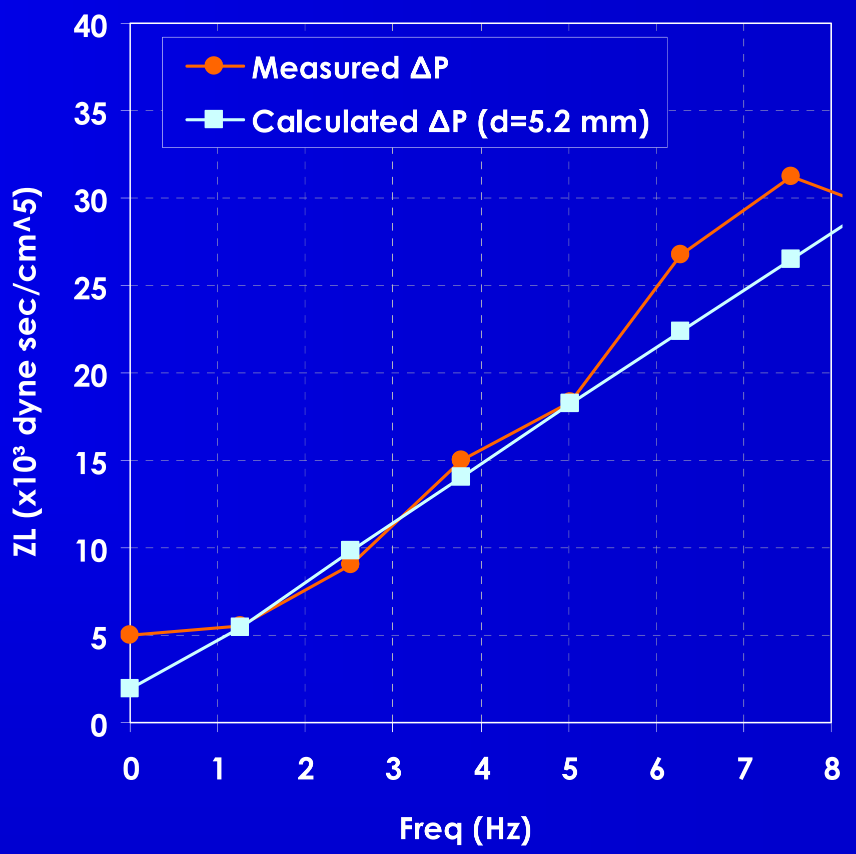
$$Z_{L_n} = \frac{\Delta P_n}{Q_n}$$



Integrate over the first 4 Hz

Calculated vs. Measured ΔP





$$\Delta P(t)=\frac{8\mu Q_0 L}{\pi R^4}+\sum_{n=1}^{\infty}\frac{i\mu L\alpha_n^2 Q_n}{\pi R^4}\left[1-\frac{2J_1(i^{3/2}\alpha_n)}{2J_1(i^{3/2}\alpha_n)-i^{3/2}\alpha_n J_0(i^{3/2}\alpha_n)}\right]e^{i\varpi_n t}$$

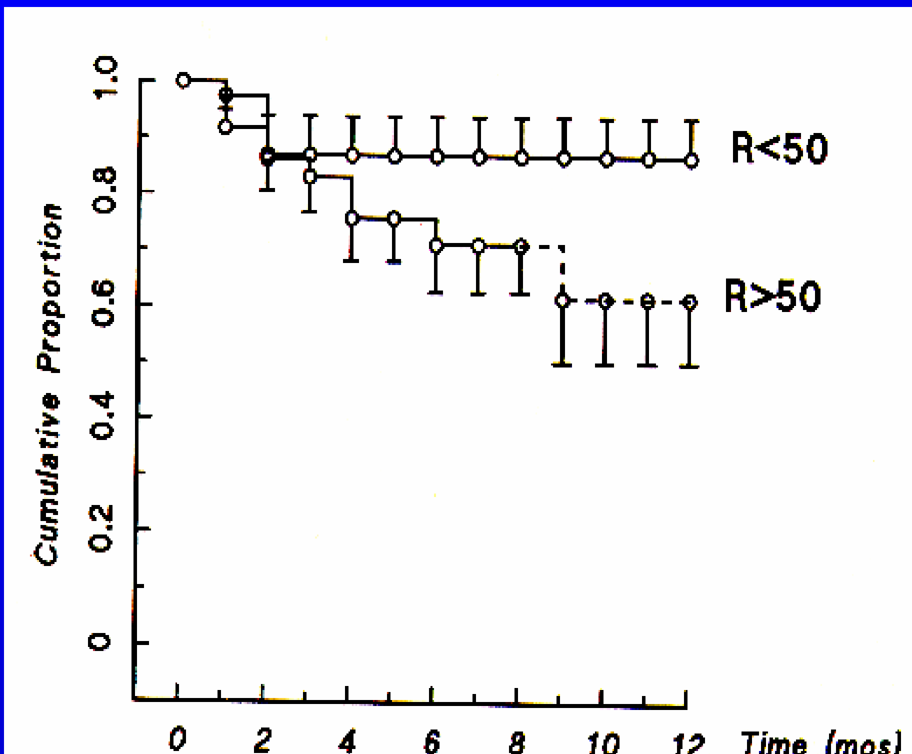
Table III. Vein graft hemodynamics

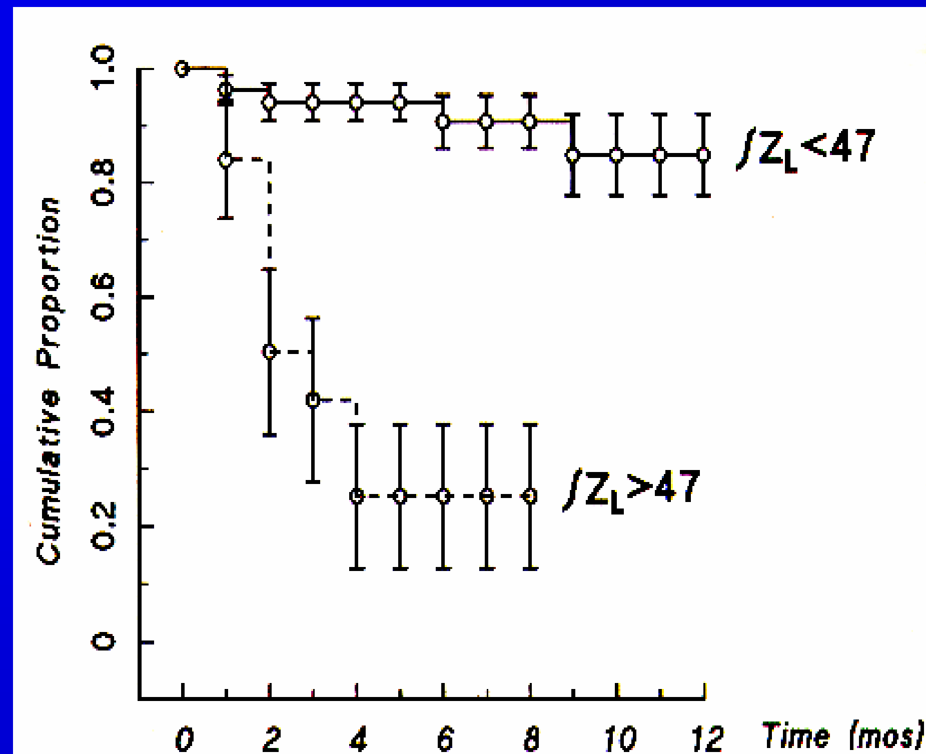
Variable	*Baseline (mean ± SD)*	*Stimulated (mean ± SD)*	*p*
$\bar{P}_{prox}$ (mm Hg)	75.2 ± 16.2	73.4 ± 17.3	0.015
$\Delta\bar{P}$ (mm Hg)	3.9 ± 4.0	6.3 ± 6.6	0.0001
$\bar{Q}$ (ml/min)	78.2 ± 58.7	126 ± 89	0.0001
$\Delta\bar{P}/\bar{Q}$ ($\times 10^3$ dynes · sec · cm^{-5})	4.8 ± 5.2	4.6 ± 4.6	NS
R ($\times 10^3$ dyne · sec · cm^{-5})	134 ± 140	72.7 ± 52.3	0.0001
$\int Z_L$ ($\times 10^3$ dyne · cm^{-5})	31.2 ± 23.6	30.8 ± 24.1	NS

N=73

JVS 1997;11:35-43.

Outflow resistance and Longitudinal impedance vs. patency





What is the effect of Taper?

- Examined L_Z for straight grafts100 cm in length with internal diameters:

  {1.2, 2.2, 3.2, 4.2,…8.2 mm}

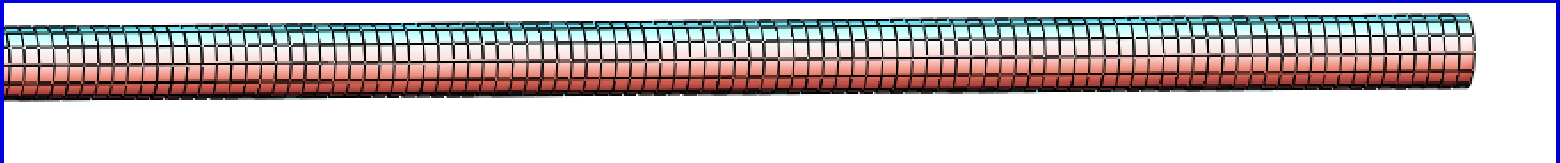
- Examined a series of tapered grafts 100 cm in length with $D_{mean:}$

  {3.2, 4.2 and 5.2mm} and taper {0 → 83%}

$$Taper = \frac{\left(D_{proximal} - D_{distal}\right)}{D_{proximal}} \times 100\%$$

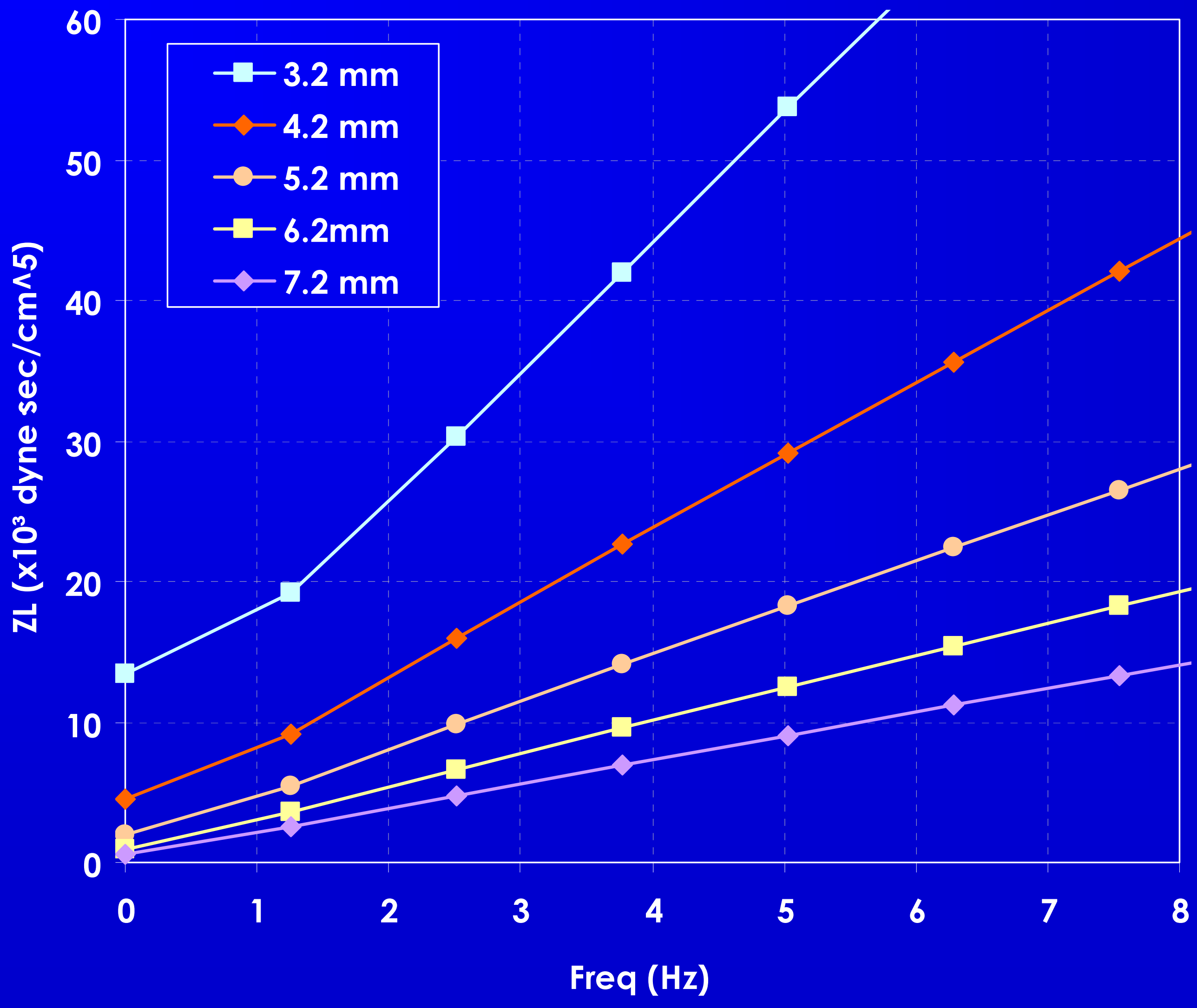
Methods-Straight Graft

ΔP computed from Womersley solution. This is a reduced form of the full Navier-Stokes solution where the tube is straight, constant diameter and infinitely long such that an analytical solution is possible

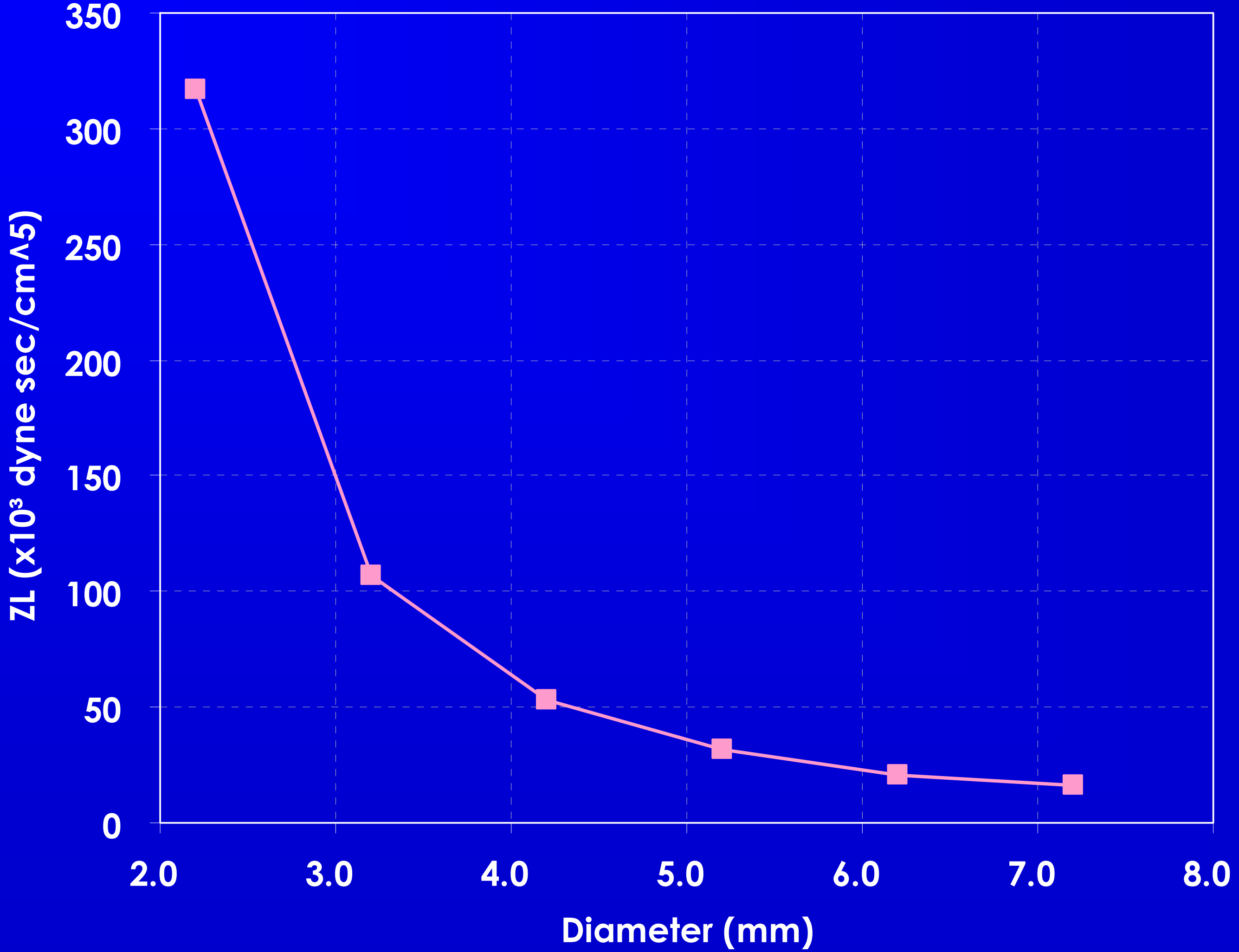


$$\Delta P(t) = \frac{8\mu Q_0 L}{\pi R^4} + \sum_{n=1}^{\infty} \frac{i\mu L \alpha_n^2 Q_n}{\pi R^4} \left[1 - \frac{2J_1(i^{3/2}\alpha_n)}{2J_1(i^{3/2}\alpha_n) - i^{3/2}\alpha_n J_0(i^{3/2}\alpha_n)} \right] e^{i\varpi_n t}$$

Non-Tapered Grafts-Z_L



Non-Tapered Grafts-Integral Z_L

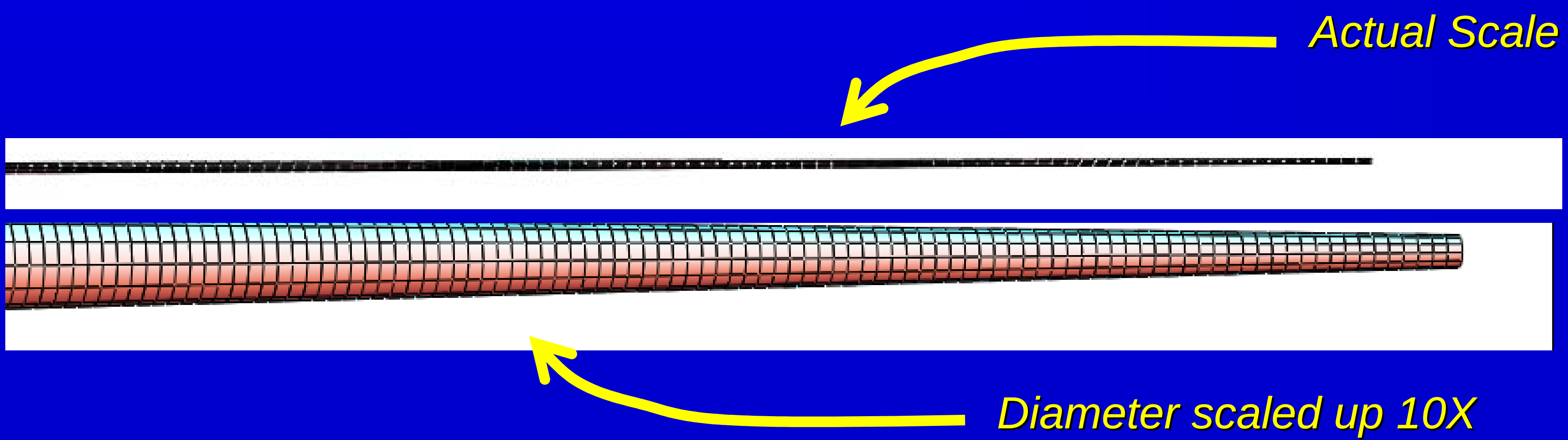


Methods-Tapered Grafts

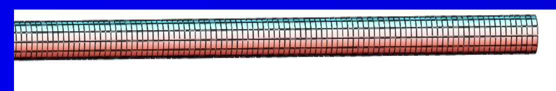
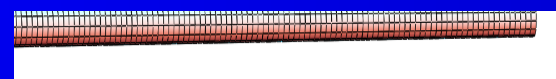
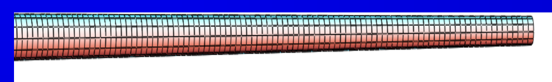
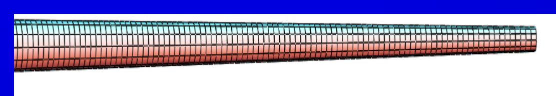
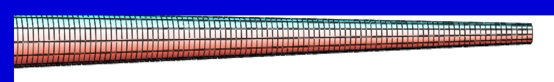
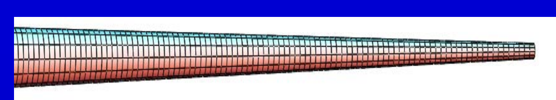
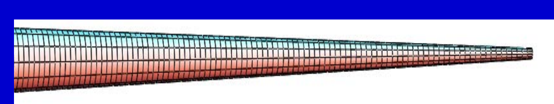
ΔP computed from the solution of the incompressible, axisymmetric Navier-Stokes equations in cylindrical coordinates using finite volume method

(15 hours CPU time on a PC for each calculation)

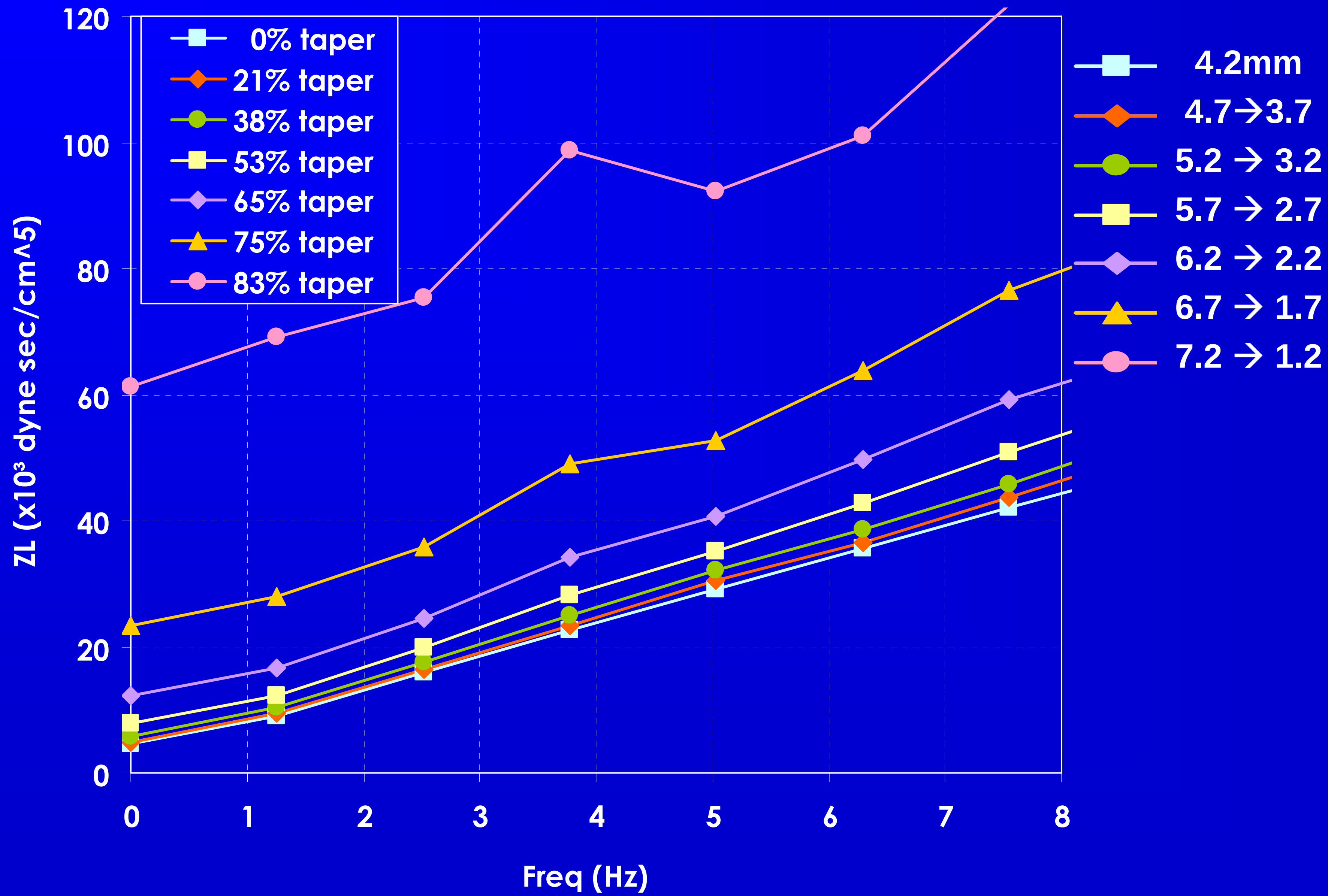
D_{mean} = 4.2mm with 64% taper (6.2 → 2.2mm)



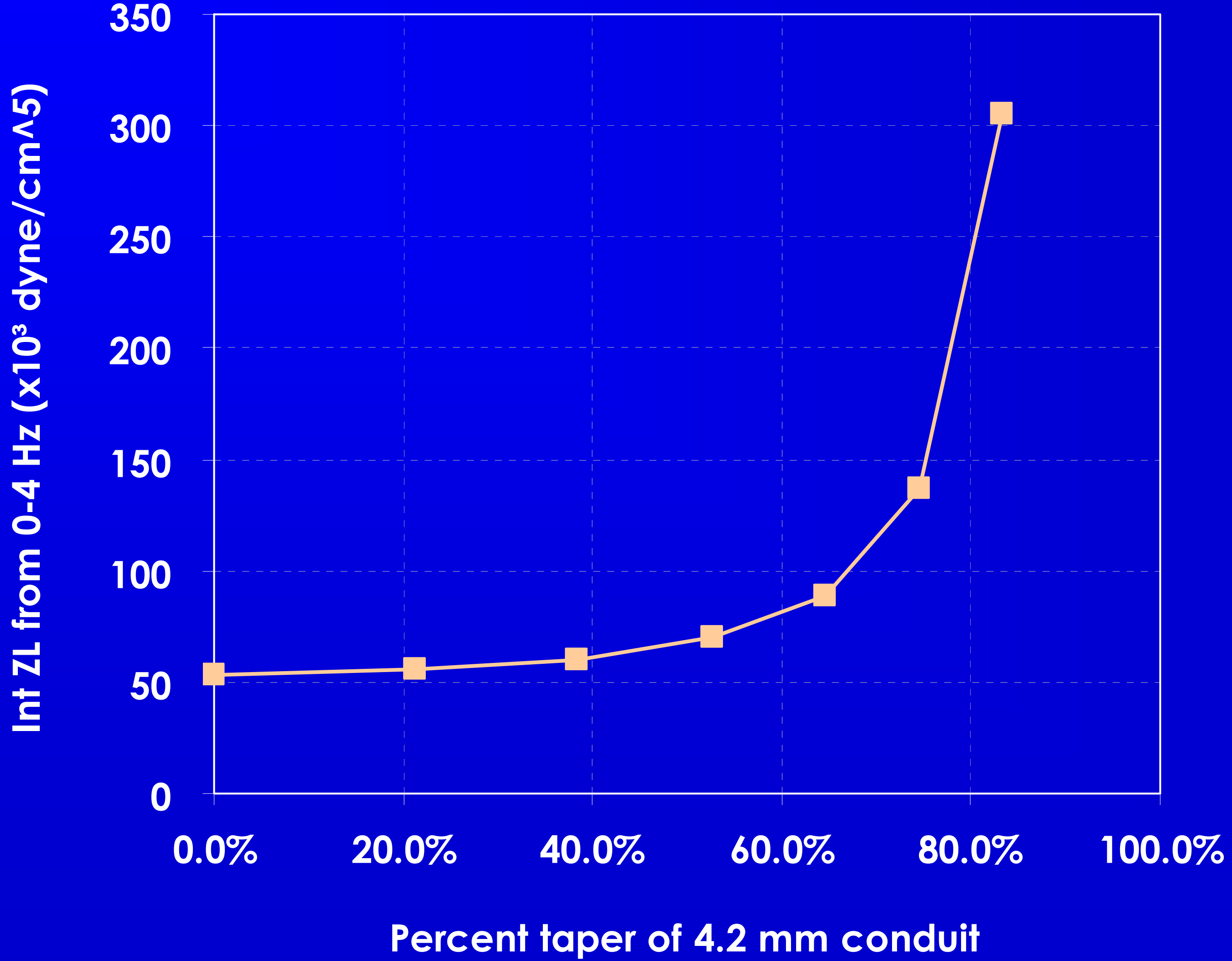
Tapered Grafts (D_{mean} =4.2 mm)

% taper	*prox diam.*	*scaled-up 10X*	*distal diam.*
0%	*4.2*		*4.2*
21%	*4.7*		*3.7*
38%	*5.2*		*3.2*
53%	*5.7*		*2.7*
65%	*6.2*		*2.2*
75%	*6.7*		*1.7*
83%	*7.2*		*1.2*

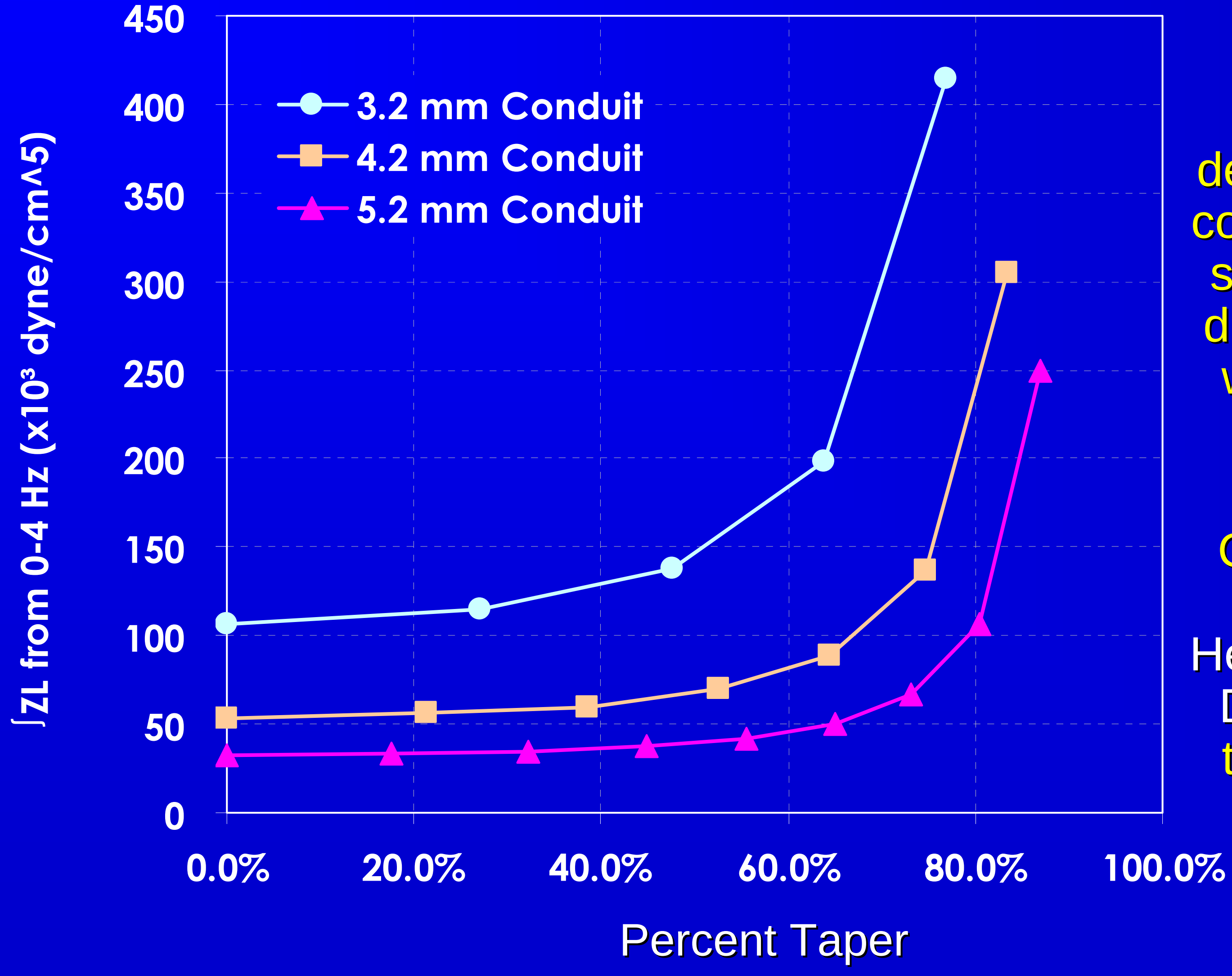
Tapered Grafts-Z_L (D_{mean} =4.2 mm)



Tapered Graft-Integral Z_L



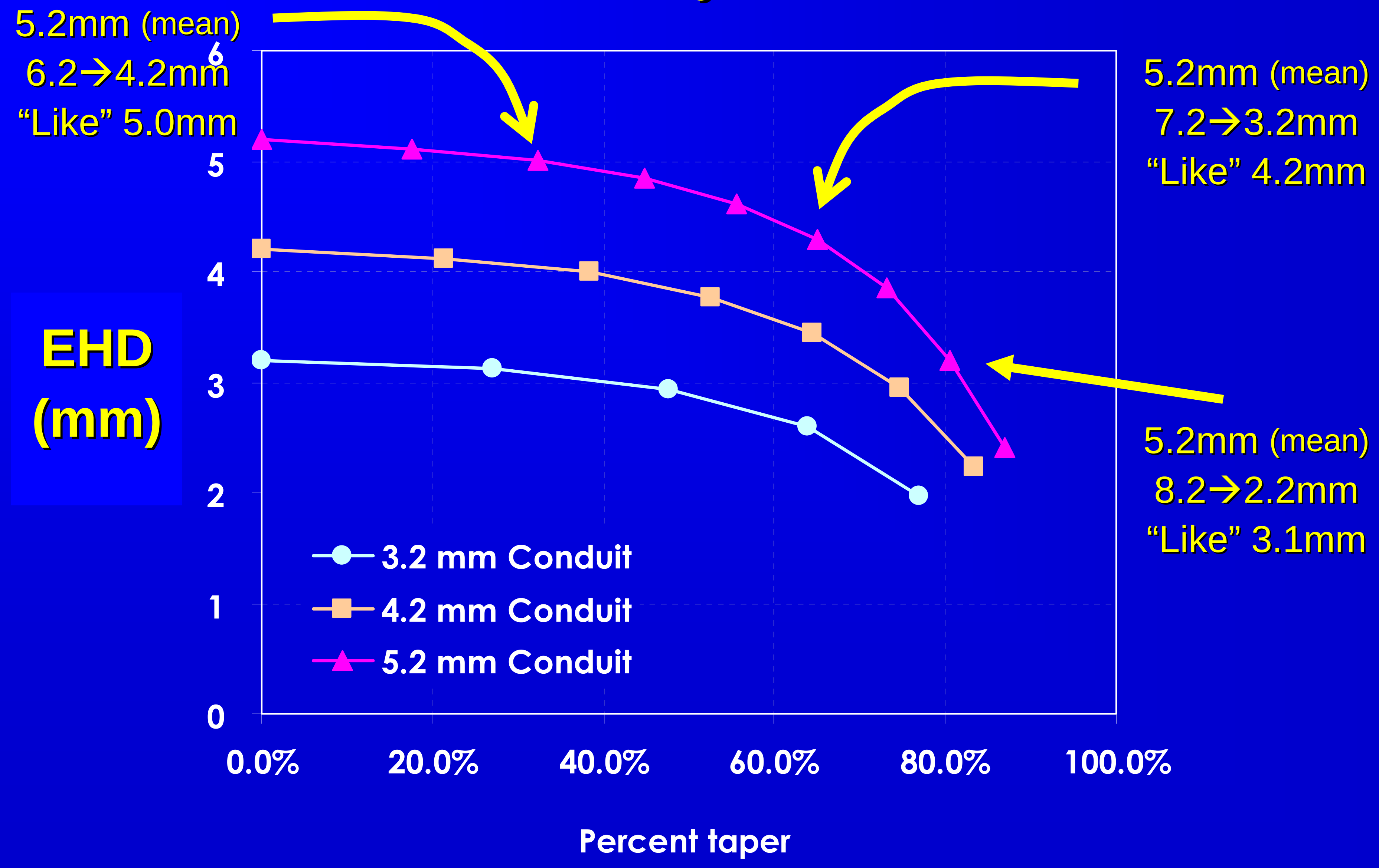
Tapered Grafts-Integral Z_L



Take each Integral Z_L value and determine the corresponding straight graft diameter that would have the same value

Call this the Effective Hemodynamic Diameter of the tapered graft

Effective Hemodynamic Diameter



Summary

- Z_L increases rapidly in conduits with D<4mm
- Tapered grafts behave hydraulically like straight grafts provided that:
  - D_{mean} > 4mm
  - Degree of taper < 40%

Future work: Computed Z_L for veins before they are harvested based on preoperative duplex vein mapping

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