Welcome to the 4th European Bifurcation Club
26-27 September 2008 - PRAGUE

Structure-Function Relation in the Coronary Arterial Tree

Ghassan S. Kassab
Guidant Chair Professor
Biomedical Engineering, Indiana/Purdue University
Applications

- Hypothesis-driven research
- Simulator training, teaching tools...
- Virtual PTCA and stenting
- Improved stents and other PCI devices
- Etc...
• Epicardial vs. Intramyocardial Vessels: “Delivering” vs. “Distributing” Vessels

• Intramyocardial Vessels: “Conductive” vs. “Transportive” Vessels
Cross-Sectional Area (CSA) and Flow: RCA Trunk and Primary Branches
CSA and Flow: LAD Trunk and Primary Branches
Segment Velocity: Entire LAD Tree
CONCLUSIONS

Structure-Function Relation: Functional Hierarchy

Transition from “Distributing” to “Delivering” Vessels – Uniform distribution of blood to 3D heart

Transition from “Conductive” to “Transportive” Vessels – Flow slows down towards the capillaries with minimum energy losses

Kassab, GS. Am. J. Physiol., 2006
“Physiological organization, like gravitation, is a ‘stubborn fact,’” and it is one task of theoretical physiology to find quantitative laws which describe organization in its various aspects.”

Cecil D. Murray, 1926
What physical or physiological principles dictate the design of vascular trees?
Minimum Energy Hypothesis

Cost Function = Friction Power Loss + Metabolic Energy Dissipation
Stem-Crown Relations
Minimization of Cost Function: Scaling Laws

(1) Crown Volume-Crown Length:
    Volume ~ Length^{9/7} (1.28...)

(2) Crown Volume-Stem Diameter:
    Volume ~ Diameter^3

(3) Stem Diameter-Crown Length:
    Diameter ~ Length^{3/7} (0.428...)

(4) Stem Flow-Crown Length:
    Flow ~ Length

(5) Stem Flow-Stem Diameter:
    Flow ~ Diameter^{7/3} (2.333...)
Volume-Length Relation

Normalized Crown Volume

Normalized Crown Length

Frequency
- 0.000001
- 0.000010
- 0.000100
- 0.001000
- 0.010000
Angiography – Porcine Hearts
Conclusions

• The design of coronary vasculature obeys the “minimum energy hypothesis” (principle of economy or efficiency).

• A set of scaling laws relate the various morphological (e.g., diameter, length and volume) and function (e.g., flow): Structure-Structure and Structure-Function Relations, respectively.
Clinical Implications

Validate the power-law relationships for the human coronary arterial tree

Diagnose the extent of DCAD in patients
Atherosclerosis: Breakdown of Structure-Function Relation