Architecture Guided Fluid Propulsion in a Simulated Nephron

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Introduction

- Computational fluid dynamics (CFD) allows engineers to solve problems related to fluid-flow, -velocity, and -shear.
- CFD has successfully been applied to predict plaque rupture in coronary artery disease and for other uses in vascular pathology/physiology.
- We **hypothesize** that the form and function of a human nephron are intrinsically linked and that the Venturi effect results in meaningful changes in fluid velocity within the loop of Henle.

Materials and Methods

- ANSYS SpaceClaim 18.2 software was used to model the loop of Henle
  - Modifications to nephron length and removal of the thin limb are depicted in the figure.
    - Length ratios: 1:4 and 2:1
    - Diameter ratios: 8:3 for thick to thin loop
- ANSYS Fluent 18.2 package used to model particle velocity in a simulated nephron.
  - Laminar flow at 10mm Hg pressure
  - Navier-Stokes equations was used.
  - Rigid body boundary conditions were implemented.

Objectives

To create a CFD representation of a nephron and examine the effect of the changes in:

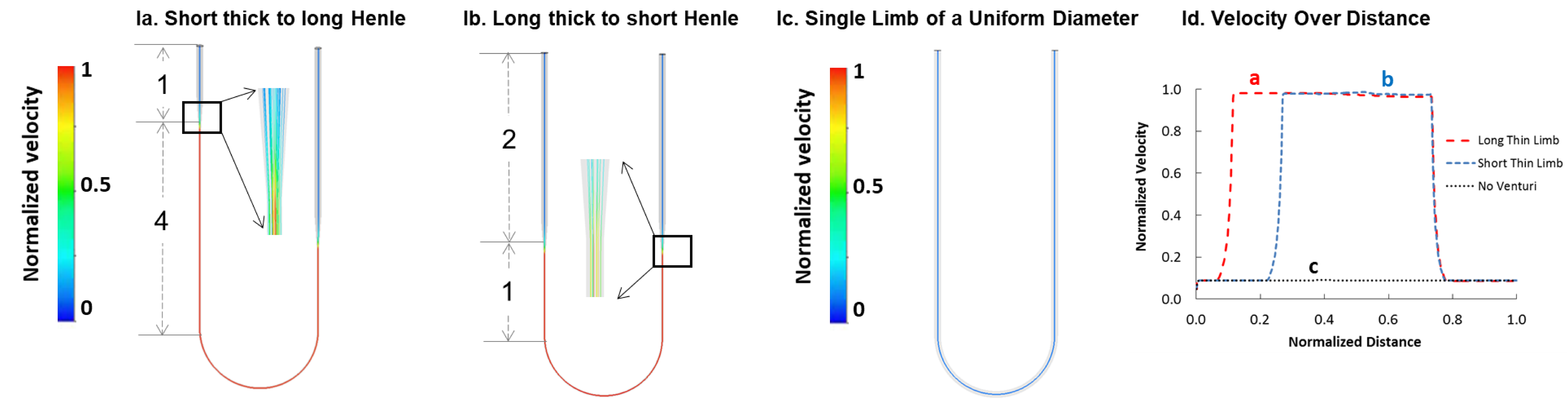
- length and
- the diameter

of the loop of Henle have on fluid flow.

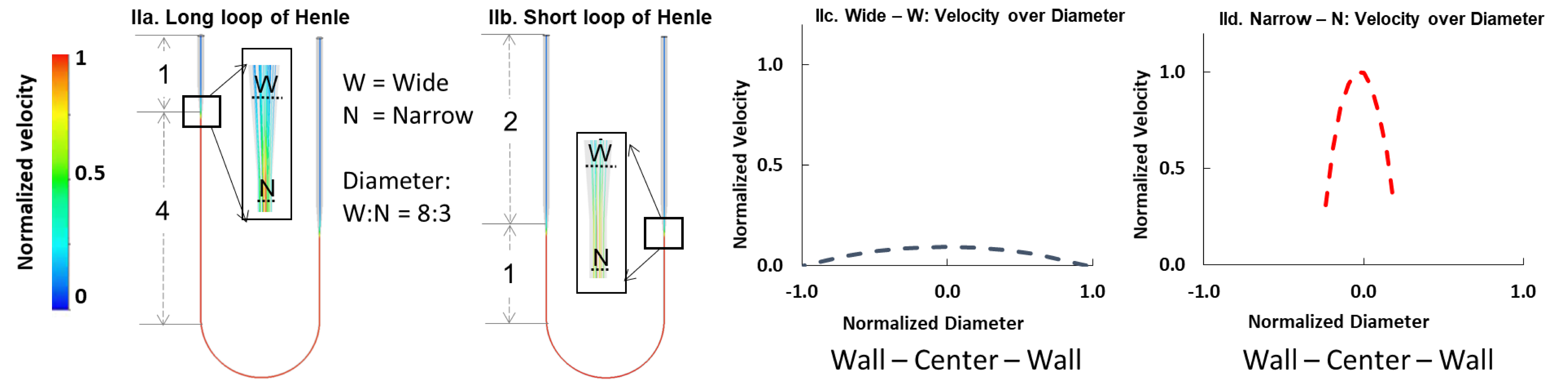
Results

- The presence of a thick to thin transition created a Venturi effect (Figs. Ia, Ib contrasting uniform diameter Fig. Ic).
- This increased particle velocity over 10 fold within the thin limb (Figs. Ia, Ib, Id lines a & b).
- Particles exhibited laminar flow with increased central velocity (Figs. IIc, IId).
- The length of the thin segment did not change maximum velocity, but increased length resulted in particles moving faster for a greater proportion of their transit (Figs. Id a vs. b).

I. THE VENTURI EFFECT AND CHANGES IN LENGTH OF THE THIN LIMB OF THE LOOP OF HENLE



II. VELOCITY PROFILES IN THE THICK AND THIN LIMBS OF THE LOOP OF HENLE



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Conclusions

- Form and function of the nephron are intimately linked.
- Variations in nephron diameter, particularly at the junction of thin and thick limbs of the loop of Henle, may alter flow dynamics in the human papilla.
- The thick to thin limb transition is a critical architectural component resulting in enhanced fluid transit.
- Architecture guided microfluidics is relevant to pathologic processes causing particulate deposition and subsequently Randall's plaque formation.