Computational Analysis of Altered Hemodynamics in Iliac Vein Compression Syndrome

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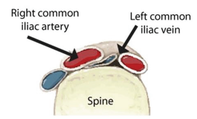
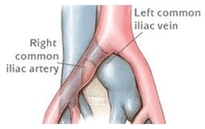
Introduction

Background

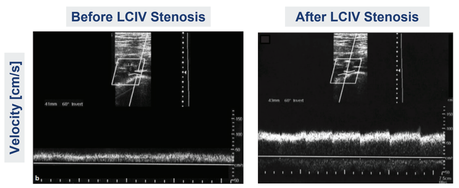
Iliac Vein Compression Syndrome (IVCS)

- Formerly known as May-Thurner Syndrome
- Anatomical variant in which the **right common iliac artery compresses the left common iliac vein** (LCIV) against the lumbar spine.
- Present in over 20% of the population. [1]
- Associated with increased risk of Deep Vein Thrombosis (DVT). [2]





O. B. Zhukov, *ESR*, 2018.

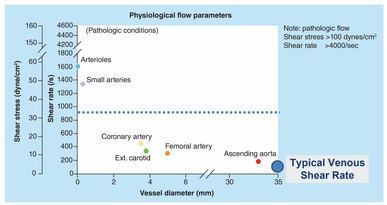


L. Oğuzkurt, *Diagn Interv Radiol*, 2007.

In IVCS, the narrowing increases LCIV velocity by as much as 10x. [3]

Shear Activation of Platelets

- High velocities in narrow vessels leads to high shear rates.
- High shear rates unravel von Willebrand protein and enable platelet adherence via the glycoprotein Ib receptor. [4]
- Shear activation of platelets begins to occur around **1000 s^{-1}**. [5]
- Thrombus initiation via platelet shear activation is typically thought to only occur in the arteries.



K.S. Sakariassen, *Future Sci. OA*, 2015.

$$\dot{\gamma} = \nabla u$$

$\dot{\gamma}$ = shear rate
u = velocity

Hypothesis

Elevated shear rates in IVCS patients trigger platelet activation and thus initiates thrombus formation.

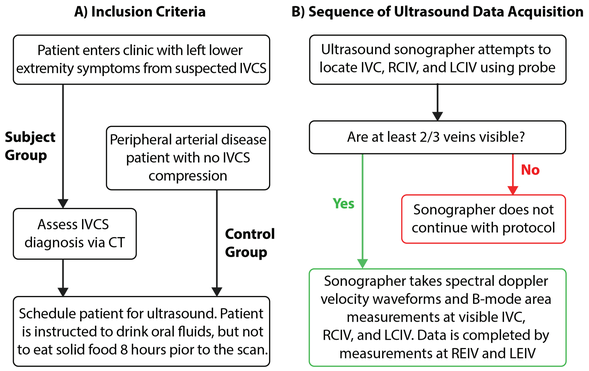
Approach

- We employed the simulation framework CRIMSON: a multi-scale modeling software that combines a 3D geometric model, inflow waveform boundary conditions, and Windkessel models to evaluate IVCS hemodynamics.

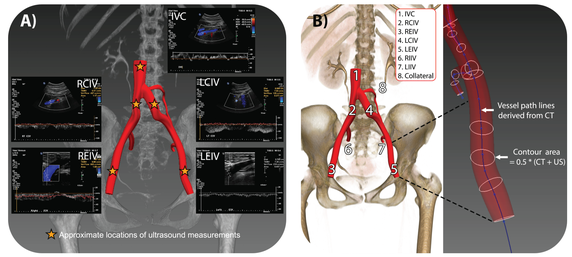
- Patient-specific models were informed by retrospective CT data and duplex ultrasound measurements (IRB-HUM00212189) of the Inferior Vena Cava (IVC), Left/Right Common Iliac Veins (LCIV/RCIV), and Left/Right External Iliac Veins (LEIV/REIV).

Methods

Ultrasound Protocol



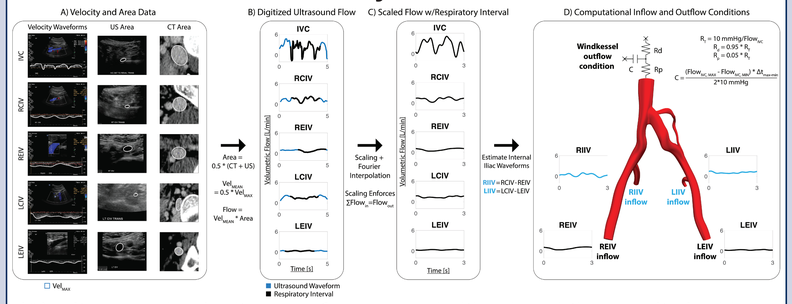
Clinical Data



(A) Target locations for ultrasound measurements.

(B) CT-derived path lines and contours. Contour area is adjusted to reflect confidence level in CT and ultrasound measurements.

Inflow and Outflow Boundary Conditions



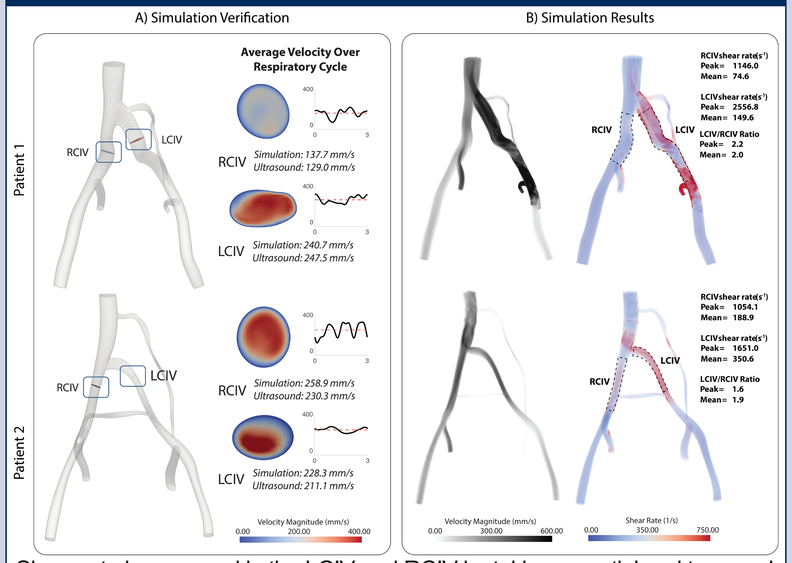
(A) Ultrasound velocity waveforms are digitized and then multiplied by a weighted area of the US and CT data to create flow waveforms.

(B) The ultrasound waveforms are scaled to enforce conservation of flow. A representative respiratory interval is selected on the waveforms.

(C) Internal iliac waveforms are estimated through subtraction of the external iliac waveforms from the common iliac flow waveforms.

(D) Flow waveforms are applied as inflow conditions to the model. A Windkessel lumped parameter is applied as the outflow condition.

Results



Shear rate is assessed in the LCIV and RCIV by taking a spatial and temporal average across the vessels. The average (n=2) LCIV/RCIV ratios are 1.9 for mean and 1.8 for peak shear rates. In both patients, **peak shear rate in the LCIV at the point of the compression is greater than 1000 s^{-1}**, indicating that shear activation of platelets may be a thrombotic mechanism in IVCS patients.

Conclusions

- We created a protocol to obtain hemodynamic measurements of the inferior vena cava and iliac veins from ultrasound, create patient-specific 3D reconstructions of the venous anatomy using CT and ultrasound, and compute shear rates using calibrated CFD methods.

- Preliminary results have indicated that IVCS patients experience elevated shear rates. Further studies are needed to assess the relationship between venous compression and shear rate in IVCS patients and a control population.

References

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[4] Ruggeri, ZM et al., *Thromb Res*, 2007; 120(1):1–10.
[5] Sakariassen, KS et al., *Futur Sci OA*, 2015; 1(4).

Acknowledgements

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