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An Ultrasound Imaging & Computational Fluid Dynamic Protocol to Assess Hemodynamics in Iliac Vein Compression Syndrome

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@BloodFlowSim

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COLLEGE OF ENGINEERING & MEDICAL SCHOOL
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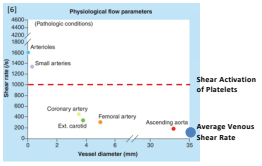
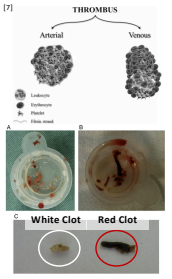
Disclosures

- Founder & Chief Science Office, AngioInsight, Inc.
- Consultant, Edwards Lifesciences.

Arterial vs Venous Thrombosis

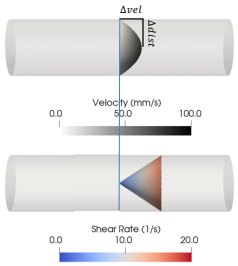
- **Arterial thrombosis** (white clots) is thought to occur due to elevated **shear rates** [5]
  - Shear rate mechanically activates platelets around **1000 s⁻¹** [6]
- **Venous thrombi** (red clots) is thought to occur due to blood stasis and low shear rates





[5] Ruggeri ZM et al., Thromb Res, 2007
[6] Sakariassen KS et al., Futur Sci OA, 2015
[7] Quadros AS et al., American Heart J, 2012

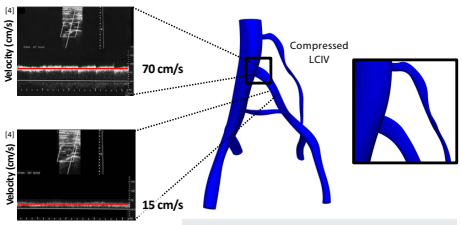
What is a Shear Rate?



$$Shear\ Rate = \frac{\Delta velocity}{\Delta distance}$$

Shear rate
- **largest at the wall** (red)
- **lowest in the middle** (blue)

Elevated LCIV Velocity Observed in IVCS Patients



Oğuzkurt L, *Diagn Interv Radiol*, 2007

Elevated velocity in a narrowed vessel
↓
Elevated shear rates

Hypothesis

Patients with IVCS have **greater iliac vein shear rates** than healthy patients, which may **increase their risk for thrombosis**

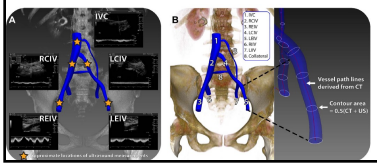
Methods

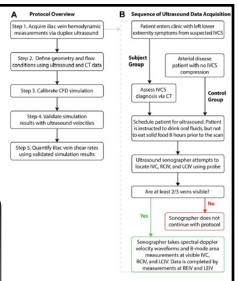
Clinical Data (IRB-HUM00212189)

Subjects: IVCS & DVT/lower extremity venous symptoms

Controls: no IVCS or DVT

Retrospective CT/MR & prospective ultrasound (US)
- Target locations ★ for ultrasound measurements
- Anatomical iliac vein model derived from CT or MR





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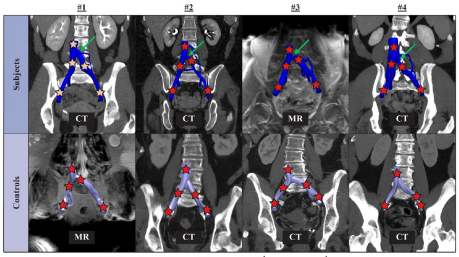
Clinical Data (IRB-HUM00212189)



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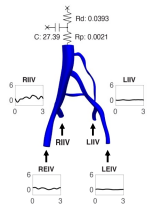
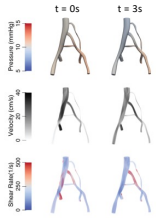
Computational Fluid Dynamics (CFD) Simulations



Input: inflow waveforms & IVC Windkessel model informed by clinical data [8]

Assi IZ et al., *JVSVI* 2023



Output: 3D-dynamic pressure, velocity, & shear rate

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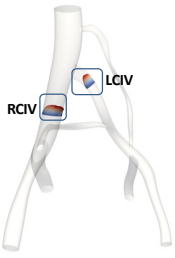
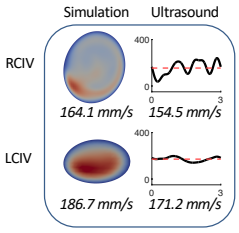
Simulation Validation Against Ultrasound Velocity



Average Velocity Over Respiratory Cycle



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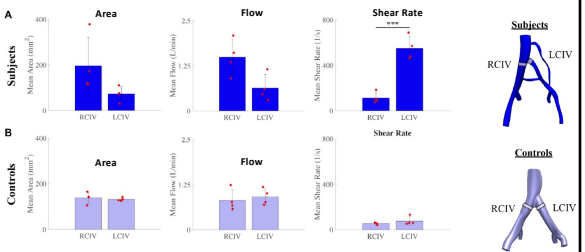
RCIV vs LCIV Statistical Analysis

Assi IZ et al., *Frontiers Bioeng & Biotech* 2024



Control have **no statistically significant differences** between RCIV and LCIV

Subjects have **large differences in shear rate** between RCIV & compressed LCIV

***p < 0.05, **p < 0.01, ***p < 0.001 (n = 4, 4)**

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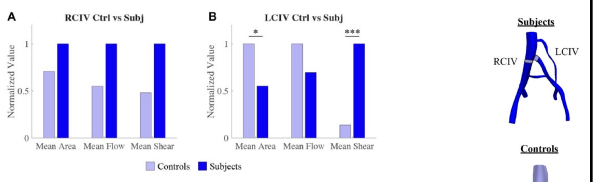
Controls vs Subjects Statistical Analysis



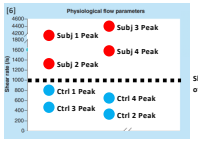
No differences in RCIV

Subject LCIV has **differences in area and peak shear**

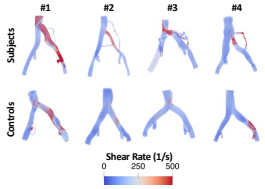
***p < 0.05, **p < 0.01, ***p < 0.001 (n = 4, 4)**

Take Home Messages

- Control patients **do not have significant hemodynamic differences** between the RCIV and LCIV
- IVCS patients **experience larger shear rates** than controls
- Mechanical activation of platelets through shear may **explain the permissive role of IVCS in thrombus formation**



Shear Activation of Platelets



[6] Sakariassen KS et al., Futur Sci OA, 2015

Ongoing Prospective Study

Goal: can we use ultrasound to risk stratify May-Thurner patients?

Study Overview

Methodology: evaluate whether demographics, traditional ultrasound metrics (velocity, diameter), or derived ultrasound metrics (% stenosis, flow, shear rate, ratios) are best to predict adverse events

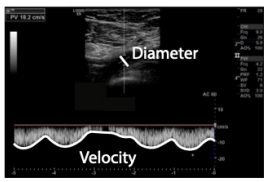
Adverse Events

1. DVT

Ultrasound measurement locations

- IVC
- LCIV at compression
- LCIV distal to compression
- RCIV
- LEIV
- REIV

Ultrasound-derived metrics



$$Flow = velocity * \pi * \left(\frac{diameter}{2}\right)^2$$

$$Shear\ Rate = \frac{2 * velocity}{diameter}$$

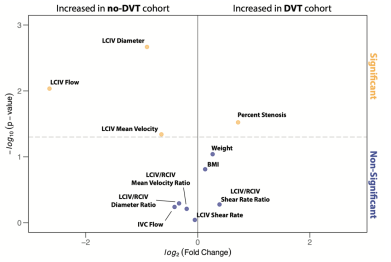
Cohort & US-derived metrics

Demographics	
Participants	30
Age (years)	38.8 ± 11.4
BMI (kg/m2)	23.5 ± 5.3
Sex	
Female	23 (76.7)
Male	7 (23.3)
Race	
White	27 (90)
Black	1 (3.3)
Other	2 (6.7)
Comorbidities	
Smoking Hx	7 (23.3)
Pregnancy Hx	20 (66.7)
Currently Postpartum	4 (13.3)
Coagulopathy	1 (3.3)
Oral Contraceptive Use	4 (13.3)
Hypertension	4 (13.3)
Adverse Events	
DVT	6 (20)
Leg Swelling	10 (33.3)
Venous Ulcer	1 (3.3)
PE	3 (10)
Any Event	12 (40)

Vessel	Mean Velocity (cm/s)	Peak Velocity (cm/s)	Diameter (cm)	Flow (L/min)	Shear Rate (1/s)
IVC	12.8 ± 7.6	39.6 ± 23.0	1.2 ± 0.4	1.0 ± 0.9	11.8 ± 7.0
LCIV compressed	13.3 ± 7.6	39.5 ± 19.9	0.5 ± 0.3	0.2 ± 0.3	32.6 ± 26.3
LCIV distal	9.9 ± 5.0	28.4 ± 12.8	0.9 ± 0.4	0.4 ± 0.4	13.6 ± 10.3
RCIV	8.7 ± 4.3	26.2 ± 13.0	1.0 ± 0.4	0.5 ± 0.6	10.1 ± 6.8
LEIV	7.7 ± 3.4	24.6 ± 15.1	1.0 ± 0.3	0.3 ± 0.2	8.7 ± 7.0
REIV	11.6 ± 14.4	34.9 ± 35.9	0.8 ± 0.3	0.4 ± 0.4	15.4 ± 19.0

Derived Metrics	
Stenosis (%)	39.8 ± 22.9
Contralateral Velocity Ratio	1.7 ± 1.0
Ipsilateral Velocity Ratio	1.7 ± 1.4
Contralateral Diameter Ratio	0.6 ± 0.3
Ipsilateral Diameter Ratio	0.6 ± 0.2
Contralateral Shear Rate Ratio	3.9 ± 3.5
Ipsilateral Shear Rate Ratio	3.8 ± 4.9

Univariable Statistics for DVT Outcome



Acknowledgements

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