

Investigating cerebral blood flow and arterial transit time as baseline measures for cerebrovascular reactivity in individual watershed areas

Gabriel Hoffmann^{1,2}, Lena Schmitzer^{1,2}, Franziska Richter¹, Matthias JP van Osch^{3,4}, Lena Václav³, Jan Kufer¹, Jannis Bodden¹, Jens Göttler¹, Claus Zimmer^{1,2}, Stephan Kaczmarz^{1,2,5}, Christine Preibisch^{1,2,6}

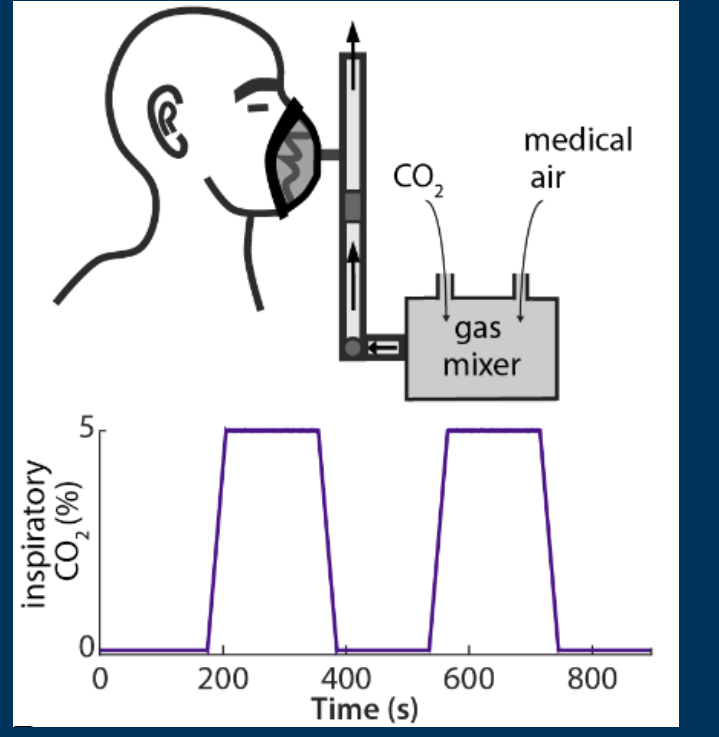
¹Technical University of Munich, School of Medicine, Institute of Neuroradiology, TUM University Hospital, Munich, Germany; ²Technical University of Munich, School of Medicine and Health, TUM-Neuroimaging Center, Munich, Germany; ³C.J. Gorter MRI Center, Department of Radiology, Leiden University Medical Center, Leiden, The Netherlands; ⁴Leiden Institute of Brain and Cognition, Leiden University, Leiden, The Netherlands; ⁵Philips Research, Hamburg, Germany; ⁶Technical University of Munich, School of Medicine and Health, Clinic of Neurology, TUM University Hospital, Munich, Germany

Purpose:

- CVR is a promising in internal carotid artery stenosis (ICAS) ^{1,2}
- **Watershed Areas**, at the junction of cerebral vascular territories, are of particular interest³⁻⁵
- CVR is usually measured using CO₂ → sophisticated gas application setup limits applicability

Aim:

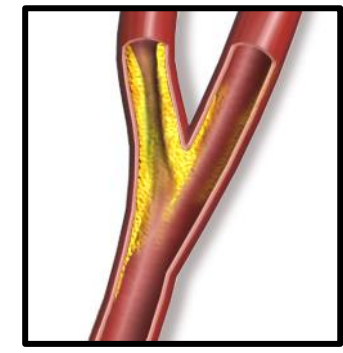
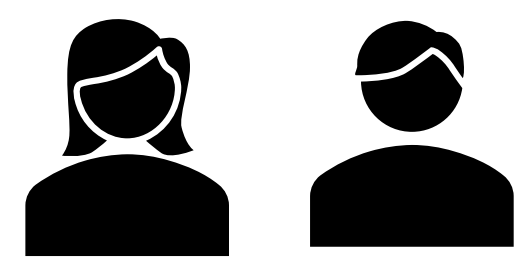
- Evaluate if baseline measures (ATT and CBF) correlate with CVR in iWSA and indicate hemodynamic alterations within ICAS patients'



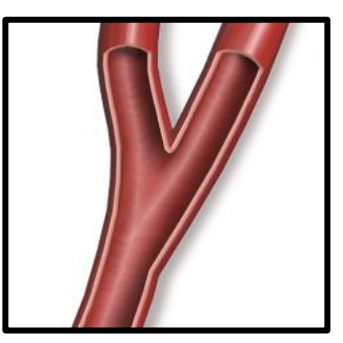
Methods:



3T Philips MRI:
Ingenia Elition X



- n = 6 (2 female)
- Age: 71.7 ± 8.8 years
- NASCET ≥ 60%



- n = 20 (12 female)
- Age: 69.2 ± 5.8 years

Data Acquisition

Analysis

Baseline mapping

M₀

3D GRASE, 3.75x3.75x3.75 mm³, TE=16 ms, TR=2000 ms, 29 slices, SENSE = 2.9, 0:12 min

Hadamard 8-pCASL

3D GRASE, 3.75x3.75x3.75 mm³, TE=16 ms, TR=4683 ms, 29 slices, PLD₁ = 2000ms, PLD₂ = 1400ms, PLD₃ = 1000ms, PLD₄ = 700ms, PLD₅ = 500ms, PLD₆ = 350 ms, PLD₇=200ms, 3 dyn., 5:37 min

CBF

ATT

iWSA

CVR vs CBF&ATT

CVR

GE-EPI

2D mb EPI, 3.0x3.0x3.0 mm³ TE=30 ms, TR=1200 ms, 40 slices, α=70°, 750 dyn., 15:04 min

CO₂ [%]

AIR 3 min CO₂ 3 min AIR 3 min CO₂ 3 min AIR 3 min

time

CVR

$$LI_P = \frac{P_R}{P_R + P_L}$$

P ∈ {CVR, CBF, ATT}

Structural

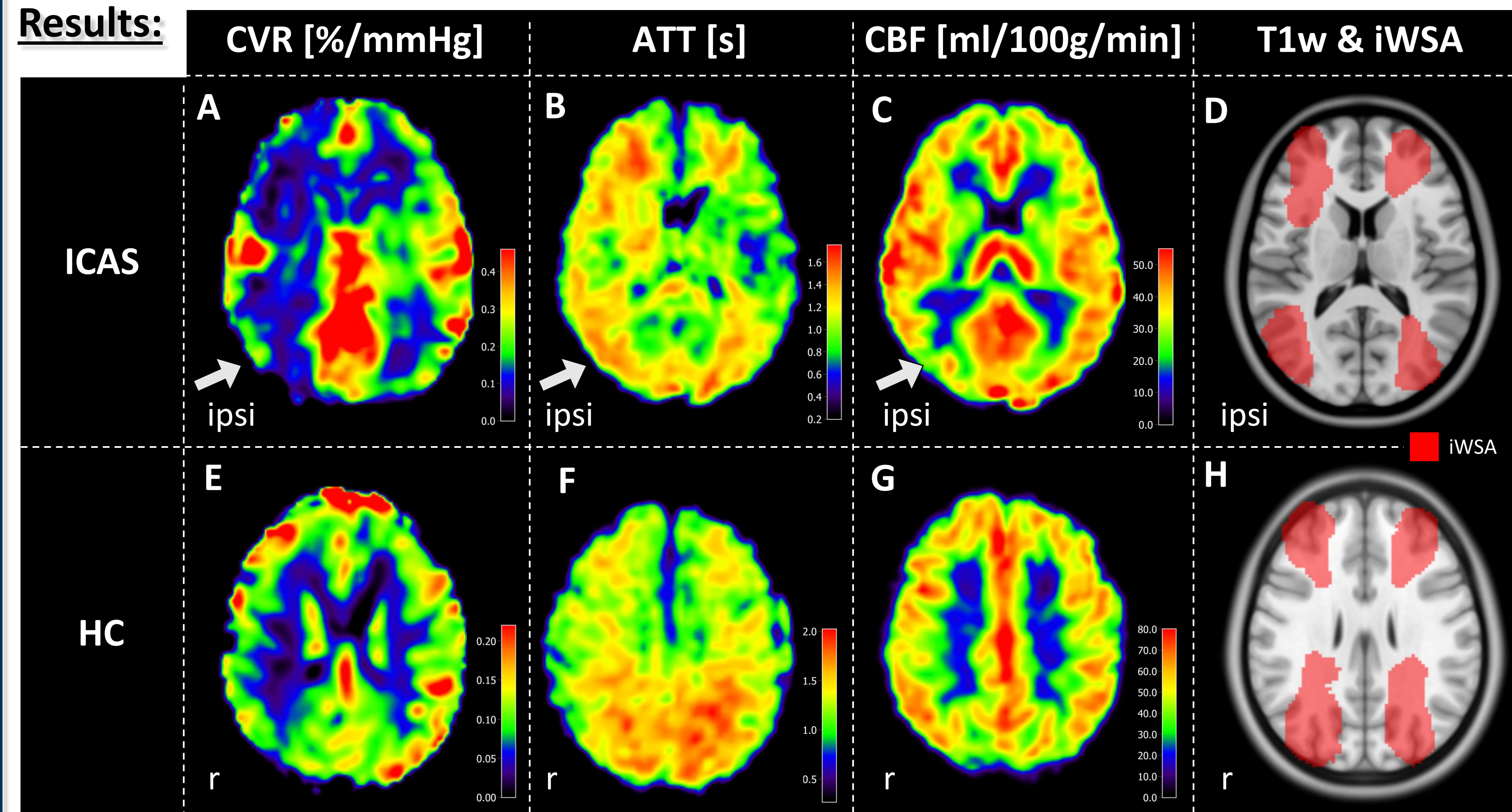
MPR

1x1x1 mm³, CS-Sense = 7.5, TE=4 ms, TR=9 ms, α=8, TI=761 ms, 2:25 min

Abbreviations

ATT: Arterial Transit Time
CBF: Cerebral Blood Flow
CVR: Cerebro-Vascular Reactivity
HC: Healthy Control
ICAS: Internal Carotid Artery Stenosis
pCASL: pseudocontinuous Arterial Spin Labeling
iWSA: individual Watershed Areas

Results:

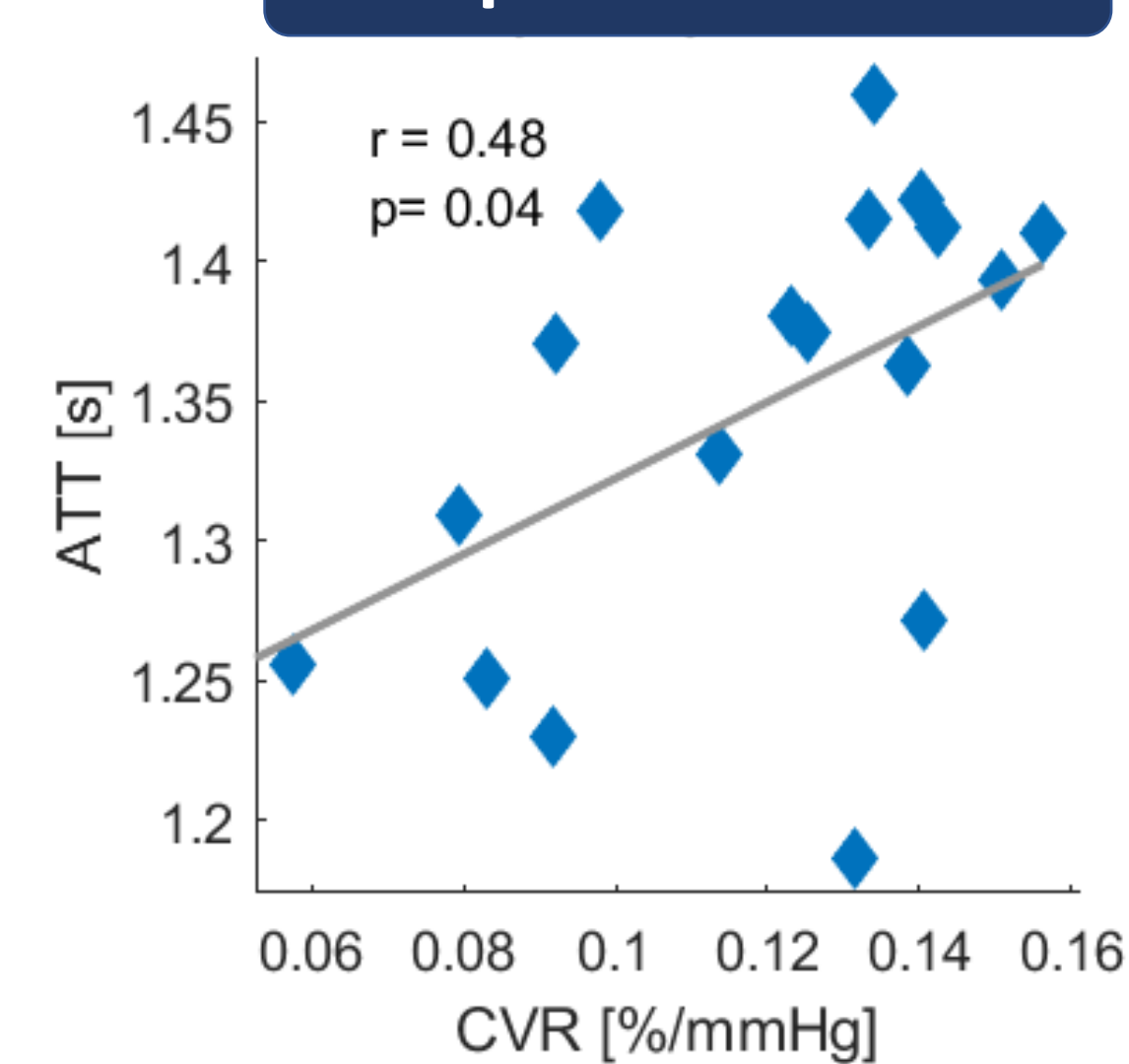


- Ipsilateral (ICAS): reduced CVR (A), increased ATT (B) and reduced CBF (C)
- HC (E-G): all parameter maps appear symmetrical

Discussion:

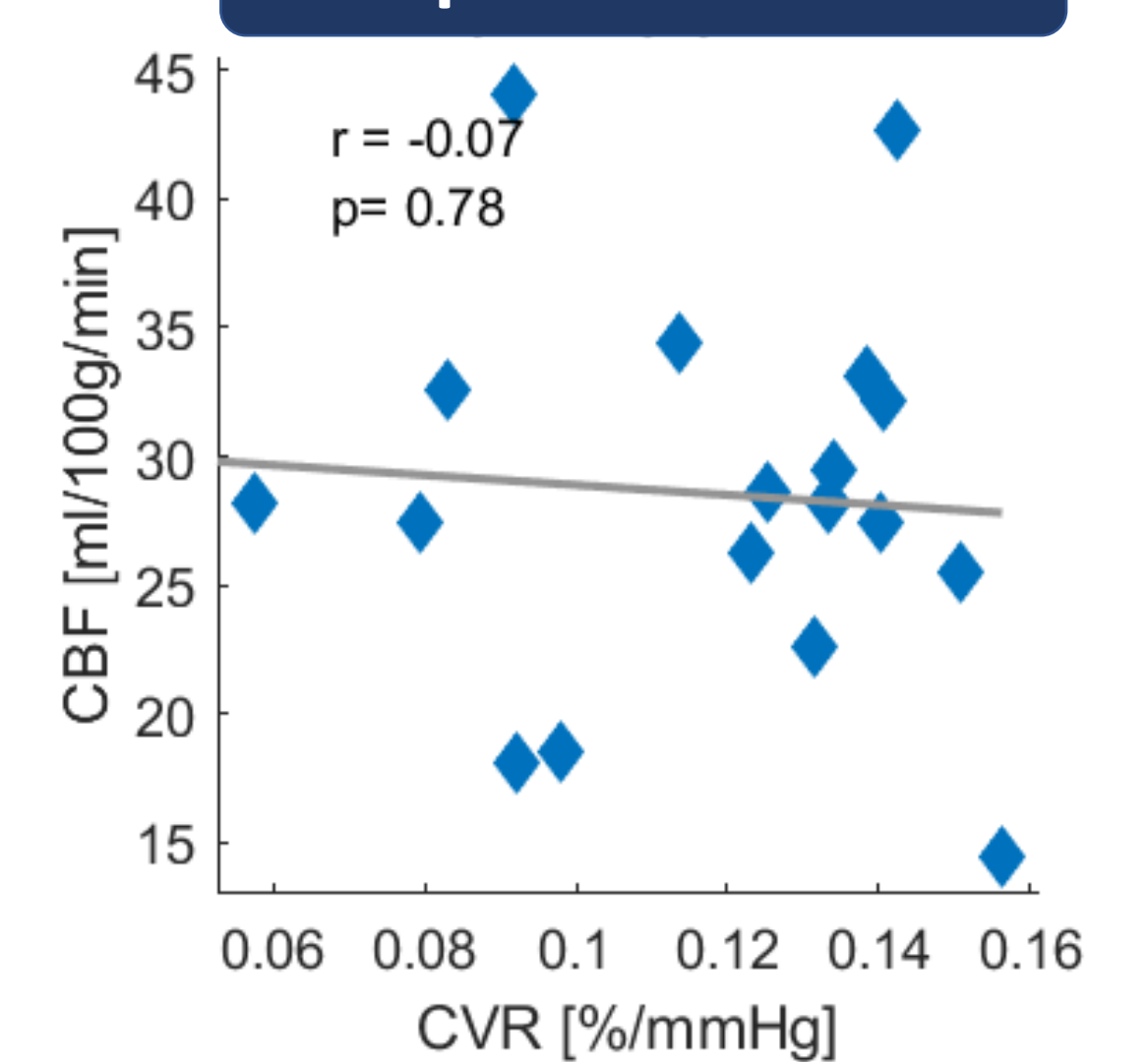
- All parameters (including CBF) showed significant lateralization for ICAS compared to HCs
- Agrees very well with previous studies demonstrating ipsilaterally impaired hemodynamics^{1,2,6}
- Importantly, baseline measures concorded within iWSAs, which are especially prone to hemodynamic impairments^{2,4}

A | CVR vs ATT



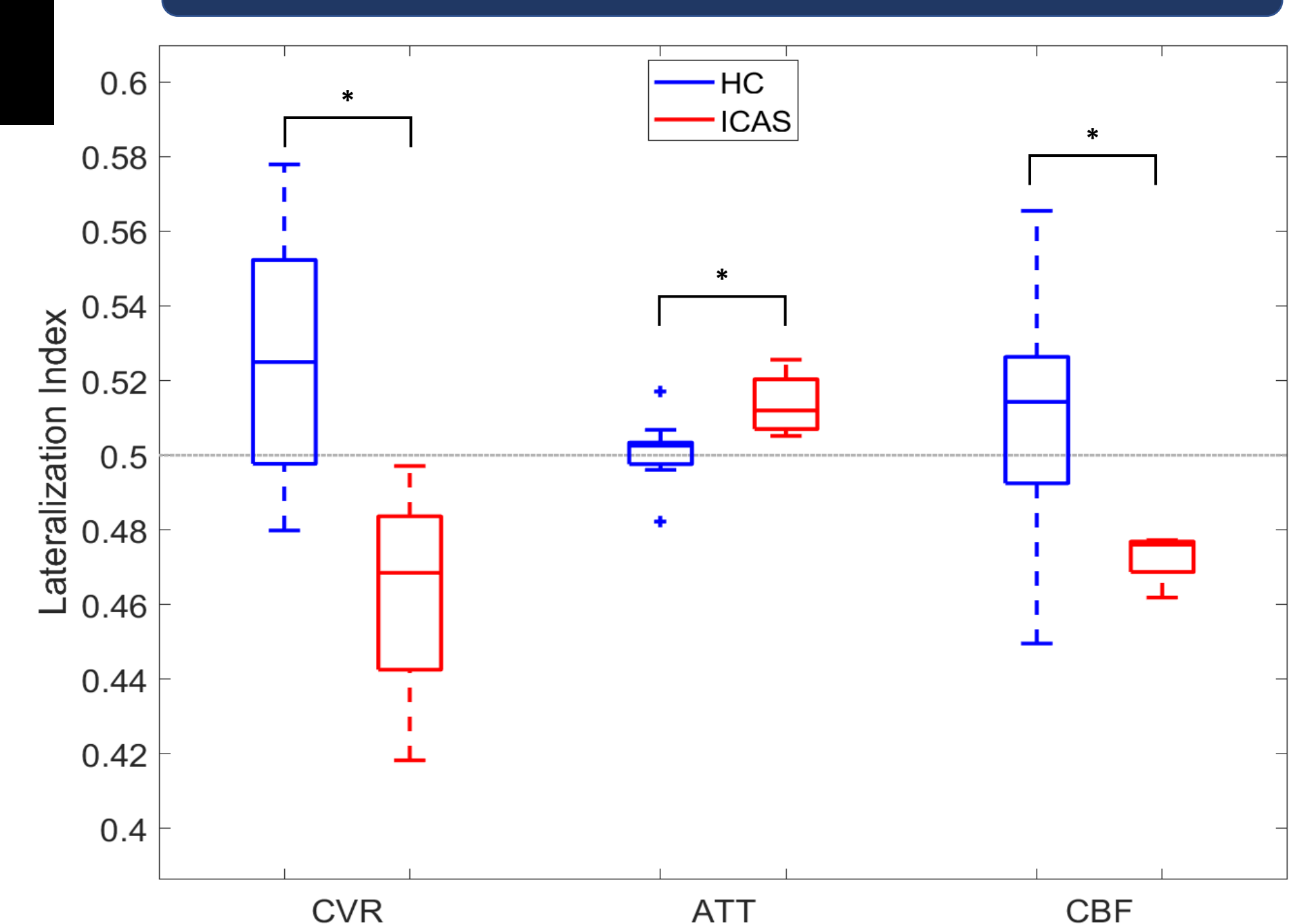
- Correlation between CVR and ATT (A, all subjects)

B | CVR vs CBF



- No correlation between CVR and CBF (B, all subjects)

Lateralization: ICAS vs HC



- Lateralization for ICAS
- LI from CVR decreased
- LI from ATT increased
- LI from CBF decreased

Conclusions:

- Impaired hemodynamics in ICAS in baseline measures of ATT and CBF in agreement with hypercapnia-based CVR
- ATT may be an especially sensitive proxy for CVR in settings where hypercapnia application is not feasible

References:

- 1: Donahue et al., *Consensus statement on current and emerging methods for the diagnosis and evaluation of cerebrovascular disease*, JCBFM, 2018
- 2: Kaczmarz et al., *Hemodynamic impairments within individual watershed areas in asymptomatic carotid artery stenosis by multimodal MRI*, JCBFM, 2021
- 3: Momjian-Mayor et al., *The pathophysiology of watershed infarction in internal carotid artery disease: review of cerebral perfusion studies*, Stroke, 2005
- 4: Kaczmarz et al., *Increased variability of watershed areas in patients with high-grade carotid stenosis*, Neuroradiology, 2018
- 5: van Laar, *Symptomatic carotid artery occlusion: flow territories of major brain-feeding arteries*, Radiology, 2007
- 6: Göttler, *The stronger one-sided relative hypoperfusion, the more pronounced ipsilateral spatial attentional bias in patients with asymptomatic carotid stenosis*, JCBFM, 2020

Contact information:

Gabriel Hoffmann
Technical University of Munich
(TUM)
gabriel.hoffmann@tum.de

Acknowledgements:

Ev. Studienwerk Villigst
German Research
Foundation (DFG)