

4D FLOW

Magnetická rezonance

Radka Kočková

**ECHODNY 2026
Olomouc**

REVIEW

Open Access

4D Flow cardiovascular magnetic resonance consensus statement: 2023 update



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ESC

European Society
of Cardiology

European Heart Journal - Cardiovascular Imaging (2022) 23, 154–165
doi:10.1093/ehjci/jeab112

REVIEW

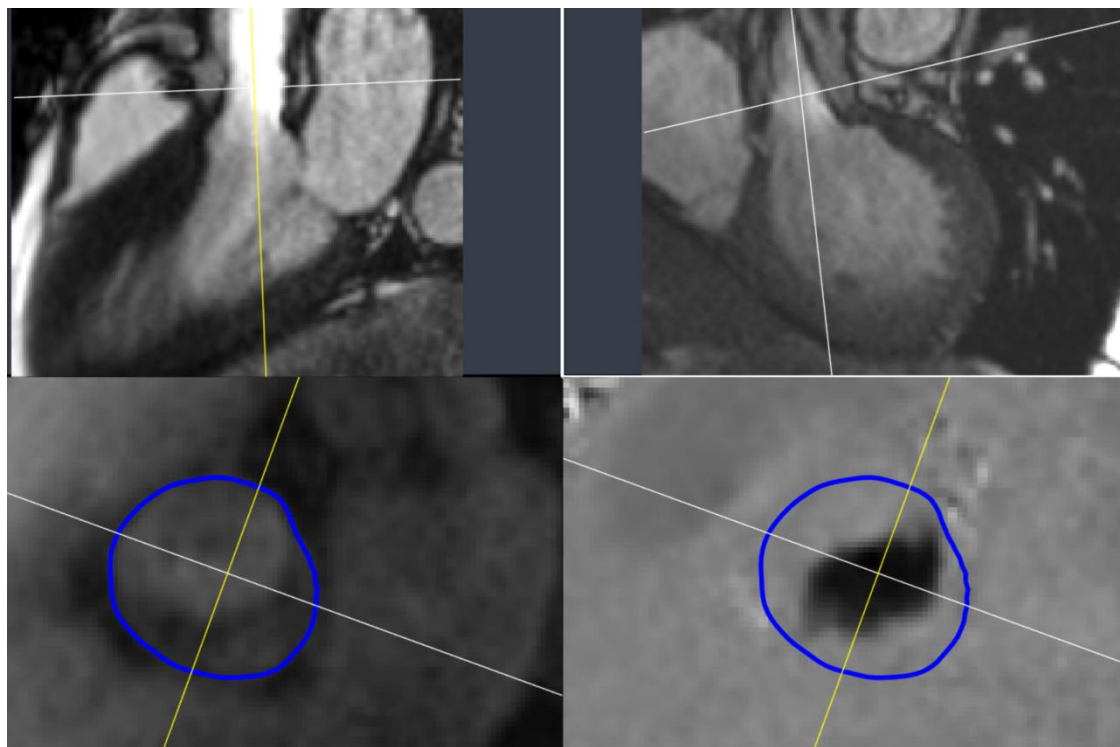
Clinical intra-cardiac 4D flow CMR: acquisition, analysis, and clinical applications

Ahmet Demirkiran ¹, Pim van Ooij², Jos J.M. Westenberg³, Mark B.M. Hofman⁴, Hans C. van Assen³, Linda J. Schoonmade⁵, Usman Asim¹, Carmen P.S. Blanken², Aart J. Nederveen², Albert C. van Rossum¹, and Marco J.W. Götter^{1*}

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Phase contrast velocity mapping

- Strictly perpendicular to blood flow



- In the isocentre of the scanner

Optimal VENC settings

VENC scout

VENG 100



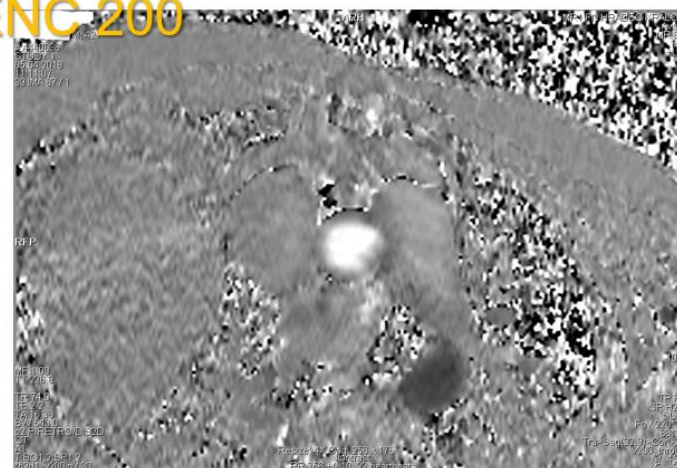
VENC 130



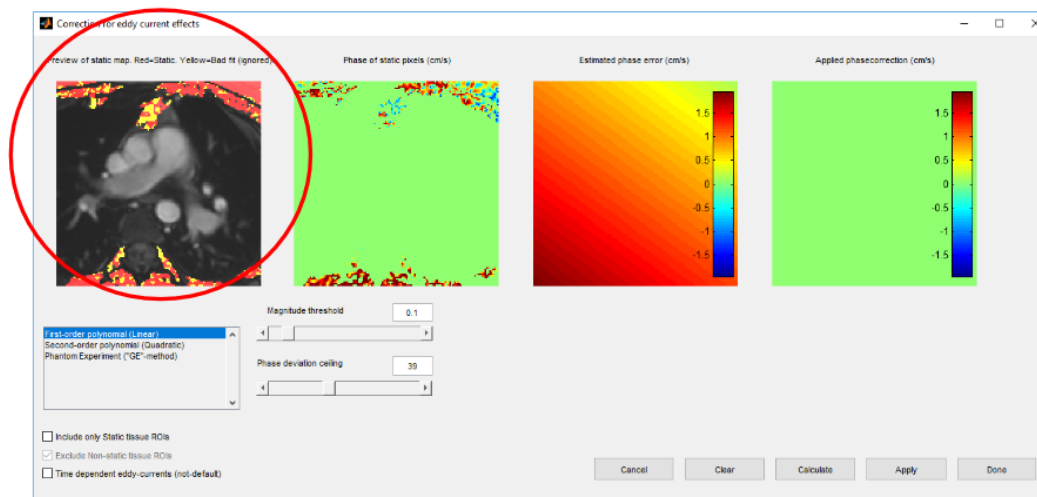
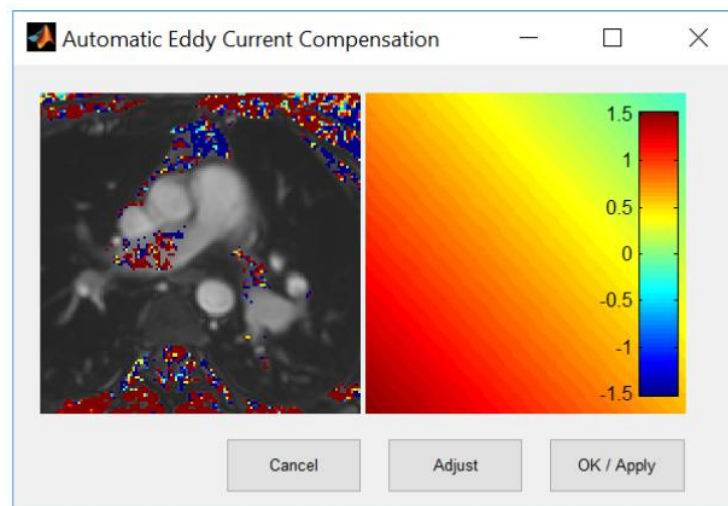
VENC 160



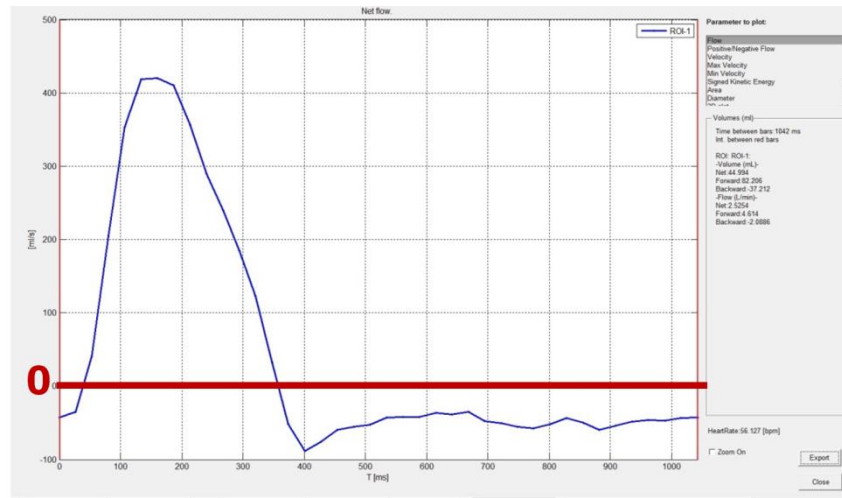
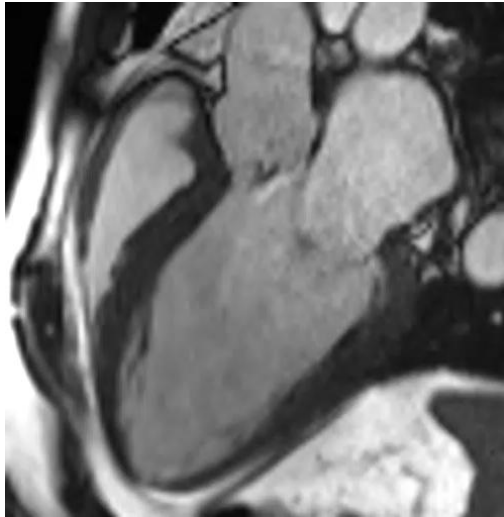
VENC 200



Eddy current compensation post-processing



Aortic valve regurgitation - quantification



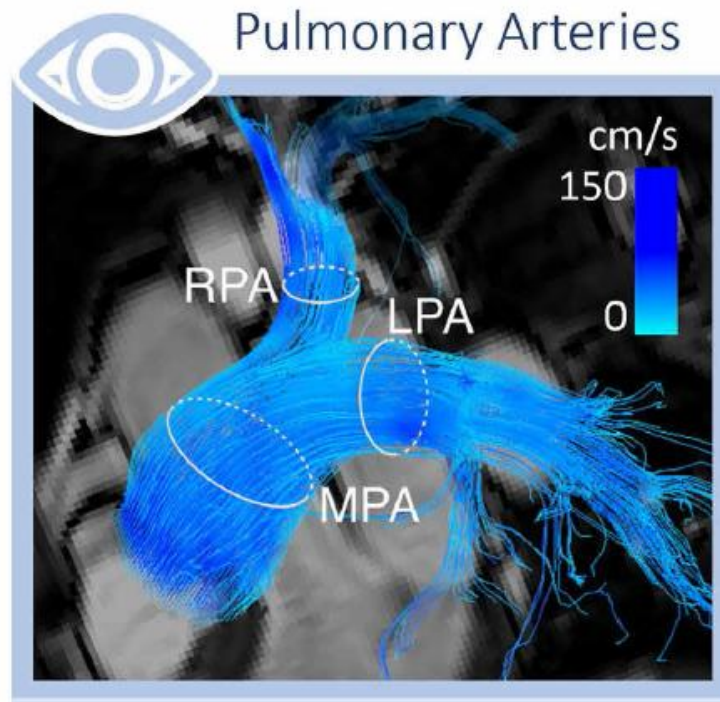
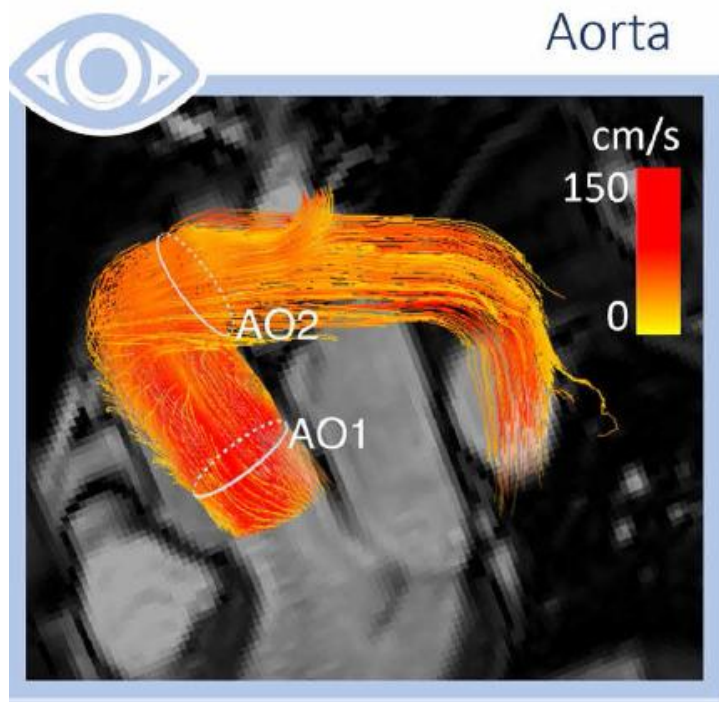
Forward flow 82 ml
Backward flow 37 ml

Forward flow 82 ml = stroke volume SV
Backward flow 37 ml = regurgitant volume RV

RF 43%

4D flow

- 4D flow = 3 D + čas



- 5-10 minut skenovacího času mezi podáním Gad a LGE

Doporučená kvalita zobrazení 4D flow

Table 1 4D flow acquisition parameters for large vessels and whole heart

Acquisition parameter	Aim for	Do not exceed	Reason	Limiting factor
<i>Acquired spatial resolution</i>				
Adults whole heart	2.5 mm ³ [2]	3 mm ³	Accuracy	Scan time
Adults' vessels	2 mm ³	2.5 mm ³	Accuracy	Scan time
Pediatric whole heart	2 mm ³ [53, 79, 82]	2.5 mm ³ [82, 167]	Accuracy	Scan time
Pediatric vessels	1.5 mm ³	2 mm ³	Accuracy	Scan time, VNR
Neonates	0.75–1 mm ³ [54]	1.5 mm ³	Accuracy	Scan time, VNR
Acquired temporal resolution	30 ms	50 ms (can be higher if aiming for visualization only)	Accuracy	Scan time
Velocity encoding limit (VENC)	Maximum expected velocity	10% higher than maximum expected velocity, do not exceed 25%	VNR, to avoid aliasing	Scan time, VNR
ECG gating	Retrospective		Complete ECG cycle included	Reconstruction
Respiratory navigation	Optional		Accuracy	Scan time
Contrast agent	Consider in neonates, dissection patients or other challenging cases		Improved contrast	Contrast administration contraindications
Flip angle	7° non-contrast 12–25° with contrast	25°	SNR	Contrast vs SNR

Doporučená kvalita zobrazení 4D flow

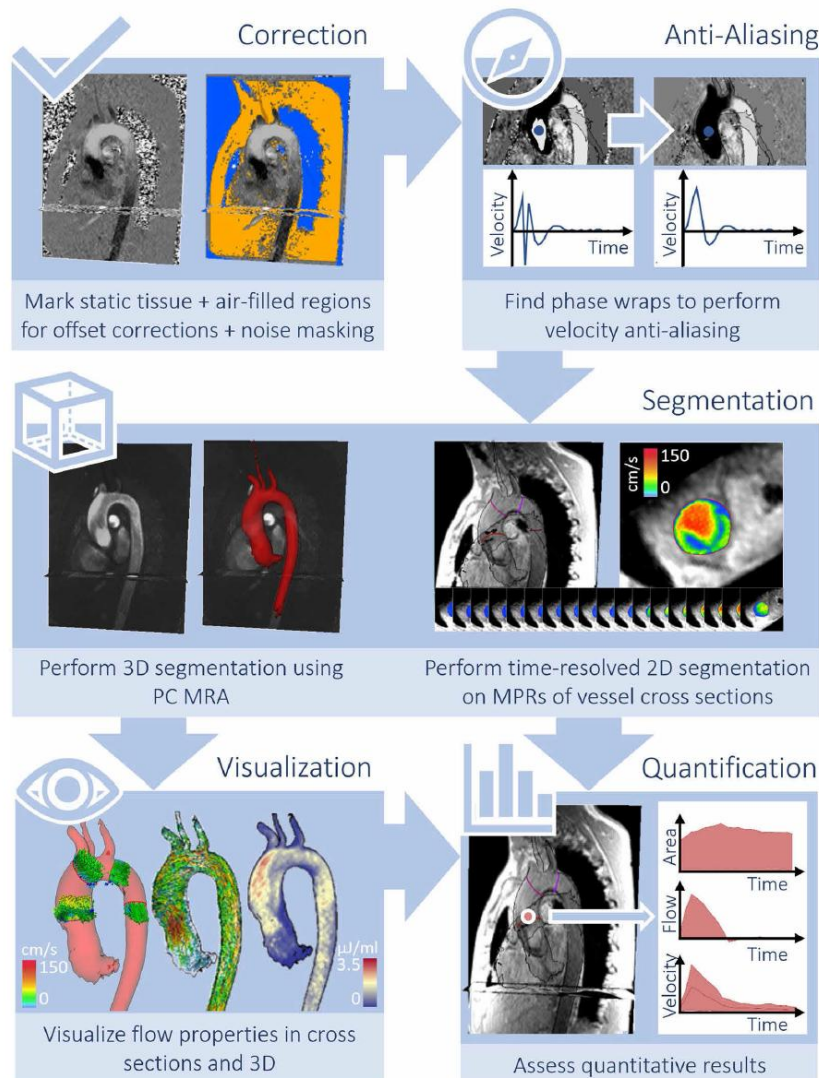
Acquired spatial resolution

Adults whole heart	2.5 mm ³ [2]
Adults' vessels	2 mm ³
Pediatric whole heart	2 mm ³ [53, 79, 82]
Pediatric vessels	1.5 mm ³
Neonates	0.75–1 mm ³ [54]
Acquired temporal resolution	30 ms
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Respiratory navigation	Optional
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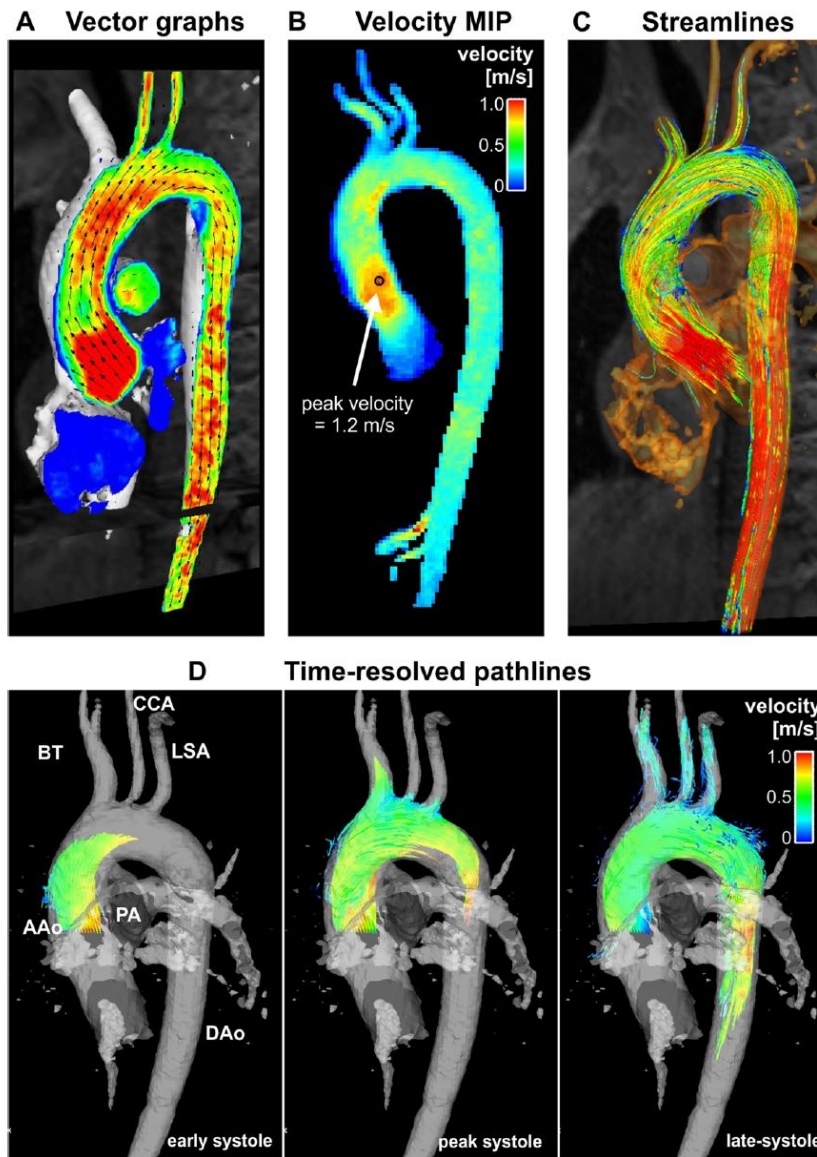
Parameter	Reason	Limiting factor
Heart rate	Accuracy	Scan time
Heart rate	Accuracy	Scan time
Heart rate	Accuracy	Scan time
Heart rate	Accuracy	Scan time, VNR
Heart rate	Accuracy	Scan time, VNR
Heart rate	Accuracy	Scan time
Heart rate	VNR, to avoid aliasing	Scan time, VNR
Heart rate	Complete ECG cycle included	Reconstruction
Heart rate	Accuracy	Scan time
Heart rate	Improved contrast	Contrast administration contraindications
Heart rate	SNR	Contrast vs SNR

Nutné korekce zobrazení

Postprocessing Workflow for 4D Flow CMR



Vizualizace

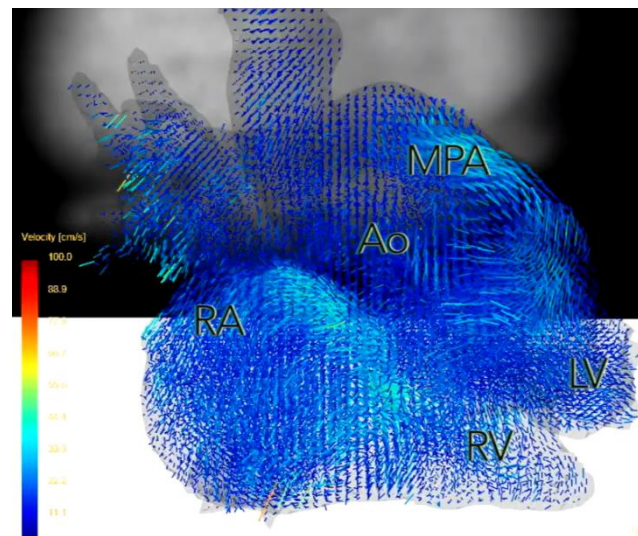


Vizualizace 4D flow

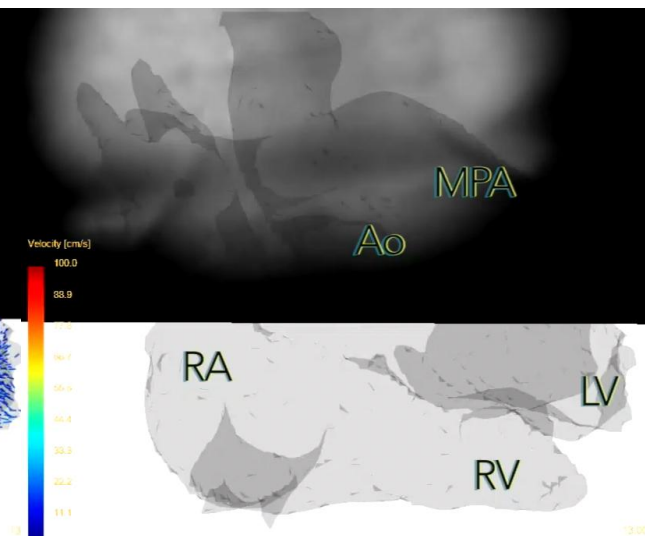
Vektory

Velocity

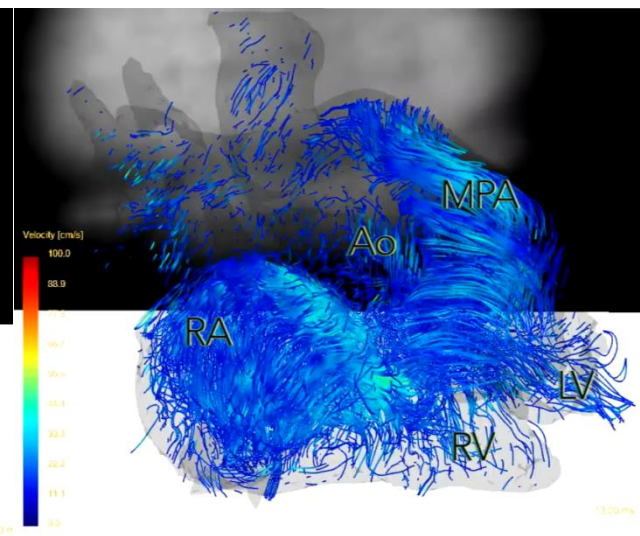
Streamlines



Směr a délka/barva
Pro srdce nepřehledné

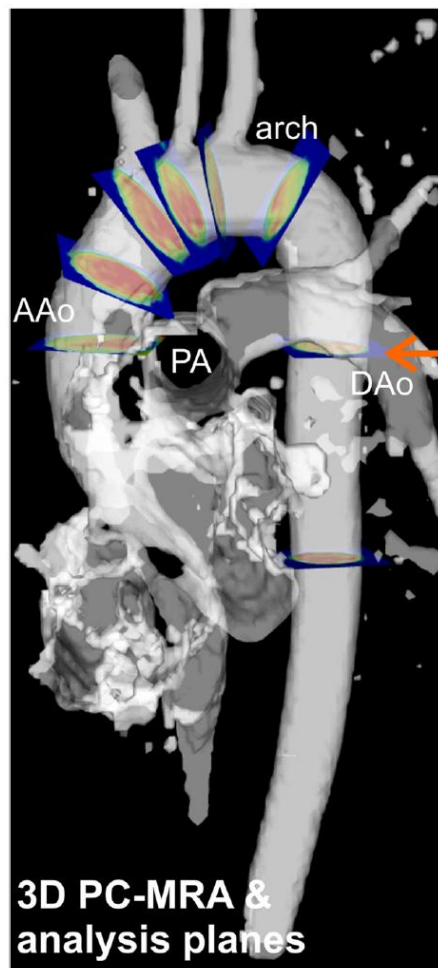


Pathlines/trajektorie
Komplexní pohyb tok v srdci
(přitéká/odtéká/zůstává)

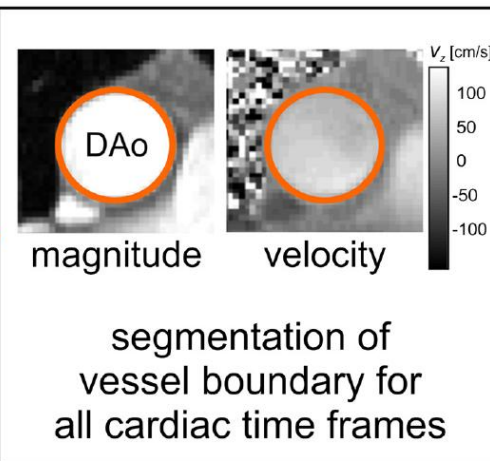


V jednom časovém
úseku
Helikální/Vířivý tok

Kvantifikace rychlostí/toku v ROI



flow quantification vessel contour



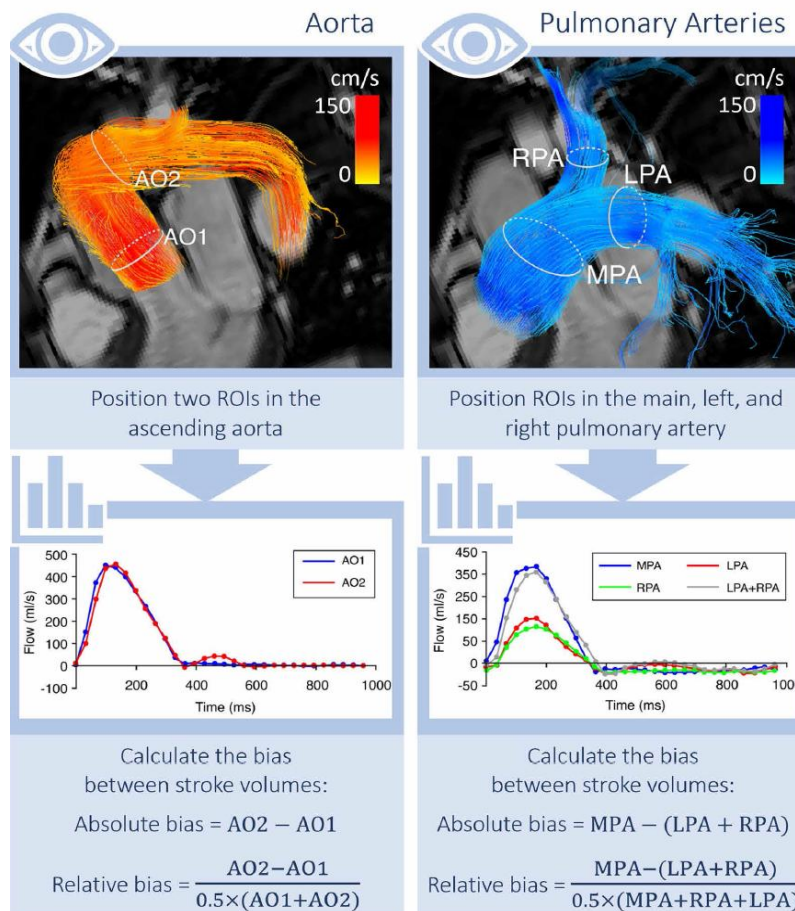
plane-wise analysis

- peak velocity (m/s)
- net flow (ml/cycle)
- regurgitation (%)

Kvantifikace rychlostí/toku v ROI

Kontrola kvality

Quality Control: Conservation of Mass Analysis



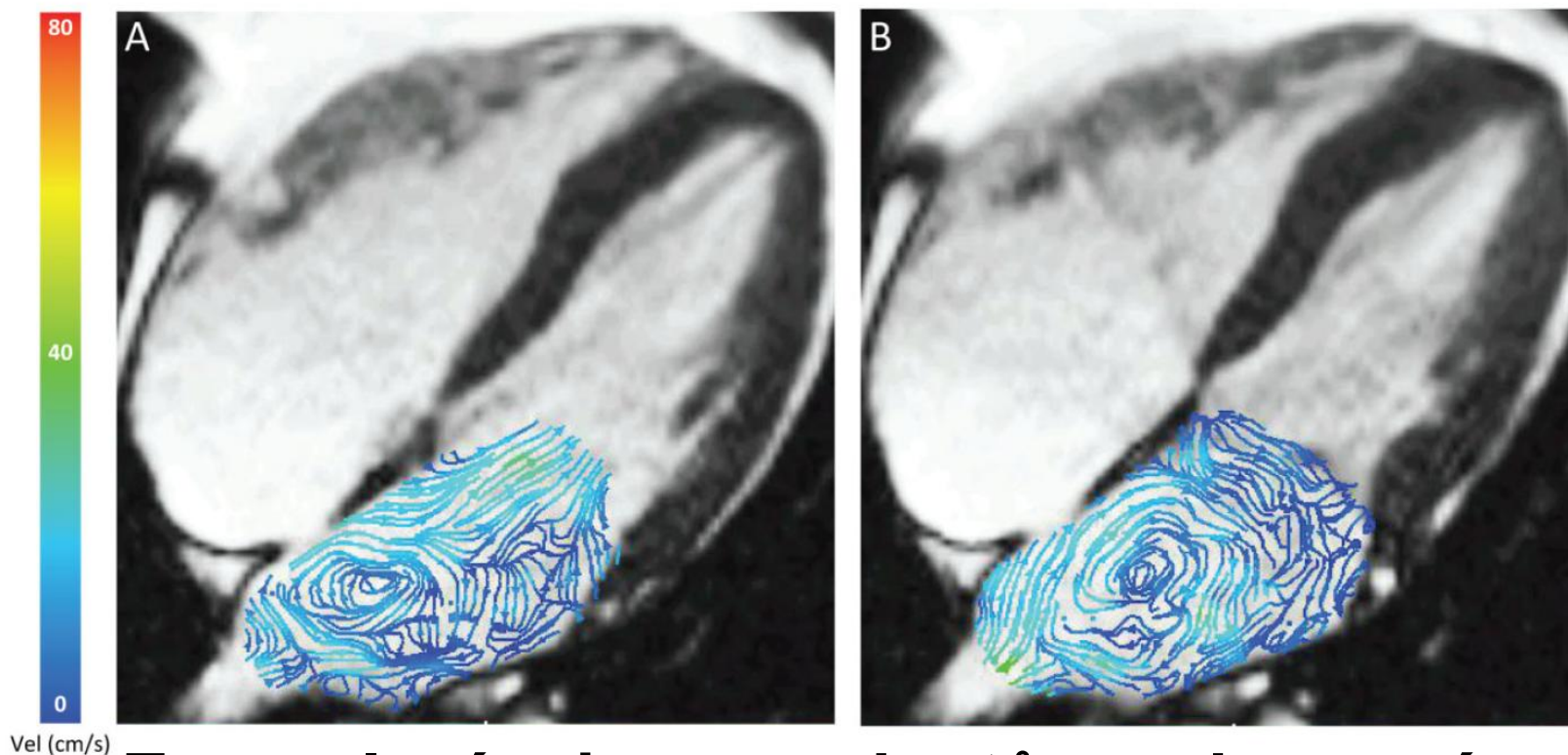
Klinické indikace

- **Aorta – hemodynamika, wall shear stress
aortic stiffness, pulse wave velocity,
falešné lumen**
- **Vrozené srdeční vady**
- **Chlopenní vady**
- **Funkce komory**

Tok v levé síni

Diastole

Systole



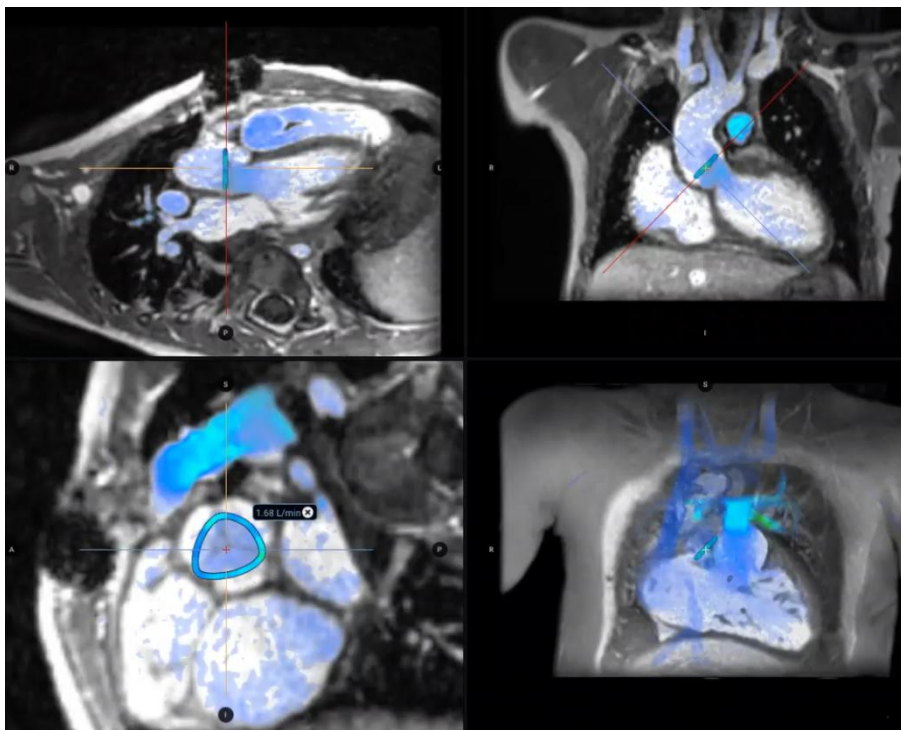
**Zpomalení toku u pacientů se sinusovým
rytmem a anamnézou parox. FIS**

Chlopenní vady

Aortální stenóza:

4D flow měří vyšší rychlosti než 2D flow

U pacientů s excetrickým jetem také vyšší než ECHO

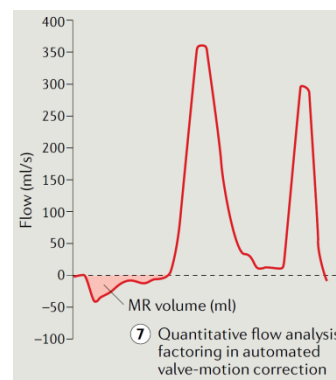
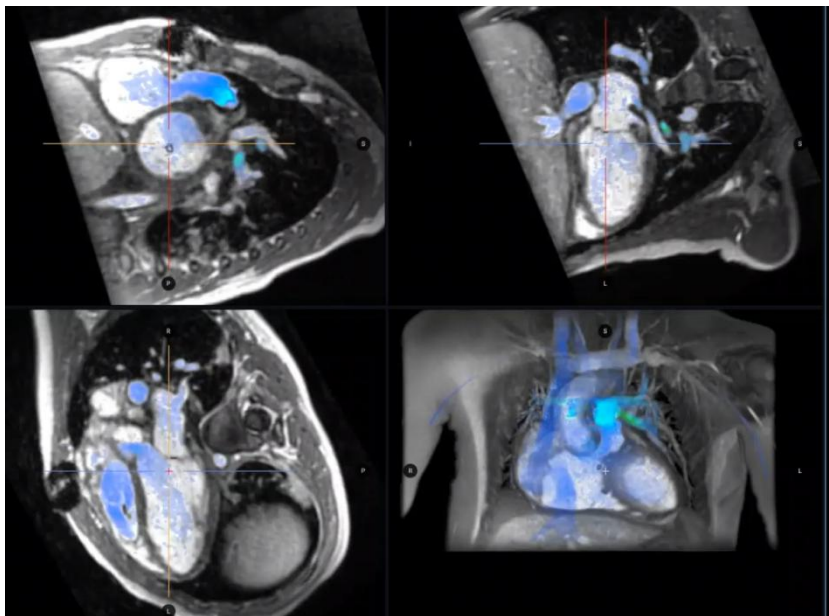
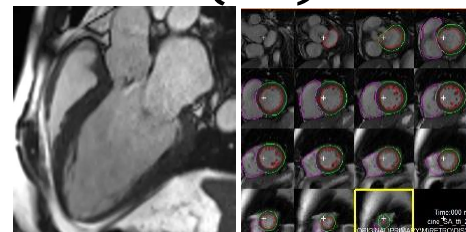


Mitrální chlopeň

Mitrální regurgitace: kvantifikace

Diastolická funkce LK

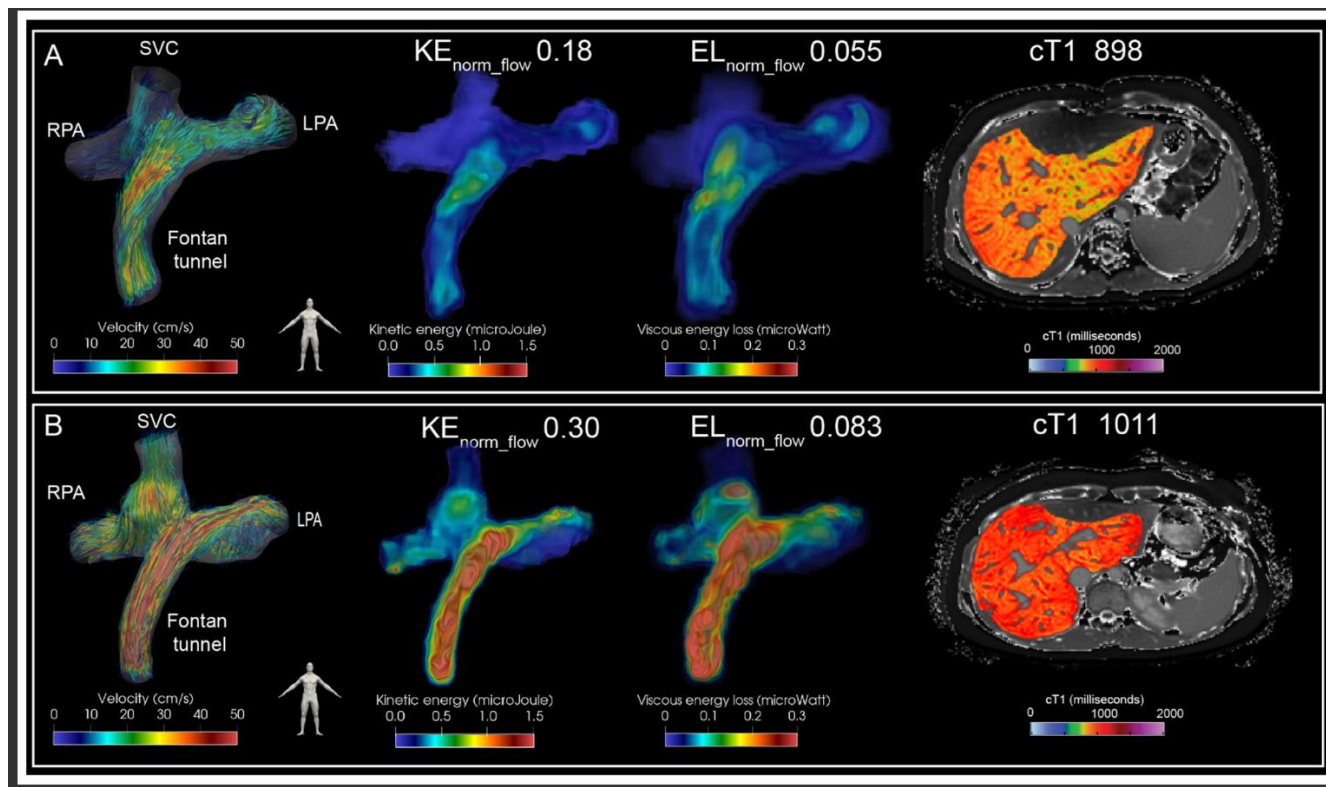
$$RV \text{ (mL)} = LV \text{ stroke volume (mL)} - Ao \text{ forward flow (mL)}$$



Komplexní vrozené vady

- Fontánovská cirkulace (TCPC extrakardiální)
- Kinetic energy (KE), viscous energy loss rate (EL)

Korelace s VO2max, jaterní stázou a přestavbou

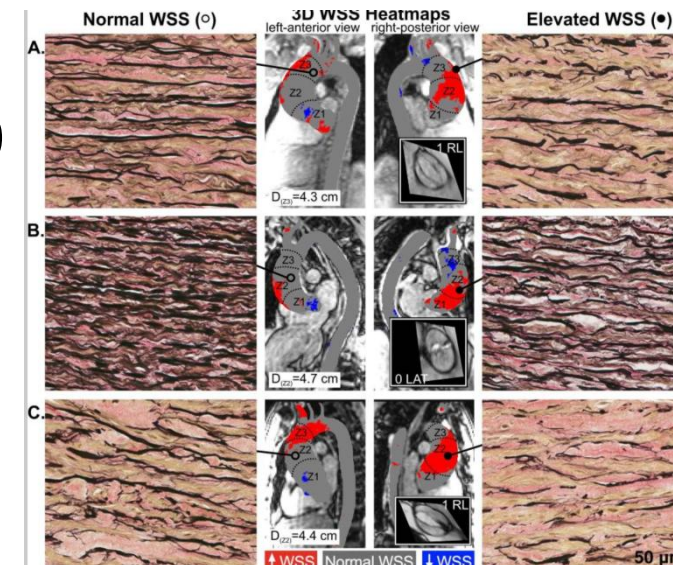


4D flow v predikci progrese či AAD

Wall shear stress

- Wall shear stress: $\tau_w = \mu \left(\frac{\partial u}{\partial y} \right)_{y=0}$
- Rychlostní vektory při stěně aorty, víření

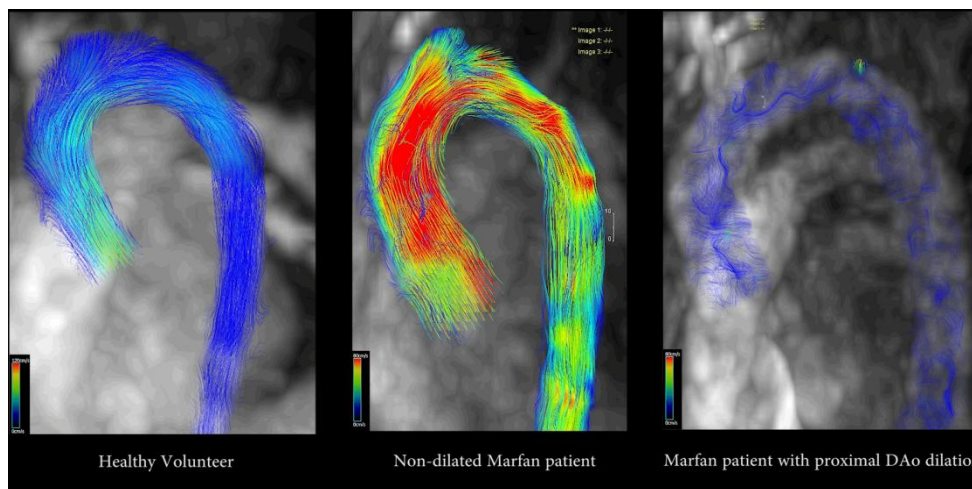
- 22 pts s BAV, plánovaná resekce aorty
- ↓ elastických vláken ↑ MMP-2, MMP-9
- Riziko ao disekce
ruptury
progrese dilatace



4D flow v predikci progresu či AAD

Wall shear stress

- **75 MS pts s remodelací aorty i bez, + zdraví jedinci**
- **MS: alterace in-plane rotational flow a circumf. wall shear stress i bez přítomnosti dilatace aorty.**
- **Prox. descendentní aorta: snížené axial a circumf. wall shear stress nezávisle korelují s lokálním průměrem (nezávisle na demografii a klinických f.**

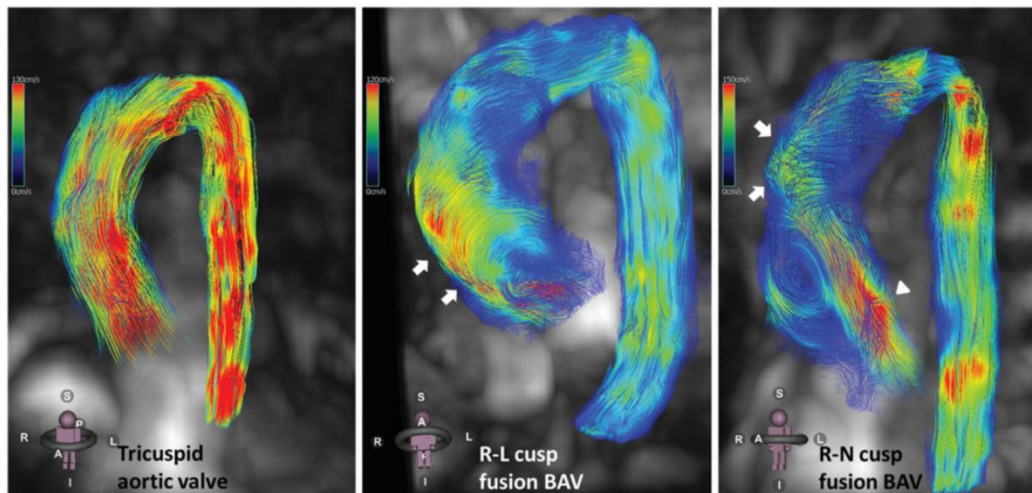


Imaging k predikci progresu či AAD

Aortic wall shear stress

- R+L fúze cípů – dilatace kořene
- R+N fúze cípů – dilatace tubulární asc. aorty ± oblouku

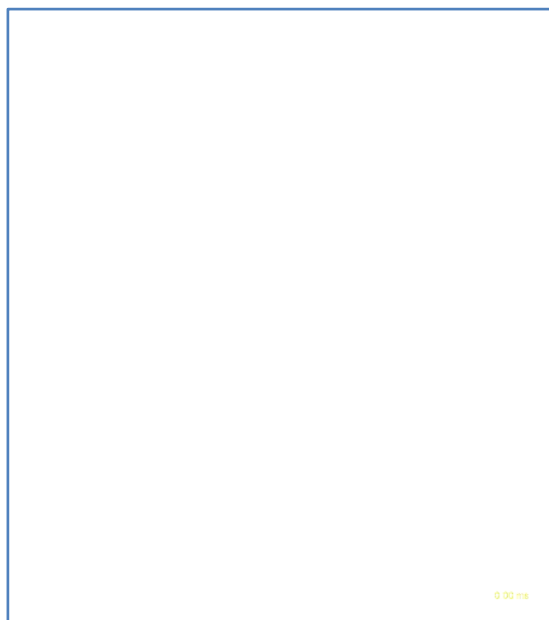
H.I. Michelena *et al.* / European Journal of Cardio-Thoracic Surgery



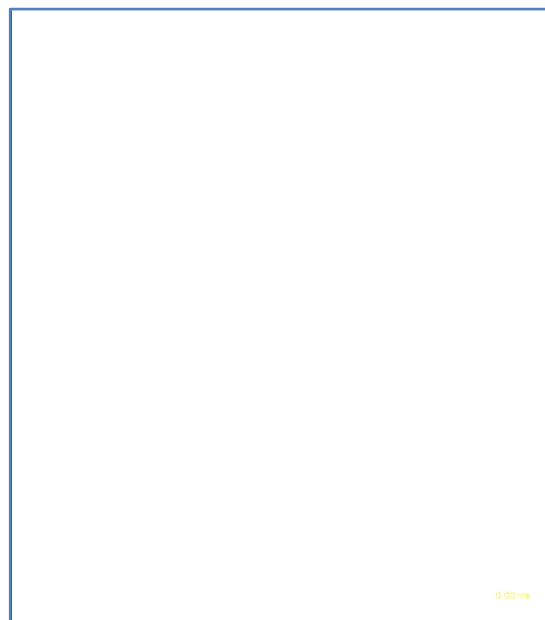
Na druhu operačního zákroku záleží

Podle Davida

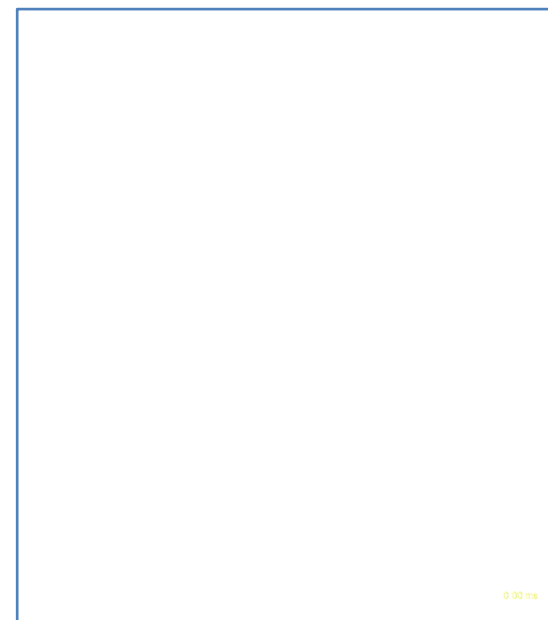
Dobrovolník 25 let



Protéza se sinusy



Tubulární graft



Ejekční frakce False lumen – predikce komplikací

Key question

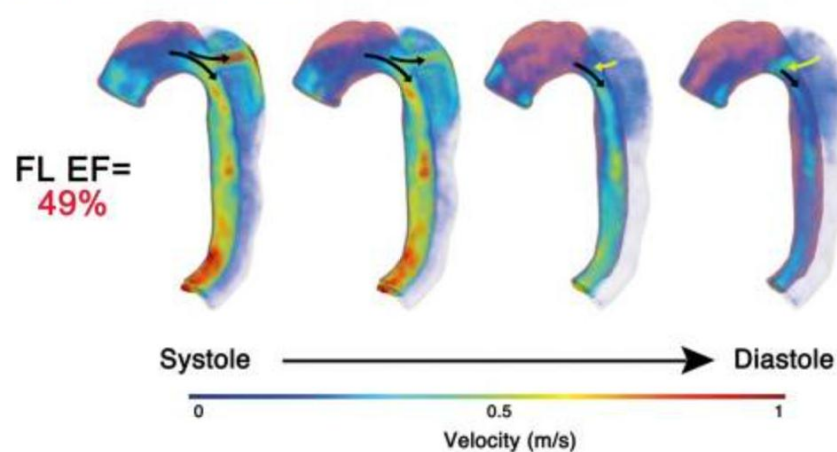
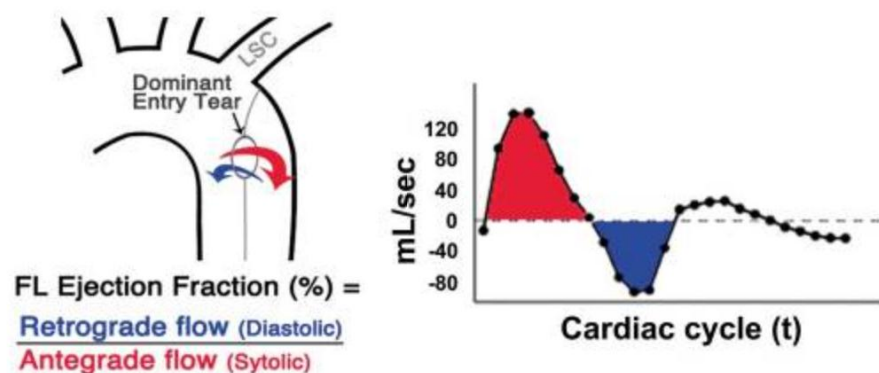
Can 4-dimensional (4D) flow magnetic resonance imaging (MRI)-derived haemodynamic parameters predict aortic growth in type B aortic dissection?

Key finding(s)

Predictors of growth rate:
False lumen ejection fraction. Baseline diameter.
Entry tear distance from the left subclavian artery.

Take-home message

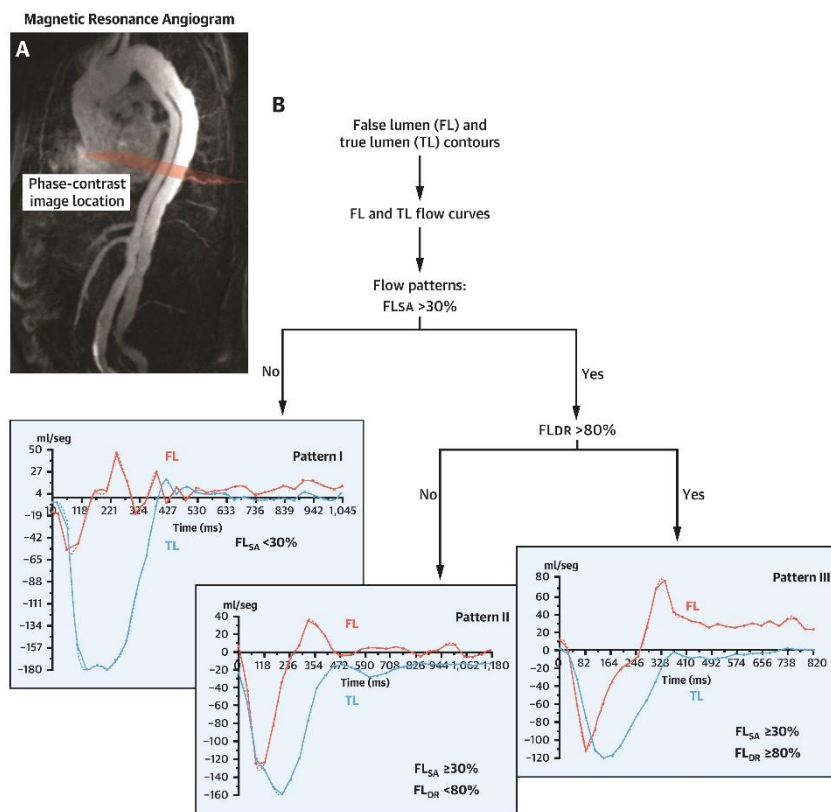
A false lumen ejection fraction measurement by 4D flow MRI can predict growth and may help refine treatment decisions in type B dissection.



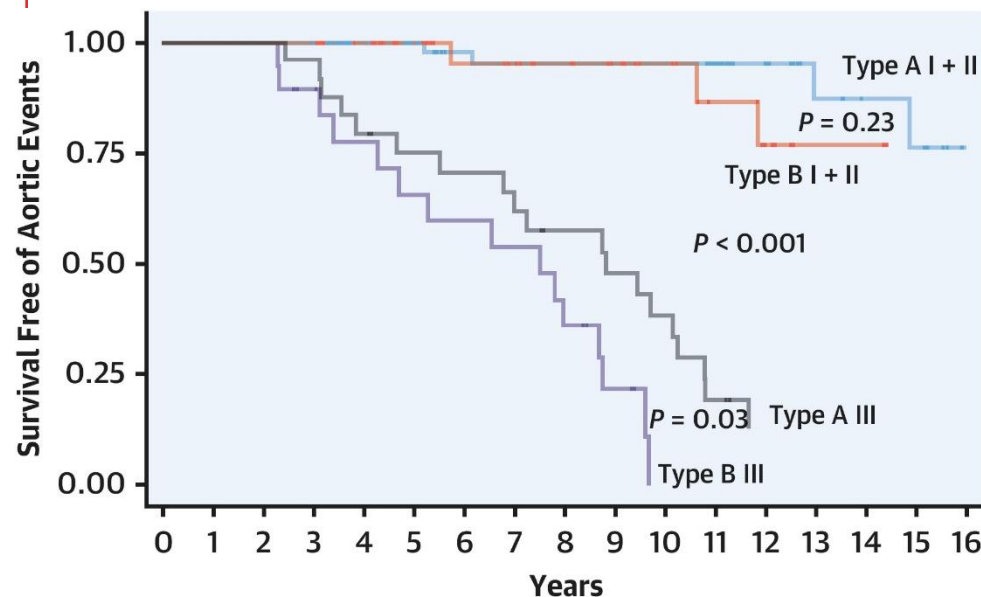
Průtoky FL – predikce ruptury

131 pts, 25 úmrtí (ao.komplikace), 18 EVAR

CENTRAL ILLUSTRATION: False Lumen Flow by Magnetic Resonance Imaging and Long-Term Outcomes of Aortic Dissection



Evangelista A, et al. J Am Coll Cardiol. 2022;79(24):2415-2427.



Evangelista et al. JACC Surg 2022

Děkuji za pozornost

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Ambulance pro vrozené vady v dospělosti

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&

Nemocnice Na Homolce