Measuring blood flow in cardiovascular diseases: clinical side

Aurelio Secinaro
Advanced Cardiovascular Imaging Unit
Department of Imaging

aurelio.secinaro@opbg.net

ISMRM Italian Chapter

15 1869 2019 Bambino Gesù OSPEDALE PEDIATRICO

I HAVE NOTHING TO DISCLOSE

I have no relevant financial intrest/arrangement or affiliation with any organizations related to commercial products or service to be discussed at this program.

Per quanto concerne i moderatori, relatori, formatori, tutor, docenti è richiesta dall'Accordo Stato-Regioni vigente apposita dichiarazione esplicita dell'interessato, di trasparenza delle fonti di finanziamento e dei rapporti con soggetti portatori di interessi commerciali relativi agli ultimi due anni dalla data dell'evento.
La documentazione deve essere disponibile presso il Provider e conservata per almeno 5 anni.

Dichiarazione sul Conflitto di Interessi

Aurelio Secinaro
Il sottoscritto_____ in qualità di:

□ responsabile scientifico □ moderatore x docente □ relatore □ tutor

dell'evento "X CONGRESSO AIRMM - RISONANZA MAGNETICA IN MEDICINA 2019:
DALLA RICERCA TECNOLOGICA AVANZATA ALLA PRATICA CLINICA"
Milano, 28-29 marzo 2019

da tenersi per conto di **Biomedia srl Provider n. 148,**

ai sensi dell'Accordo Stato-Regione in materia di formazione continua nel settore "Salute" (Formazione ECM) vigente,

Dichiara

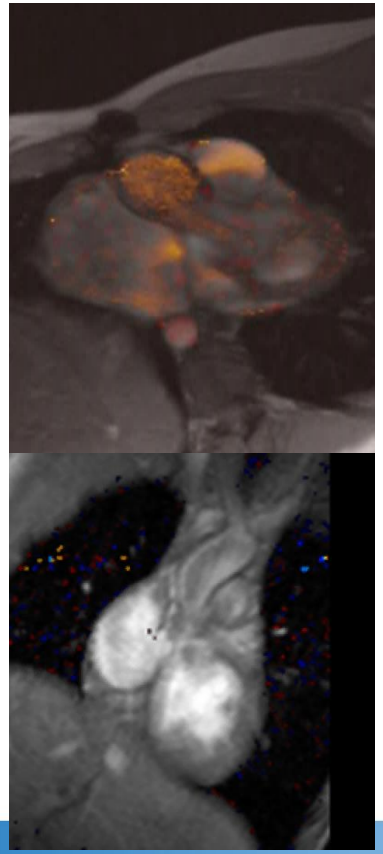
x che negli ultimi due anni NON ha avuto rapporti anche di finanziamento con soggetti portatori di interessi commerciali in campo sanitario

□ che negli ultimi due anni ha avuto rapporti anche di finanziamento con soggetti portatori di interessi commerciali in campo sanitario (indicare quali):

_____ _____
_____ _____
_____ _____
_____ _____

Phase Contrast MRA

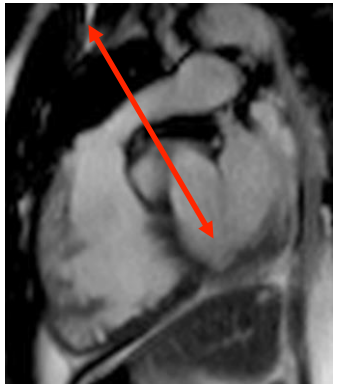
- **Accurate technique**
- **Valvular regurgitation**
- **Qp:Qs, Differential blood flow**
- **Gradients across stenoses**
- **In-vivo Gold standard**

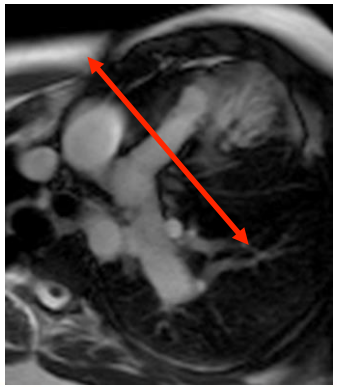


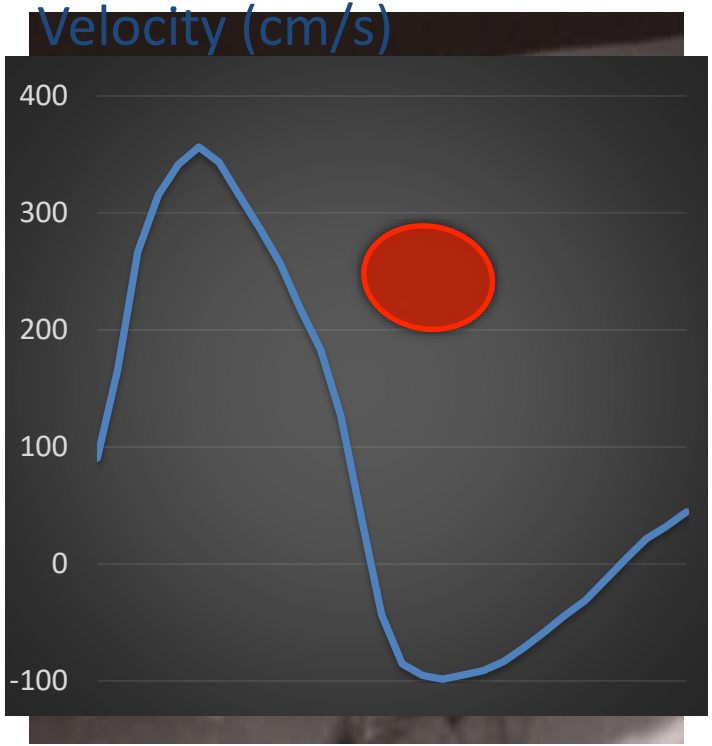
Clinical Adjustments - Fine Tuning

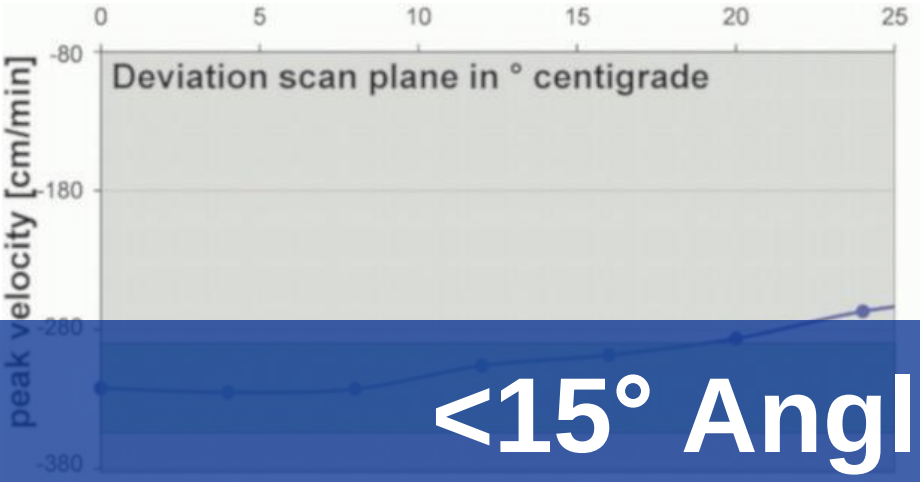
- **Plane Orientation**
- **VENC**
- **ECG Gating and T_{res}**
- **Scan Time (BH/FB)**
- **Contrast/Image resolution (16 px)**

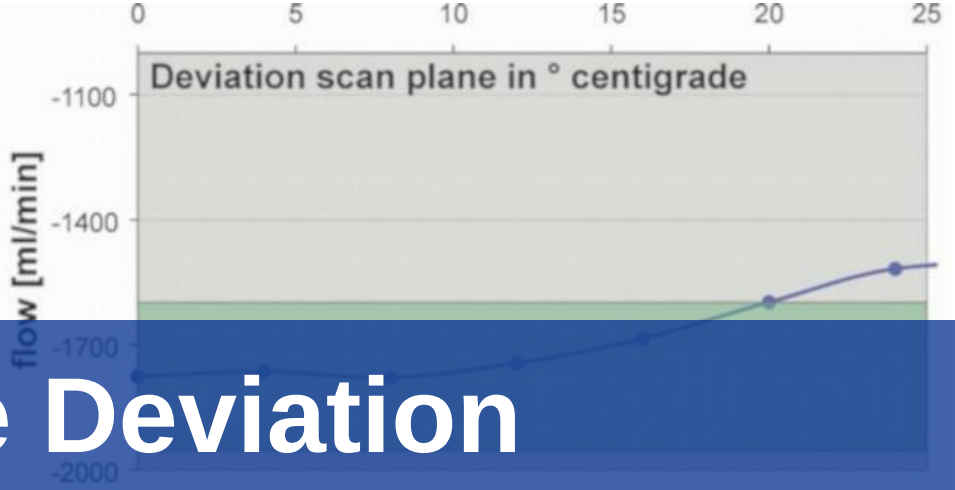
Plane Orientation



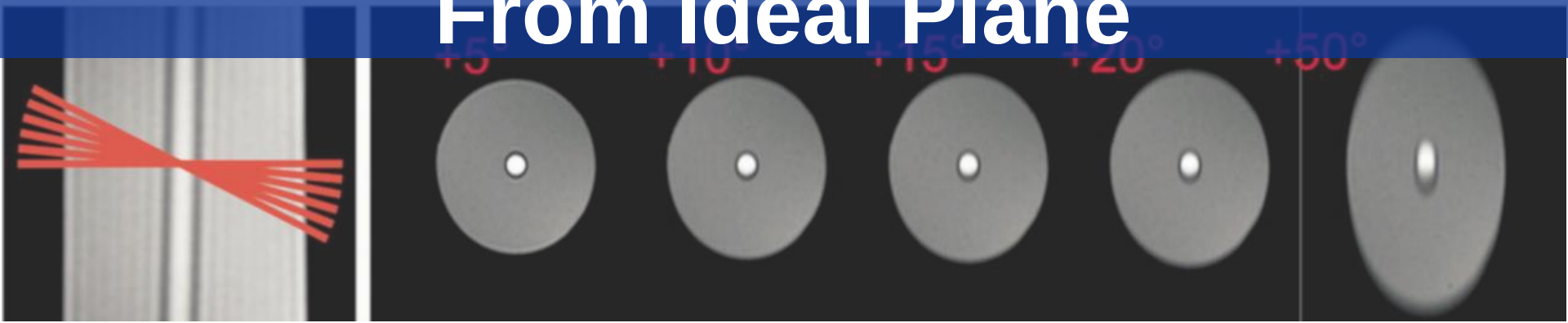








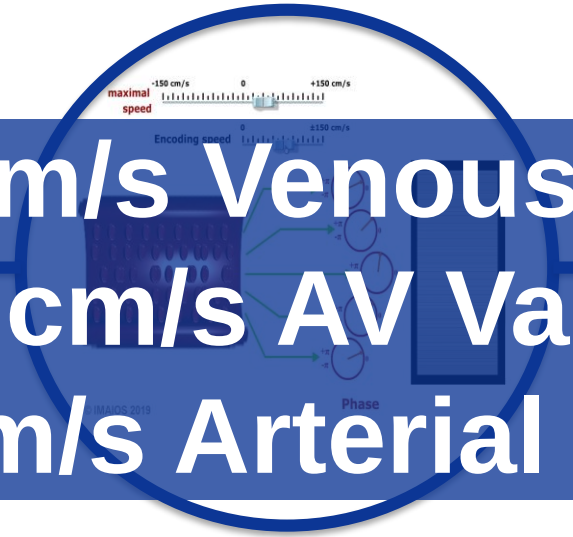
<15° Angle Deviation From Ideal Plane



VENC

NOT TOO HIGH

NOT TOO LOW



ALIASING

NOISE

100 cm/s Venous Flow

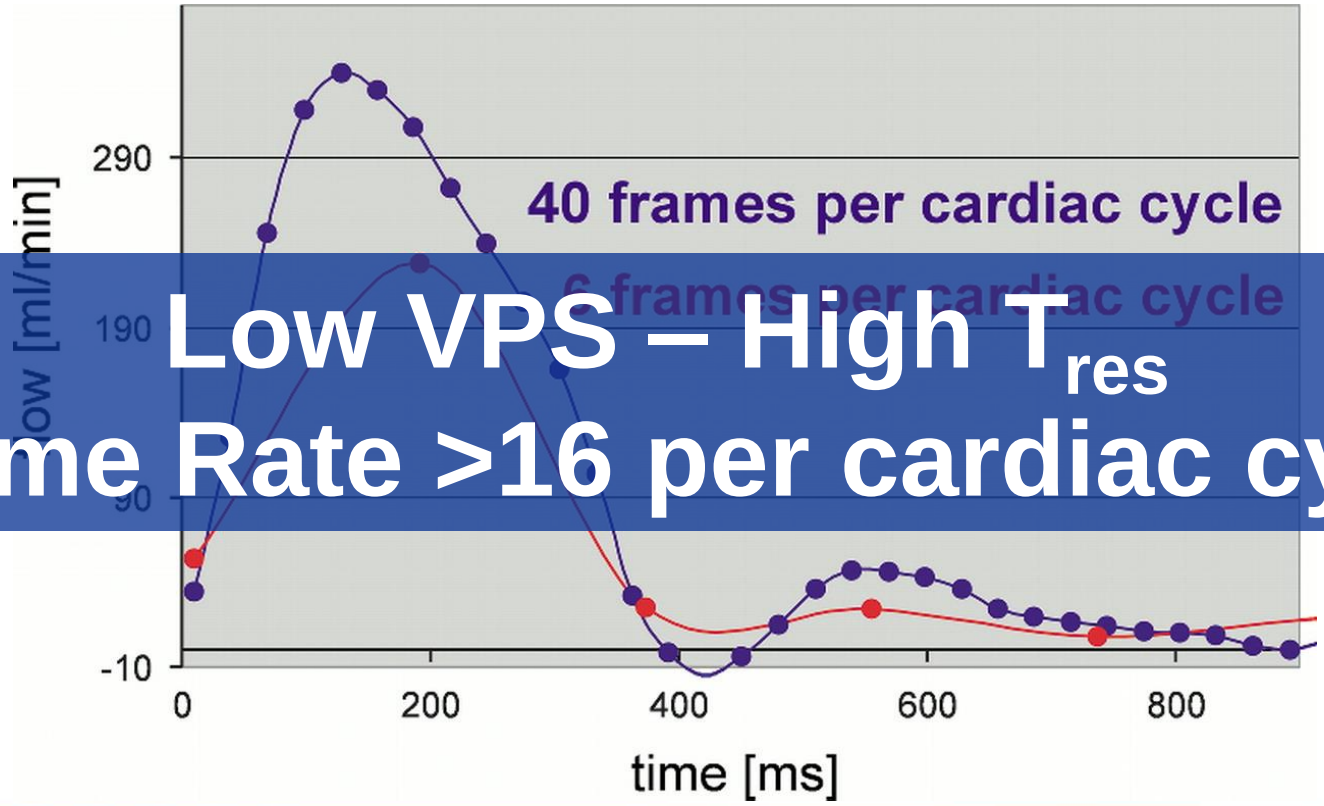
150 cm/s AV Valves

200 cm/s Arterial Flows

$$\Delta p = 4 \cdot (V_{max})^2$$

$$\sigma \sim \frac{V_{enc}}{SNR}$$

Temporal Resolution (Views per Segment)



Low VPS – High T_{res}

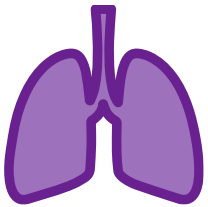
Frame Rate >16 per cardiac cycle

Main PC Acqusition Strategies

Free Breathing

1-2 minutes

Increased NSA (3-4)
High spatial/temporal res

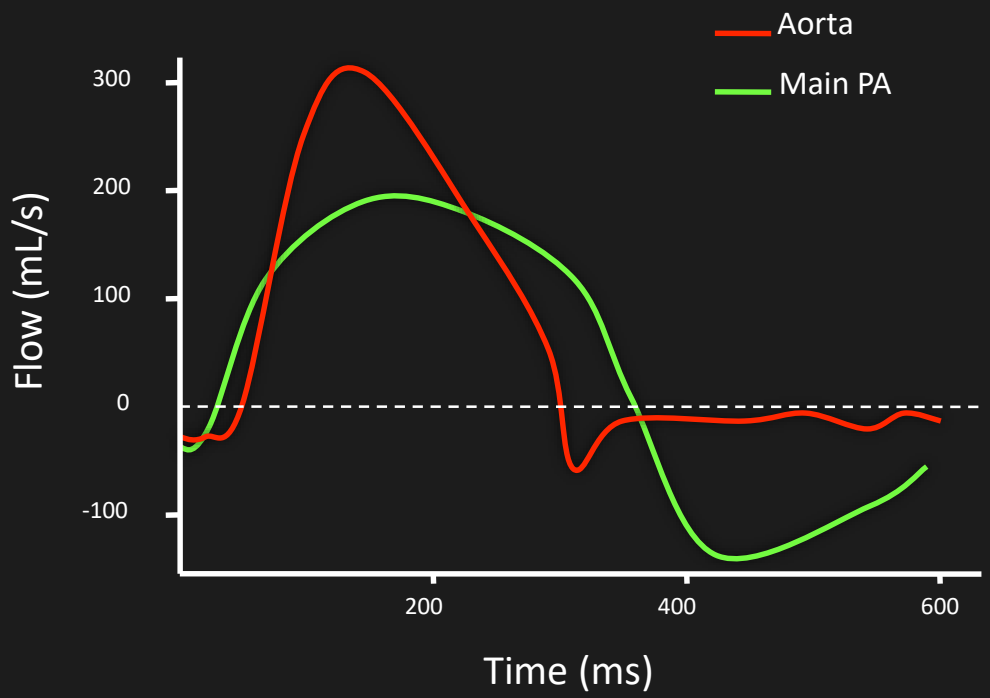


Breathold

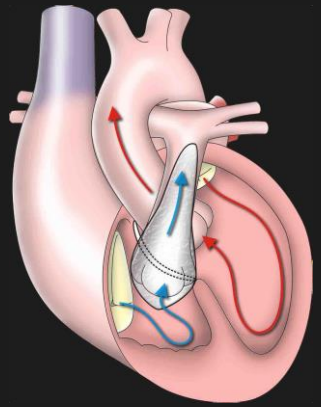
15-20 seconds

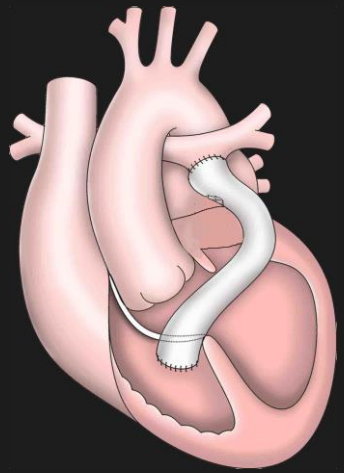
Lower spatial/temporal res

Free Pulmonary Valve Regurgitation

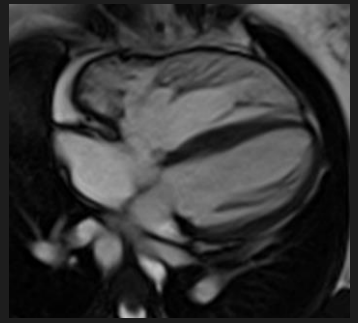


Tetralogy of Fallot

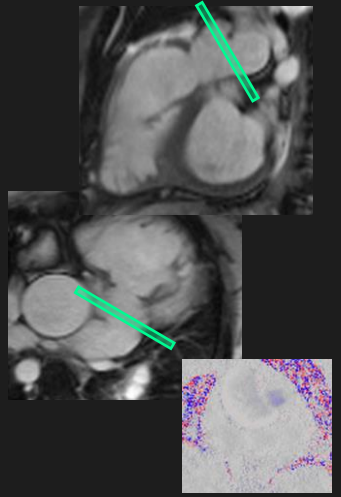


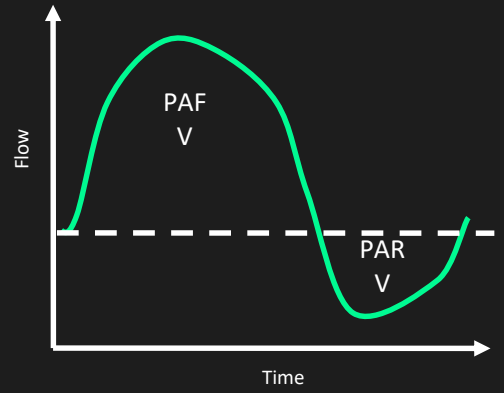


Tetralogy of Fallot - Why do we CMR



- Quantify Regurgitation
- Assess stenosis
- Quantify volumes + EF
- Detect residual VSD

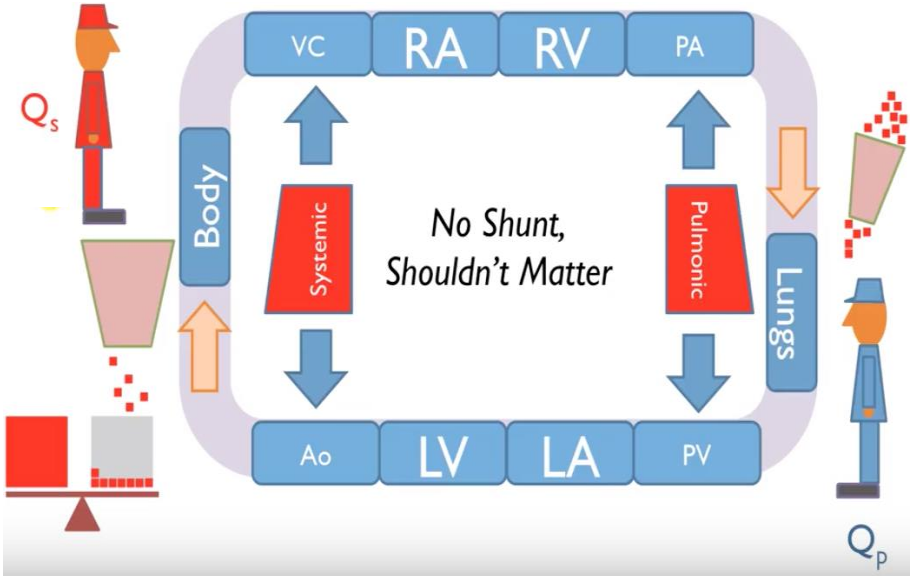




PA FV	75 mls

Principle of Qp:Qs

- Qs= effective volume of blood reaching the systemic vascular bed



- Qp= effective volume of blood reaching the pulmonary vascular

Milestones of PC CMR

ELSEVIER

Quantitative analysis

Malcolm B. Robertson

Department of Medical Physics and Me

Rec

Abstract

The accuracy of MR phase contrast (PC) velo
quantitatively assessed. Using a retrospectively g
pulsatile flow in a rigid cylindrical vessel. The ex
Navier-Stokes equations. For a sinusoidal wavefo
velocities corresponded to 13% of the peak fluid v
model. As an example of a more complicated
Velocity maps and the WSS were calculated by th
each harmonic. The velocity and experimentally d
Evaluation of the analytical models allowed an e
© 2001 Elsevier Science Inc. All rights reserved

Keywords: Phase contrast; Velocity quantification; Wa

Am J Cardiol. 2003;91:1523-5

Comparison Between Phase-Velocity Cine Magnetic Resonance Imaging and Invasive Oximetry for Quantification of Atrial Shunts

Andrew J. Powell, MD, Beverly Tsai-Goodman, MD, Ashwin Prakash, MD, Gerald F. Greil, MD, and Tal Geva, MD

Measurement of the pulmonary-to-systemic blood flow ratio (Qp/Qs) in patients with congenital heart disease and shunting lesions may be useful for determining the need for intervention or assessing outcome postprocedure. Frequently used methods to calculate Qp/Qs, such as invasive oximetry, first-pass radionuclide angiography, and Doppler echocardiography have limitations.[1] Phase-velocity cine magnetic resonance imaging (PVC MRI) is a noninvasive technique to measure blood flow that has been demonstrated to be accurate in vitro and in vivo.[2–6] We have previously reported that subjects without a shunt (n = 20) had a mean Qp/Qs of 0.99 ± 0.10 by PVC MRI.[3] The aim of this study was to prospectively evaluate the accuracy, reproducibility, and interobserver variability of PVC MRI measurements of Qp/Qs in subjects with a known shunt. Oximetry at catheterization was selected for comparison because this remains the most widely accepted clinical standard.

• • •

ability. MRI studies were performed using a 1.5-Tesla whole-body scanner (Signa LX, General Electric, Milwaukee, Wisconsin) with a torso phased-array radiofrequency receiver coil. Through-plane PVC MRI was performed using a commercially available conventional pulse sequence (Cine PC, General Electric) with retrospective electrocardiographic gating, no respiratory gating, and the following acquisition parameters: echo time 6 to 7 ms, repetition time 18 to 20 ms, flip angle 15°, field-of-view 240 to 360 mm, matrix 256 × 128, slice thickness 6 mm, signal averages 2, and velocity encoding value 150 cm/s for the aorta and 200 cm/s for the pulmonary artery. Imaging time for each measurement was 2.3 to 4.2 minutes depending on heart rate. PVC MRI data were analyzed off-line on a computer workstation (Advantage Windows 4.0, General Electric) equipped with commercially available flow analysis software (Flow, MEDIS, Leiden, The Netherlands) including automated vessel border detection. The underlying principles and analysis

to-Right Shunt in

aging Compared With

; Peter Barth, MSc;
s Meyer, MD, PhD

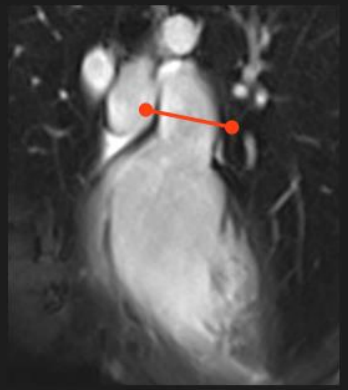
ae MRI (PC-MRI) in adults. Little is known
e.
' years) with an atrial- or ventricular-level
e ratio of pulmonary to aortic flow (Qp/Qs)
nd a range of −20% to +26% (limits of
ase but no cardiac shunting (mean age 7.9
lo difference between systemic venous and
through a secundum atrial septal defect as
erence between pulmonary and aortic flows.
location was 5.3% (SD ±4.0%, n=522),
accuracy of PC-MRI was confirmed by in

fe, and reliable compared with oximetry.
e shunt measurement within an atrial septal

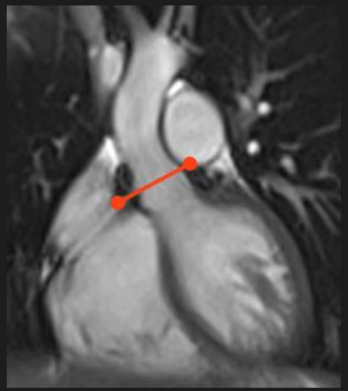
onance imaging ■ shunts ■ veins

Shunt Quantification - additional flows

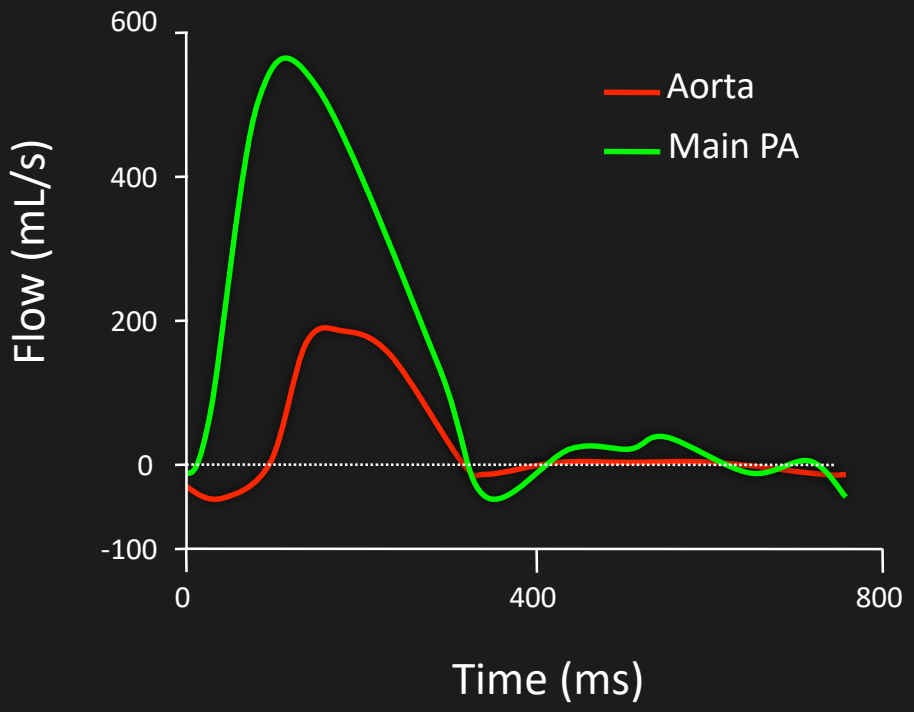
Qp



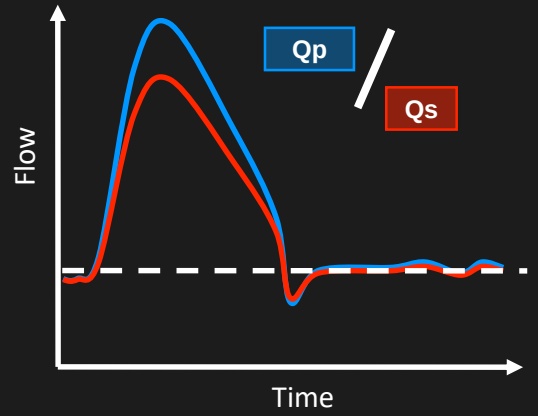
Qs



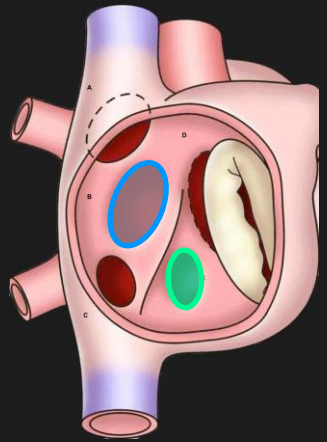
Left to right shunt

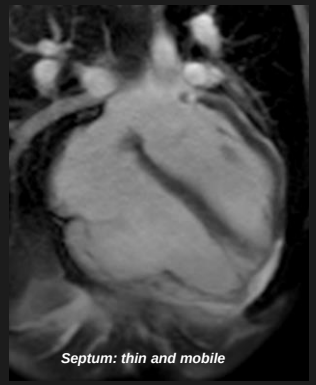


Right heart dilation



Locating the ASD - targeting the search





Secundum defect

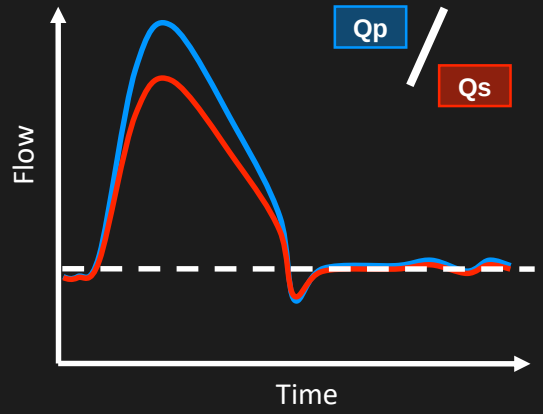
Difficult ASDs - interrogating further: 3D + 2D

Qp:Qs > 1

RVSV = PASV

Look around

Left heart dilation



Qp:QS > 1

Ao Stroke Volume	50 mls
PA Stroke Volume	100 mls

Left ventricular dilation

Ao Stroke Volume	80 mls
PA Stroke Volume	60 mls
LV Stroke Volume	80 mls
RV Stroke Volume	60 mls

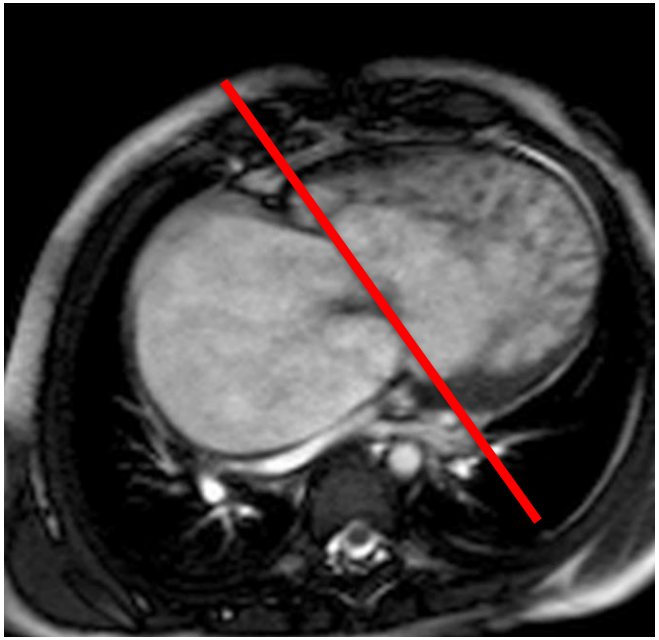
Same scenario, but different BPA flows

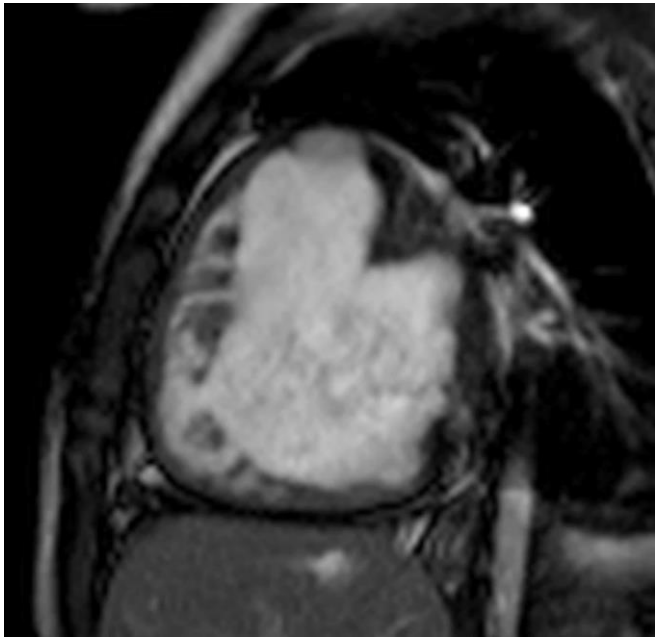
Ao =80 mls

PA =60 mls

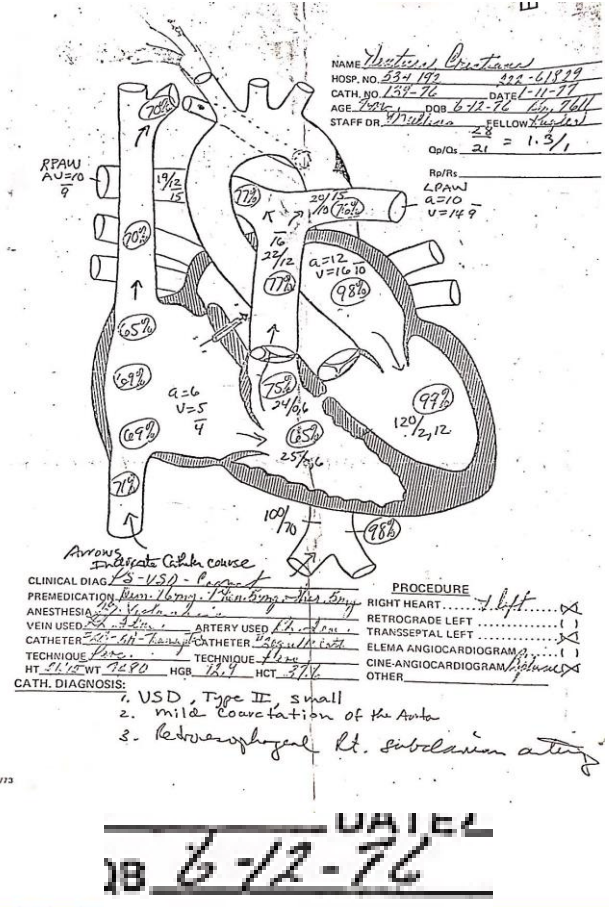
BPA = 60 mls

AV Valve regurgitation Quantification



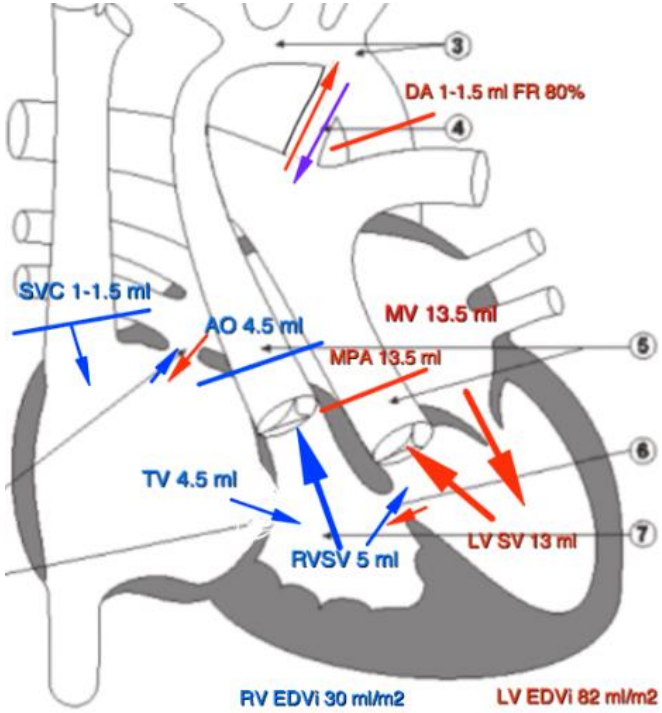


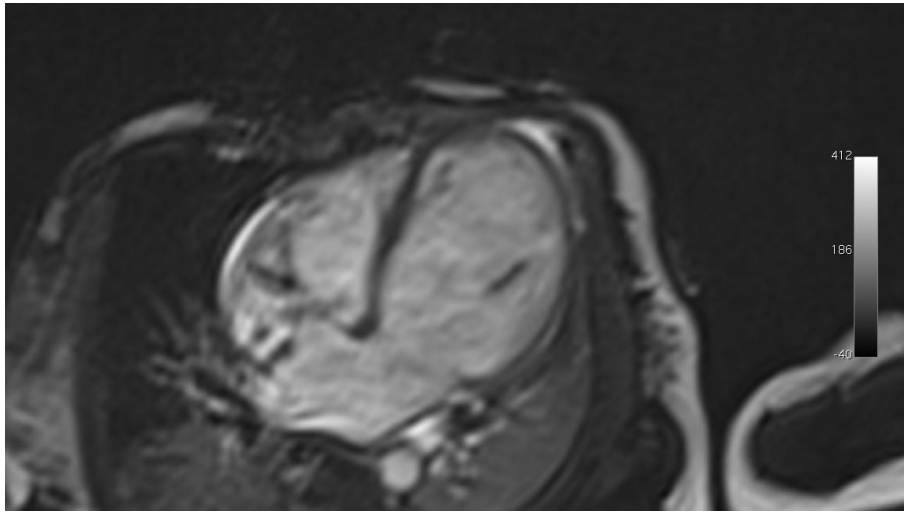
Tricuspid valve RF% = RVSV-AO Flow/RVSV



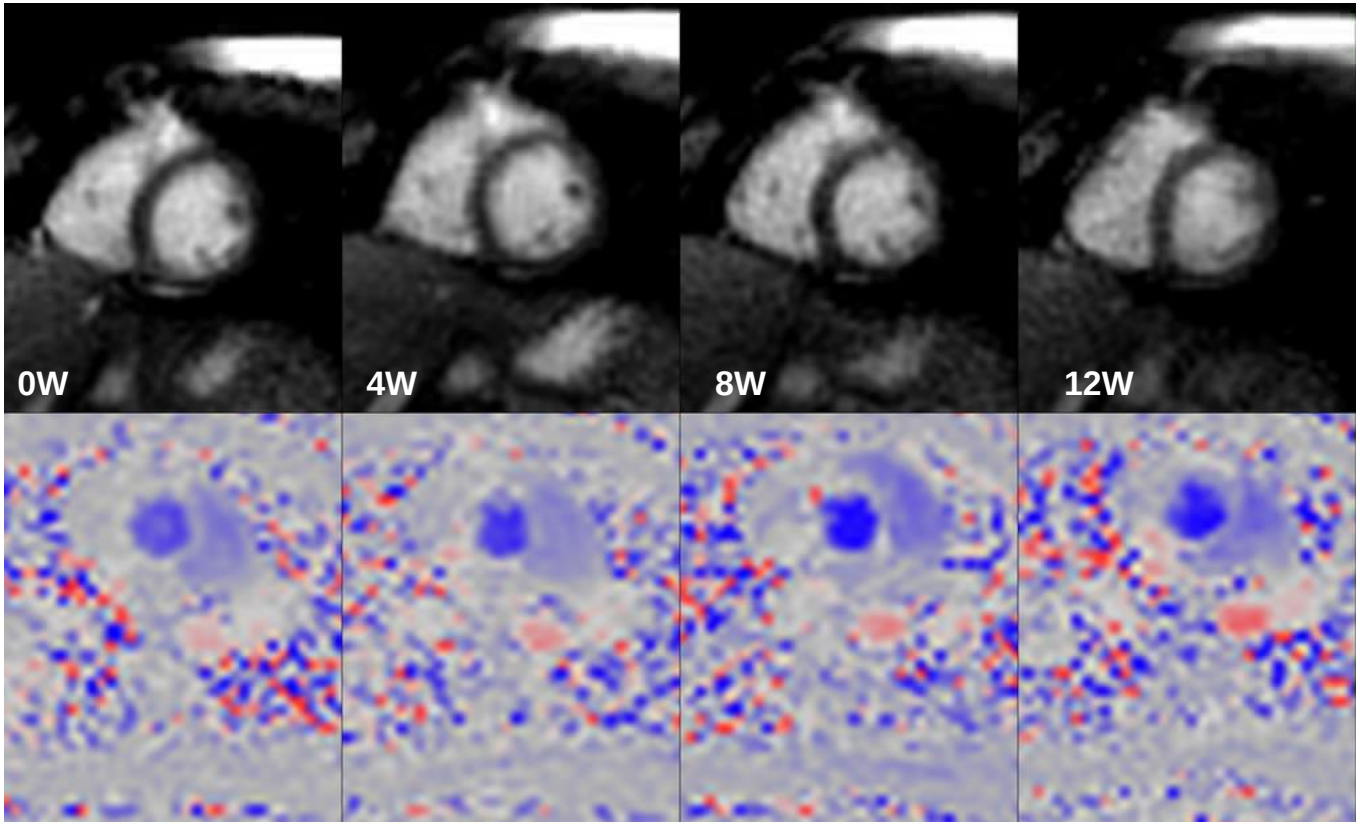
Dr Charles Mullins

MR Hemodynamical Assessment Complex CHD - TGA, CoA, VSD, Hypoplastic RV





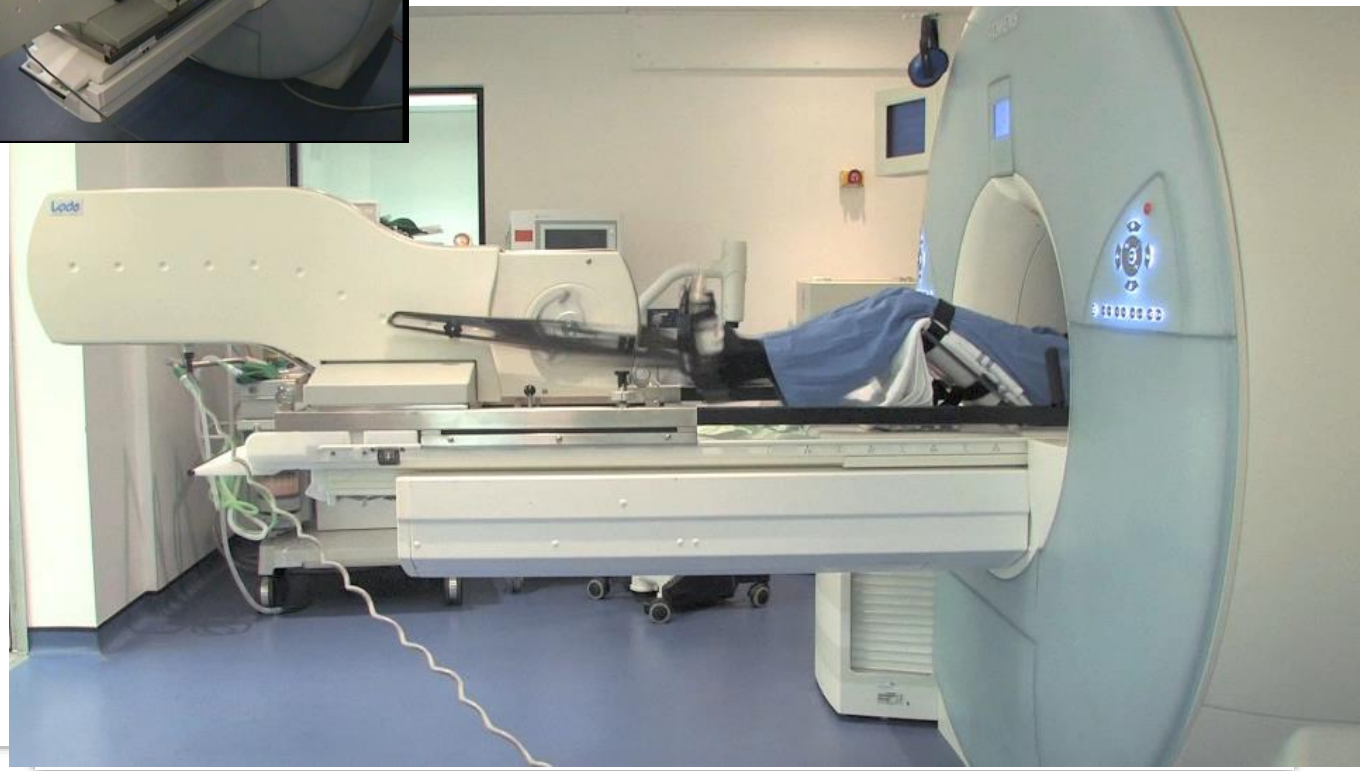
Rapid imaging – real-time 2D cine and flow acquisitions



Lurz P et al. *JMRI* 2009

Steeden JA, et al. *MRM* 2011

Exercise CMR



CMR - 4D FLOW

Anatomic data .Velocity field (3 directions) 4 dimensional Volumetric Time resolved

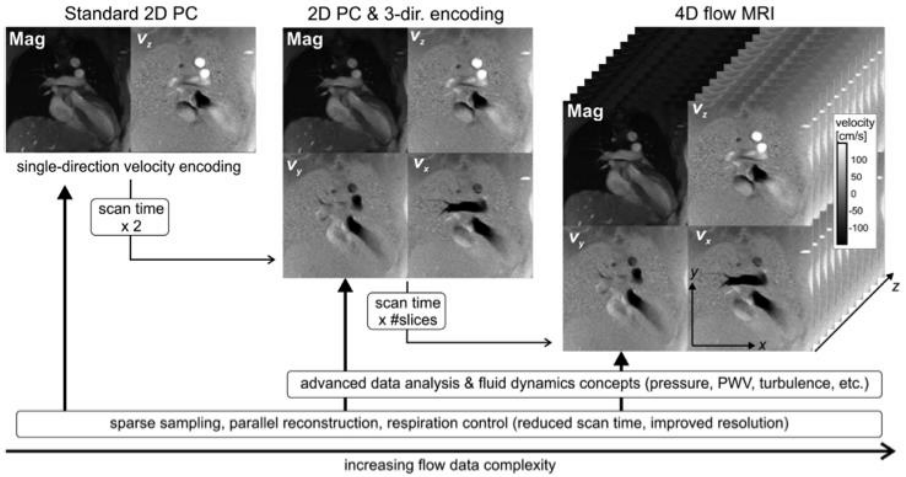
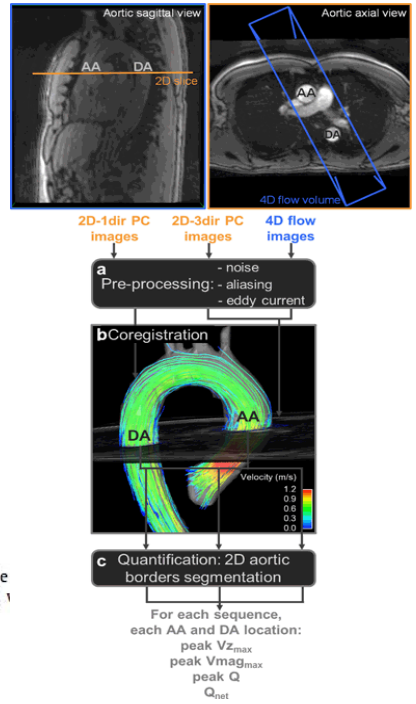
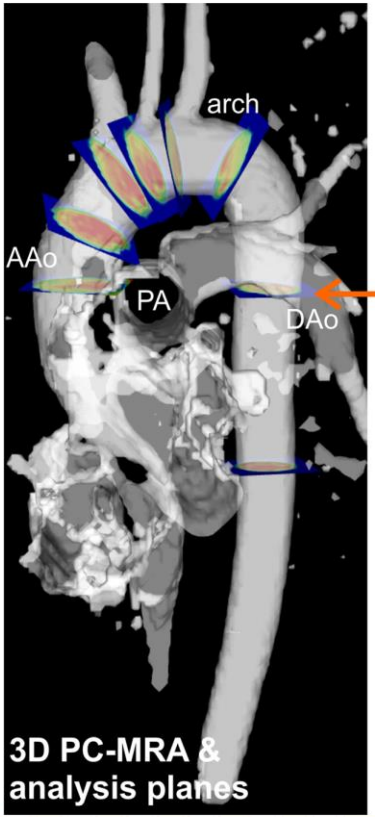


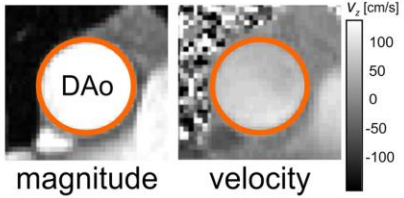
Figure 2 Chart illustrating the increased complexity and information content in flow data as a function of dimensionality and scan time. The of methods development is shown along the bottom row, with an impact spanning standard 2D cine PC (left) to 4D flow MRI (right), v volumetric coverage and three-directional velocity encoding. Mag, magnitude image.



CMR - 4D FLOW



flow quantification
vessel contour



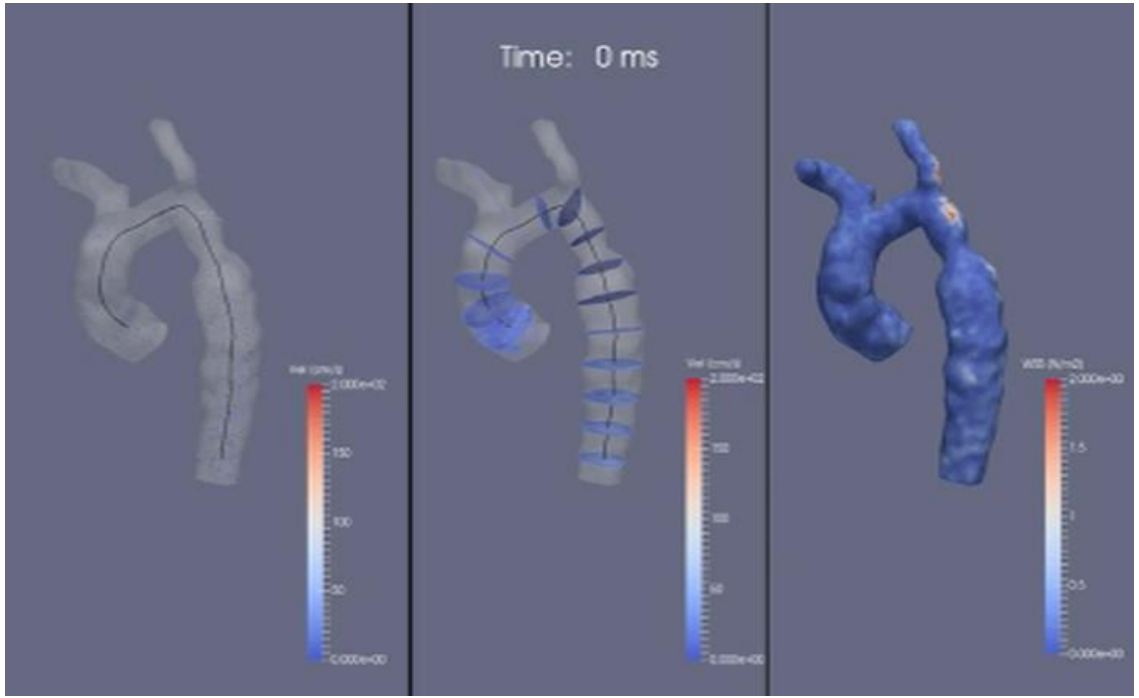
segmentation of
vessel boundary for
all cardiac time frames

plane-wise analysis

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

- single acquisition volume
- Retrospective flow through any plane
- especially advantageous where multiple 2D cine PC-CMR scans would be needed

Additional 4D FLOW parameters



Stream line

Velocities

Shear stress

4D FLOW–Congenital Heart disease

Study	Population	Contribution to understanding of CHD and 4D-flow imaging
Complex CHD		
Valverde[44] (2010)	Case report, 8-year-old female with atrial septal defect and anomalous pulmonary venous return	■ Good agreement between assessment of hemodynamics by 2D and 4D-flow, greater time efficiency and ease using 4D-flow and ability to assess offline ■ Potential for particle tracing information provided by 4D-flow to improve understanding of fluid-solid interactions including vortices, with future novel applications for treatment planning
Markl[38] (2011)	4 patients with Fontan (single ventricle) circulation, aged 12–26 years and 4 controls	■ Identification of origin of blood into pulmonary arteries, including respective contributions of both superior and inferior vena cava ■ Quantification in vivo of variability in blood flow distribution to right and left pulmonary arteries ■ Characterization of helix formation around areas of repair
Markl[39] (2012)	Case report, 5-year-old male post-repair for HLH, TGA, double-outlet right ventricle, VSD, aortic coarctation.	■ Accurate assessment of hemodynamics in complex CHD ■ Description of post-stenotic helix formation with associated dilatation at site of coarctation repair ■ Characterization of flow asymmetry in pulmonary arteries
Sundareswaran[40] (2012)	16 single-ventricle patients, Group 1: 8 patients with an extracardiac TCPC (7.5 ± 3.4 years), Group 2: 8 patients with a lateral tunnel TCPC (8.8 ± 4.3 years).	■ First time in vivo volumetric flow structures inside TCPC quantified in a sizable patient group using widely available MRI sequences ■ Comparison of mean flow velocities through extracardiac and lateral tunnel TCPC, with no significant difference observed. ■ Characterization of vortex and flow formation.
Bachler[22] (2013)	10 patients with Fontan (single ventricle) circulation, aged 16 ± 6 (range 9–30 years) and 12 controls	■ Confirmation of good correlation of parameters as assessed using 4D-flow when compared to two-dimensional MRI ■ Agreement between measurements of net flow across various regions ■ Identification of highly asymmetric flow distribution from the inferior and superior vena cave to the right and left pulmonary arteries
Cibis[42] (2015)	6 patients with Fontan (single ventricle) circulation, aged 9–21 years.	■ Ability of 4D-flow to detect viscous dissipation in subjects with elevated viscous dissipation, some underestimation of magnitude

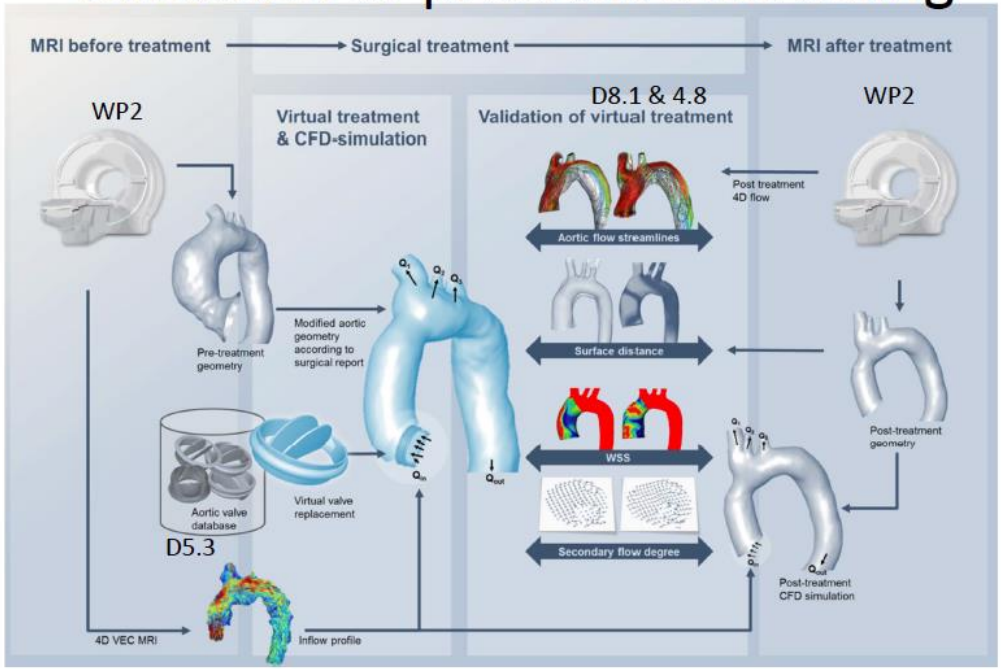
Lawley et al. Journal of Asian Cardiovascular & Thoracic Annals 0(0) 1–10

Validation of predictive modeling

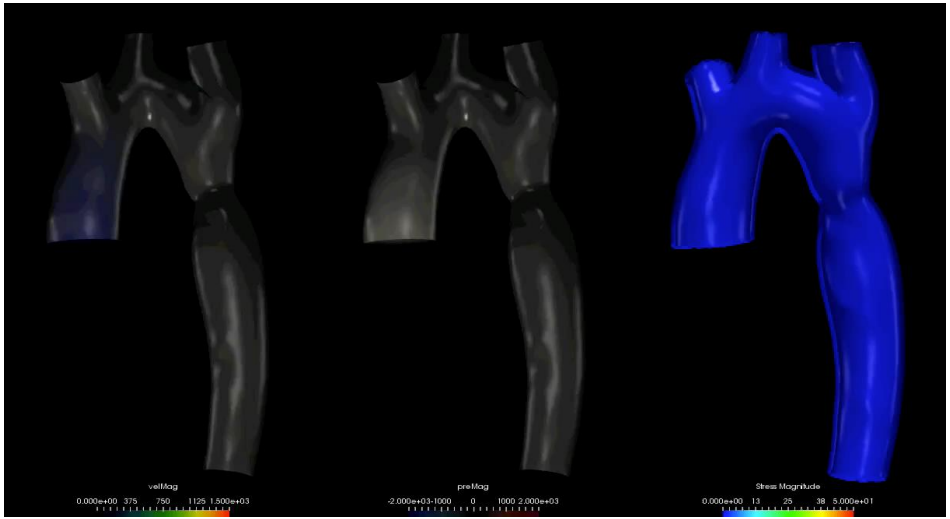
Patient-Specific Requirements and Clinical Validation of MRI-Based Pressure Mapping: A Two-Center Study in Patients With Aortic Coarctation

Leonid Goubergrits, PhD,[1] Florian Hellmeier, MS,[1] Dominik Neumann, PhD,[2] Viorel Mihalef, PhD,[3] Mehmet A. Gulsun, PhD,[3] Marcello Chinali, MD,[4] Aurelio Secinaro, MD,[5] Kilian Runte,[1,6] Stephan Schubert, PhD,[6] Felix Berger, PhD,[6,7,8] Titus Kuehne, PhD,[1,8] Anja Hennemuth, PhD,[1] and Marcus Kelm, MD[1,6,8*]

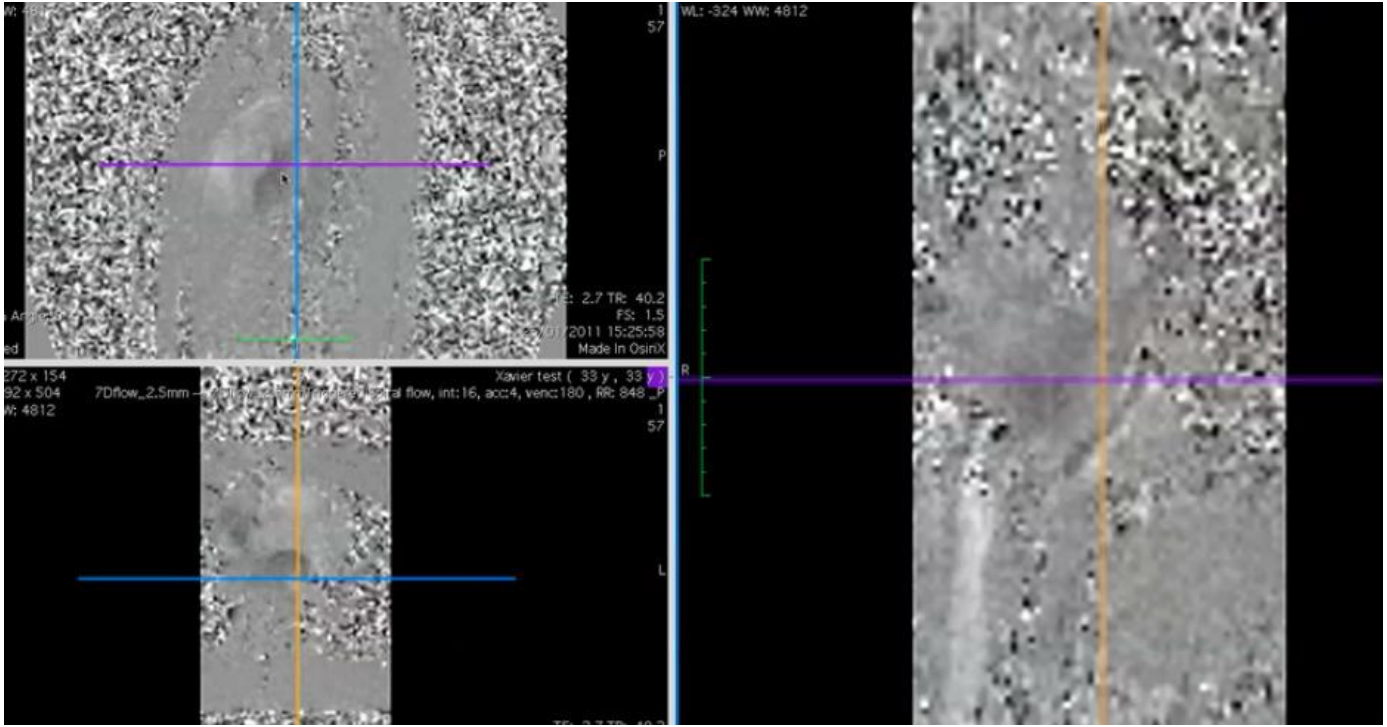
J. MAGN. RESON. IMAGING 2019;49:81–89.



Pre-op CFD data from CMR …and after Virtual Stenting



Rapid imaging - 4D flow acquisition



20 minutes to 100 seconds

Teaching Points

- 2D CMR flow calculation is feasible, accurate and highly reproducible
- Relialbility in flow volume calculations (RF, Qp/Qs and CO) makes the difference, especially for CHD
- Specific Technical and Clinical skills are fundamental for data interpretation.
- Rapid imaging techniques (AI?) will further improve ability to acquire flow data in younger children
- 4D flow mainly applied in research. Faster scan time and post-processing tools will expand its role into clinical

29-30-31 Maggio 2019

Aula Salviati – Sede Gianicolo
Ospedale Pediatrico Bambino Gesù
Piazza S. Onofrio, 4 - 00165 Roma

150 1869 2019 Bambino Gesù OSPEDALE PEDIATRICO

ESC European Society of Cardiology

The ESC | Congresses & Events | Journals | Guidelines | Education | Research

European Society of Cardiology › Education › Career Development › Certification › Congenital heart disease CMR

Career Development

- Certification
- Training Grants and Fellowships
- Accreditation

Cardiovascular Magnetic Resonance in Congenital and Paediatric Heart Disease (CMR CHD) Certification

Certification organised by the European Association of Cardiovascular Imaging (EACVI)

The next certification exam in CMR in congenital and paediatric heart disease (CMR CHD) will be held prior to EuroCMR 2019, 1 May 2019 in Venice, Ital.

Registration will open 3 months prior to the exam's date.

More information about the venue and schedule will be communicated in due time.

EACVI European Association of Cardiovascular Imaging

ESC European Society of Cardiology

EUROPEAN CERTIFICATION

The European Association of Cardiovascular Imaging herewith confirms

Aurelio Secinaro

Is certified in EACVI

Cardiovascular Magnetic Resonance - Congenital Heart Disease

Level 3

from September 2018 certification valid until September 2023

Professor Bogdan Alexandru Popescu
President,
European Association of Cardiovascular Imaging

Mark Westwood
Chairperson,
EACVI Certification & Accreditation Committee

Oliver Tann
Chaiperson(s),
EACVI CMR CHD Certification & Accreditation Committee

GRAZIE