MRI Assessment of the Right Ventricle and Pulmonary Blood Flow, Perfusion and Ventilation

Dr. Richard Thompson
Department of Biomedical Engineering
University of Alberta

Heart and Lung Imaging

Many Constantly Evolving Modalities:
- Echocardiography
- Computed Tomography (CT)
- SPECT
- ...

Magnetic Resonance Imaging (MRI)

Goals – Understand the Present and Future Capabilities of MRI in Childhood Heart and Lung Imaging
Heart and Lung Imaging - MRI

Weaknesses

• Limited Availability / Long Wait-Time for Studies (expensive)
• Long Scan Times (sedation of younger children/newborns)
• Requirement for Breath-holding / Breathing Artifacts

MRI offers much more than RV assessment—pulmonary artery anatomy and blood flow, perfusion, ventilation (Comprehensive and Quantitative - Endpoint)
MRI for RV Imaging – Is it still the Best?


2D and 3D-Echo have similar (moderate) correlation to MRI RV volumes and systematically underestimate volumes


3D-Echo underestimates volumes, and has technical limitations, should still be used in conjunction with conventional 2D methods


MRI, CT and 3D-Echo are all similar for RV volume analysis

Several Additional Studies Indicate that Echocardiography is similar to MRI for RV Volume Assessment in Children - Dependent on the Institution, hardware and software

RV Imaging – Depends on Your Tools!

Reproducibility is strongly dependent on volume assessment protocol

2-3% coefficient of variation in RV volumes
RV Imaging – Summary

RV imaging alone is not sufficient impetus to perform MRI, typically acceptable with echocardiography – new hardware and software improving the robustness of Echo.

Reproducibility can still be highly variable depending on hardware and software (MRI, Echo, CT) – should be determined at each site for the purpose of clinical research.

Ventricular Tissue Characterization

Delayed Enhancement - of myocardium following injection of contrast (Gd-DTPA) - identification of fibrosis and cell death (viability)

Usefulness of Magnetic Resonance Imaging of Left Ventricular Endocardial Fibroelastosis in Infants After Fetal Intervention for Aortic Valve Stenosis

Wayne Tworetzky, MD*, Pedro J. del Nido, MD**, Andrew J. Powell, MD*, Audrey C. Marshall, MD*, James E. Lock, MD*, and Tal Geva, MD**

This report describes the use of myocardial delayed-enhancement magnetic resonance imaging to delineate the extent of endocardial fibroelastosis (EFE) in 4 infants after fetal balloon aortic valvuloplasty. The preoperative imaging of EFE, followed by extensive resection led to biventricular physiology in 2 patients.

All rights reserved. (Am J Cardiol 2005;96:1568–1570)
**Ventricular Tissue Characterization**

**T₁-Mapping – Imaging of Diffuse Fibrosis**

**Evaluation of Diffuse Myocardial Fibrosis in Heart Failure With Cardiac**

![Graph showing T₁ values against myocardial collagen content (%)](image)

**Quantitative T₂ Values (Normal: 55-60 ms)**

**Ventricular Tissue Characterization**

**T₂-Mapping – Imaging Edema**

![Delayed Enhancement Image - MI](image)

![Quantitative T₂ Values](image)
Ventricular Tissue Characterization

$T_2$-Mapping – Imaging Edema

Regional or Global Diffuse Changes

- Any change in local tissue environment that affects the mobility of water (fibrosis, ischemia)
- Early marker of transplanted heart rejection

Ventricular Tissue Characterization - Summary

MRI offers the ability to image regional or diffuse fibrosis and edema as part of a standard clinical exam.

Delayed Enhancement imaging (regional fibrosis) is available on all modern MRI scanners.

Quantitative $T_1$ and $T_2$ imaging (diffuse fibrosis and edema) is increasingly available – will be on all next generation scanners.

Studies in younger children still needed to determine normal/abnormal values.
MR Imaging of Blood Velocity and Flow

Phase-Contrast MRI – Measures Blood Velocity in all Directions

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MR Imaging of Blood Velocity and Flow

5 yrs of age
Hypoplastic Left Heart Syndrome
Post Fontan Operation
MR Imaging of Blood Velocity and Flow

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Calculation of timing parameters (acceleration time)

MRI-Volume measurements known to have systematic errors (10%)
MR Imaging of Blood Velocity and Flow

Other Applications:
Visualization of Blood Flow
MR Imaging of Blood Velocity and Flow

Other Applications:
Visualization of Blood Flow

PAH Patient

MR Imaging of Blood Velocity and Flow - Summary

*Phase-Contrast blood velocity imaging is available on all modern MRI scanners*

*Similar to Color Doppler with Echocardiography (standard metrics, e.g. acceleration time)*

*Offers unique 3-Dimensional flow imaging.*

*Data-processing tools do exist but are not generally available (research)*
Magnetic Resonance Angiography

MR Pulmonary Angiography (contrast enhanced) is well established in the clinic with significant improvements in the last decade

Pulmonary MR Angiography Techniques and Applications

Elizabeth M. Hecht, MD*, Andrew Rosenkrantz, MD

KEYWORDS
- Magnetic resonance angiography
- Pulmonary
- Pulmonary embolism
- Thoracic

Department of Radiology, New York University School of Medicine, 560 First Avenue, TC-W2003, New York, NY 10016, USA
* Corresponding author. Email address: elizabeth.hecht@nyumc.org (E.M. Hecht).


*Courtesy of Dr. Scott Reeder, University of Wisconsin

Magnetic Resonance Angiography
Lumenography (1-2 mm spatial resolution)
Magnetic Resonance Angiography
Qualitative assessment of perfusion

*Magnetic Resonance Angiography

Summary

Pulmonary angiography with MRI has improved significantly in recent years (faster and higher resolution) - similar sensitivity and specificity to computed tomography (CT) for the detection of thrombus.

Excellent for visualization of characteristic patterns (pruned arteries in PAH)
Lung Perfusion and Ventilation - MRI

1) Regional Perfusion (Delivery of Blood to Capillaries/Tissue)
   • Contrast Enhanced
   • Non-Contrast (Arterial Spin Labeling)

2) Spatially Matched Regional Ventilation

Contrast-Enhanced Lung Perfusion

Pulmonary Blood Flow (PBF) – Estimated using the rate and extent of MRI signal enhancement immediately following an injected contrast agent (indicator dilution theory)

\[
C_{\text{Tissue}}(t) = PBF \int_0^1 C_{\text{Artery}}(t) \otimes R(t - \tau)d\tau
\]

\[
PBF = \frac{\int_0^1 C_{\text{Tissue}}(t)dt}{\int_0^1 C_{\text{Artery}}(t)dt}
\]

\[
MTT = PBV / PBF
\]

Blood Flow (PBF) – calculated from arterial(input) and tissue contrast agent concentrations
**Contrast-Enhanced Lung Perfusion**

*Sample Perfusion Time Intensity Curves*

*Patient with iPAH (axial slices)*

*Images acquired every 600 ms following injection of standard contrast agent (Gd-DTPA)*

*Calculate perfusion using measured $C_{Tissue}(t)$ and $C_{Artery}(t)$*

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*Contrast-Enhanced Lung Perfusion*

*Pulmonary Blood Flow (PBF) images are calculated using the $C_{Tissue}(t)$ time curves in each pixel.*

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*MR Angiogram*

*Low Flow Region*

*RA*  
*PA*

*MR Perfusion Image (PBF)*

*High Flow Region*
**Case Study: Pre-Thromboarterectomy**

Upper Right Lung
No Visible Arteries

**Case Study: 1 Week Post-Thromboarterectomy**
**Case Study: 3 Months Post-Thromboarterectomy**

Lung Perfusion without Contrast Agents (Arterial Spin-Labeling)

*Pulmonary Blood Flow (PBF) – Estimated using the reduction in MRI signal intensity with labeling (saturation) of MRI signal in the arterial blood.*
Imaging Ventilation with MRI

1) Direct quantification of lung deformation during breathing

2) Changes in MRI signal intensity with breathing – Imaging Ventilation indirectly by measuring regional changes in water density

Image morphing is used to correct for breathing deformation of the lungs (reflects regional changes in volume – ventilation)

Validation: Comparison with Spirometer
Imaging Ventilation with MRI

2) Changes in MRI signal intensity with breathing - Imaging Ventilation indirectly by measuring regional changes in water density

![Diagram showing changes in MRI signal intensity with breathing](image)

- Ventilation Image
- Perfusion Image

Example – Ventilation and Non-Contrast Perfusion in a patient with iPAH

- MR Angiogram
- Sagittal Slice

Ventilation and perfusion images acquired in ~30 seconds without the need for breath-holding or contrast

Ventilation is ~2 times larger than perfusion
Summary

In a 45 minute study, MRI offers:

- RV anatomy and function (standard)
- RV tissue characterization (standard/emerging)
- Pulmonary Angiography (standard)
- Doppler-like blood velocity imaging (standard)
- 3D blood flow visualization and analysis (emerging)
- Contrast-enhanced perfusion (emerging)
- Non-Contrast perfusion and ventilation (emerging)

Clinicians and Imaging Scientists/Radiologists Need to Work Closely Together: Emerging→Standard

MRI Offers Single Stop Diagnostics and Novel Endpoints Based on both RV and Pulmonary Function

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