Magnetic Resonance Imaging Evaluation of Pulmonary Artery Hypertension and Regurgitation

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I will discuss the use of a medical device/drug that is classified by the Food and Drug Administration (FDA) as investigational for the intended use.

I do not have any relevant financial relationships with any commercial interests.

*Cardiovascular MRI (CMRI)*:

Capable of providing complementary and unique evaluation techniques useful in comprehensive assessment of right ventricular mechanics, pulmonary circulation and structural abnormalities with multi-dimensional or dynamic illustration formats.

*I. Pulmonary Hypertension*:

A disorder characterized by abnormally elevated blood pressure and resistance within the pulmonary circulation. A potentially life-threatening chronic progressive disorder that leads to right heart failure and the development of functional limitations and potential and untimely death. It results in RV remodeling with dilatation, hypertrophy and leftward septal bowing.
**Diagnostic Categories:**

*Pulmonary Artery Hypertension (PAH)*

A. Primary / Idiopathic – PAH  
B. PAH with left-sided heart disease  
C. PAH with lung disease / hypoxemia  
D. PAH and chronic thrombotic / embolic disease  
E. Miscellaneous

*Emerging role (CMRI) Magnetic Resonance Imaging Diagnosis and Management of Pulmonary Hypertension*

*CMRI - advantages over other methods:*

**Cine** - volumetric and functional variables; RV volumes, mass, stroke volume, ejection fraction and cardiac output  
**Impaired RV contractility and function** - ventricular septal bowing and pressure-volume loops  
**Flow-derived parameters** - peak velocity, acceleration time and volume, pulmonary flow profile using velocity-encoded imaging may detect signs of remodelling  
**MR angiography** – pulm perfusion and thrombo-embolic lesions; monitor disease, evaluate new therapeutic approaches. Delayed enhancement imaging.

*Ventricular Mass Index Using Magnetic Resonance Imaging Accurately Estimates Pulmonary Artery Pressure*

CMRI provides accurate means of estimating PA pressure, possibly more accurate than Doppler. This may reflect RV response to chronic PAH and is not influenced by short-term variables - heart rate, posture, hydration, oxygen supplement) which may effect echo.
Ventricular Mass Index Using Magnetic Resonance Imaging Accurately Estimates Pulmonary Artery Pressure

Extent of MRI Delayed Enhancement of Myocardial Mass is related to RV Dysfunction in Pulmonary Artery Hypertension

Delayed enhancement (DE) of the myocardium. 15 pts with PAH (45.6 +/- 13 yrs; 13 NYHA III (11 idiopathic, 4 systemic sclerosis)). Pressures (54 +/- 16 mm Hg) - confirmed at catheterization. CMRI (1.5-T) w MDE 10-20 min post 0.2 mmol/kg, gadopentetate. All showed hyper-DE at insertion points of the RV free wall to the interventricular septum, (15 inferior, 13 anterior).

McCann,G. et al., Am J Roentgenol. 2007 Feb;188(2):349-55

Extent of MRI Delayed Enhancement of Myocardial Mass related to RV Dysfunction in Pulmonary Artery Hypertension

The extent of MDE was Inversely related to:
RV ejection fraction (r = -0.63, p = 0.001).
RV stroke volume (r = -0.67, p = 0.006),
RV end-systolic volume index (r = -0.51, p = 0.05).

MDE occured frequently in pts with severe symptomatic PAH and was inversely related to measures of right ventricular systolic function.

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Quantitative pulmonary perfusion from 3D dynamic contrast enhanced MR perfusion data - to assess primary pulmonary hypertension (PPH) as indicated by pulmonary vascular resistance (PVR) and mean pulmonary artery pressure (MPAP).
Comparison of Quantitative Pulmonary Perfusion Parameters Between Healthy and Primary Pulmonary Hypertension (PPH)

- Pulmonary blood flow (mL/100 mL/min) 129.6 ± 14.6 vs. 70.9 ± 10.0a < 0.0001
- Pulmonary blood volume (mL/100 mL) 10.1 ± 2.5 vs. 8.8 ± 1.0 0.09
- Mean transit time (s) 4.7 ± 0.9 vs. 7.6 ± 0.8a < 0.0001

Significant difference compared with healthy volunteers (p < 0.05).

1. PAH - causes RV remodeling; dilatation, hypertrophy, left septal bowing (LSB).
2. PE - effects restoration of RVR in CTPH.

17 pts. before and >/= 4 months post PE were c/w 12 controls

- RV and LV end diastolic and systolic (ESV) volumes, mass (gm/m2)
- and LSB (1 / radius of curvature (cm) were determined by MRI.

**RESULTS:** RV/ LVEDV-ESV, mass, and LSB differed between CTPH and controls.

- Post PE: Hemodynamics improved; volumes and LSB normalized; RV mass decreased (46+/14 to 31+/9 g x m(-2), P< .0005), did not normalize.
- Change in pulmonary resistance correlated with RVEF (r = 0.50, P < .05), RV mass (r = 0.63, P < 0.01), and LSB (r = 0.50, P < .05).

**CONCLUSIONS:** RVR in PAH can restore after PE. CMRI is a valuable in evaluation of remodeling / function in patients with PAH.

**Estimation of Pulmonary Vascular Resistance by MRI Patients with Congenital Cardiovascular Shunt Lesions**

- CMR signal Intensity (PA’s) assessed. ECG-gated spin-echo images-near end diastole; the signal disappeared in systole.
- Ten (10) severe PAH pts (sys press > 80 mmHg) elevated PVR (>787 dynes cm sec1) signal persisted in systole.

**RESULTS:**

- Intensity (quantitative) had direct linear relationship with PVR in PA (r = 0.84).
- Correlation (linear) between ratio PVR/SVR and signal in the right PA (r = 0.93).

Thus, MR sensitivity to slow-flow conditions can provide clinical information in disease states with severe elevation of PVR c/w normal volunteers.
**Value of MR Phase-Contrast Flow Measurements Functional Assessment of PA Hypertension**

Pulmonary hemodynamics - 25 volunteers and 25 pts with PAH at 1.5 T. Phase-contrast flow in asc aorta - pulmonary trunk c/w echo and cath:

**PAH patients:**
Reduced pulmonary flow velocities (P = 0.002),
Reduced blood flow volumes (P = 0.002)
Reduced pulmonary artery distensibility (P = 0.008).
Shorter time to peak velocity in PA’s (P<0.001)
Steeper velocity rise gradient (P = 0.002).
Significant broncho-systemic shunt (P = 0.01).

No correlation found between MRI, Echo or Cath.

**Pulmonary Arterial Hypertension: Noninvasive Detection with Phase-Contrast MR Imaging**

Retrospective study - PAH flow parameters using PCMRI
Fifty-nine pts (49 f ; mean age, 46 yrs; range, 16-85 yrs) breath-hold PCMRI and cath. PAH (mean pa pressure [mPAP], >25 mm Hg) confirmed in 42 pts.

Statistics-Spearman rho, curve analysis, and Bland-Altman plots.

**RESULTS:**
Avg flow velocity: mPAP, sPAP, PVRI
(r = -0.73, -0.76, -0.86, respectively; P < .001).  
Avg velocity (cutoff value = 11.7 cm/sec) 
PAH sensitivity 92.9% (39 of 42), specificity 82.4% (14/17).  
Sensitivity and specificity for the minimum PA area (cutoff value = 6.6 cm(2)), 92.9% (39 of 42) and 88.2% (15 of 17), respectively.

**CONCLUSION:**
The average blood velocity throughout the cardiac cycle is strongly correlated with pulmonary pressures and resistance.
Noninvasively Assessed Pulmonary Artery Stiffness Predicts Mortality in Pulmonary Arterial Hypertension

Compliance of pulmonary vascular bed and mortality in PAH
Eighty-six pts -cath and MRI / followed up to 48 mos. 70 pts w PAH.

PA’s of PAH pts distended (685+/-214 mm2 vs 411+/-153 mm2, p < 0.001),
less distensible (area distens=0.46+/-0.38.10(-2) mm Hg(-1) vs 3.69 +/-
1.96.10(-2) mm Hg(1), p < 0.0001), Relative area change (RAC) smaller (20+/-
10% vs 58 +/- 21%, p <0.0001) [mean +/- SD].
RAC showed inverse relation with mean PA pressure (R2 = 0.47).

Eighteen pts (26%) died / cardiopulmonary. Pts with RAC <or=16%,
worse prognosis than value >16% (log-rank p < 0.001).
RAC - predicted mortality better than distensibility.

CONCLUSION: Noninvasively measured PA RAC predicts mortality in patients with PAH.
Kaplan-Meier plot, Cox proportional hazards regression analyses.

Non-Invasive Stroke Volume Assessment in Pulmonary Arterial Hypertension: Left-Sided Data Mandatory

Accuracy of stroke volume (SV) calculation from pulmonary flow curves. Thirty-four PAH pts w CMR and Cath. CMR-SV determined from PA flow; Left (LV), right ventricular (RV) volumes and aortic flow.
SV compared with invasive - Fick - method.

RESULTS:
CMR SV by PA flow versus Fick, r = 0.71, mean difference -4.2 ml, limits of agreement
26.8 and -18.3 ml. SV by LV volumes versus Fick, r = 0.95, mean difference -0.8 ml.,
limits of agreement of 8.7 and -10.4 ml. SV by RV volumes versus Fick, r = 0.73, mean
difference -0.75 ml., limits of agreement 21.8 and -23.3 ml.
In nine patients, SV by aorta flow versus Fick yielded r = 0.95, SV by pulmonary flow
versus Fick yielded r = 0.76. Regression analyses, p < 0.0001.

CONCLUSION: In conclusion, SV from PA flow - limited accuracy. LV volumes and aorta flow are preferred for measurement of SV.
Pulm Vasc Resistance determined w venc MRI pulm (PA) volumes and simultaneous cath PA pressures. MR Flow directed catheters guided - 1.5 T. Bland-Altman showed agreement between methods. Inter-exam variability high for thermodilution (6.2 (2.2)%), low for MRI (2.1 (0.3)%). MRI method applied in 10 patients with PHT, 5 controls. Baseline study and inhalation of nitric oxide.

Compared with controls; PVR significantly increased in the PHT group (1.2 (0.8) v 13.1 (5.6) Wood units.m2, p < 0.001). Decreased to 10.3 (4.6) Wood units.m2 w inhalation of nitric oxide (p < 0.05). Inter-examination variability of MRI PVR measurements was 2.6 (0.6)%. In all, MR flow directed catheters were successful under MRI.

**CONCLUSIONS:** Guidance of flow directed catheters is feasible under MRI. PVR can be determined with precision.
**II. Pulmonary Regurgitation**

Chronic Regurgitation and volume overload of the right ventricle leads to RV dilatation and dysfunction despite etiology. It is related to remodeling of the right ventricle and associated with the development of arrhythmias and increased risk of adverse clinical events. The late development of tricuspid regurgitation and chronic pulmonary congestion is related to further clinical decline. CMRI can be used to assess volume changes associated with increasing chamber size and provide serial information useful in surgical planning and assessment of therapeutic intervention.

*Influence of the Pulmonary Annulus Diameter on Pulmonary Regurgitation and Right Ventricular Pressure Load after Repair of tetralogy of Fallot*

*Differential Regurgitation in Branch Pulmonary Arteries after Repair of tetralogy of Fallot: Phase-Contrast Cine MR Study*

**Pulmonary Regurgitation: Not a Benign Lesion**

**CONCLUSION:**

Developments and innovations in PC-MRI has resulted in widely applicable methods for acquisition and analysis of flow, volume and cardiac function. Direct and simultaneous analysis through emerging X-MR studies are providing comparative data. These data and other studies are allowing for increasing application into the analysis of reactive pulmonary vascularity and resistance.

Higher spatial resolution is needed to reduce partial volume effects causely related to small vessel size. Problems with in plane flow, motion or dephasing (related to flow obstruction / turbulence) still provide challenges to accurate analysis.