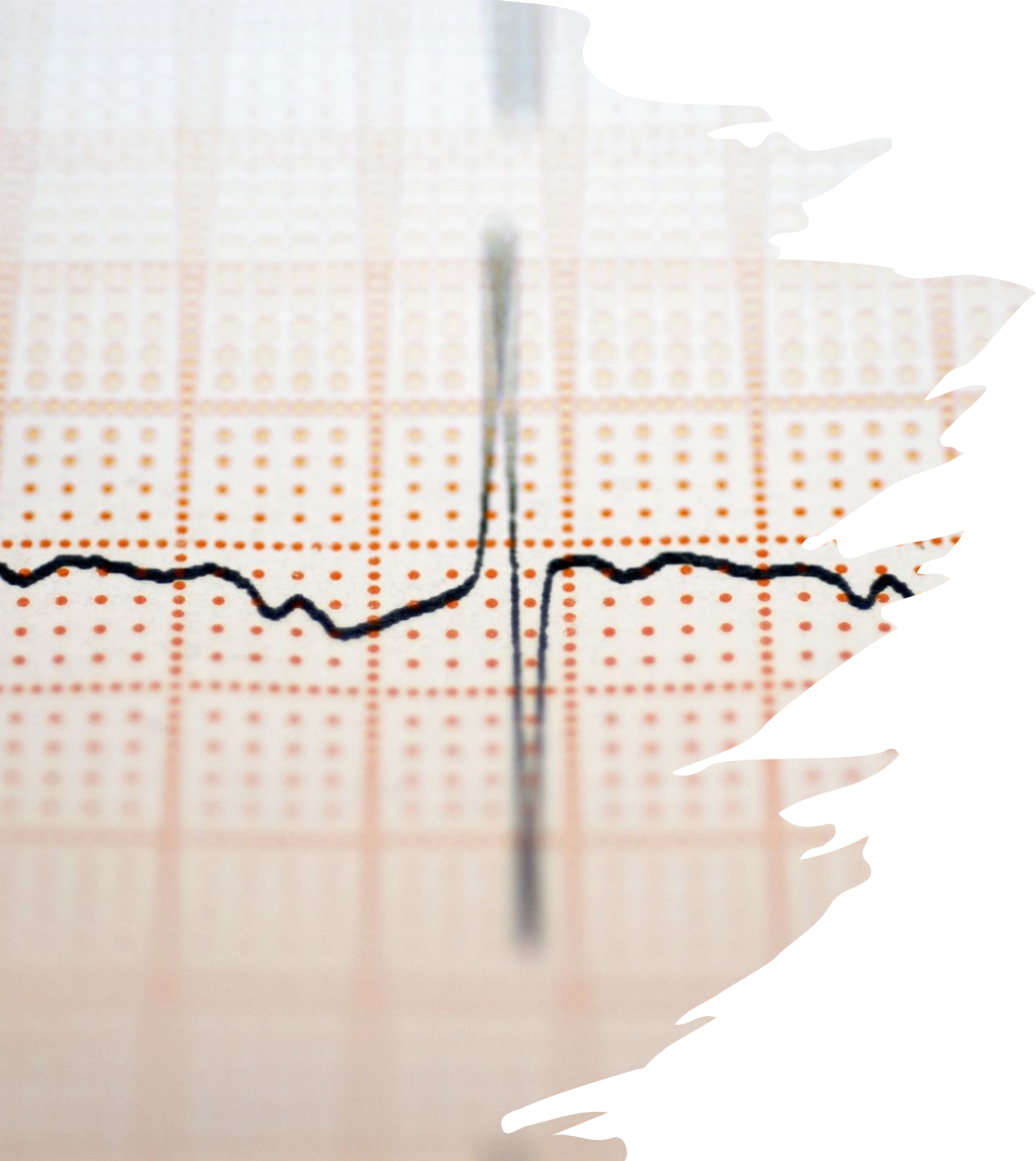
Cardiac MRI
Myocardial Perfusion

Ulrich Lindberg, M.Sc., Ph.d.
Department of Clinical Physiology, Nuclear Medicine and PET
Rigshospitalet, Copenhagen, Denmark

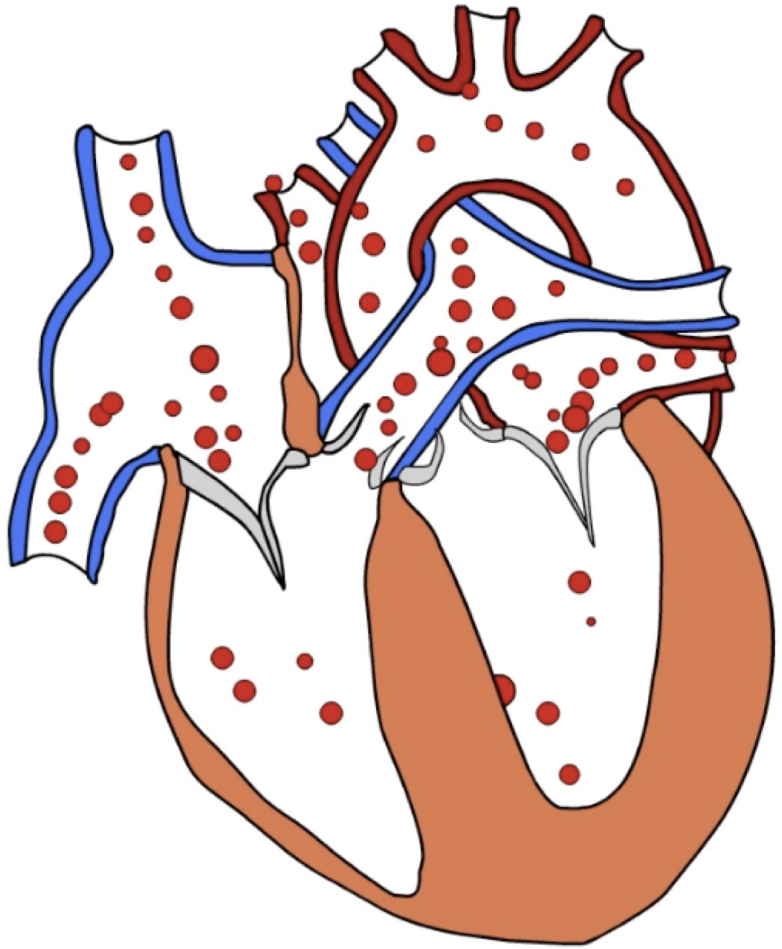


Outline

- Anatomy of the Heart
- Imaging
- MR Contrast Agent
- Tracer Kinetic Modelling
- Clinical Cases
- Summary

Heart Anatomy

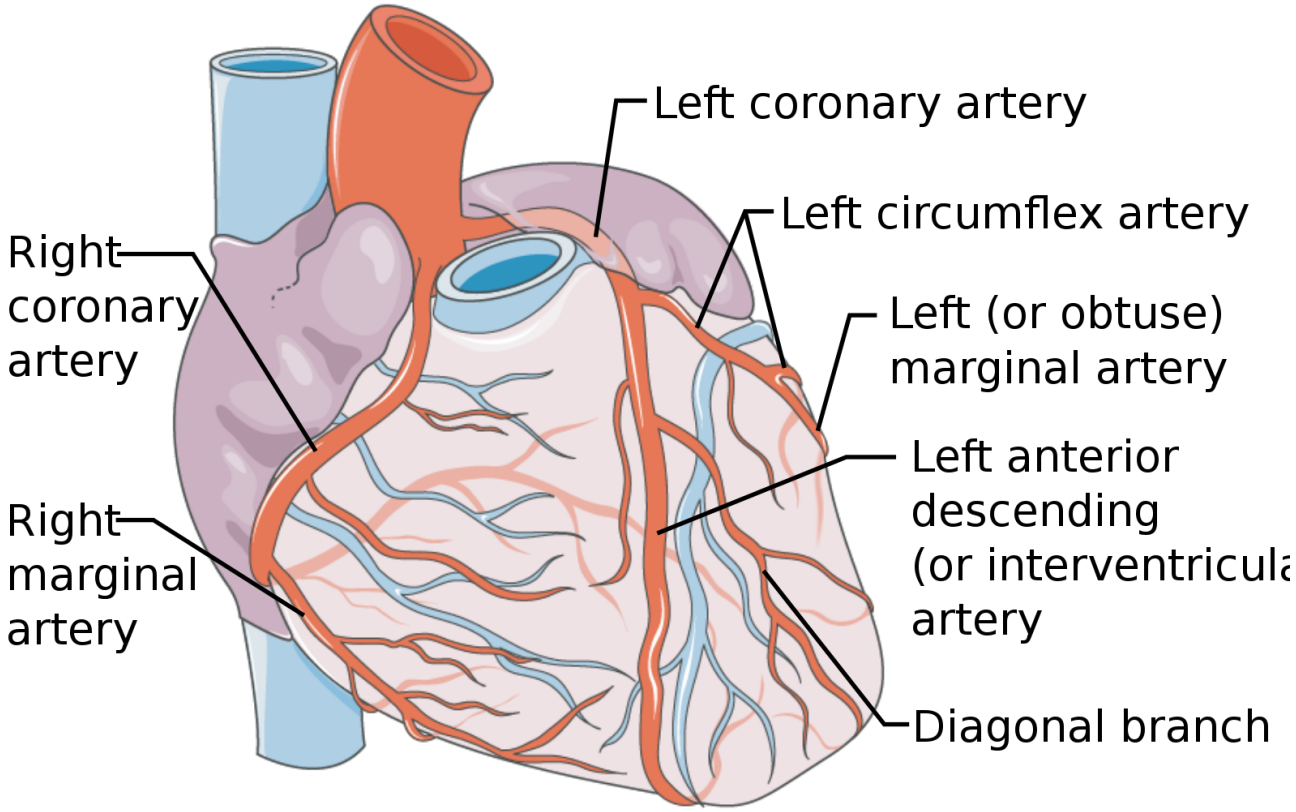
- 4 Chambers
  - Right atrium
  - Right Ventricle
  - Left Atrium
  - Left Ventricle
- 4 Valves
  - Tricuspid valve
  - Pulmonic valve
  - Mitral valve
  - Aortic valve
- Average heart beat 40-80 BPM
  - 100.000 beats every day
- During exercise up to ~200 BPM
- Myocardial blood flow (MBF) at rest
  - 1 mL/g/min



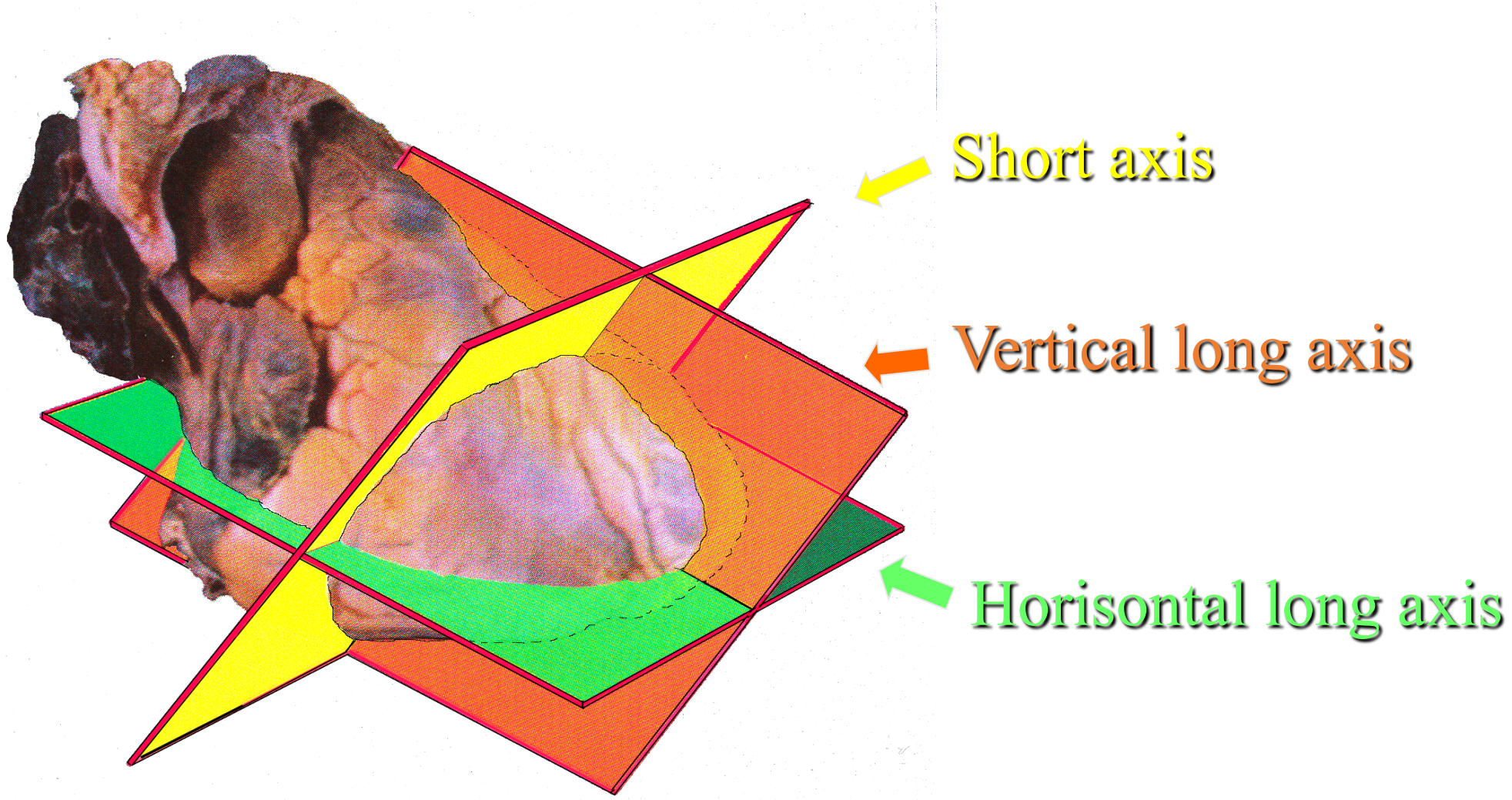
https://www.imaios.com/en/e-Courses/e-MRI/Cardiac-MRI

Heart Anatomy

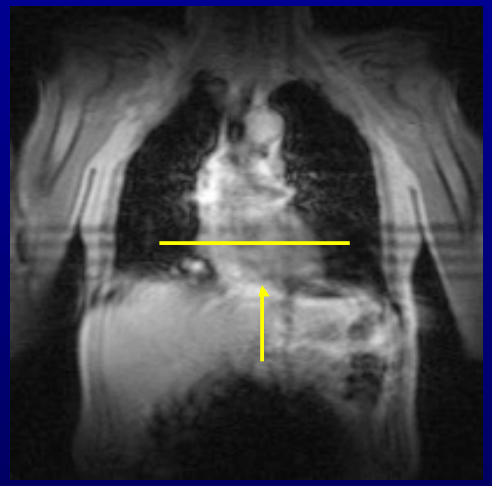
- Right coronary artery
  - supplies the right atrium and right ventricle
- Left main coronary artery
  - branches into the circumflex artery and the left anterior descending artery
  - The circumflex artery supplies blood to the left atrium, side and back of the left ventricle.
  - The left anterior descending artery supplies the front and bottom of the left ventricle and the front of the septum

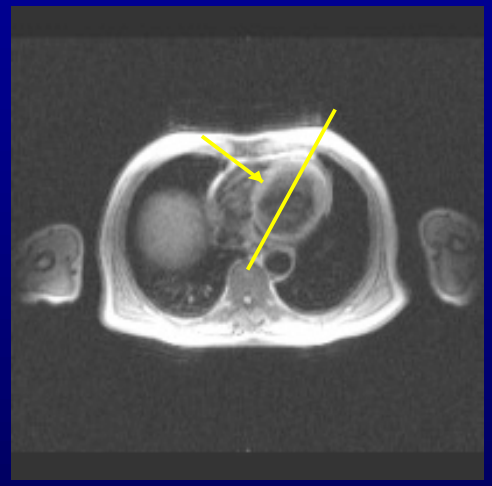


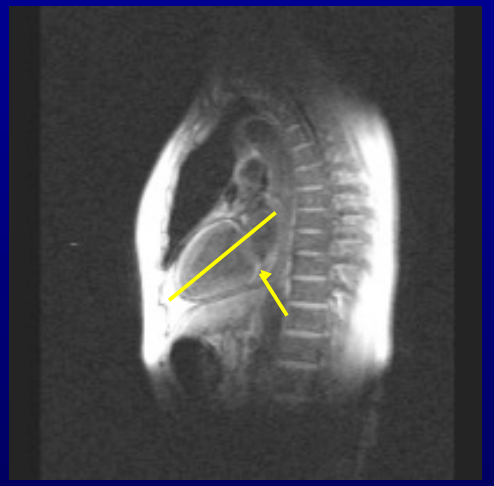
Imaging planes

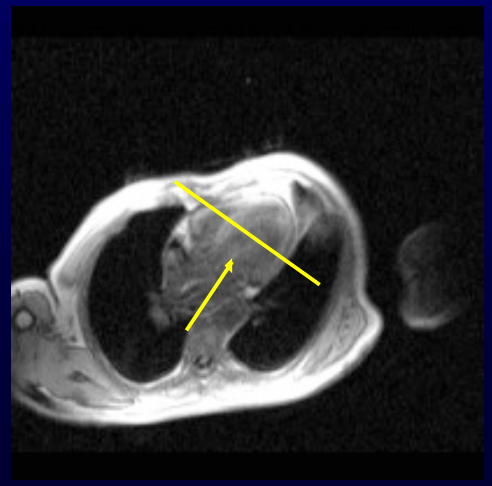


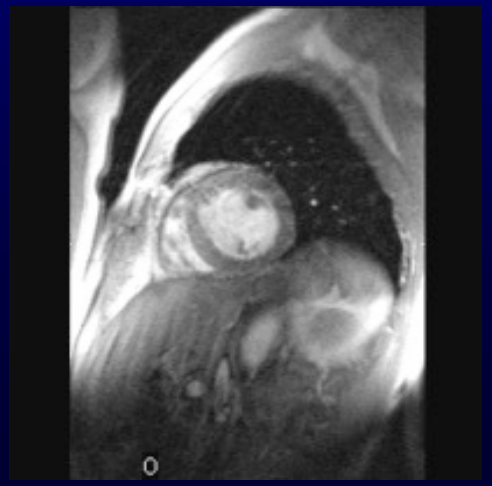
MR: How to select the image plane





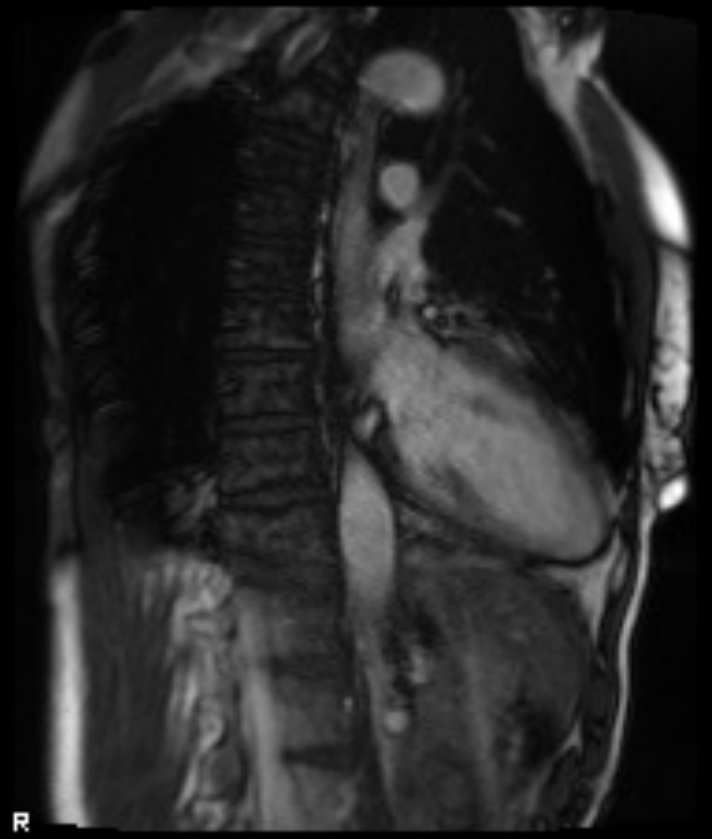






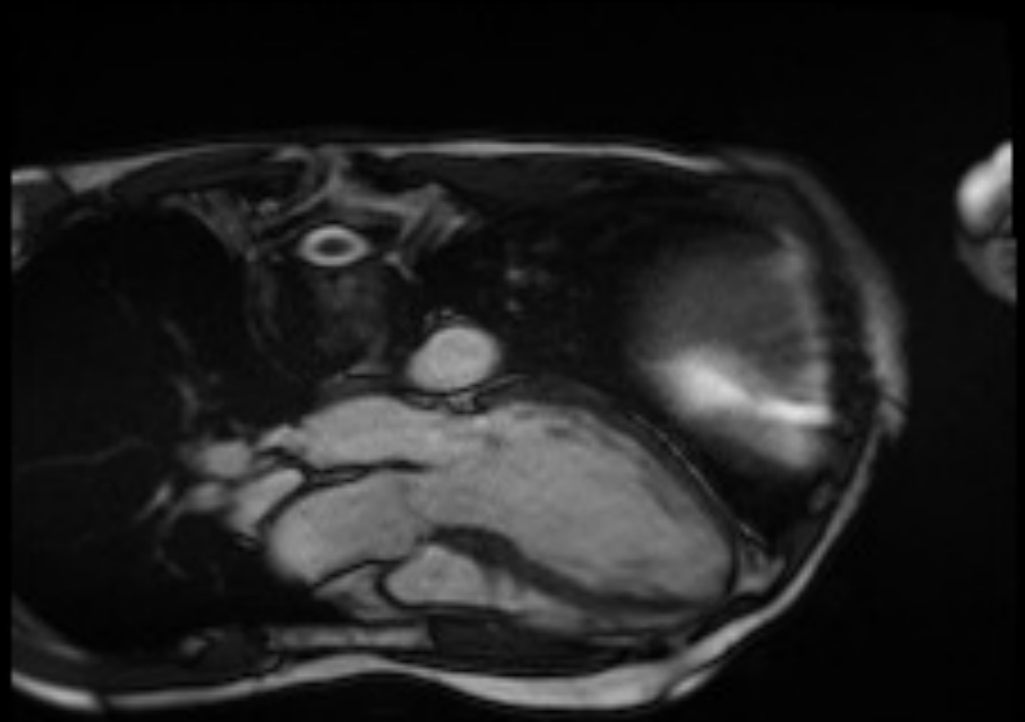
2 chamber view

- Left Atrium(LA)
- Left Ventricle (LV)



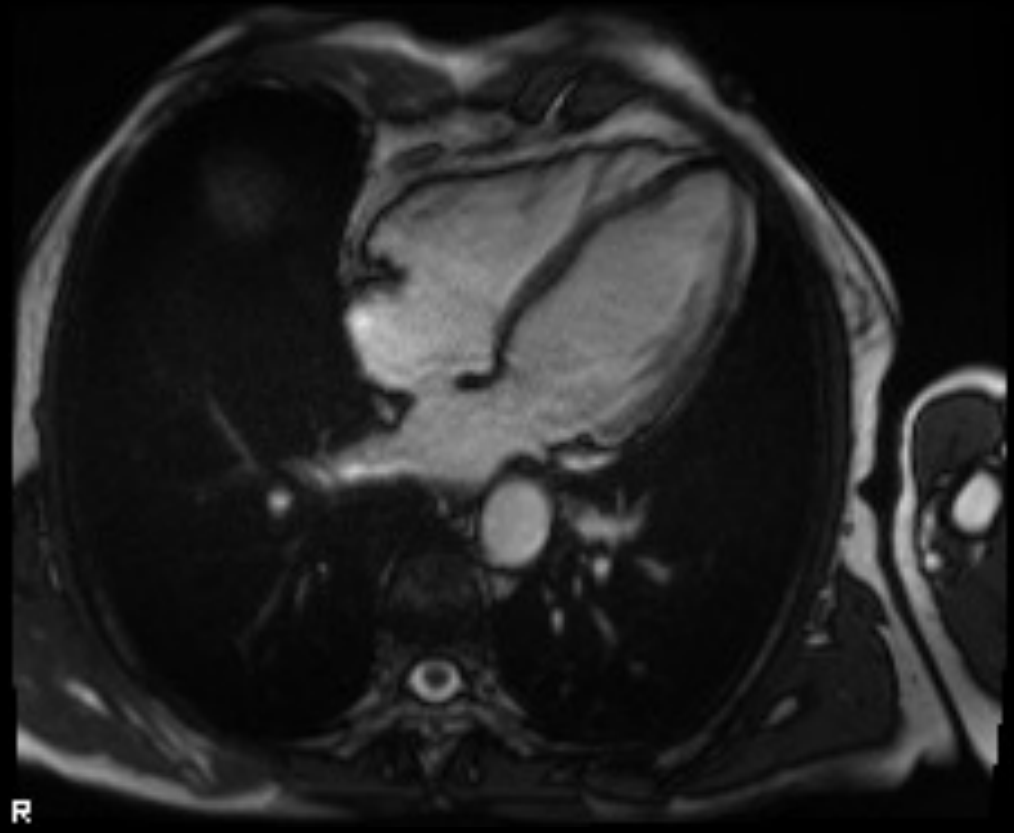
3 chamber view

- Left atrium (LA)
- Left ventricle (LV)
- Aorta (AO)



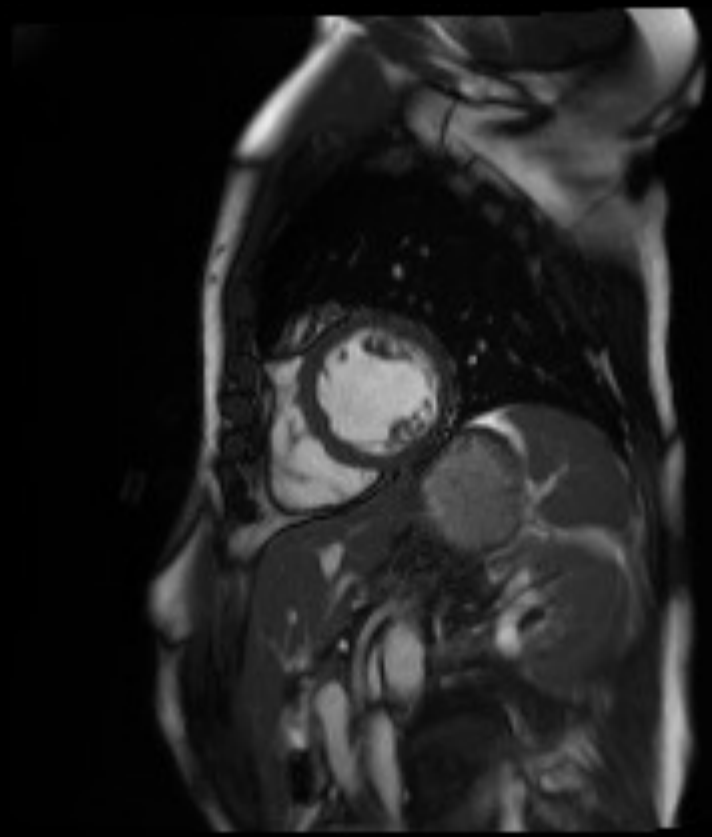
4 chamber view

- All 4 chambers
  - Right Atrium (RA)
  - Right Ventricle (RV)
  - Left Atrium (LA)
  - Left Ventricle (LV)



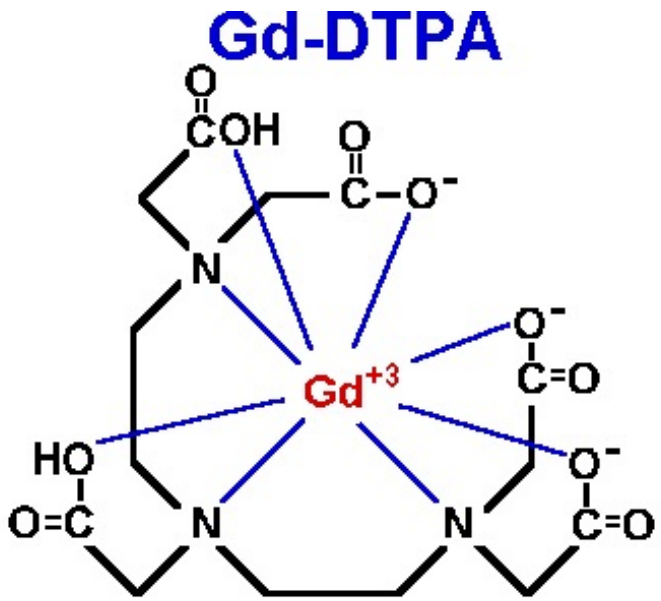
Short axis

- Left ventricle (LV)
- Right ventricle (RV)



MR Contrast agent

- Gadolinium
  - Toxic
  - Chelated in cyclic structure
- Paramagnetic properties
  - Interacts with water molecules
  - Increases relaxation speed
- MR contrast
  - Increased T1 signal (Signal Gain)
  - Decreased T2* signal (Signal Loss)



MR Contrast Agent

- Linear effect until a certain point
- Correction for non-linearity needed
  - Additional acquisition of T1 map

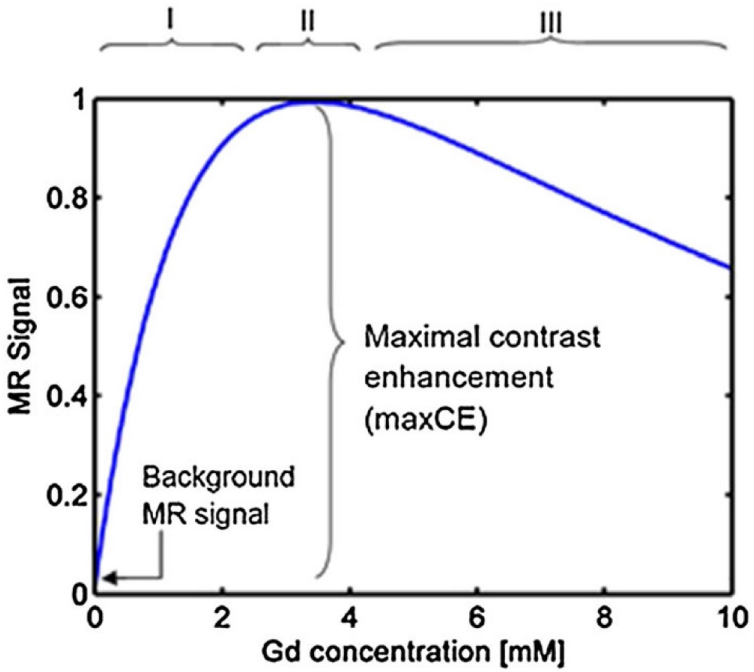
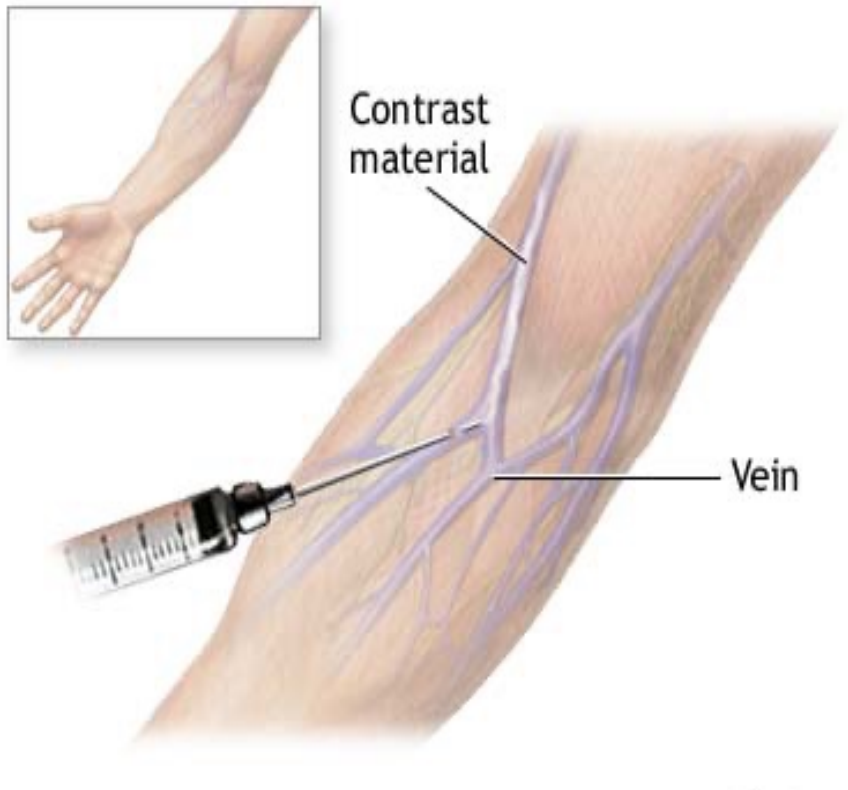


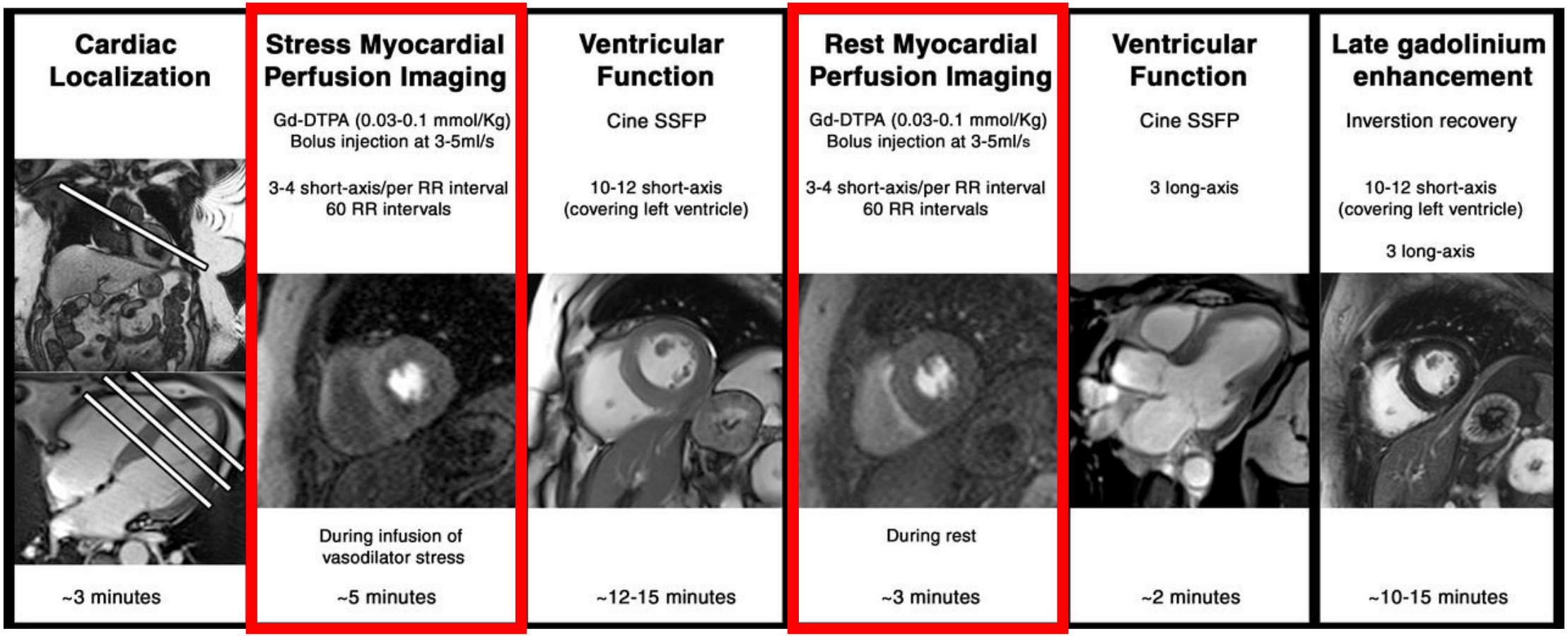
Figure 1. T_1-weighted MR signal as a function of gadolinium concentration. Three ranges can be identified: I, linear and nonlinear signal increase; II, plateau; III, T_2 or T_2*-related signal decay. The maxCE corresponds to the maximal contrast enhancement and is defined as the difference in MR signal between the unenhanced background signal level and the signal level of enhanced tissue at the plateau, II.

Hagberg et al. 2013, DOI: 10.1002/cmmi.1565

Cardiac MRI Examination

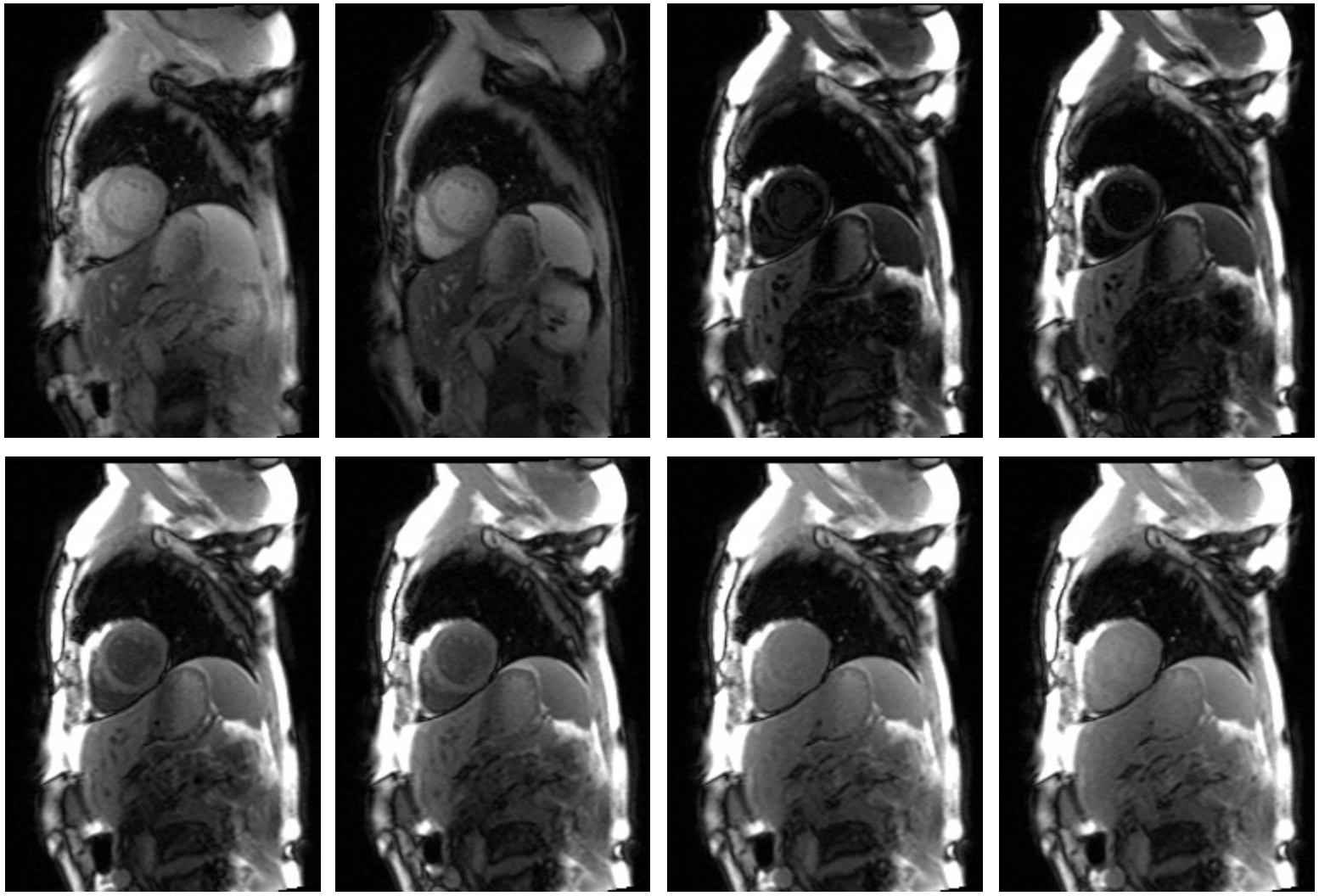


Cardiac MRI Examination

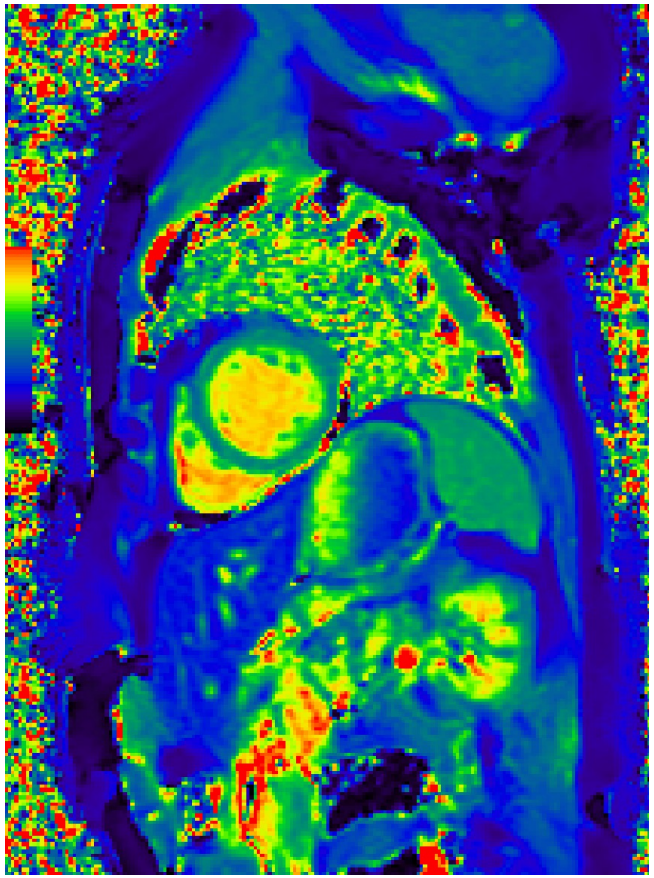


Coelho-Filho et al., 2013, DOI: 10.1148/radiol.12110918

T1 mapping

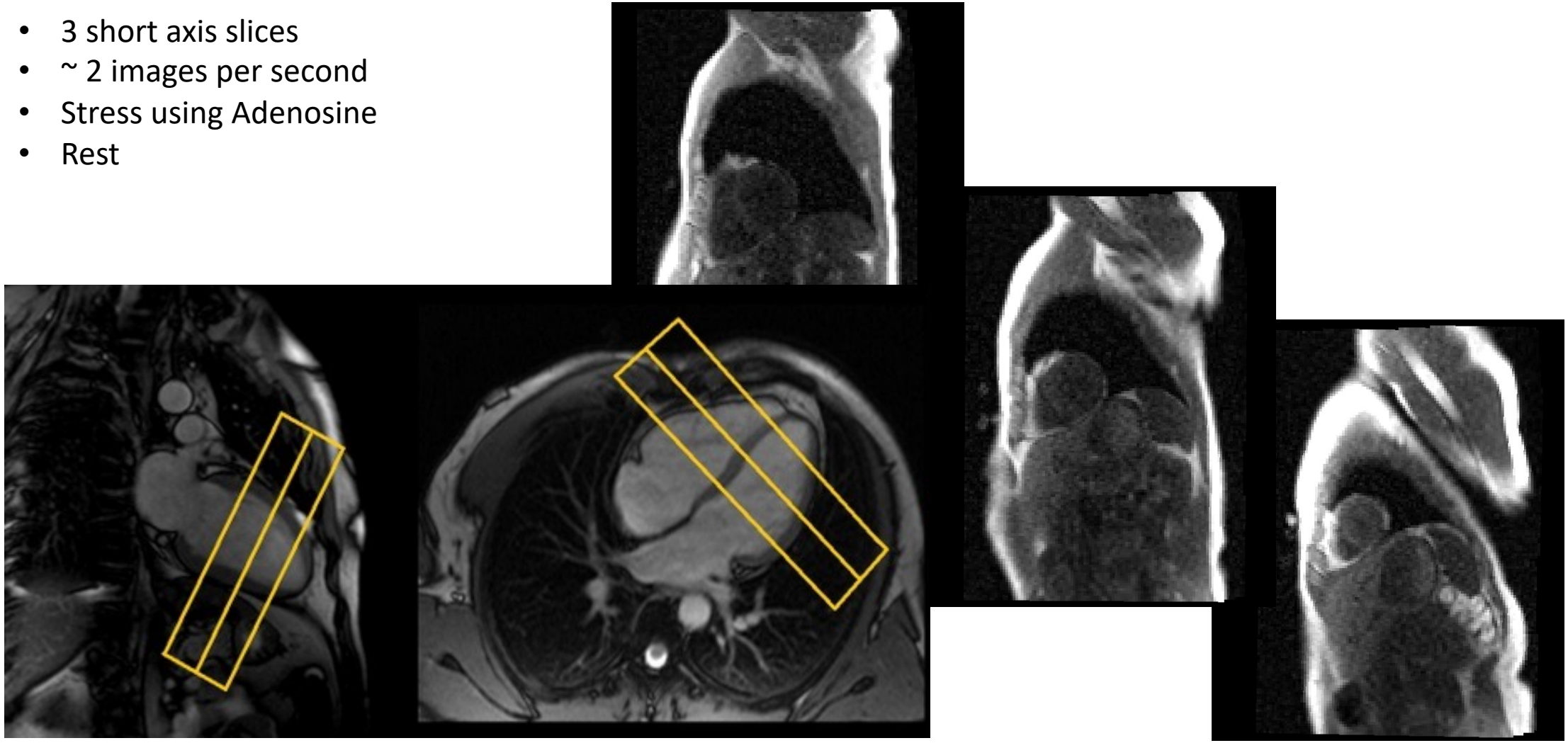


T1 Map
Range: [0-2 sec]



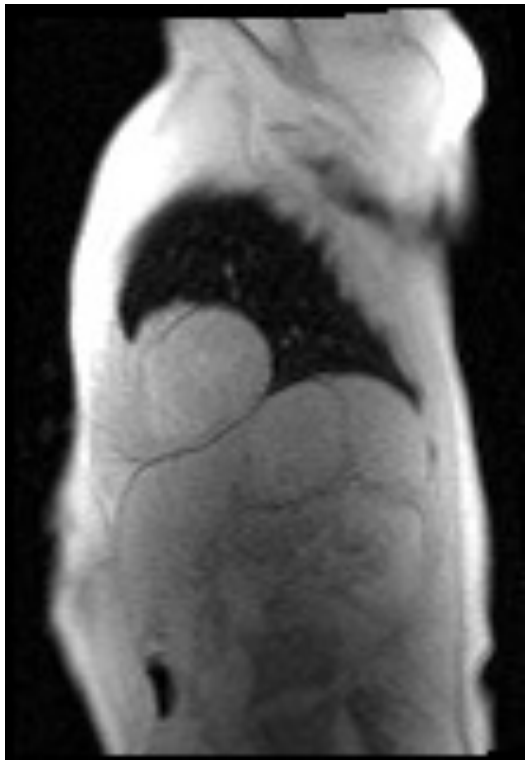
Myocardial Perfusion Imaging

- 3 short axis slices
- ~ 2 images per second
- Stress using Adenosine
- Rest

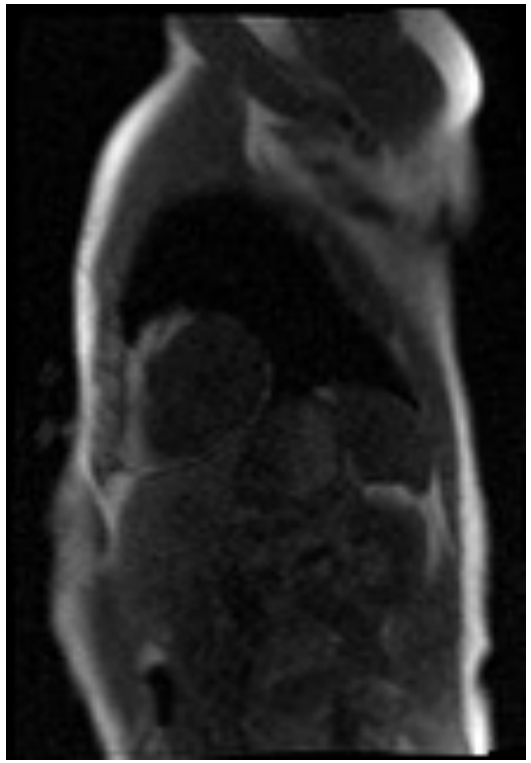


Myocardial Perfusion Imaging

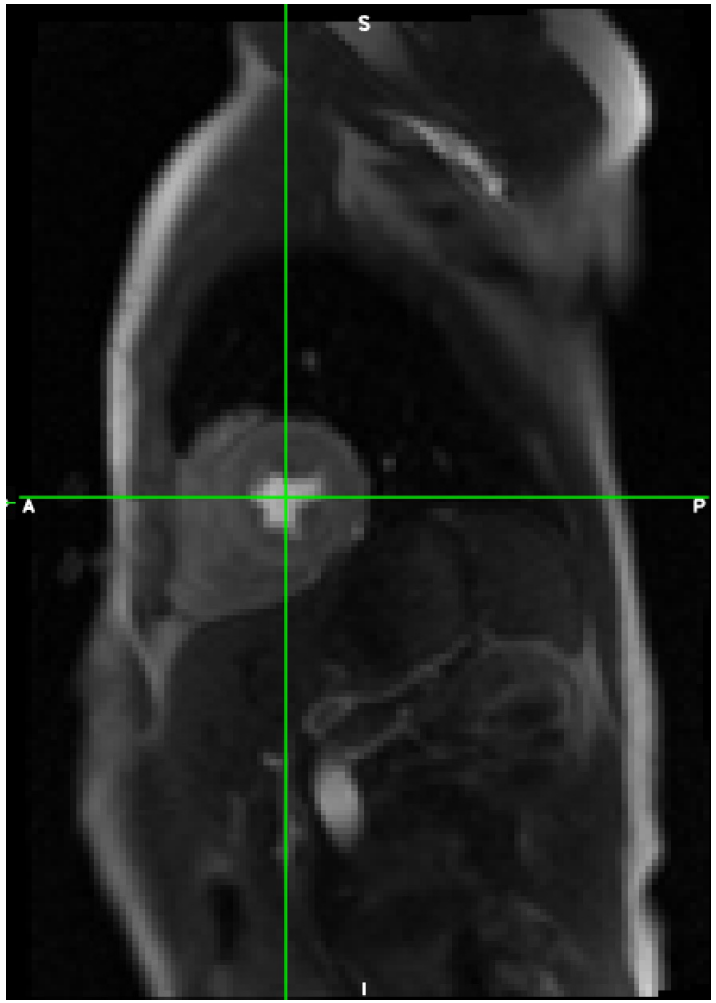
Raw data



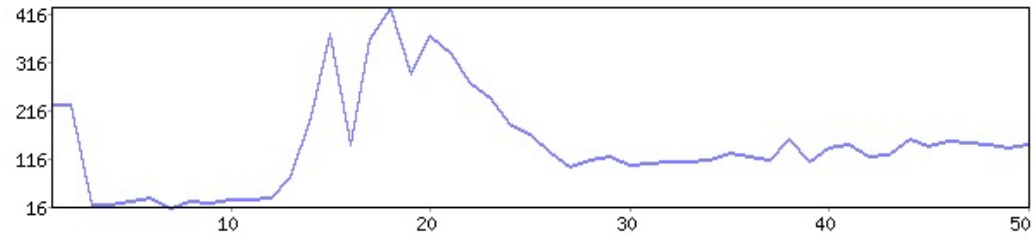
Motion Corrected and filtered



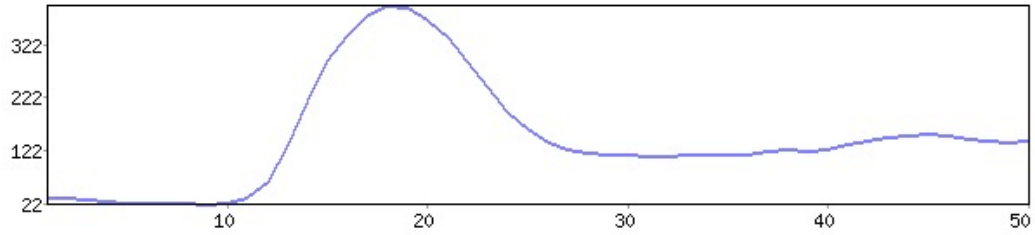
Arterial Input Function (AIF)



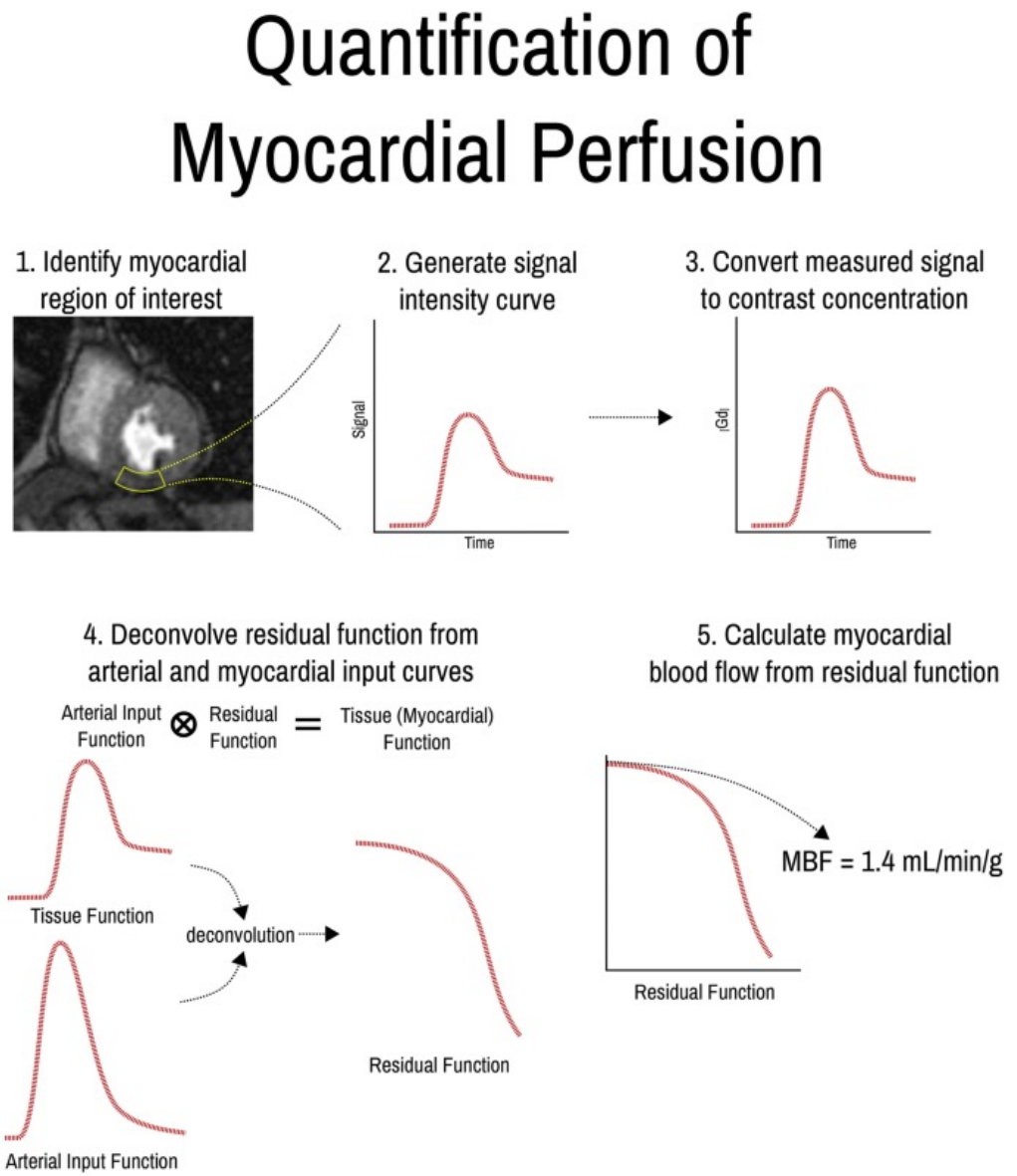
Raw data



Motion Corrected and filtered

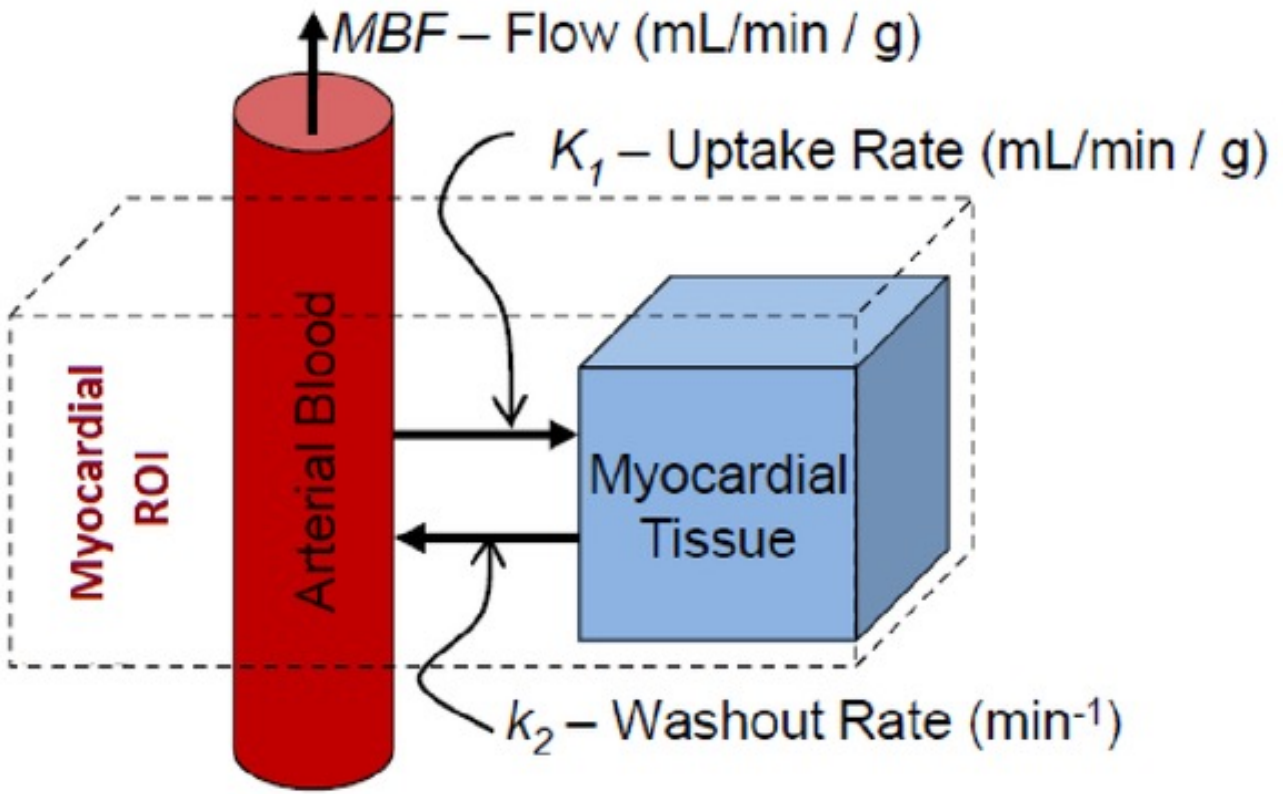


Tracer Kinetic Modelling



Robinson et al, 2019, Cardiac Magnetic Resonance (E Nagel and V Puntmann, Section Editors)

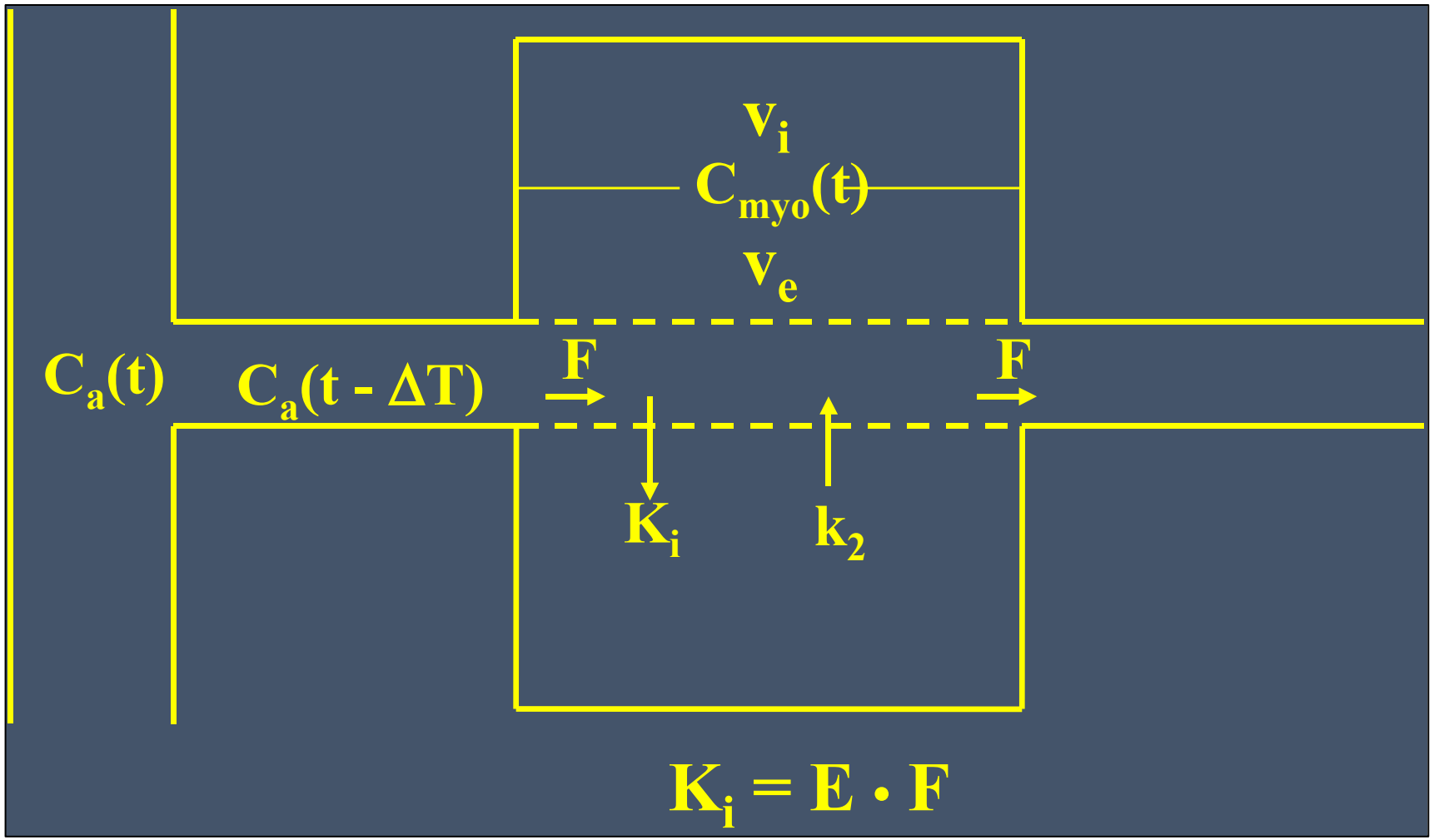
Tracer Kinetic Modelling



Mohy-ud-Din, 2014, SPIE DOI: 10.1117/12.2043947

Tracer Kinetic Modelling

2 compartment model



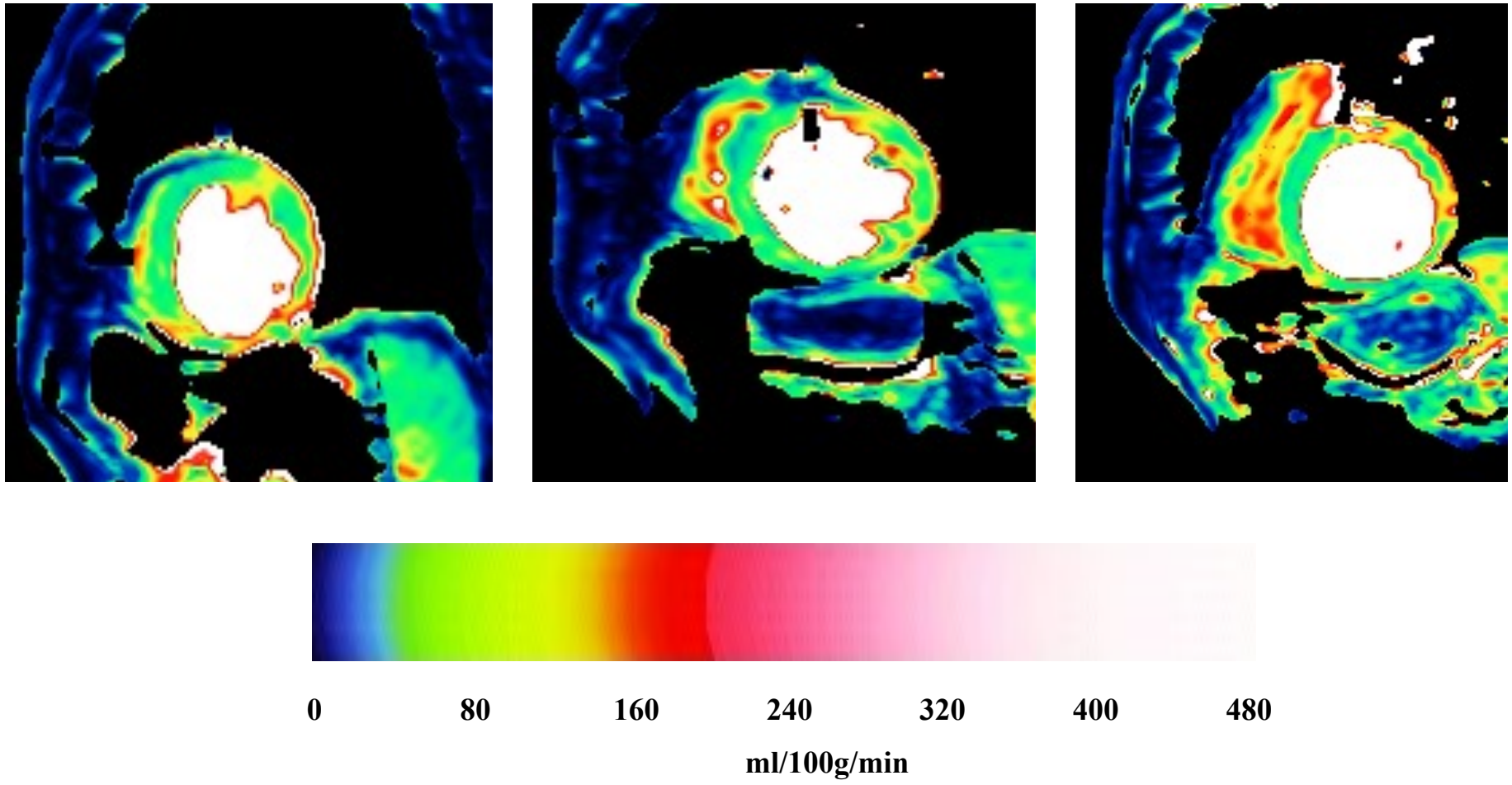
Extraction in myocardium is ~60%

Perfusion limited

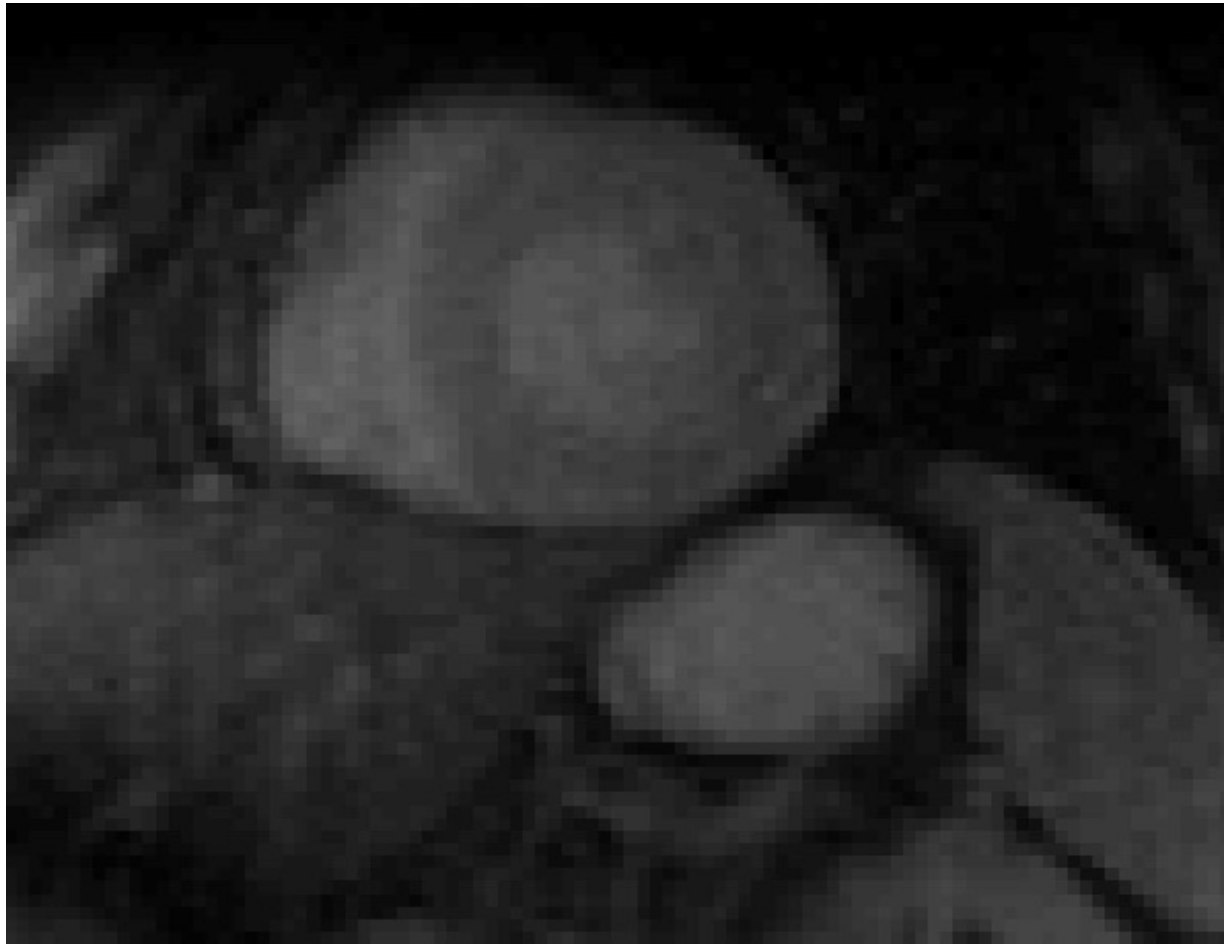
Model	Output parameters	Impulse response function (IRF)
Distributed parameter	F, PS, MTT_c, MTT_e, v_p, v_e	Not available in time domain
Tissue homogeneity	F, E, MTT_c, v_p, v_e	
Adiabatic approximation of tissue homogeneity	F, E, MTT_c, v_p, v_e (assuming $v_p \ll v_e$)	See Figure 5(a) $\mathrm{IRF}(t) = \begin{cases} F, & 0 < t \leq \frac{F}{v_p} \\ EF\exp^{-(EF/v_e)(t)}, & t > \frac{F}{v_p} \end{cases}$
2-compartment	F, PS, v_p, v_e	See Figure 5(b) $\mathrm{IRF}(t) = F\exp^{-(F/v_p)(t)} + \mathrm{PS}\exp^{-(\mathrm{PS}/v_e)(t)}$
1-compartment (Extended Toft's)	K_{trans}, v_p, v_e	See Figure 5(c) $\mathrm{IRF}(t) = K_{\mathrm{trans}}\exp^{-(K_{\mathrm{trans}}/v_e)(t)} + v_p\partial(t)$
1-compartment (Toft's)	K_{trans}, v_e (assuming $v_p \ll v_e$)	See Figure 5(d) $\mathrm{IRF}(t) = K_{\mathrm{trans}}\exp^{-(K_{\mathrm{trans}}/v_e)(t)}$
Fermi	F, MTT_c, k (in extravasating contrast agent, only F is of physiological value)	See Figure 5(e) $\mathrm{IRF}(t) = \frac{F}{\exp^{k(t-\mathrm{MTT}_c)} + 1}$
Model-independent deconvolution	F (estimated as initial IRF magnitude)	No specific formulation

F: perfusion rate.
PS: extracellular extravascular space (EES) exchange rate.
MTT_c: capillary mean transit time.
MTT_e: EES mean transit time.
v_p: EES volume fraction.
v_e: intravascular plasma volume fraction.
K_{trans}: compound transfer constant (perfusion and EES exchange).
k: venous clearance rate for intravascular contrast agent.

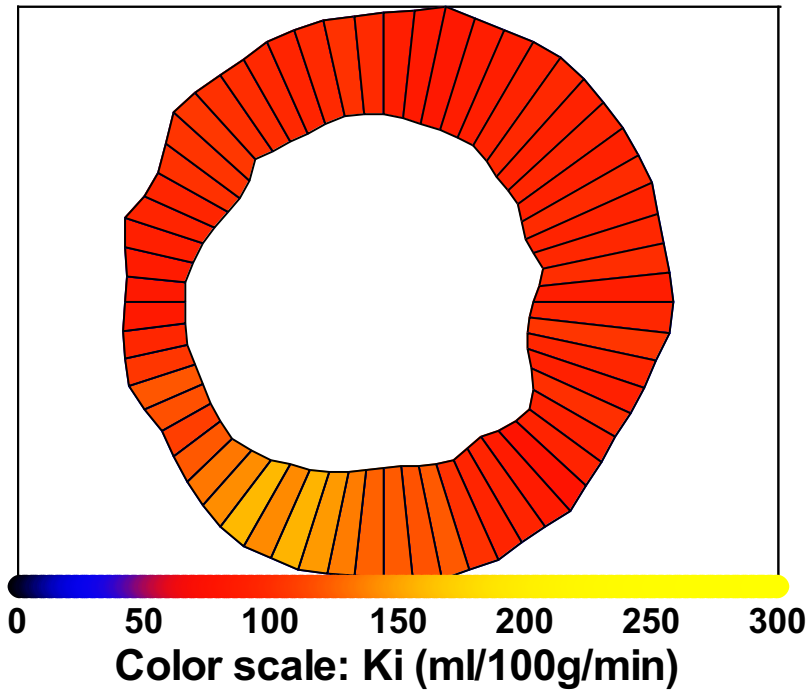
Perfusion map

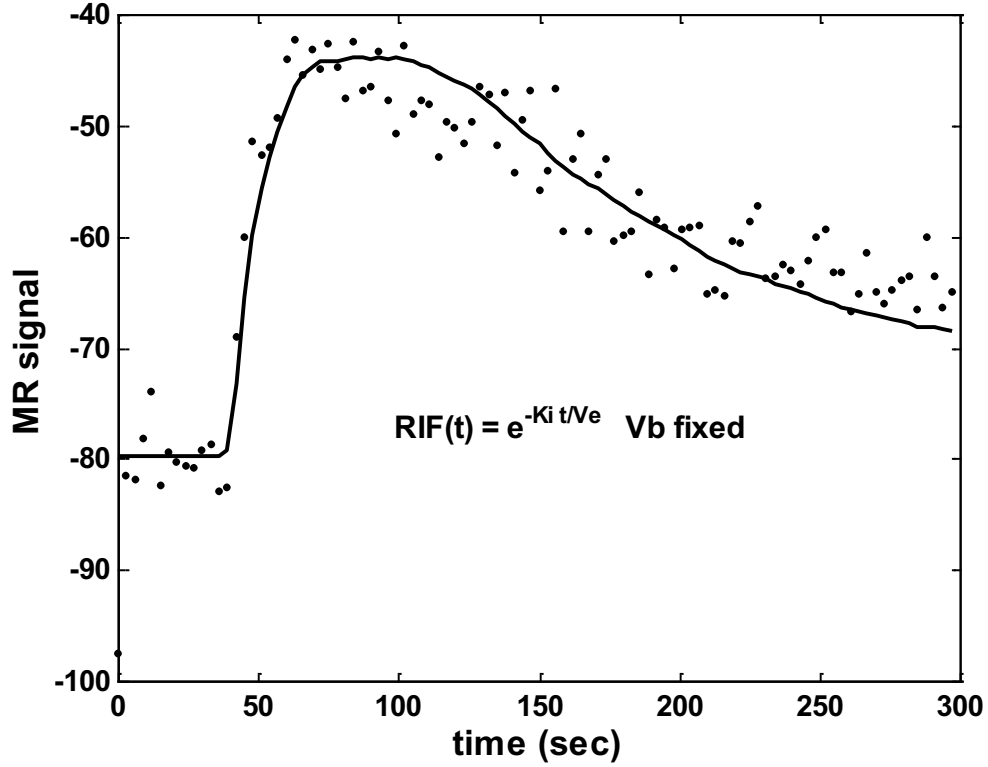


Sectors on short axis

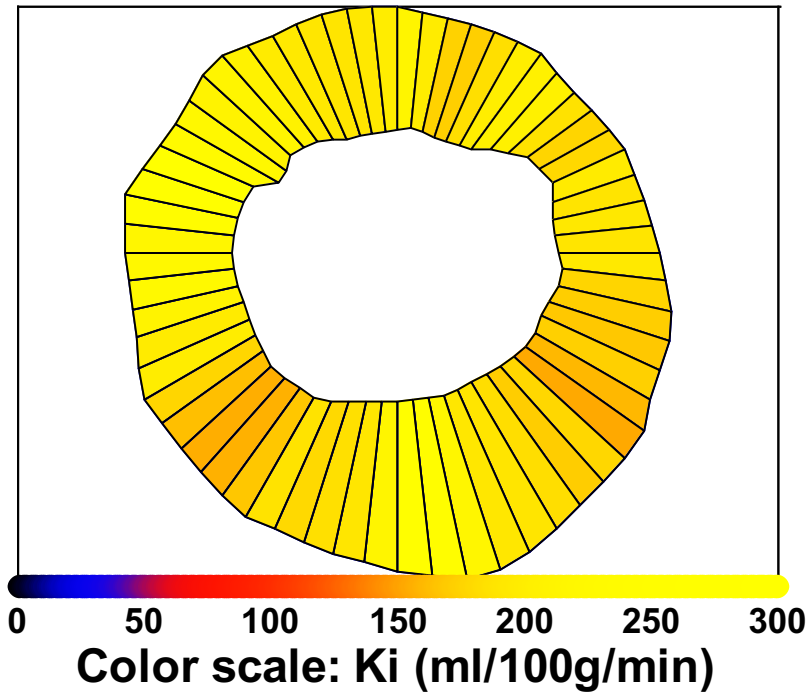


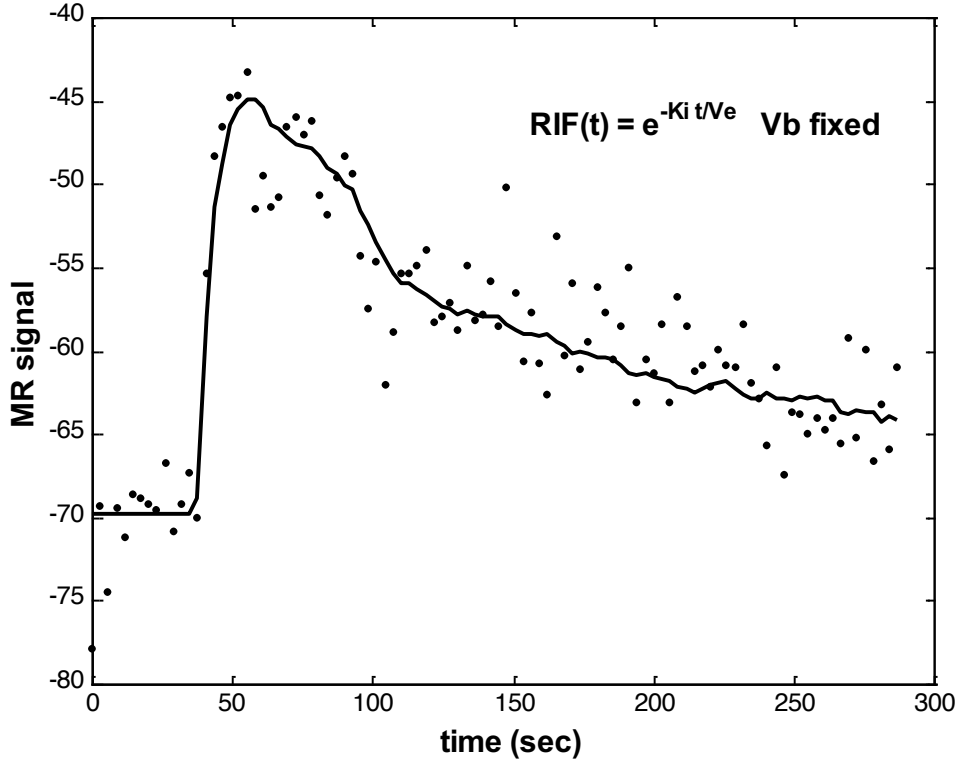
Healthy subject: Rest





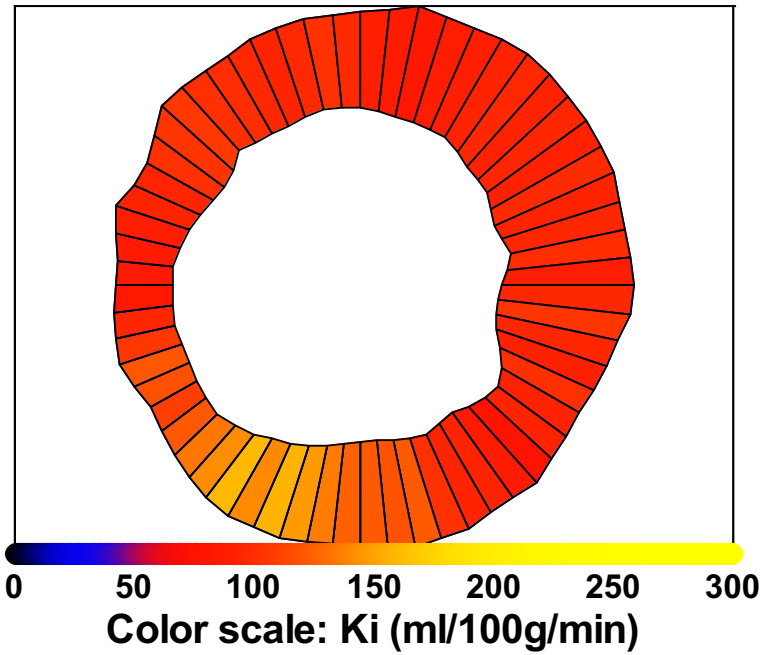
Healthy subject: Stress



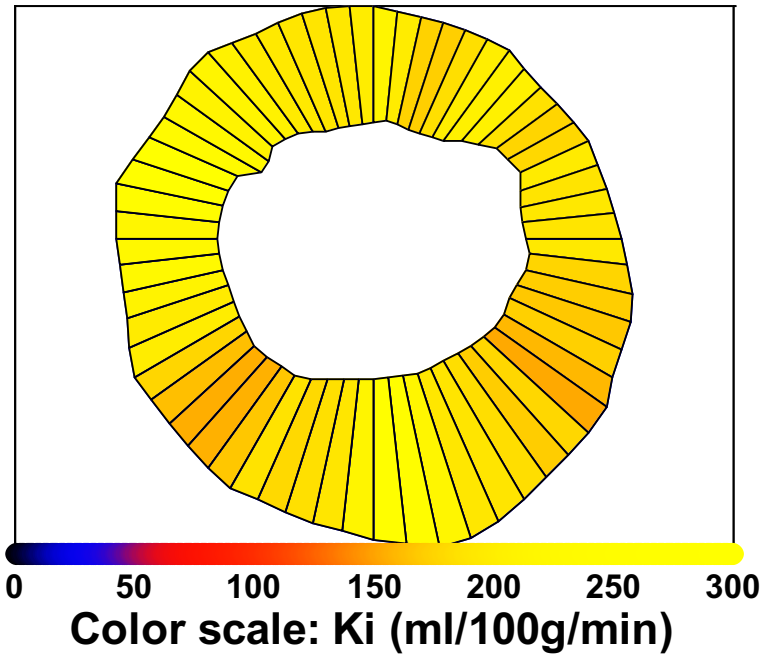


Healthy subject

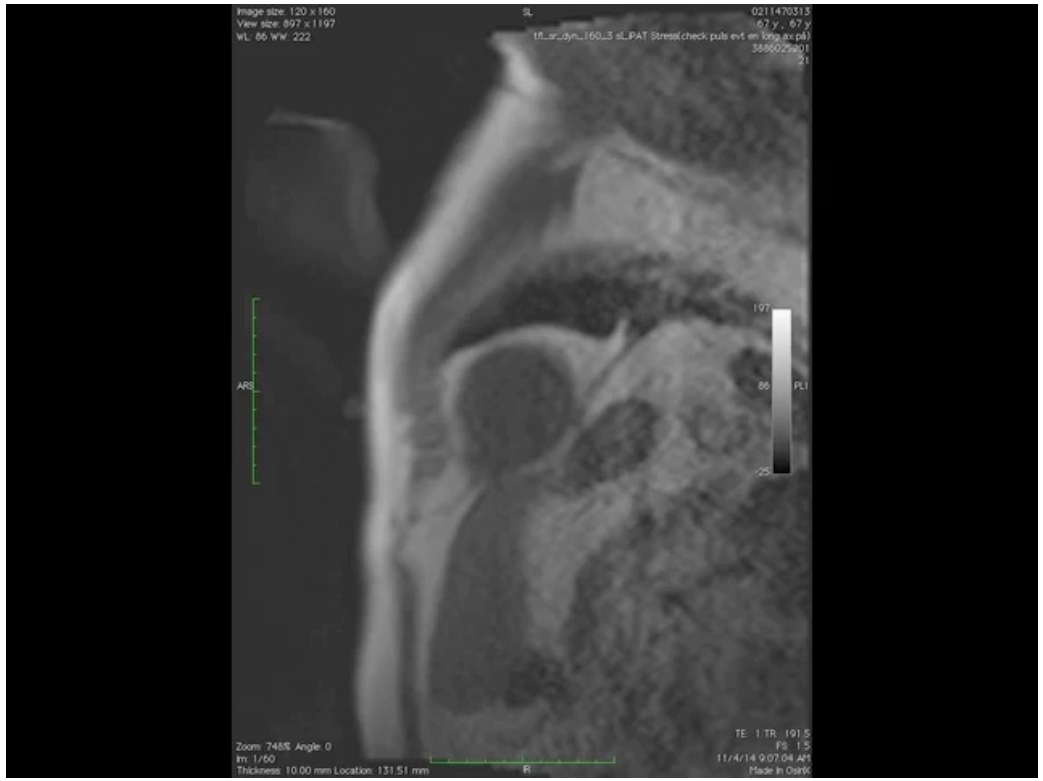
Rest



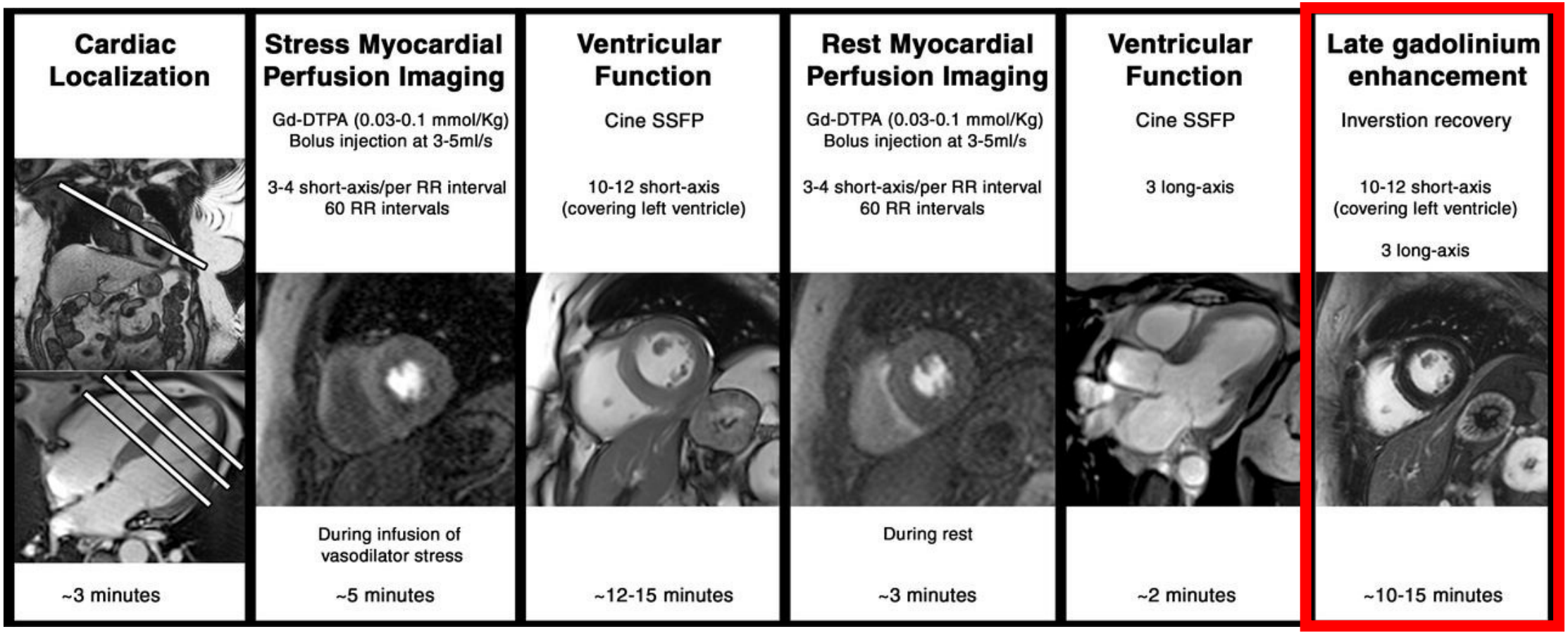
Stress



Clinical cases



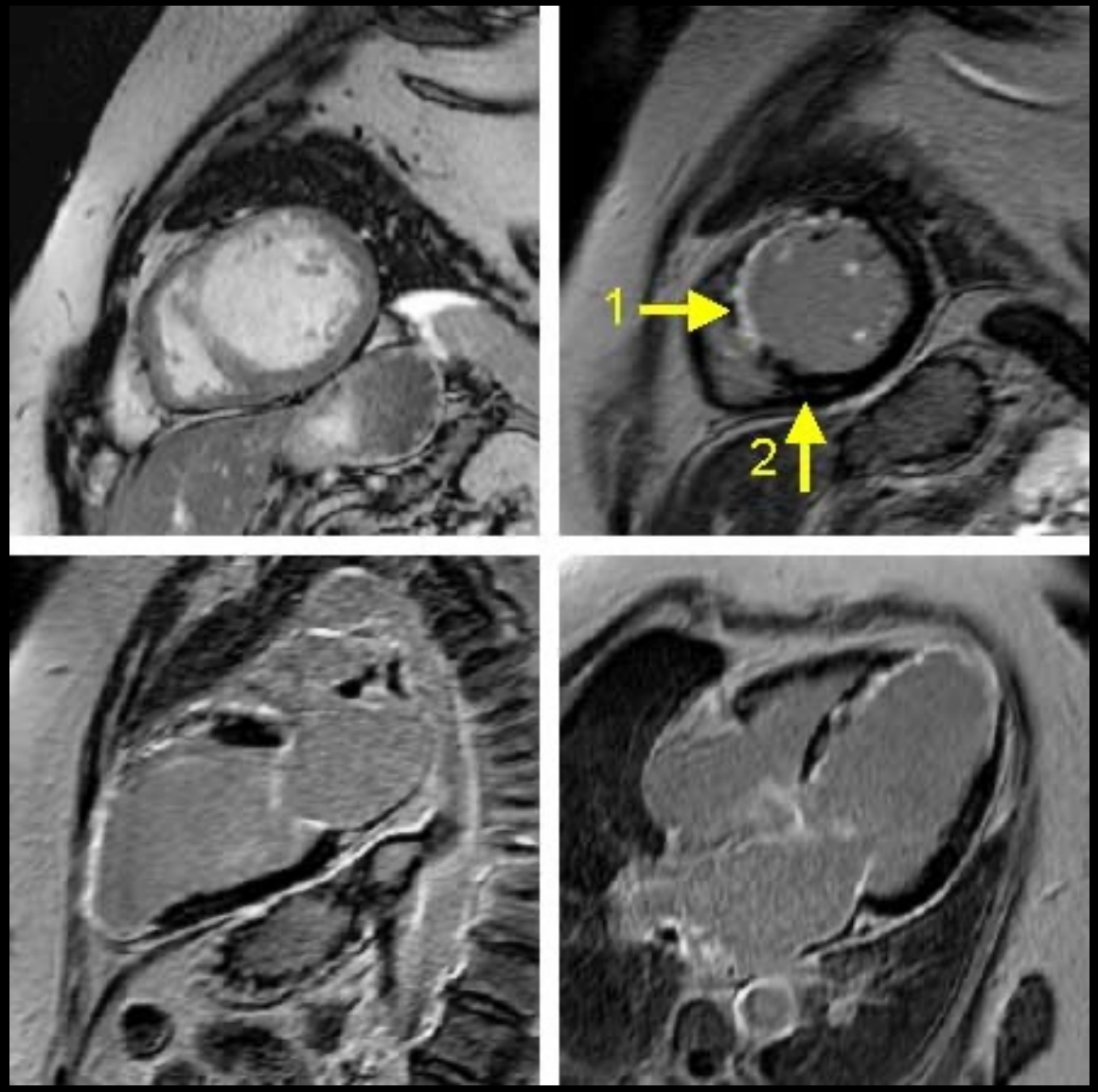
Cardiac MRI Examination

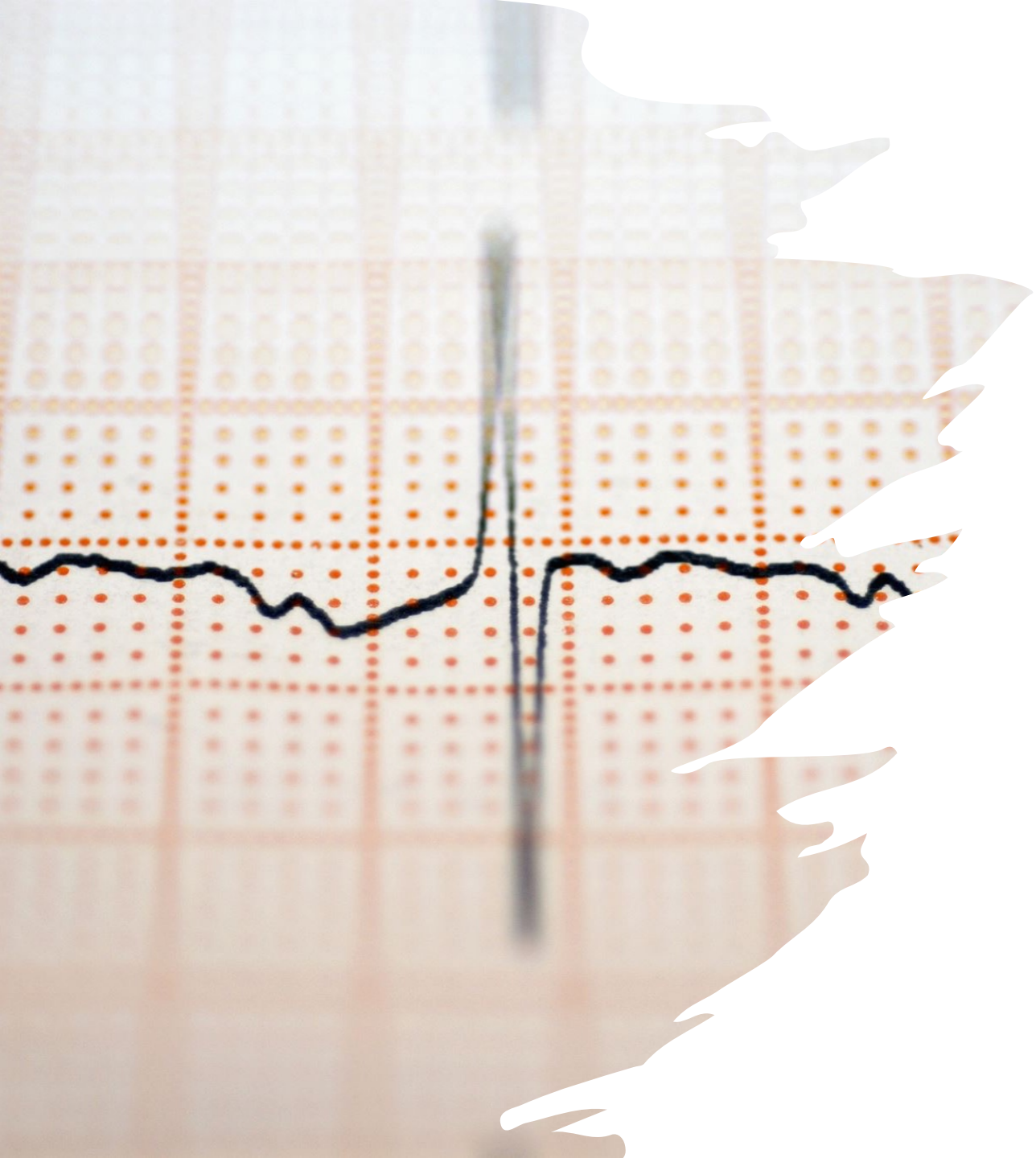


Coelho-Filho et al., 2013, DOI: 10.1148/radiol.12110918

Late enhancement

- Nulling of myocardium
- Assessment of myocardial scar formation
- Acquired 15-20 min after gadolinium injection
- Result of regional differences in myocardial extracellular volume and different uptake and washout patterns within the extracellular space





Summary

- Non-invasive measurement of myocardial perfusion status
  - Stress and resting conditions
- Gadolinium is used as tracer
  - Increase the signal on T1 weighted images
- Fast imaging gated to heart frequency
  - ~2 images pr second
- Tracer kinetic modelling to extract physiological parameters (MBF)
  - Compartment modelling
  - Model-free deconvolution