Semmelweis Egyetem

KARDIOLÓGIAI KÖZPONT

Cardiac Center, Radiology Unit

Clinical Cardiovascular Physiology

Magentic resonance

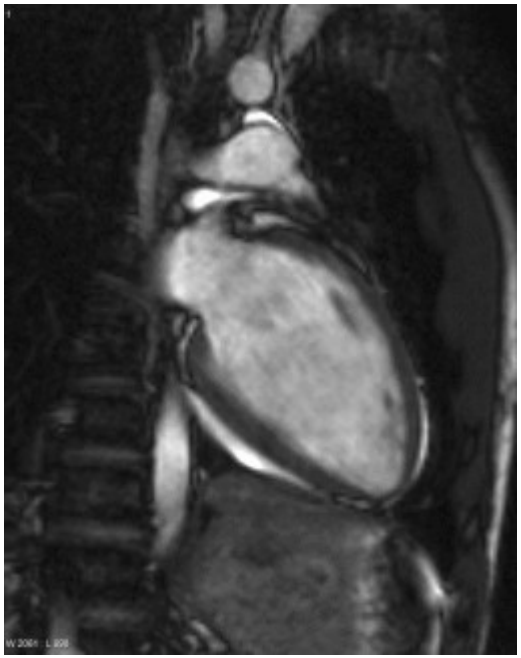
- History
  - Steady-state free precession in nuclear magnetic resonance
    - **Phys Rev 112(5):1693-1701 (1958), HY Carr**
  - Gadolinium-DTPA as a contrast agent in MRI: initial clinical experience in 20 patients
    - **Am J Roentgenol 143(2):215-227 (1984)**
  - Magnetic resonance imaging of the heart: a review of experience in 172 subjects
    - **Radiology 155(3):671-679 (1985), CB Higgins**

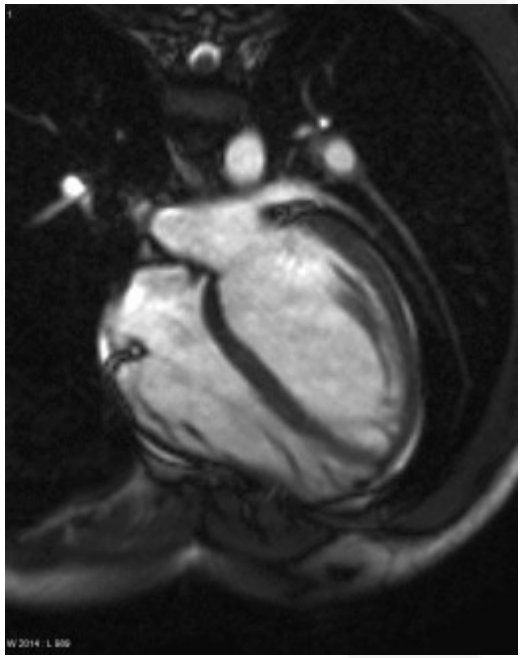
Magentic resonance

- No ionizing radiation
- Superb CNR
- Accurate
- Flow quantification

- Time consuming
- Monitoring
- Requires cooperation
- Complicated

Long axis

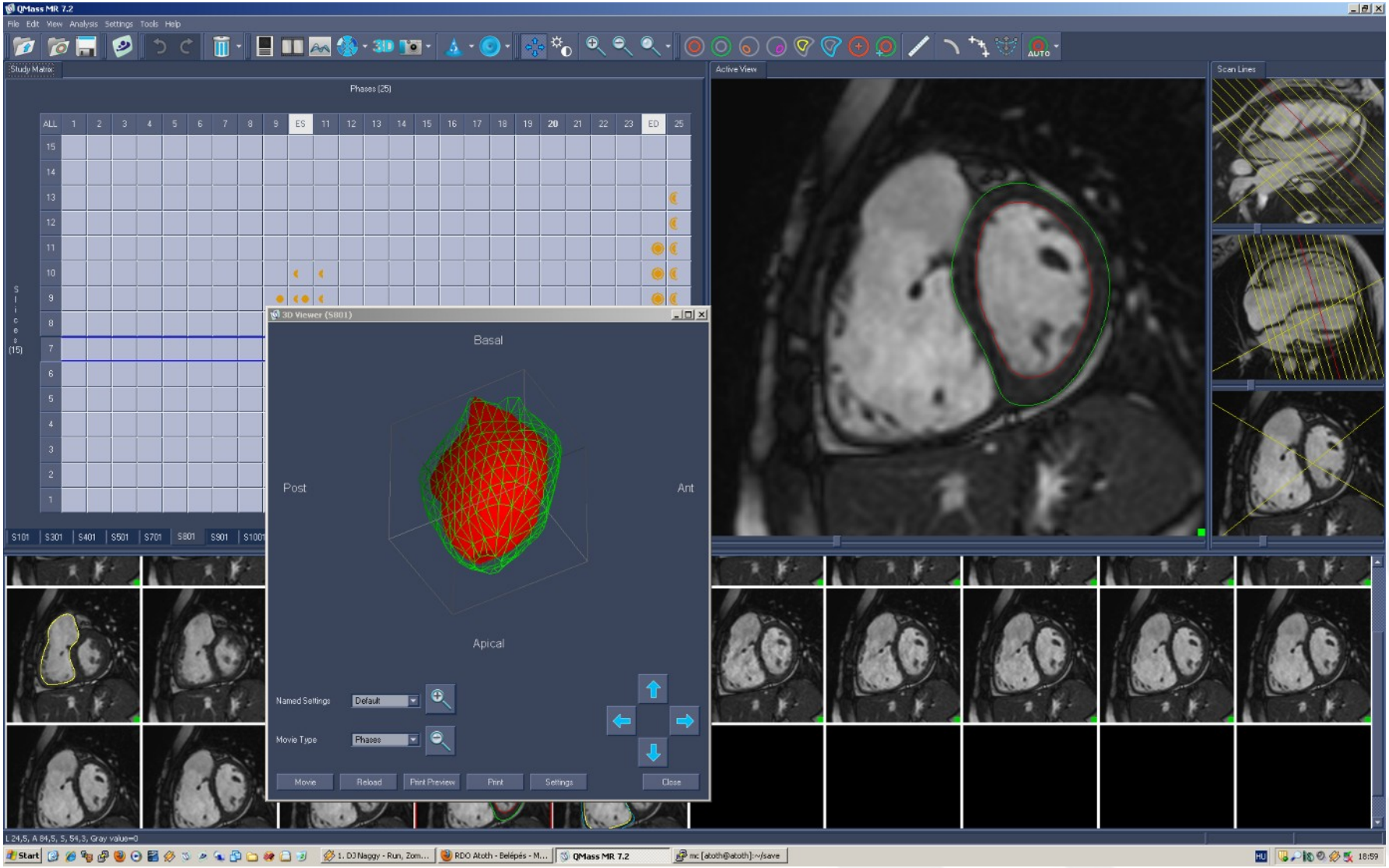




Constant volume theorem

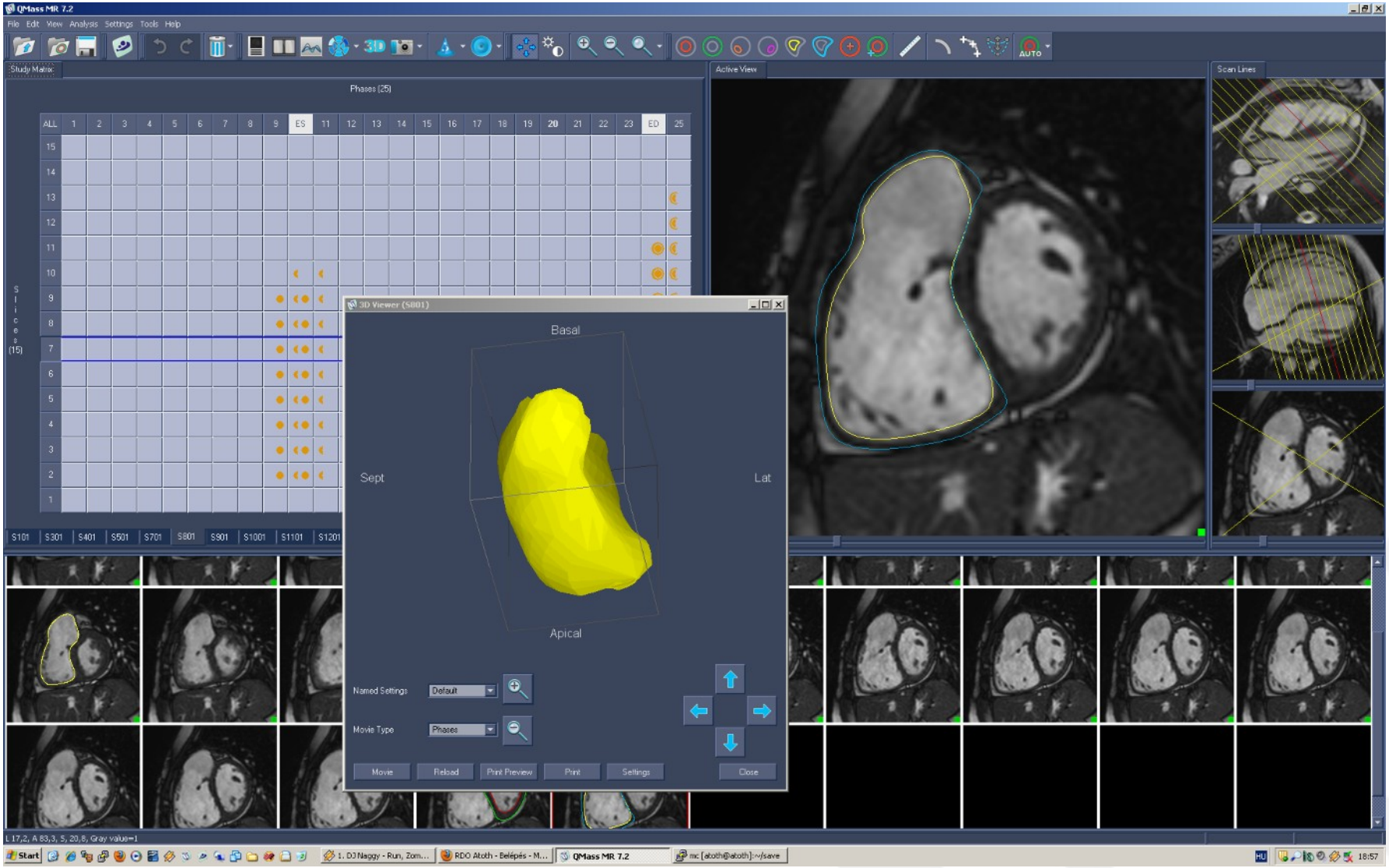
- The volume of the pericardial sac remains nearly constant over the cardiac cycle
  - It deviates less than 5% from the equilibrium
  - Prof Kovács J Sándor
    - **AJP Heart Circ Physiol 285(5):H2027 (2003)**
    - **http://cbl1.wustl.edu**

LV evaluation

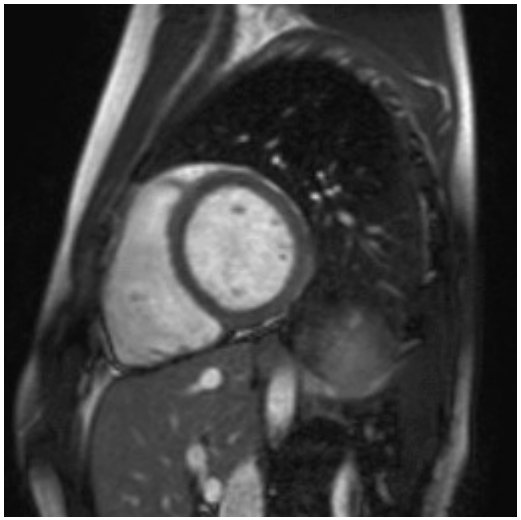
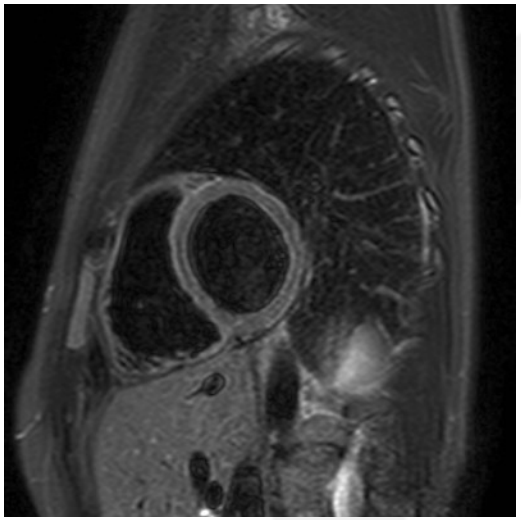
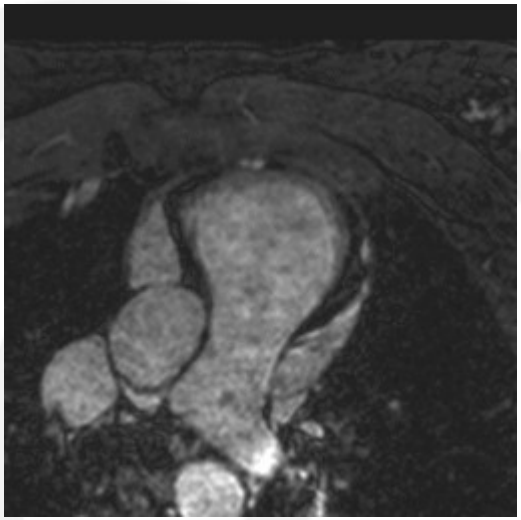
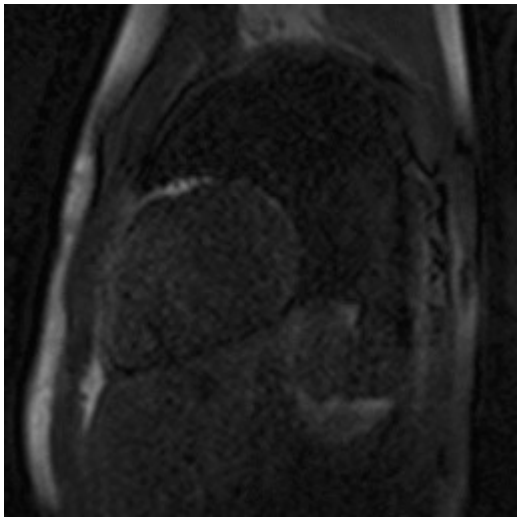
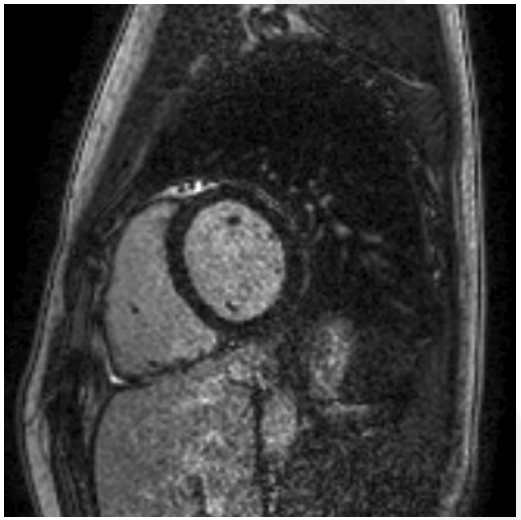
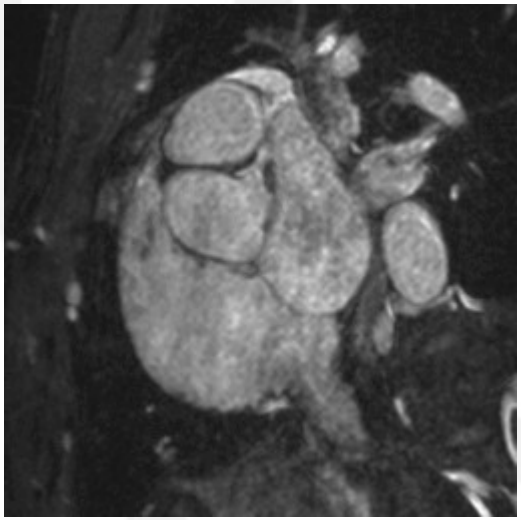


Low inter- & intraobserver variability

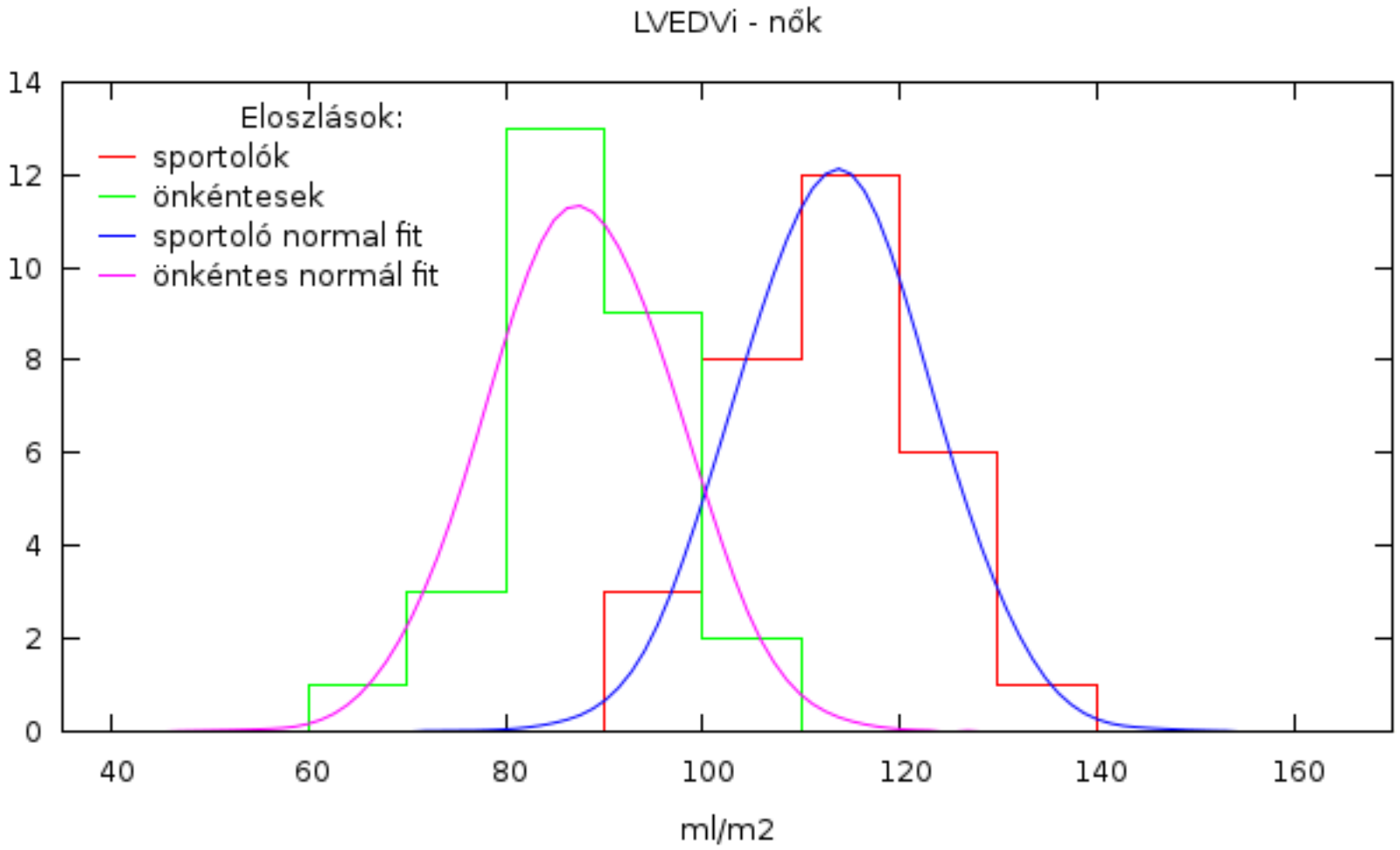
Right ventricular evaluation



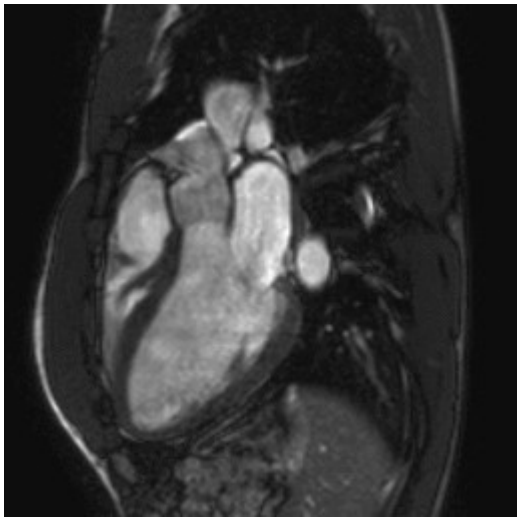
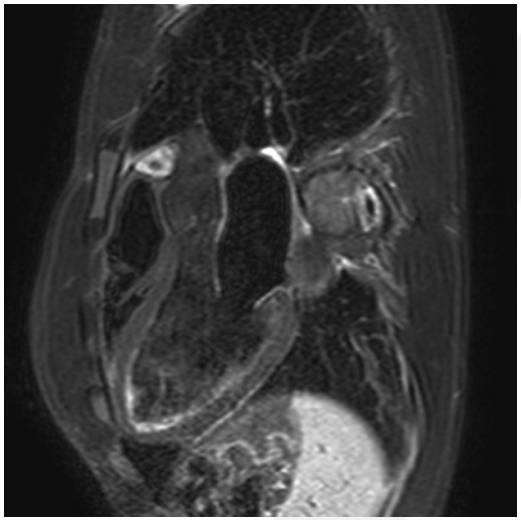
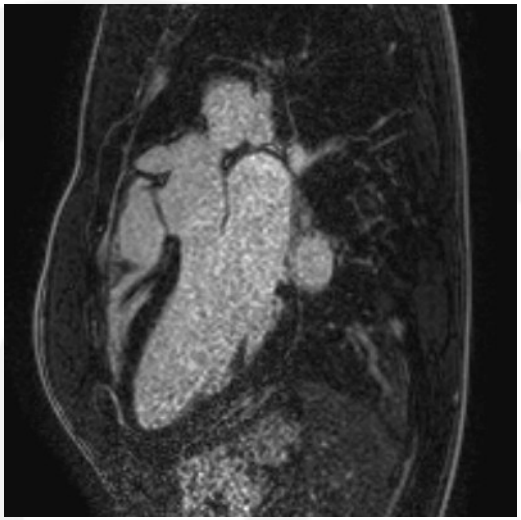
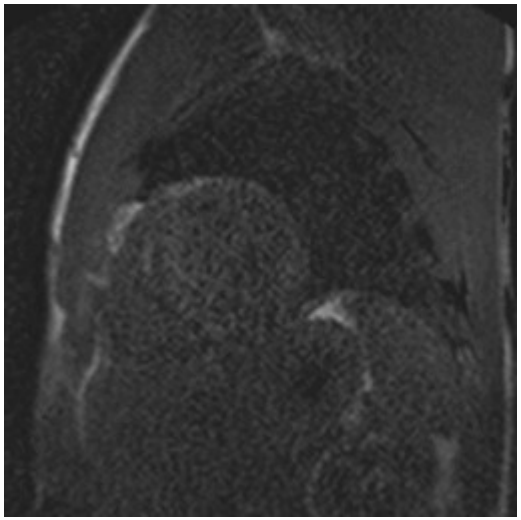
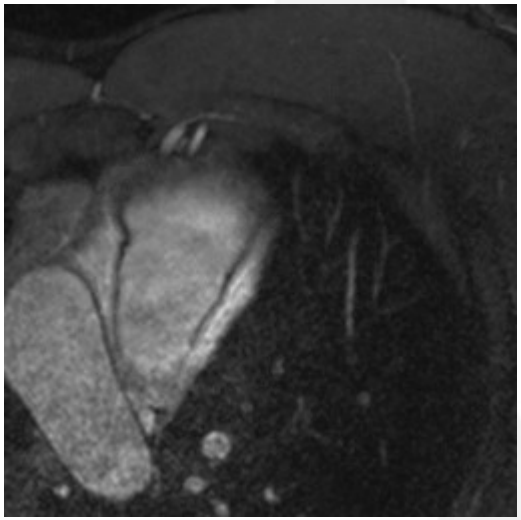
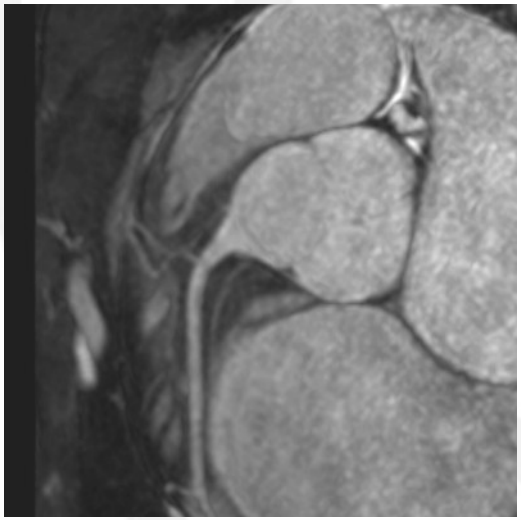
Female water-polo player

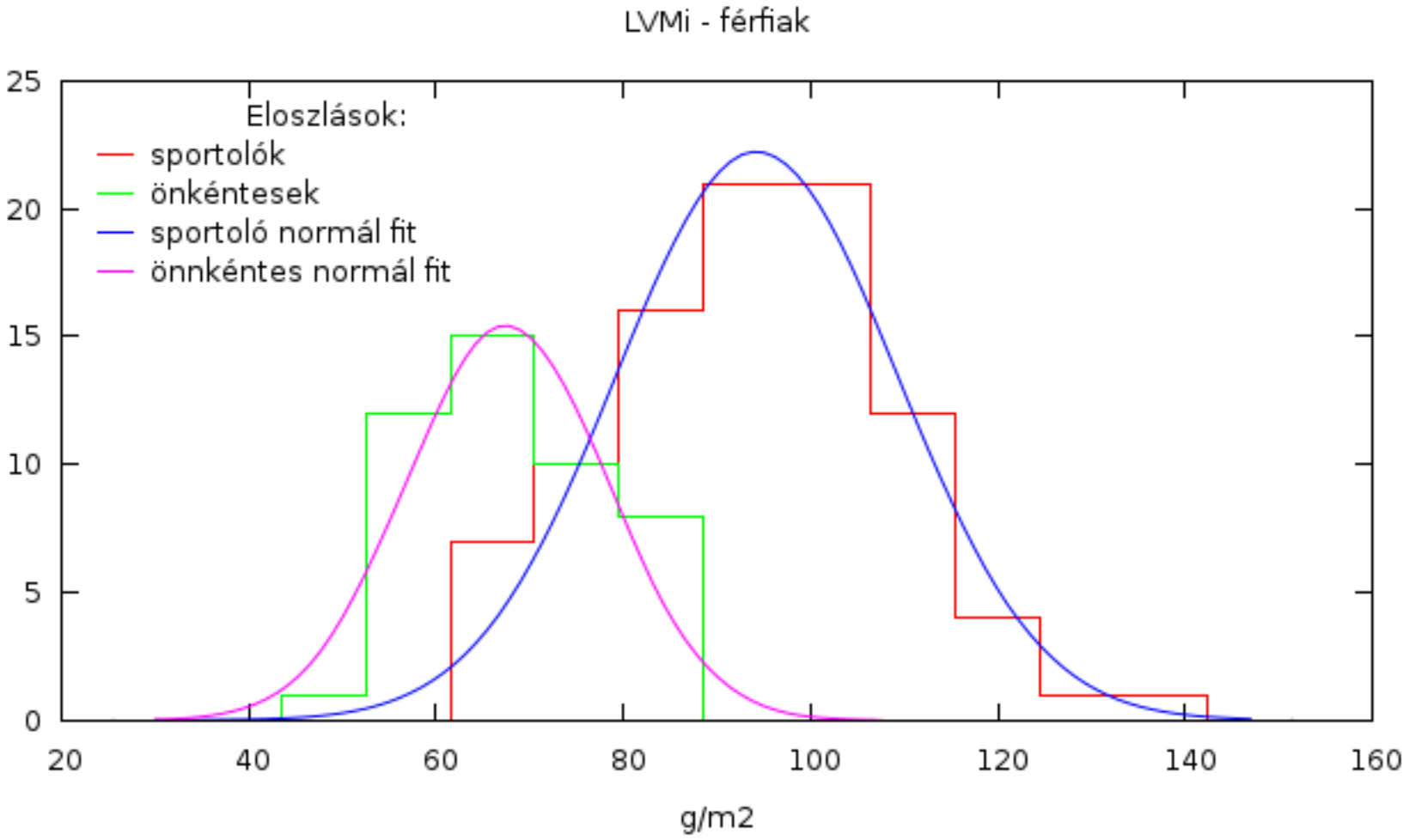
LV EDV index – females



Male kayaker

Left ventricular mass index – males



Male normal values

Parameter	Volunteers (48)	Water-polo (N = 23)	Kayak (N = 21)	Canoe (N = 15)	Cycling (N = 9)	Ultra running (N = 5)	Rowing (N = 15)	Goalball (N = 6)
BSA (m^2)	2.04 ± 0.18	**2.33 ± 0.09**	2.08 ± 0.13	2.00 ± 0.08	**1.87 ± 0.10**	**1.82 ± 0.08**	2.00 ± 0.11	2.13 ± 0.19
LVEF	60.2 ± 5.3	57.0 ± 3.4	57.7 ± 4.8	56.9 ± 3.4	56.8 ± 3.5	58.1 ± 3.5	56.2 ± 4.0	58.7 ± 4.4
LVESVi	38.1 ± 8.3	53.0 ± 8.0	52.2 ± 10.5	**56.5 ± 8.7**	54.3 ± 5.9	46.9 ± 2.8	54.8 ± 9.2	41.6 ± 8.0
LVEDVi	95.2 ± 12.1	123.0 ± 13.3	122.5 ± 14.7	**131.0 ± 14.6**	125.3 ± 6.4	112.1 ± 5.0	124.5 ± 12.5	99.8 ± 12.2
LVSVi	57.1 ± 7.0	70.0 ± 7.8	70.3 ± 7.6	74.5 ± 8.2	71.1 ± 4.8	65.2 ± 6.3	69.6 ± 5.9	58.3 ± 6.0
LVMi	63.5 ± 10.3	86.4 ± 14.7	**95.7 ± 11.1**	**102.2 ± 13.4**	78.1 ± 15.4	79.5 ± 9.7	**90.2 ± 9.0**	62.6 ± 7.2
RVEF	59.1 ± 4.8	56.2 ± 4.4	55.7 ± 4.3	53.6 ± 3.9	55.1 ± 4.8	57.9 ± 3.0	54.6 ± 3.9	57.1 ± 1.2
RVESVi	40.1 ± 8.3	56.3 ± 11.6	58.1 ± 11.6	64.3 ± 8.9	60.1 ± 10.1	51.4 ± 10.5	59.8 ± 9.4	42.1 ± 5.2
RVEDVi	97.5 ± 13.2	127.7 ± 17.4	130.4 ± 16.7	**138.5 ± 14.4**	133.3 ± 9.6	122.1 ± 10.5	131.0 ± 12.9	98.3 ± 12.7
RVSVi	57.4 ± 7.7	71.4 ± 8.5	72.3 ± 7.8	74.2 ± 9.0	73.2 ± 5.3	70.7 ± 8.3	71.2 ± 6.2	56.2 ± 7.6
RVMi	24.9 ± 3.6	30.6 ± 3.7	34.2 ± 5.2	34.5 ± 4.9	34.5 ± 4.4	28.2 ± 2.8	33.6 ± 2.7	22.0 ± 2.4
LVED FVS	11.02 ± 1.38	13.17 ± 1.64	13.52 ± 1.91	12.87 ± 1.60	12.00 ± 1.23	12.25 ± 1.26	13.07 ± 1.39	10.50 ± 0.55
Sport index	.118 ± .0246	.107 ± .0149	.112 ± .0231	.099 ± .0181	.096 ± .0122	.109 ± .0119	.106 ± .0150	.106 ± .0115

HCM & DCM example

Parameter	Volunteers	Athletes	DCM	HCM
HR	66,74 (11,24)	59,52 (10,10)	46	53
BSA	2,056 (0,191)	2,046 (0,184)	2,08	2,04
LVEF	59,53 (5,57)	57,51 (4,26)	40,4	63,78
LVESVi	38,72 (8,69)	53,50 (9,63)	112,45	39,99
LVEDVi	95,09 (12,77)	125,25 (13,87)	188,57	110,41
LVSVi	56,37 (7,53)	71,76 (7,21)	76,13	70,42
LVMi	62,93 (11,21)	88,09 (17,66)	125,98	160,90
RVESVi	41,30 (8,10)	59,19 (11,45)	68,52	36,86
RVEDVi	98,37 (13,61)	132,66 (15,40)	144,45	102,08
RVSVi	57,08 (8,33)	73,46 (7,28)	75,94	65,22
RVMi	25,11 (3,97)	34,16 (5,17)	34,30	36,17
ED WT	11,09 (1,46)	12,78 (1,93)	–	29
Sport index	0,119 (0,026)	0,103 (0,021)	–	0,26

DCM example

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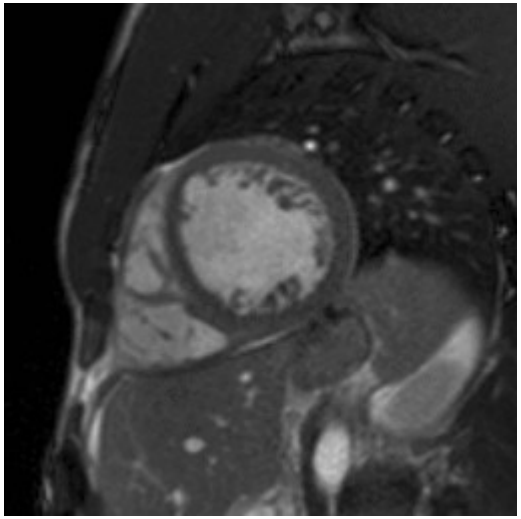
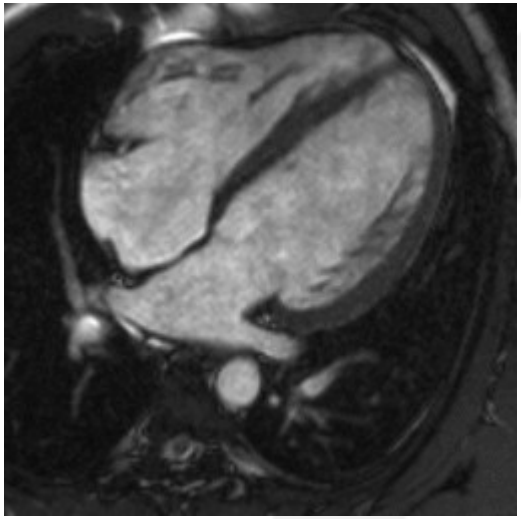
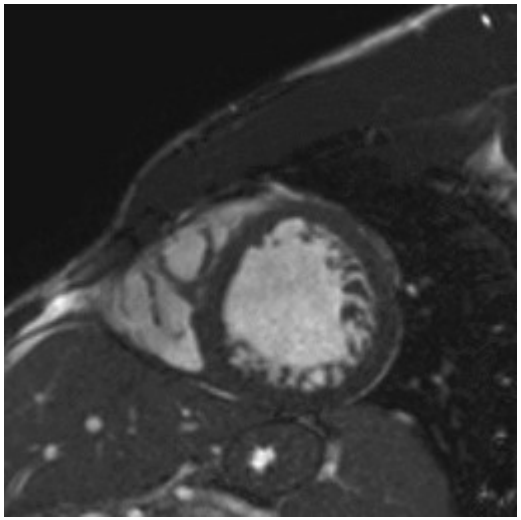
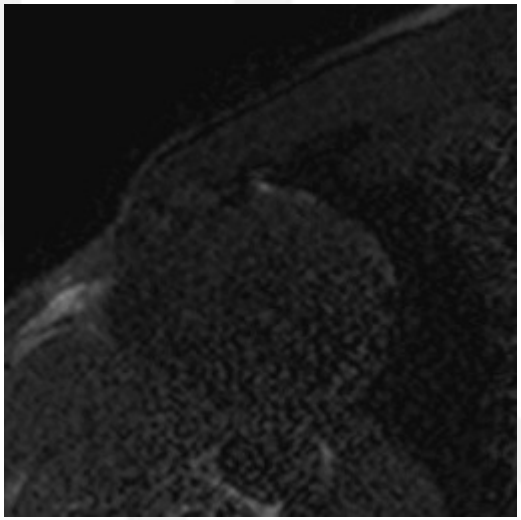
Hockey player: dilatative CMP





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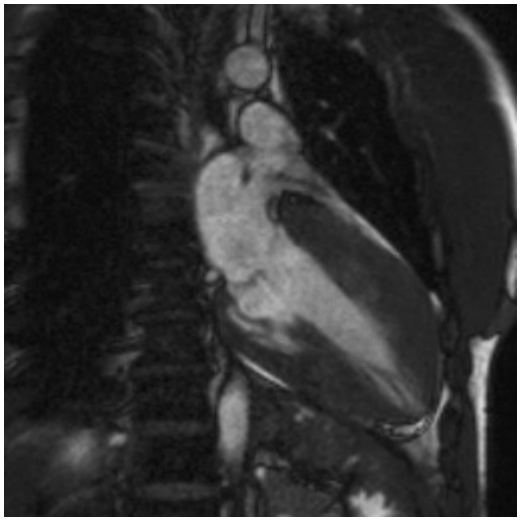
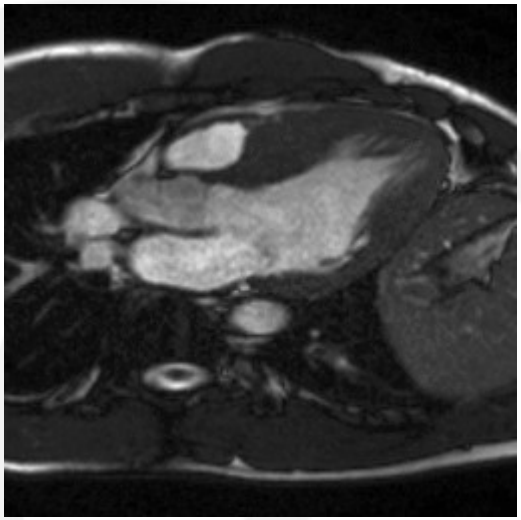
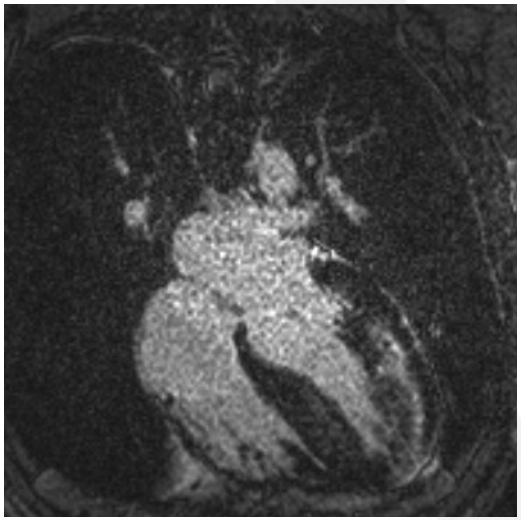
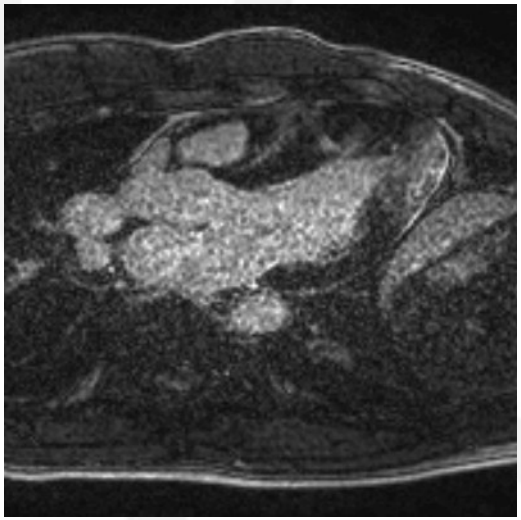
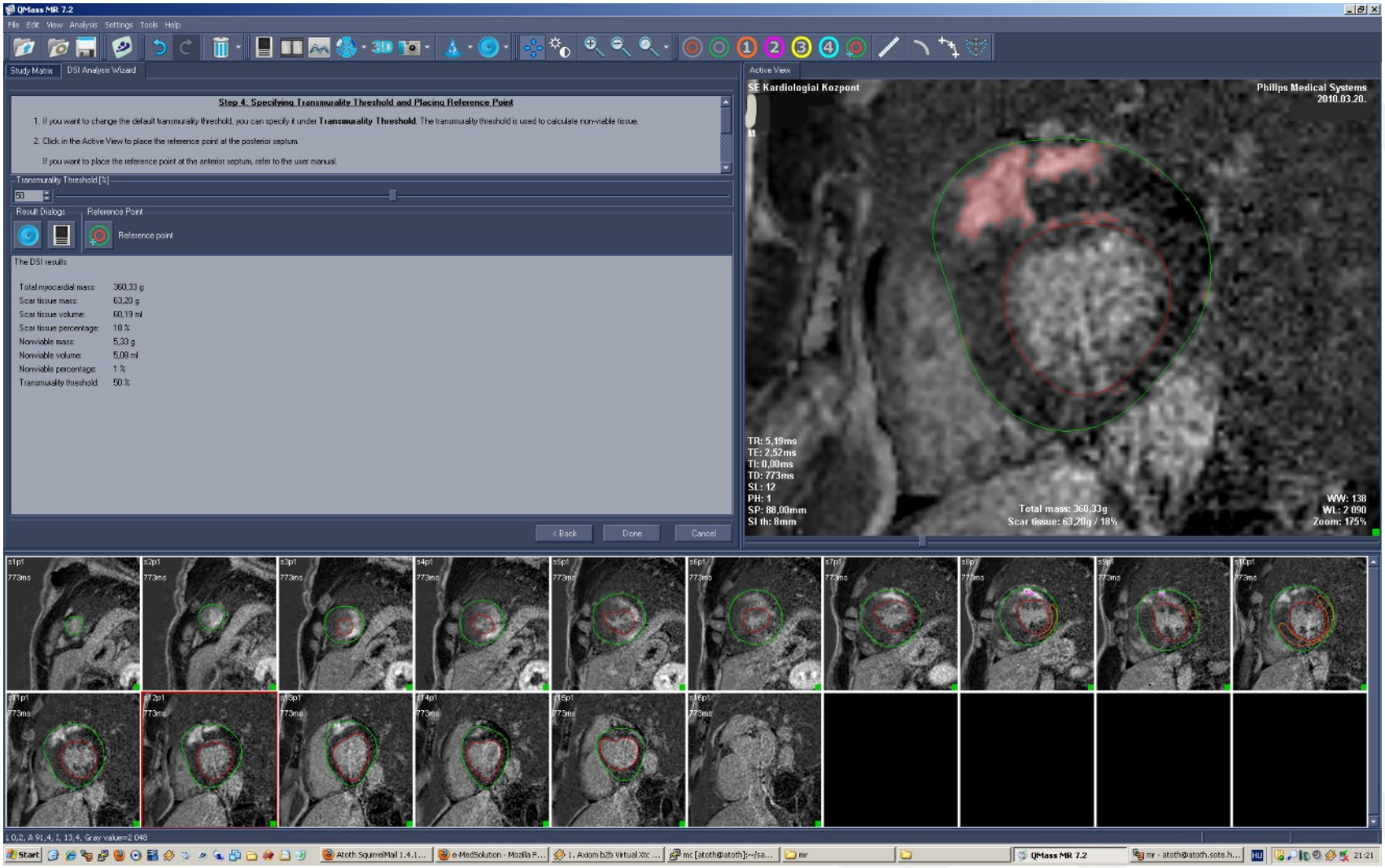
HCM in an athlete



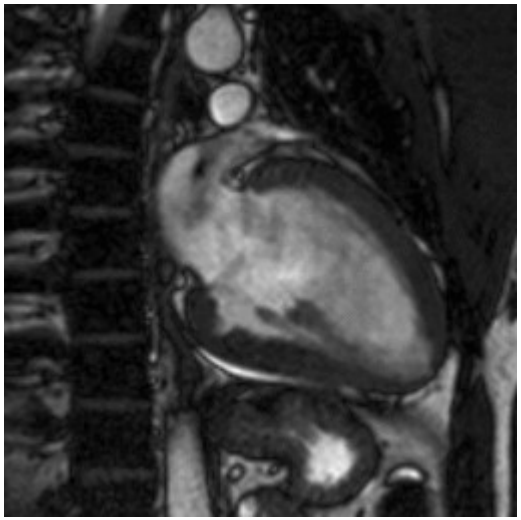
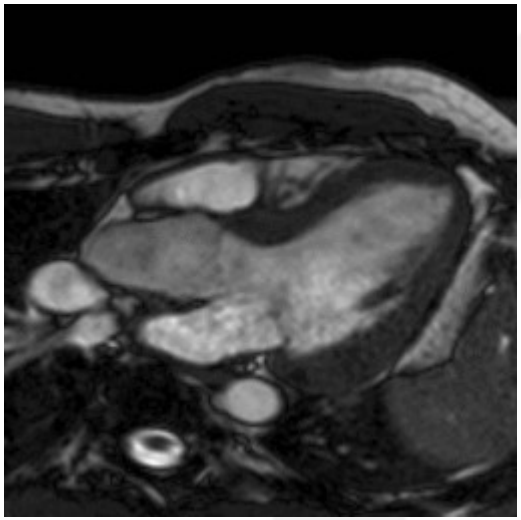
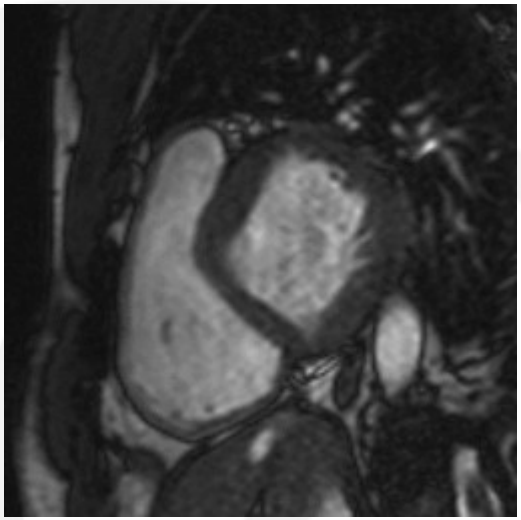


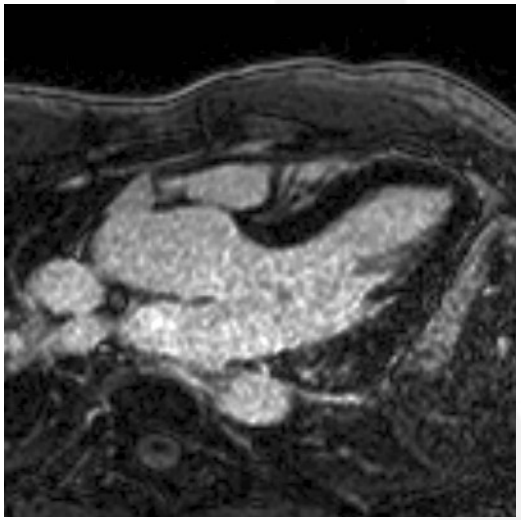
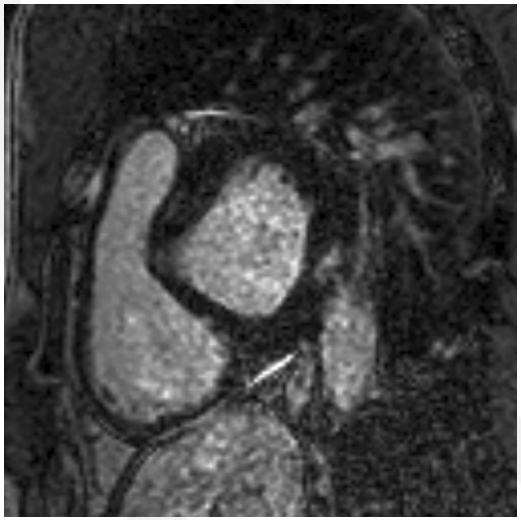



DE kvantification: 63g scar out of 360g



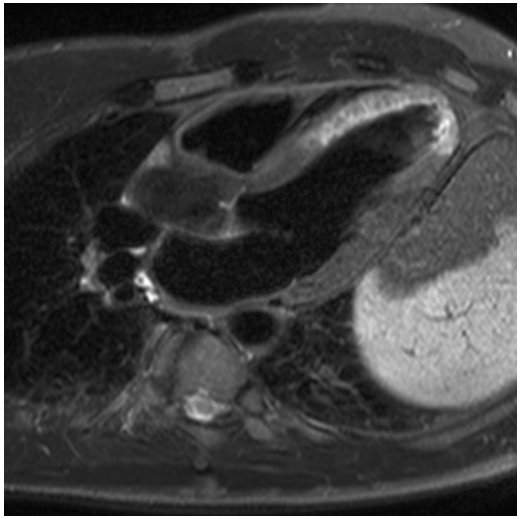
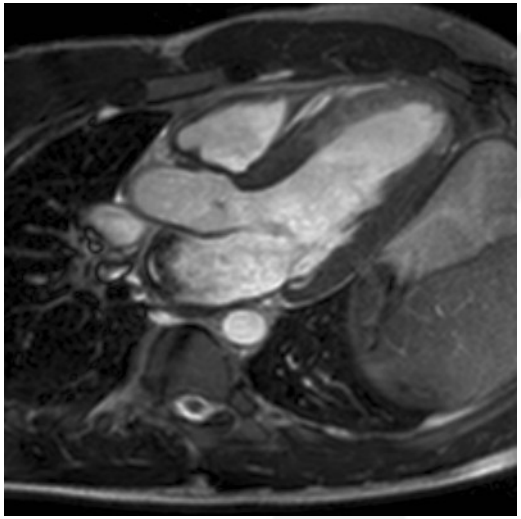
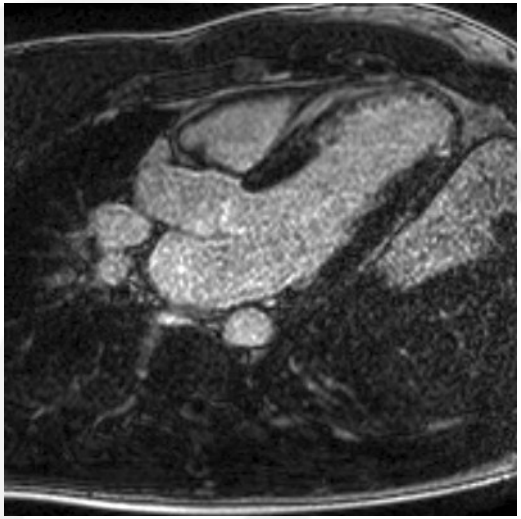
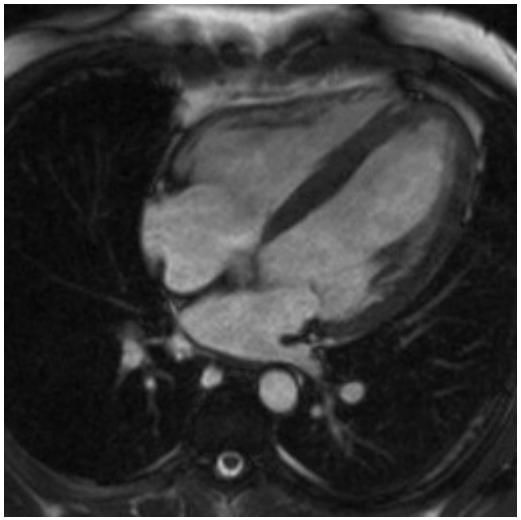
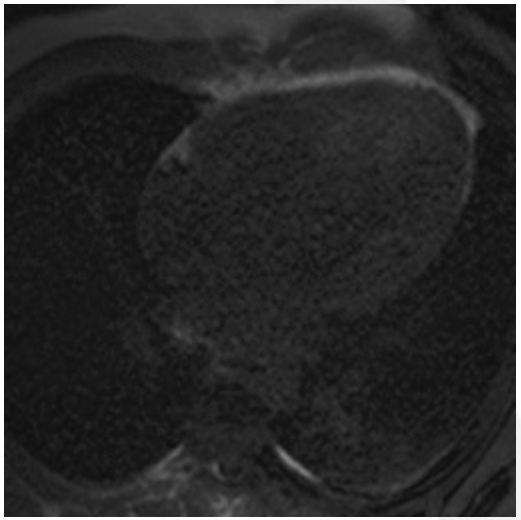
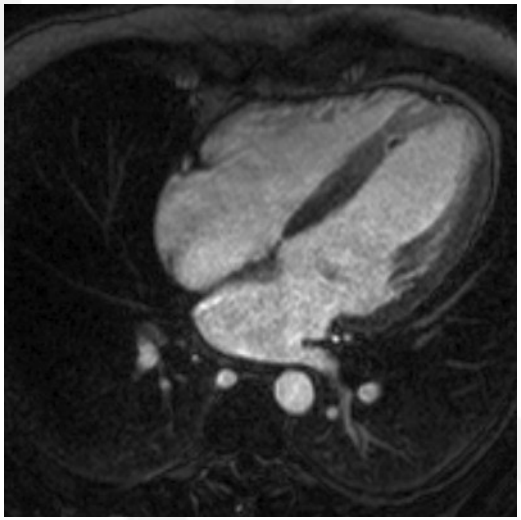
Muaj thai: Anderson-Fabry (19mm)

LV: EF 60, ESVi 40, EDVi 100, SVi 60, Mi 109
RV: EF 55, ESVi 50, EDVi 111, SVi 61, Mi 30

Acute infarct: 21% non-viable

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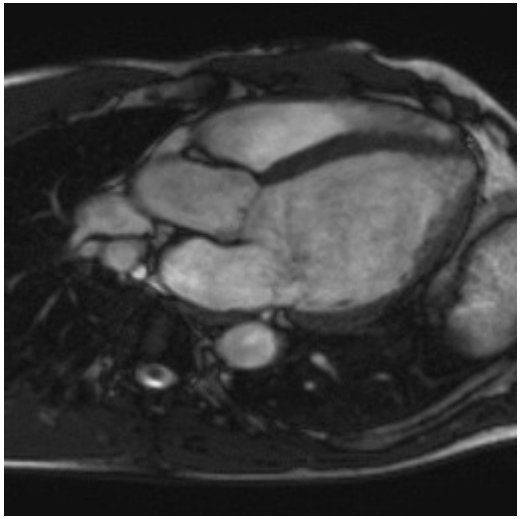
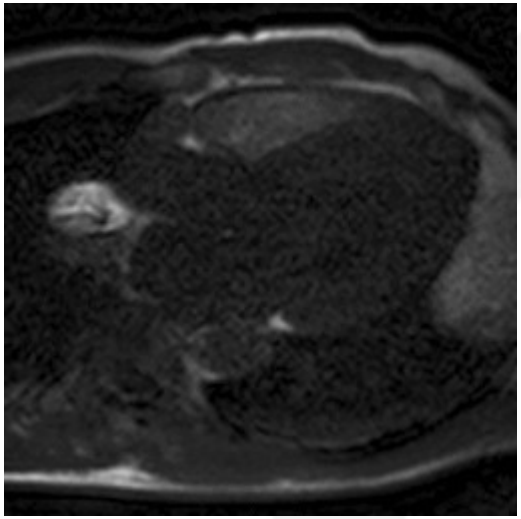
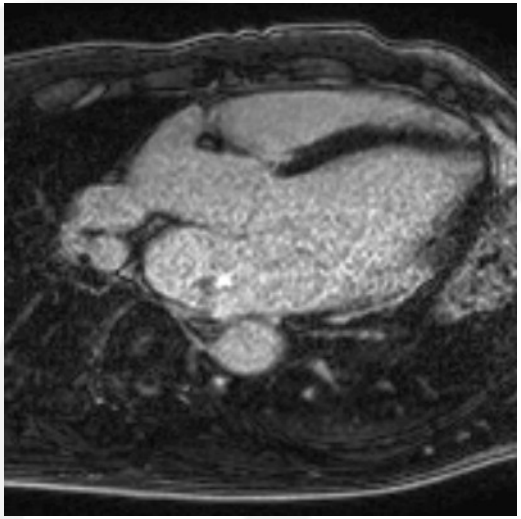
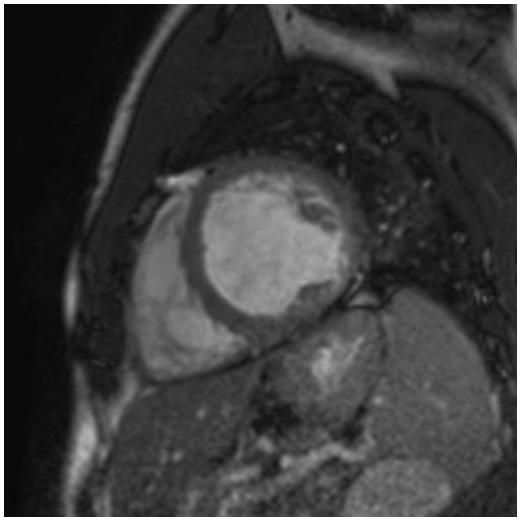
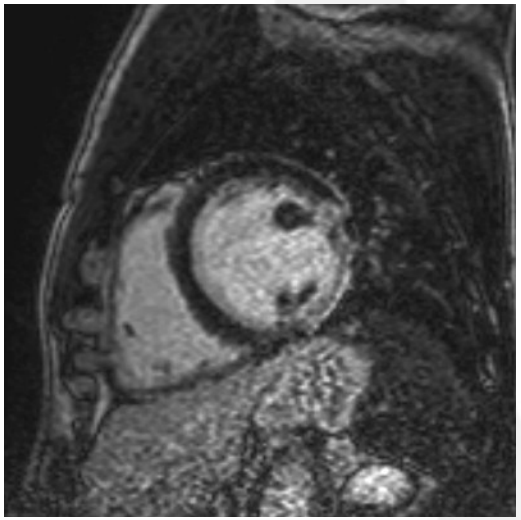
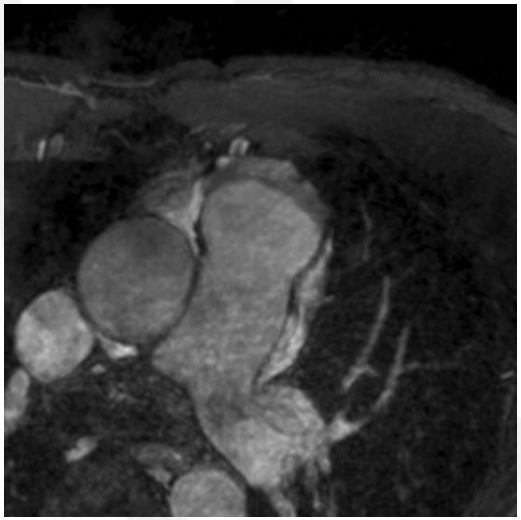
RV: EF 60, ESVi 48, EDVi 122, SVi 73, Mi 31 max diast fvs: 16mm

Duathlon, ultra-marathon: chrn. infarct

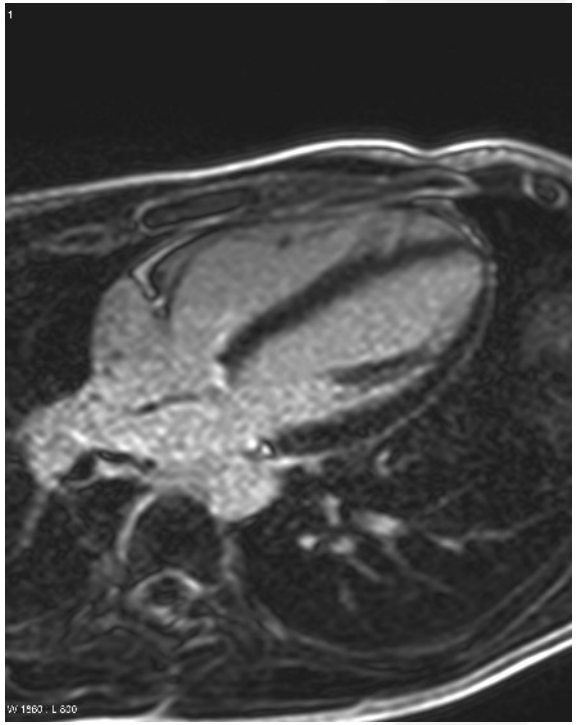







LV: EF 37, ESVi 112, EDVi 177, SVi 65, Mi 102
RV: EF 47, ESVi 95, EDVi 178, SVi 83, Mi 39

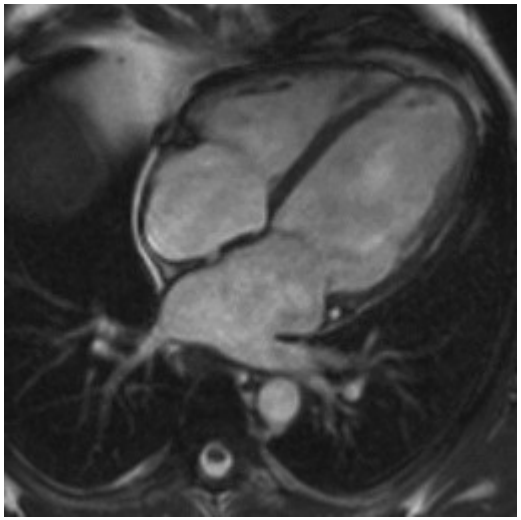
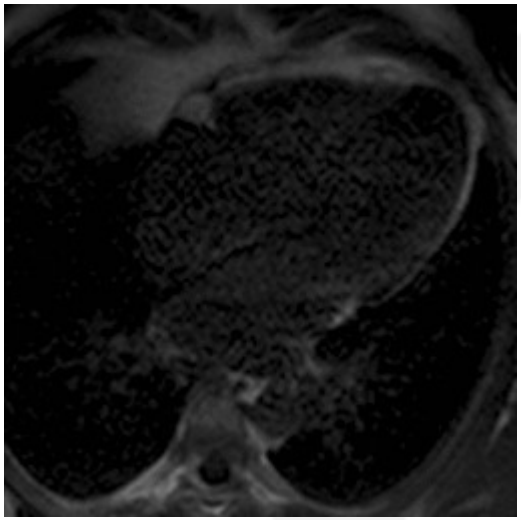
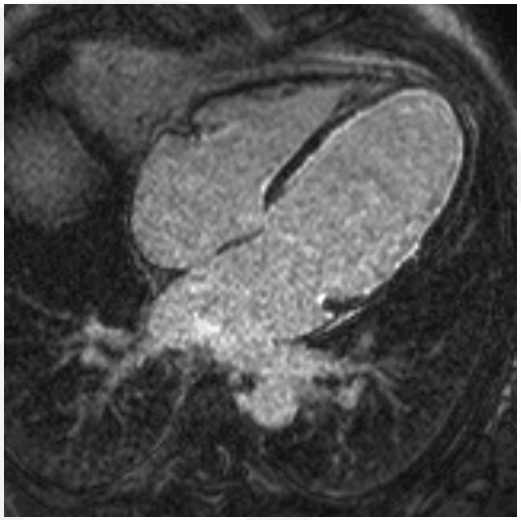
Late/delayed enhancement

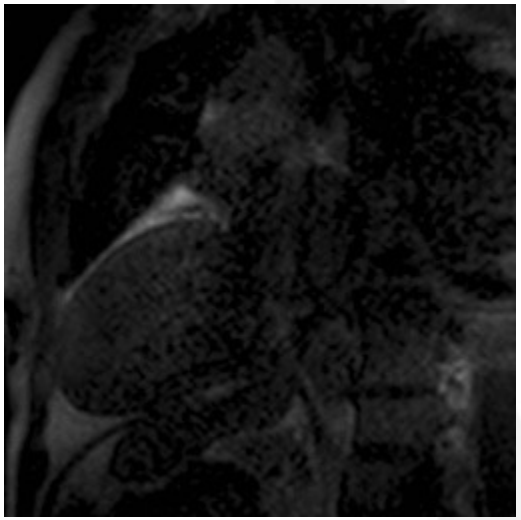
- Circulation 104:1101-1107 (2001)
  - Raymond J Kim, Romert M Judd
  - Transmurality ~ Viability

Late/delayed enhancement



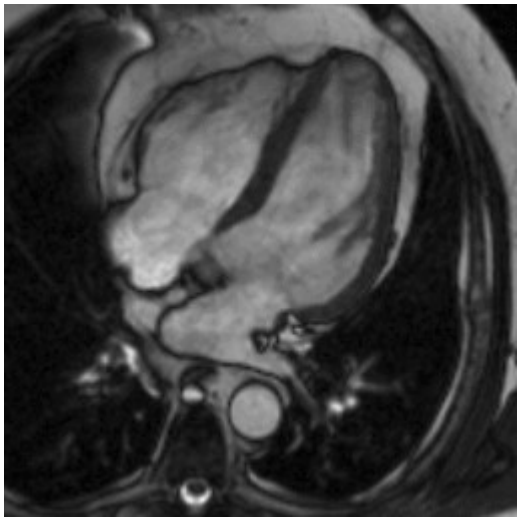
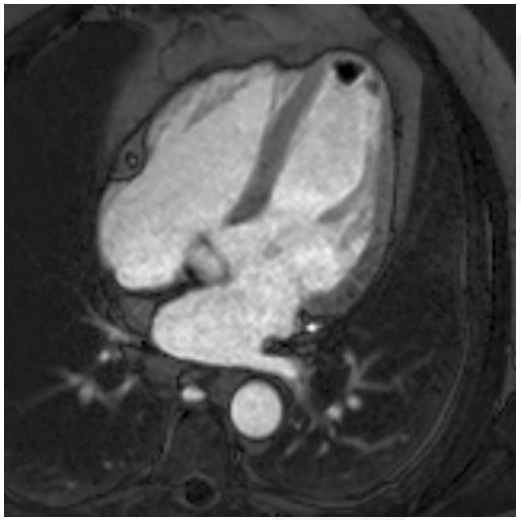
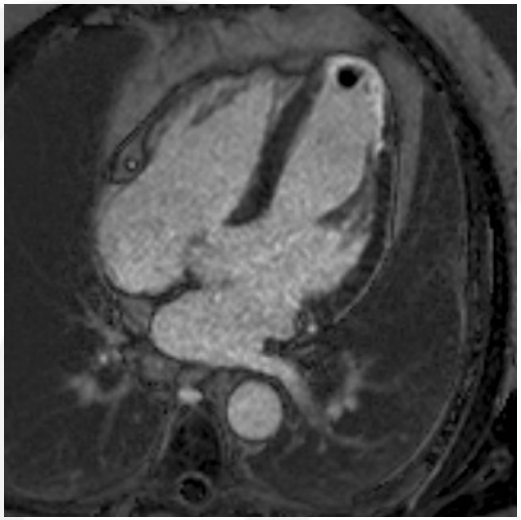
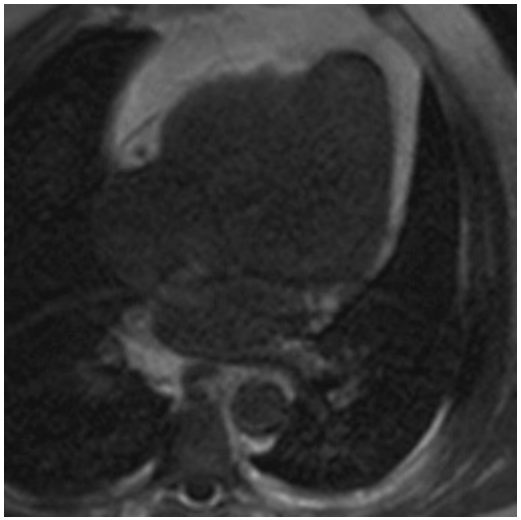
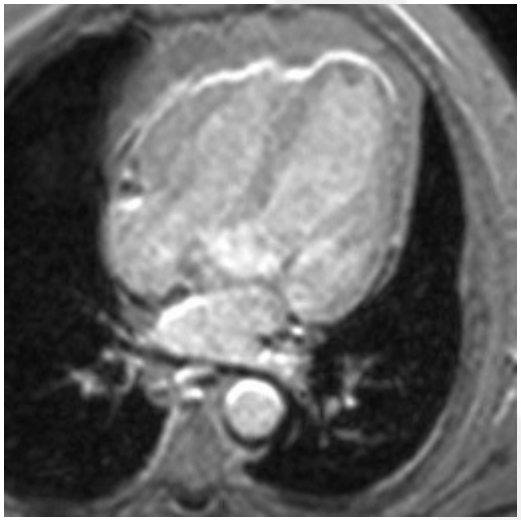
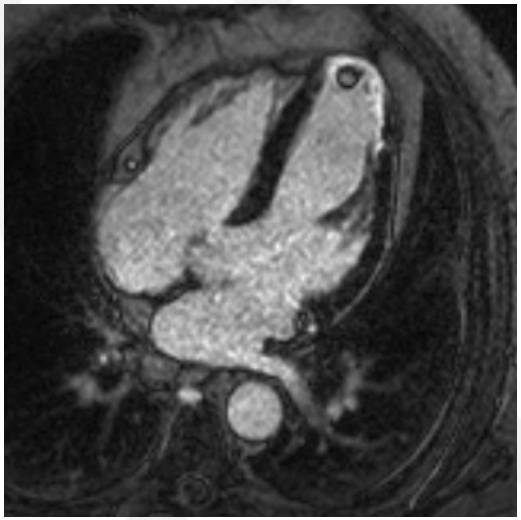
RCA & LCX CTO, LMA & LAD stenosis

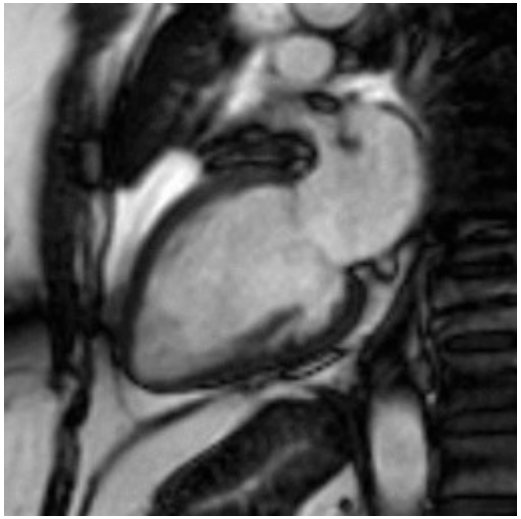


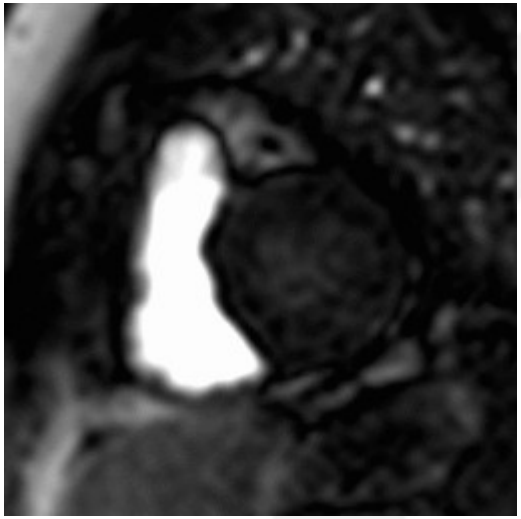
LV: EF 24, ESVi 115, EDVi 151, SVi 36, Mi 75
RV: EF 38, ESVi 62, EDVi 100, SVi 38, Mi 32

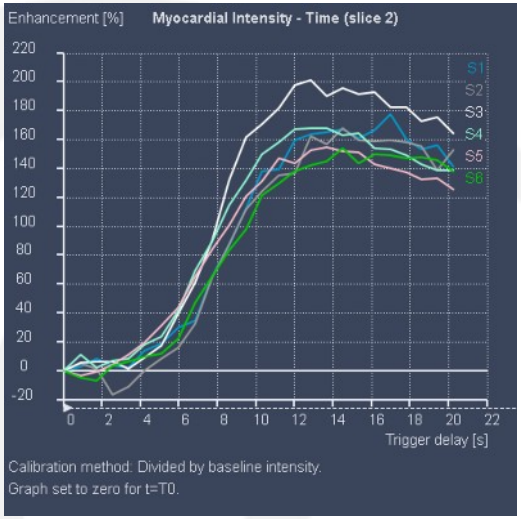
Apical infarct & thrombus (4CH)

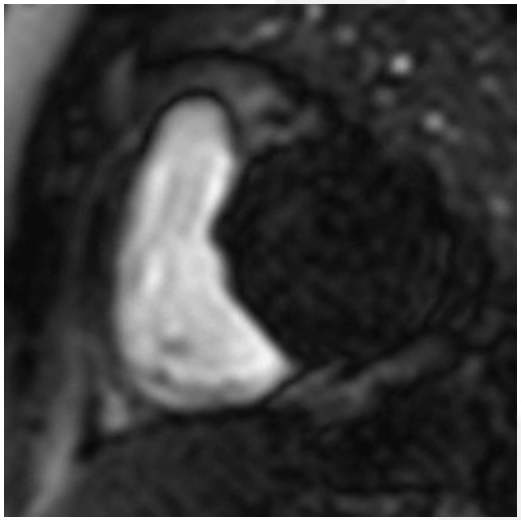







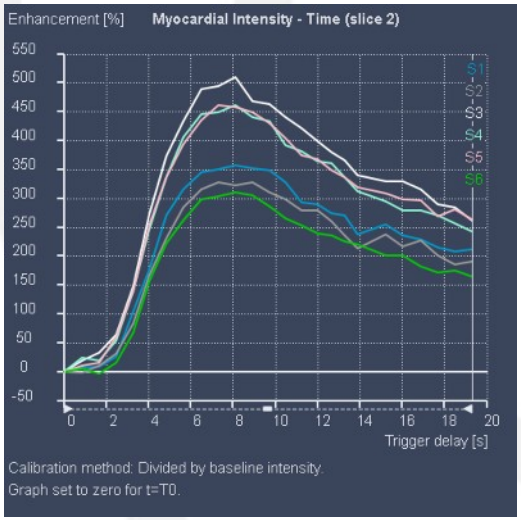
Upslope analysis: MPRI





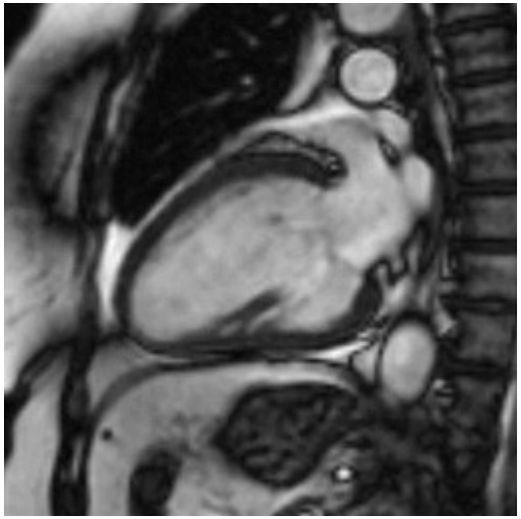


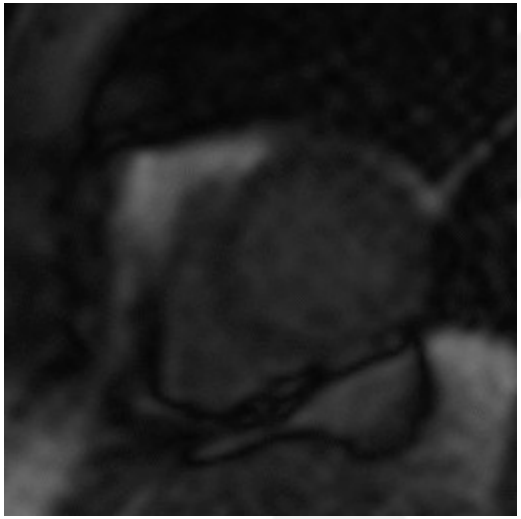


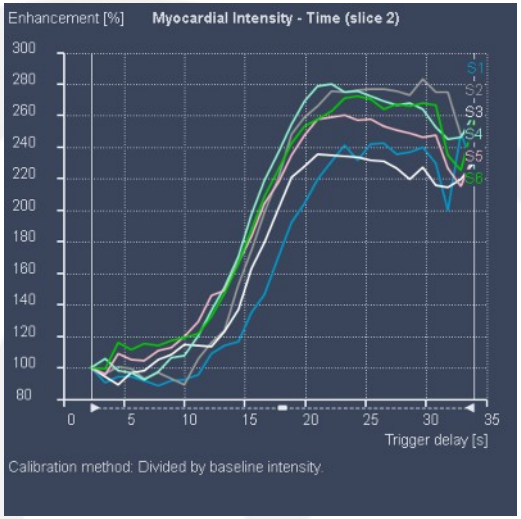


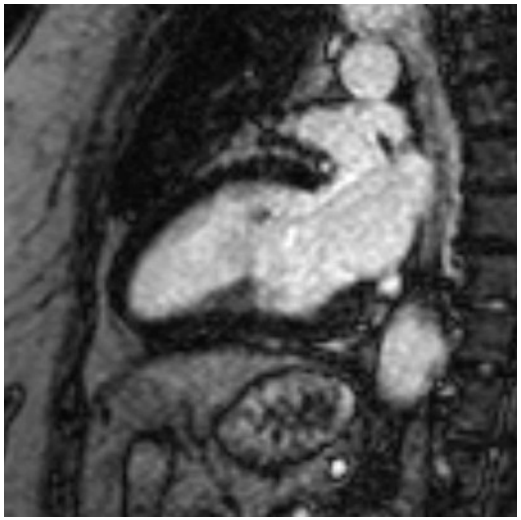
LV: EF 68, ESVi 19, EDVi 59, SVi 40, Mi 48
RV: EF 70, ESVi 17, EDVi 57, SVi 40, Mi 16

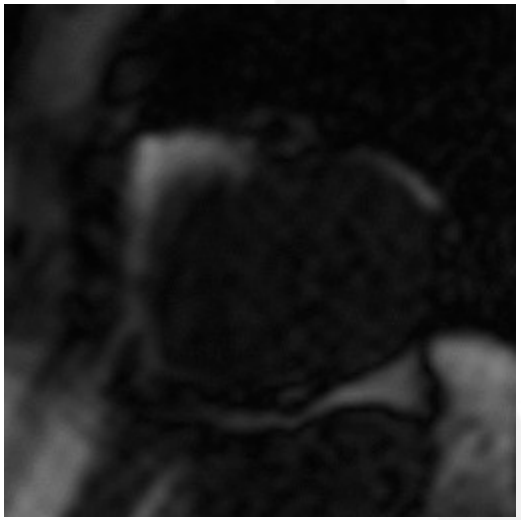
Inferoseptal stress perfusion problem

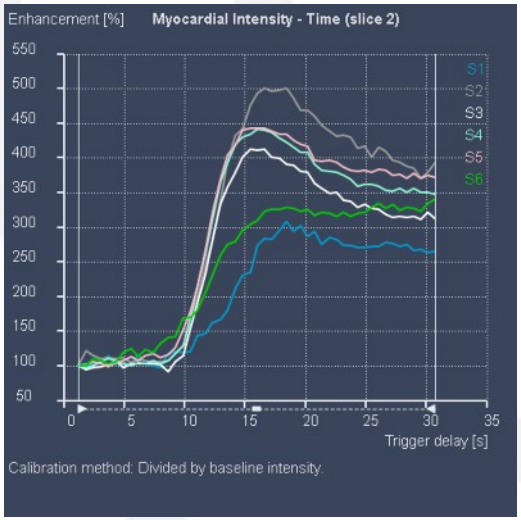






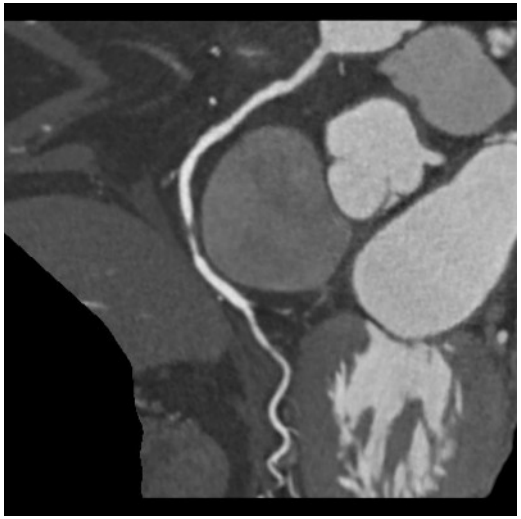
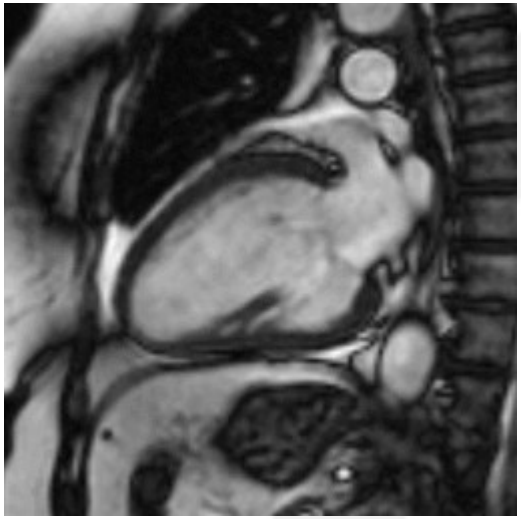
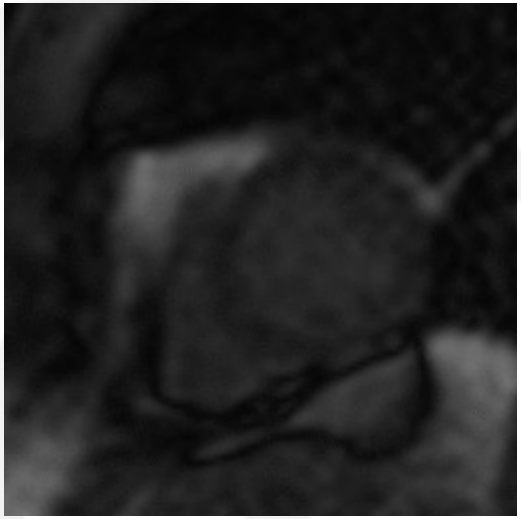
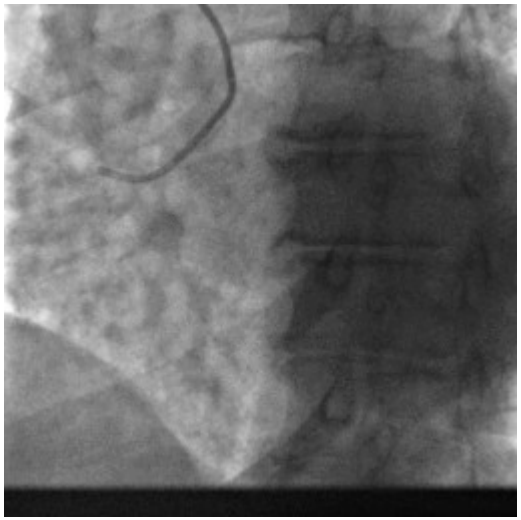
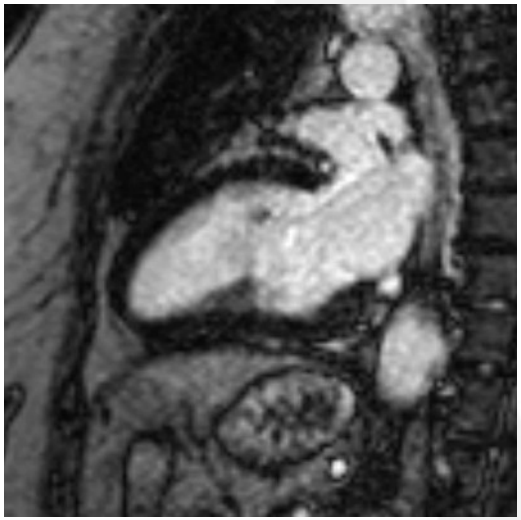
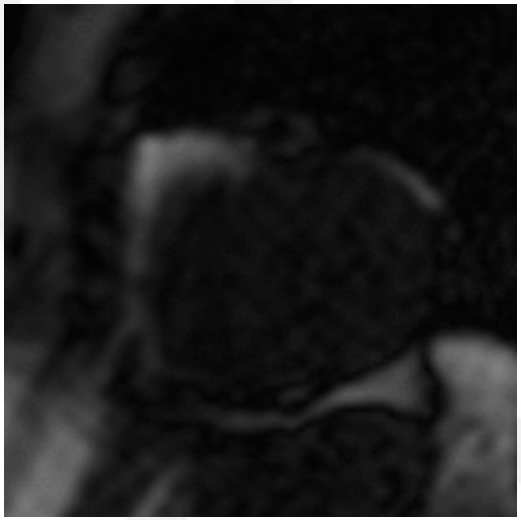






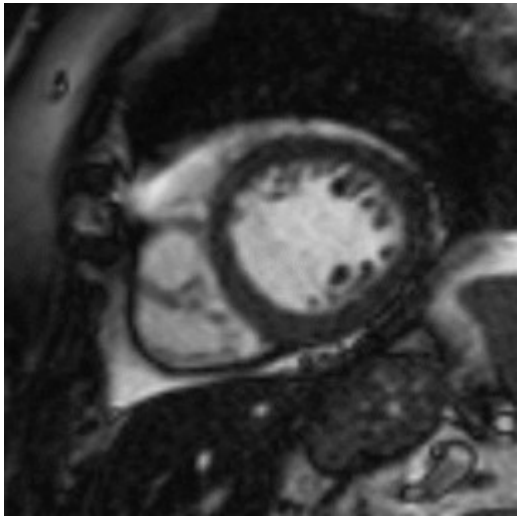
LV: EF 61, ESVi 31, EDVi 79, SVi 48, Mi 50
RV: EF 62, ESVi 26, EDVi 70, SVi 43, Mi -

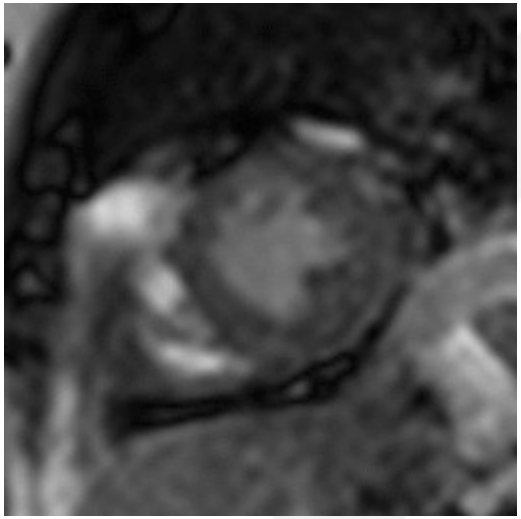
Inferoseptal stress perfusion problem

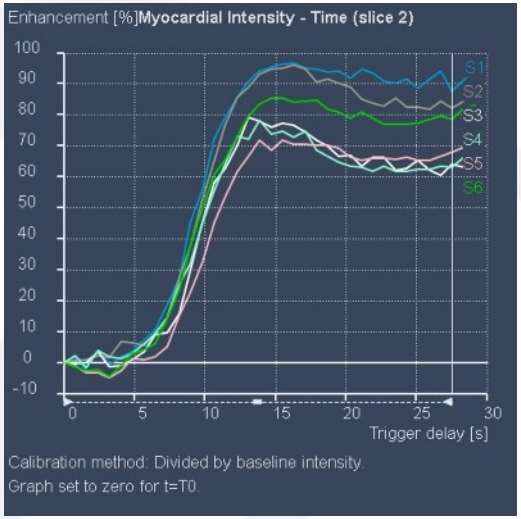







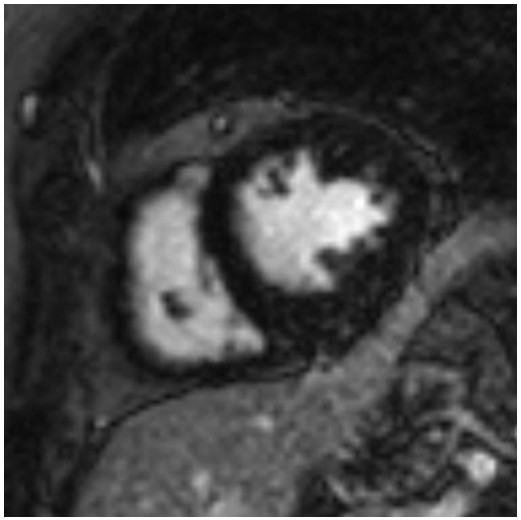
LV: EF 61, ESVi 31, EDVi 79, SVi 48, Mi 50
RV: EF 62, ESVi 26, EDVi 70, SVi 43, Mi -

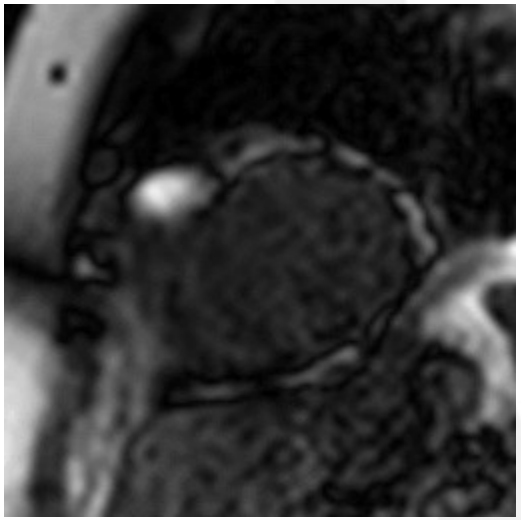
Inducible LAD ischemia

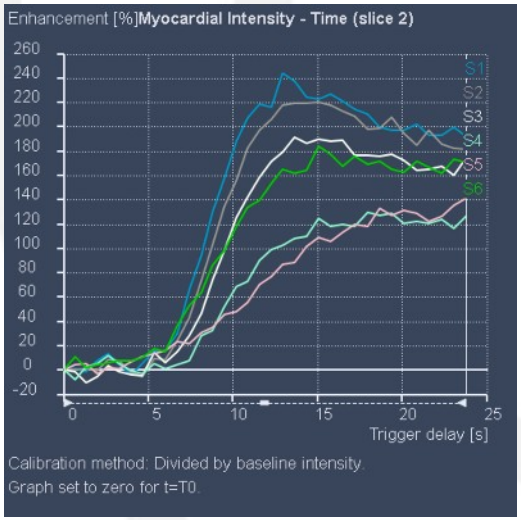








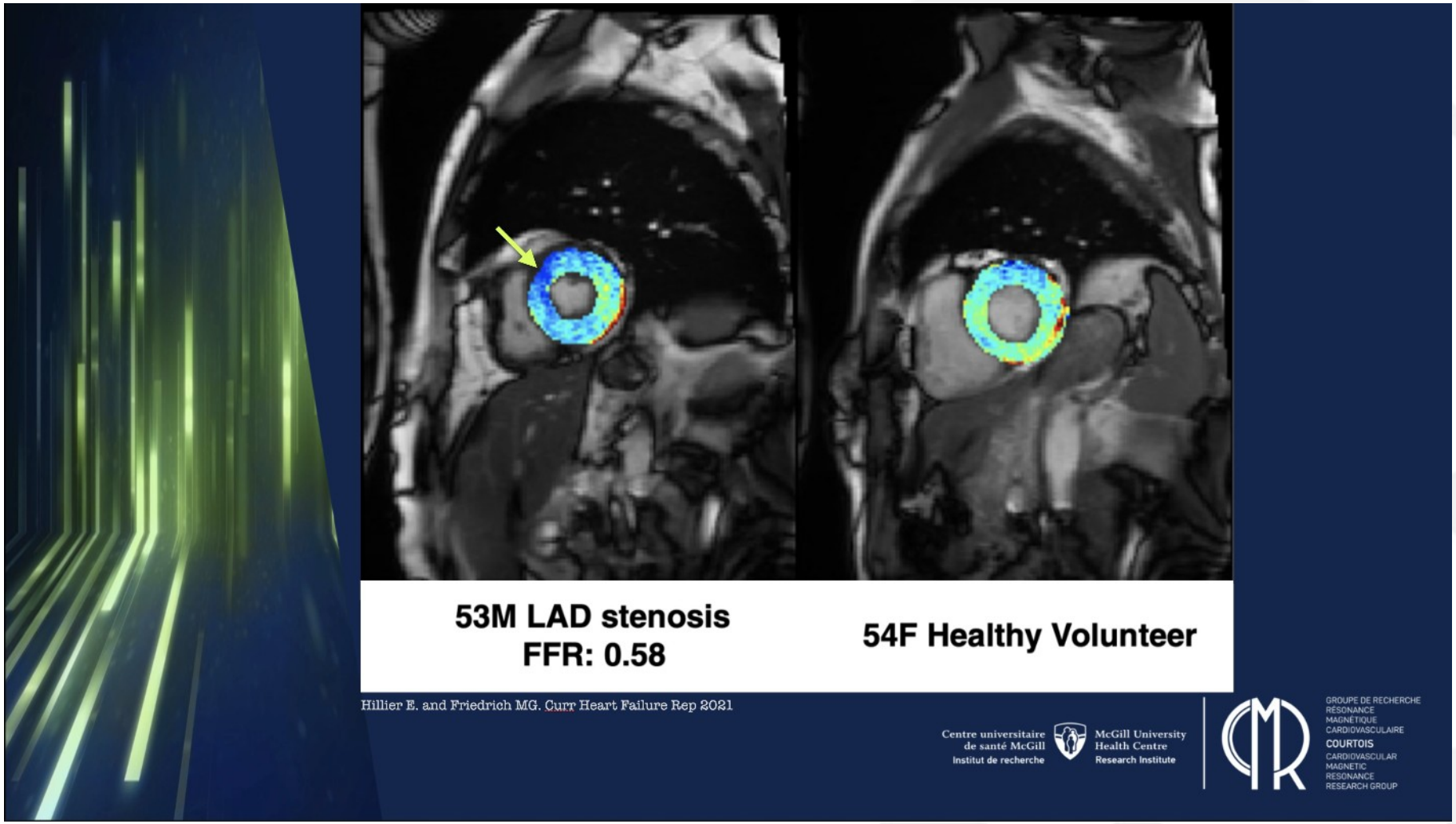




LV: EF 59/69, ESVi 29/16, EDVi 69/51, SVi 41/36, Mi 57/76
RV: EF 68/72, ESVi 19/14, EDVi 58/50, SVi 39/37, Mi 16/24

Breathing maneuvers + O2-sensitive MR

Breathing maneuvers + O2-sensitive MR



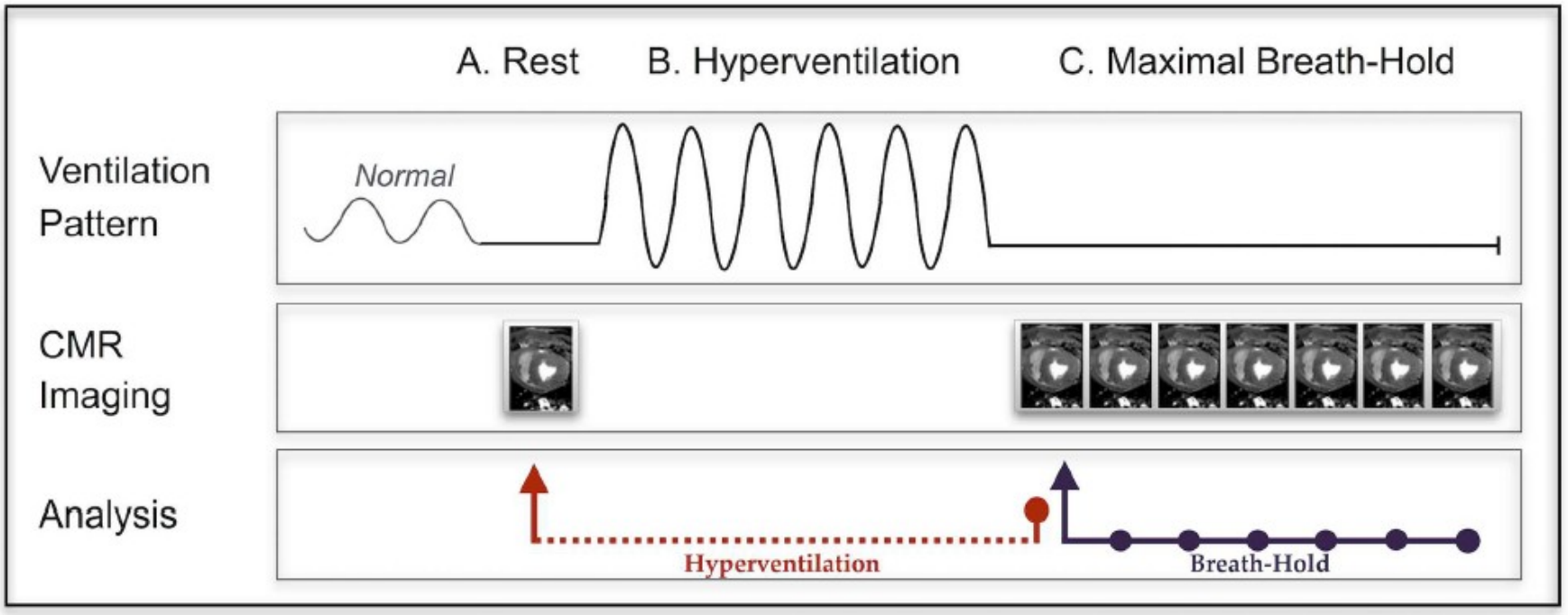


Fig 2. Breathing maneuver protocol. For the combined hyperventilation breath-hold (HVBH) maneuver, a single rest measurement was obtained in a short breath-hold (A). The animal was then manually hyperventilated for 60s (B) followed immediately by a long breath-hold (C) that was imaged throughout, with a repeating OS sequence. Hyperventilation analysis was always compared between rest and the start of the breath-hold (red arrow), while the breath-hold could be analyzed at multiple time points with comparison to data obtained at the beginning of the breath-hold (purple arrow). The long breath-hold (LBH) followed step C, starting after a normal ventilation pattern.

doi:10.1371/journal.pone.0164524.g002

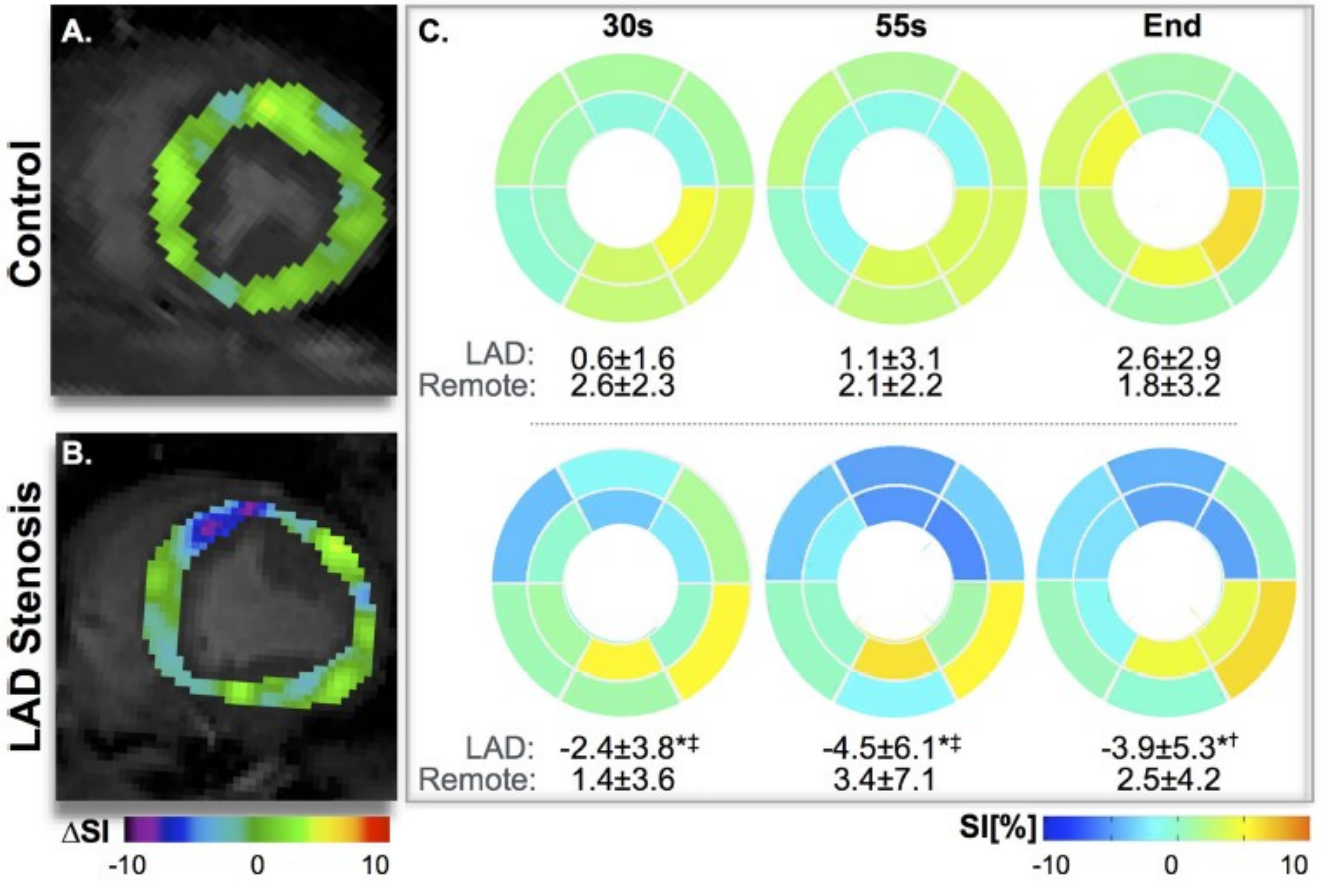


Fig 4. Segmental changes of myocardial oxygenation during the HVBH. Subtraction images (smoothed using a 6mm Gaussian filter) demonstrate that at the 30s, SI increased homogeneously in the control animal (A), while there was a decrease in the territory of the stenosed LAD (B). The mean response for each segment from all animals similarly shows that in control animals (top row, n = 8), ΔSI[%] is consistently larger for all segments, whereas for the stenosis animals (bottom row, n = 10) in the LAD regions a significant decrease is already observed at 30s, and this continues throughout the breath-hold. (*p<0.05 between LAD and remote territory within the group, †p<0.05, <0.05‡p<0.01 for the difference in LAD response between groups).

doi:10.1371/journal.pone.0164524.g004

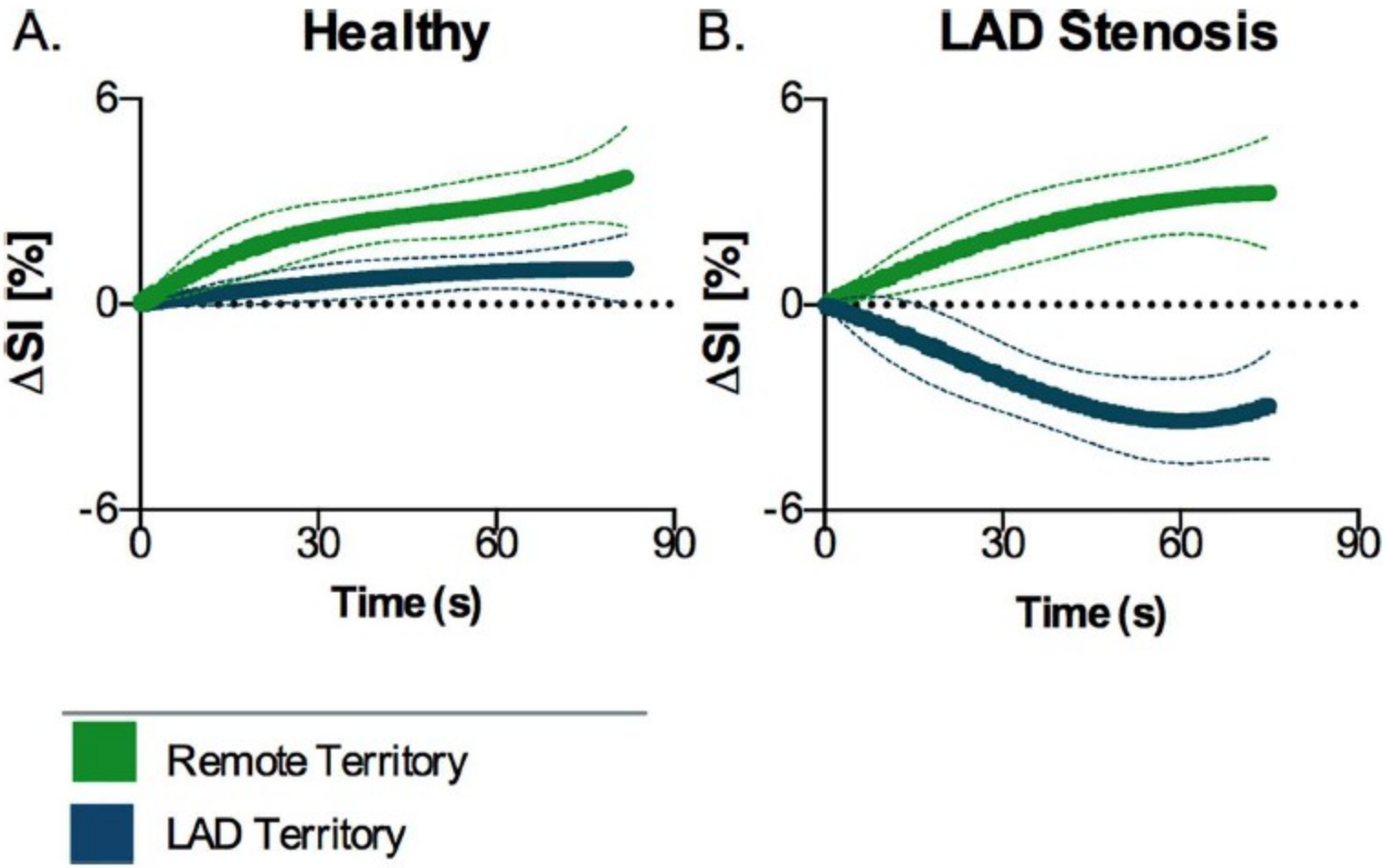
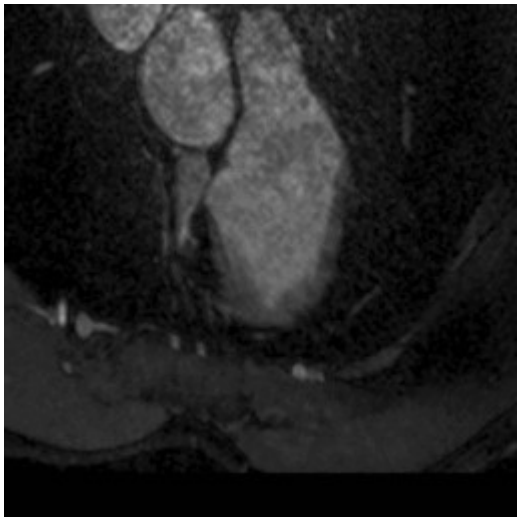
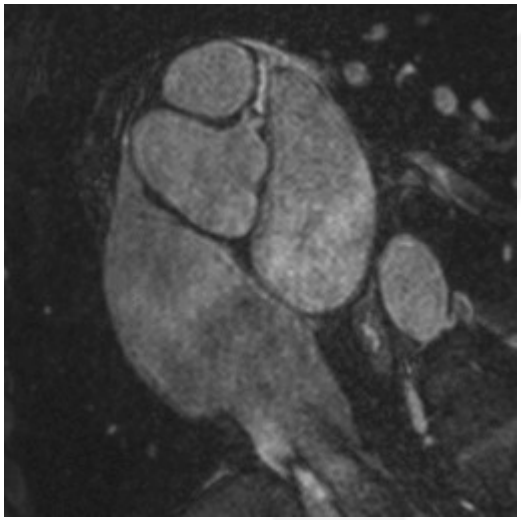
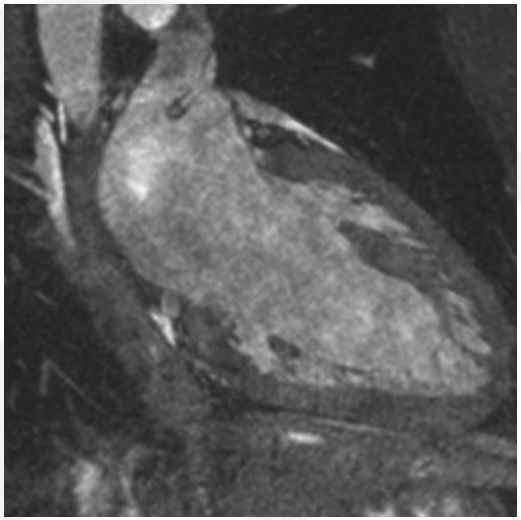
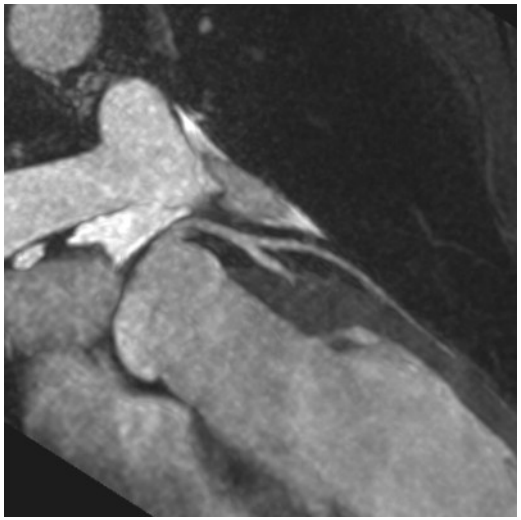
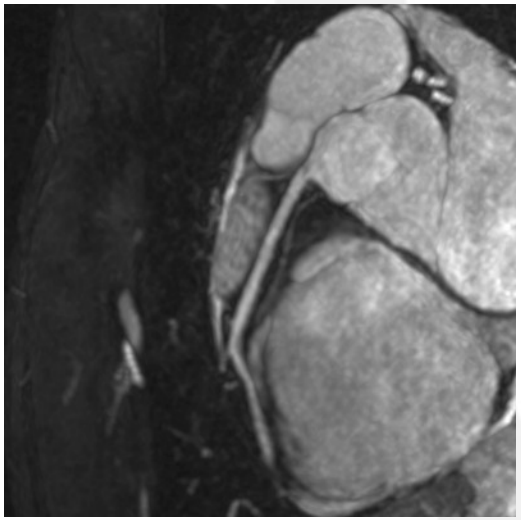
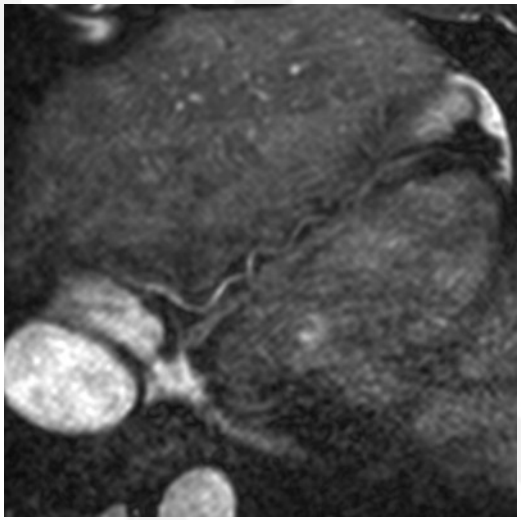


Fig 5. Myocardial oxygenation response curve during the HVBH. Signal intensity increases globally during the HVBH in control animals (A), yet the animals with a stenosis (B) show a significant decrease in the LAD territory (blue), while the remote region (green) remains above baseline with a similar characteristic of the control animals.

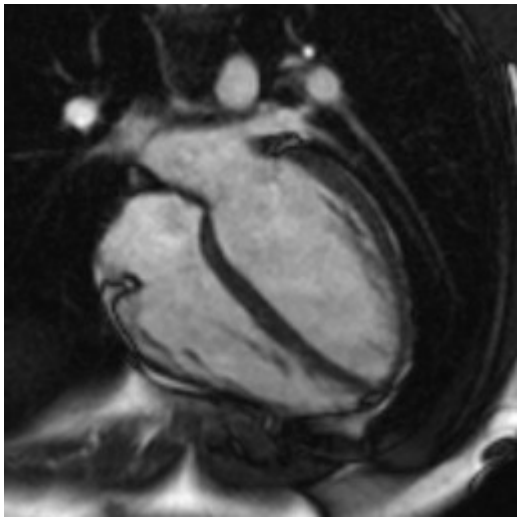
doi:10.1371/journal.pone.0164524.g005

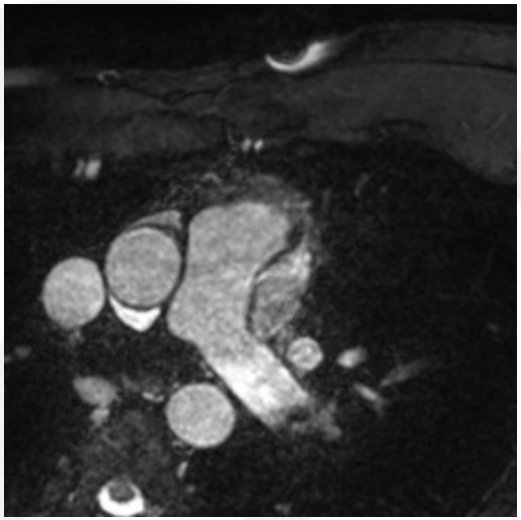
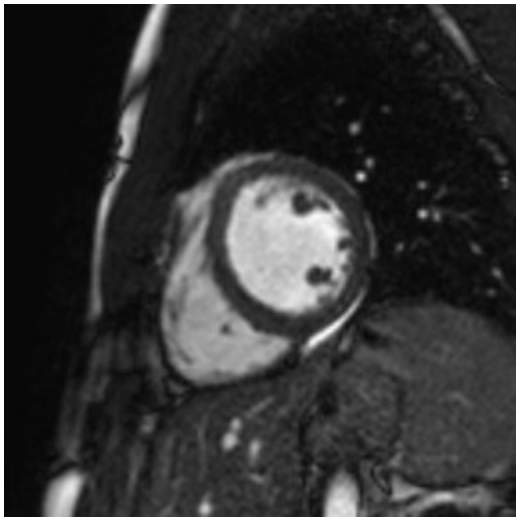
Kawasaki syndrome

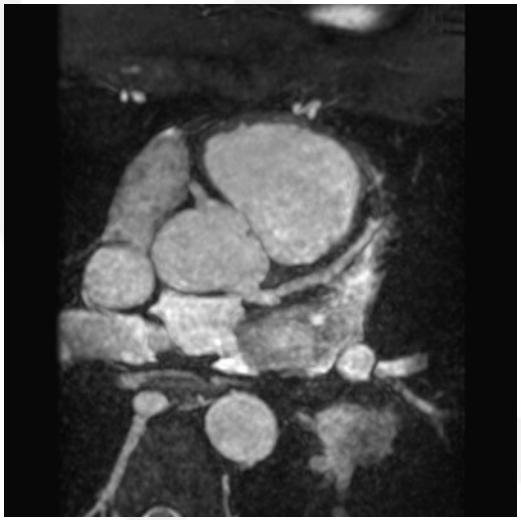
Cs: 3D NAV MRCA

Kawasaki, RCA ectasia, stenosis?



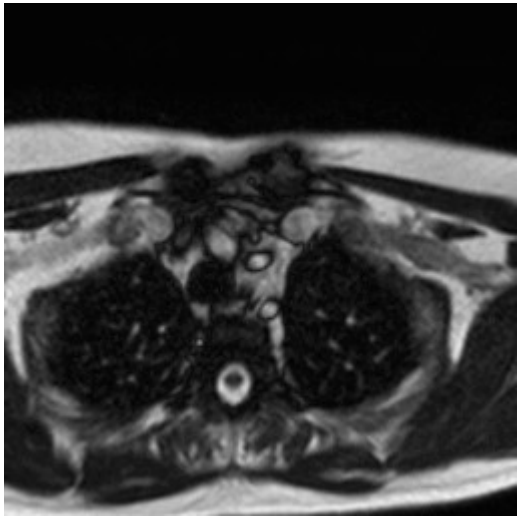
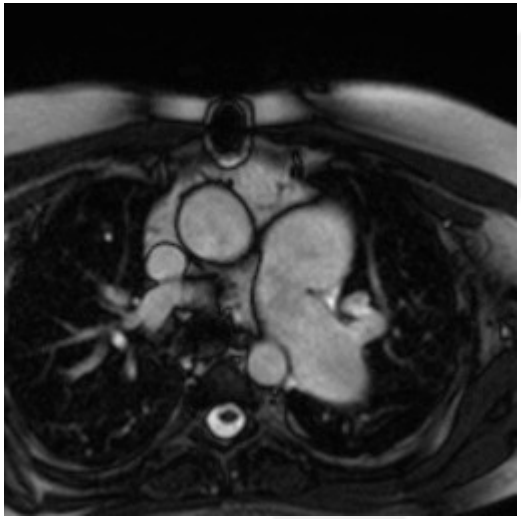
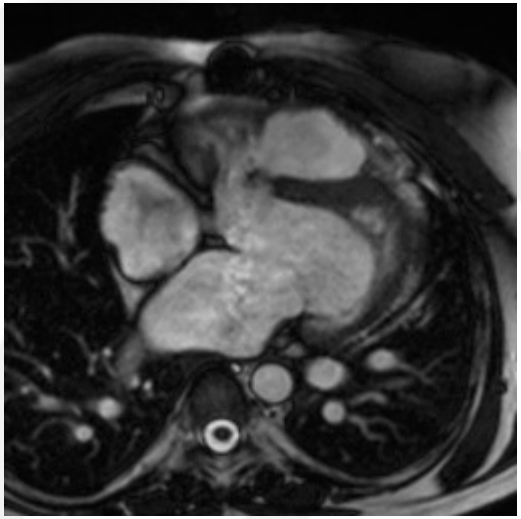
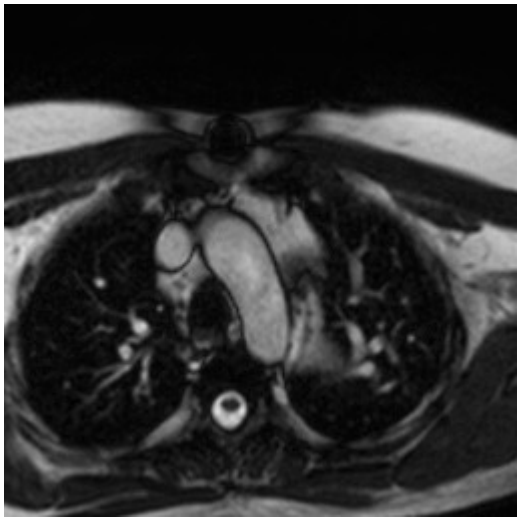
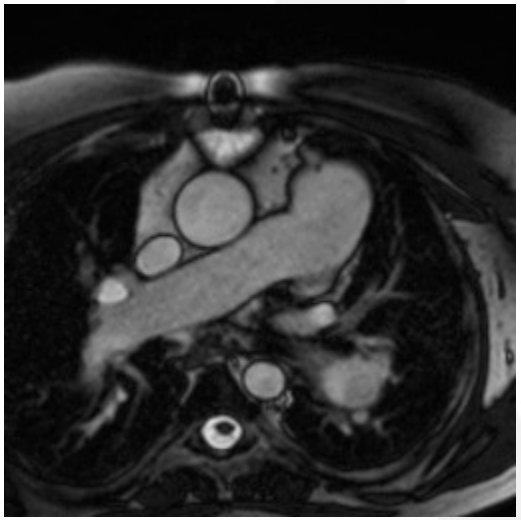
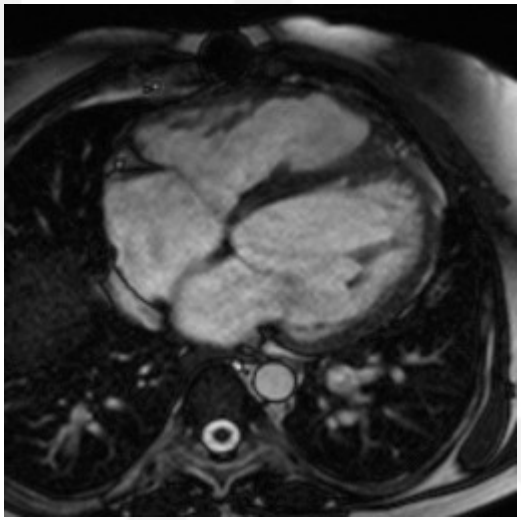





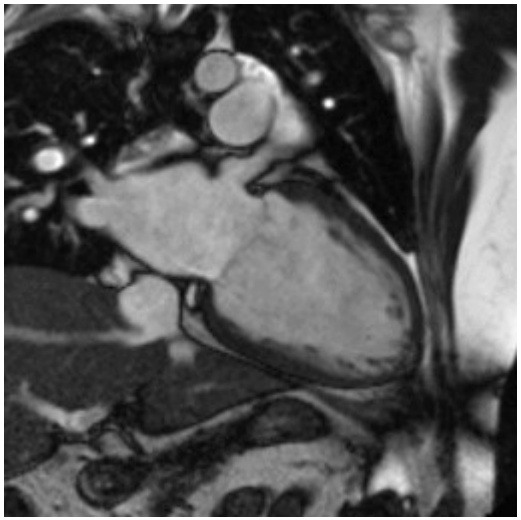
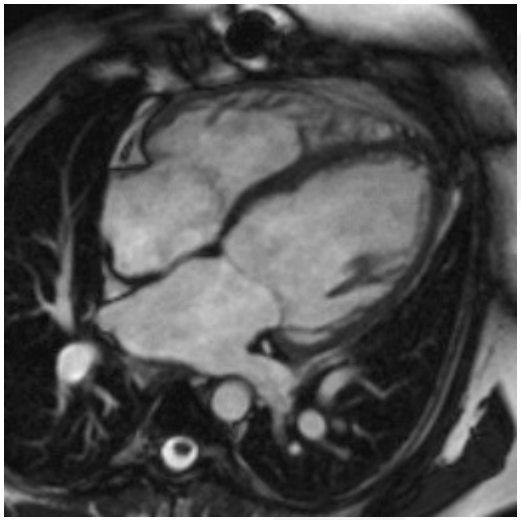
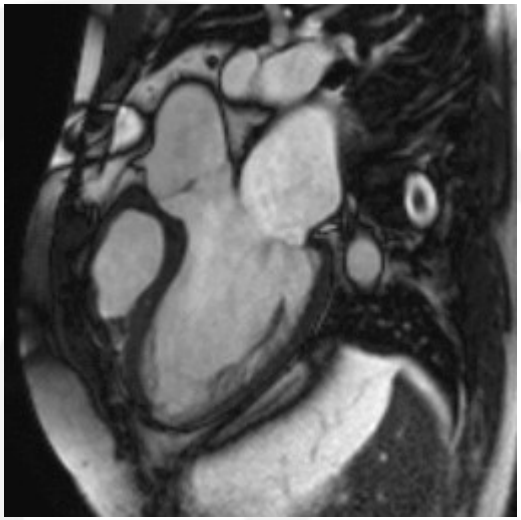
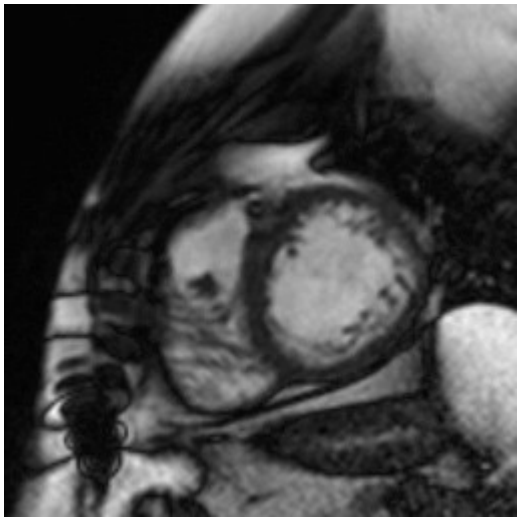
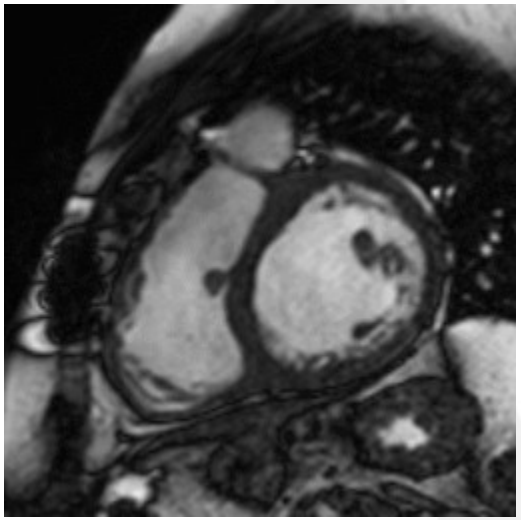
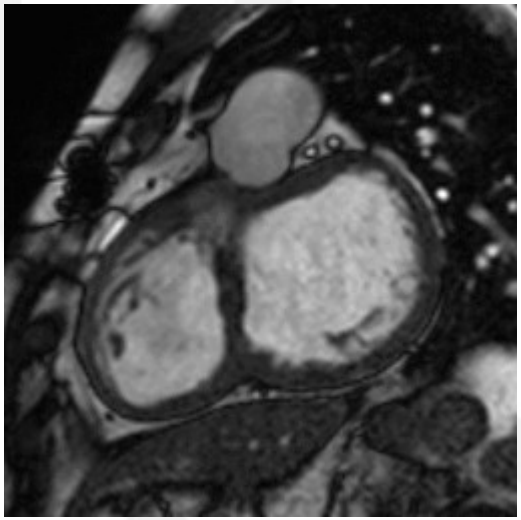
LV: EF 61[68], ESVi 38[25], EDVi 96[78], SVi 57[53], Mi 63[82]
RV: EF 59[69], ESVi 41[31], EDVi 101[86], SVi 60[55], Mi 19[34]

Reconstructed tetralogy of Fallot (TOF or FIV)

Axial/transversal cine stack

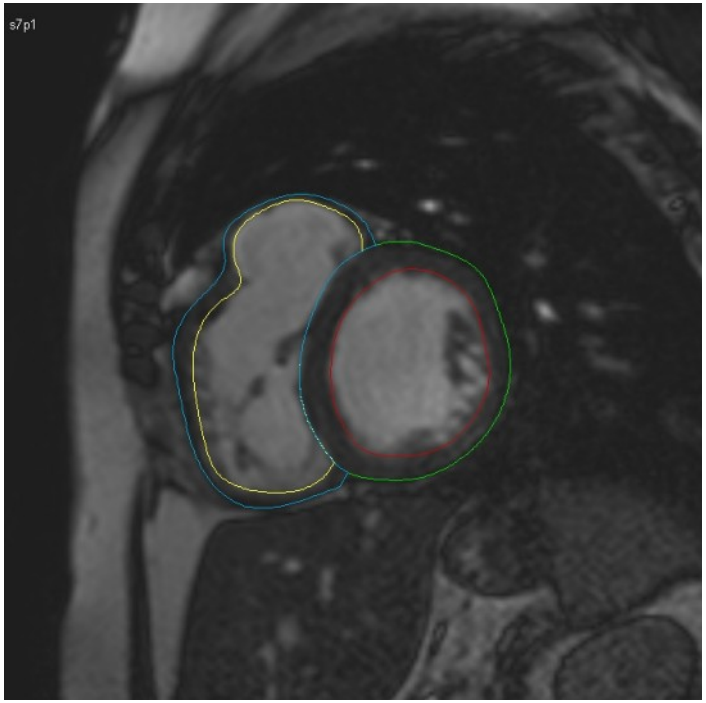







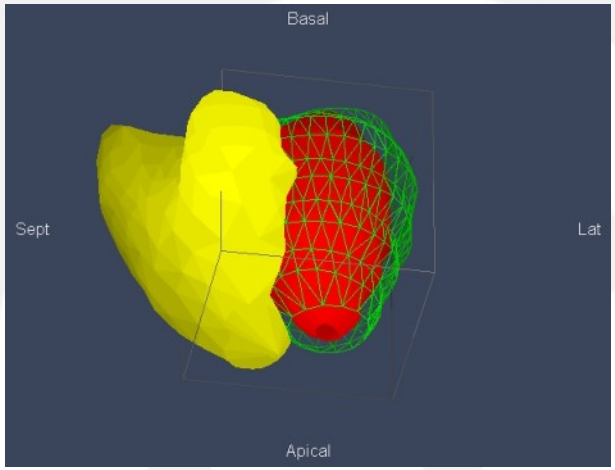
Long & short axis stack

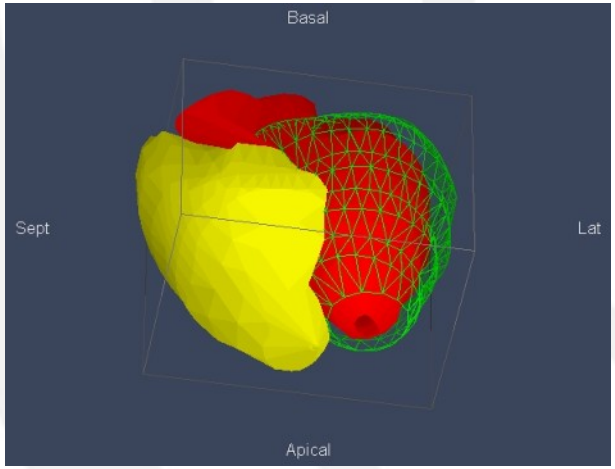







LV: EF 54/64, ESVi 80/51, EDVi 174/140, SVi 94/89, Mi 87/123
RV: EF 42/47, ESVi 72/49, EDVi 126/93, SVi 53/43, Mi 40/75

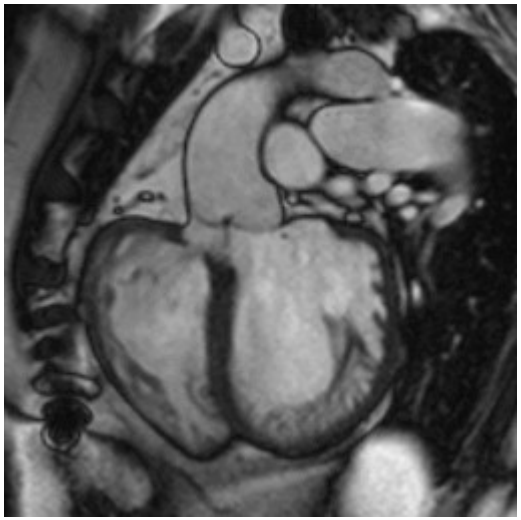
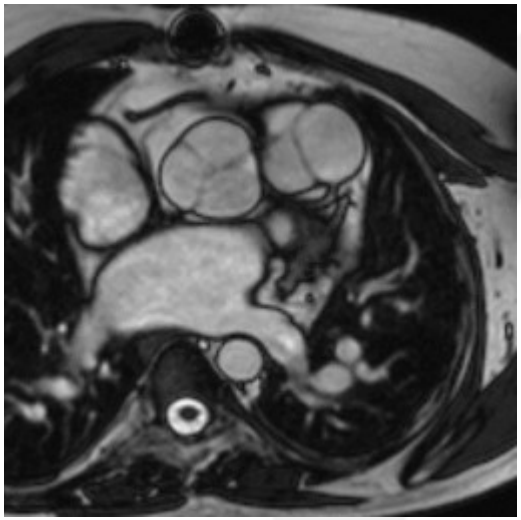
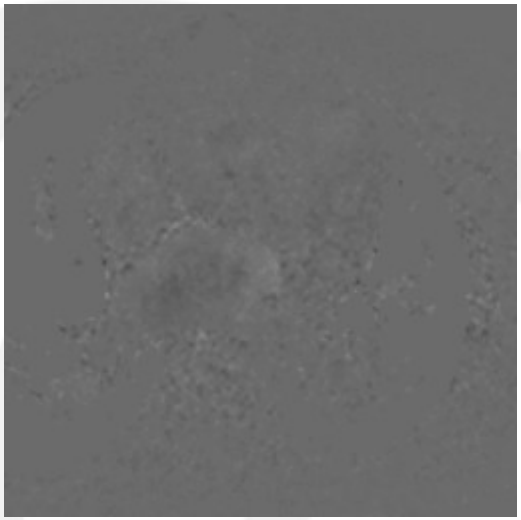
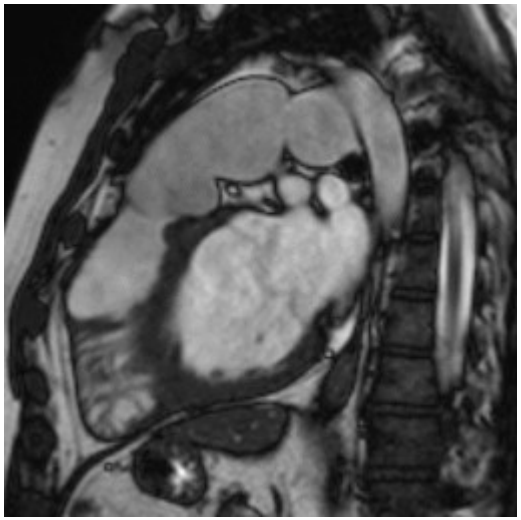
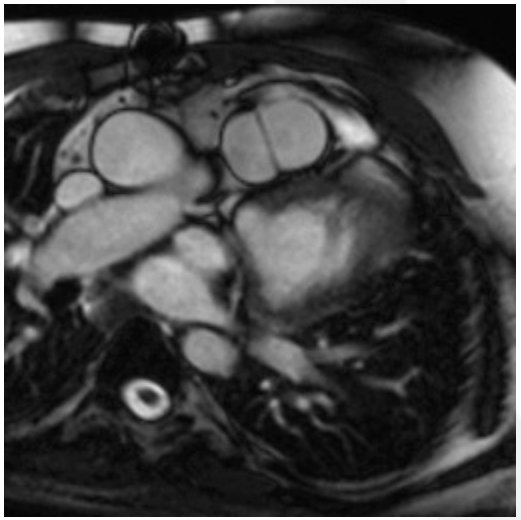
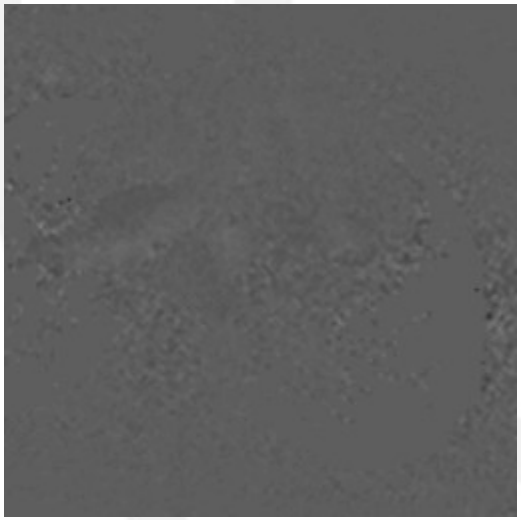
Functional evaluation



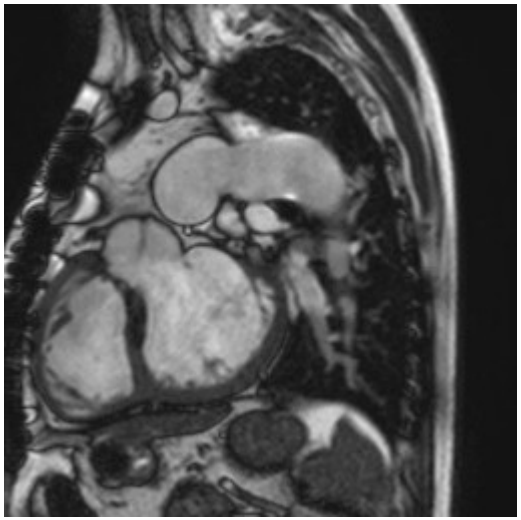
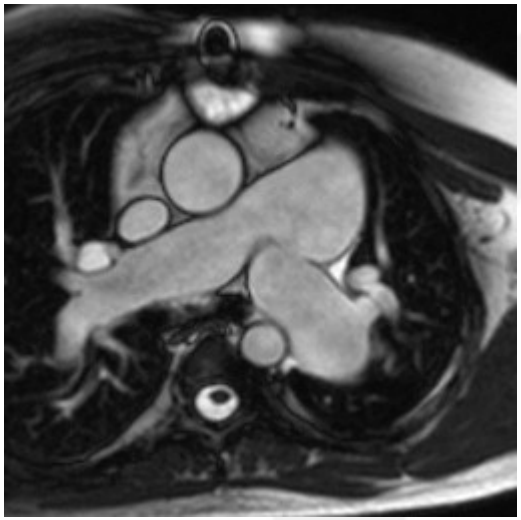
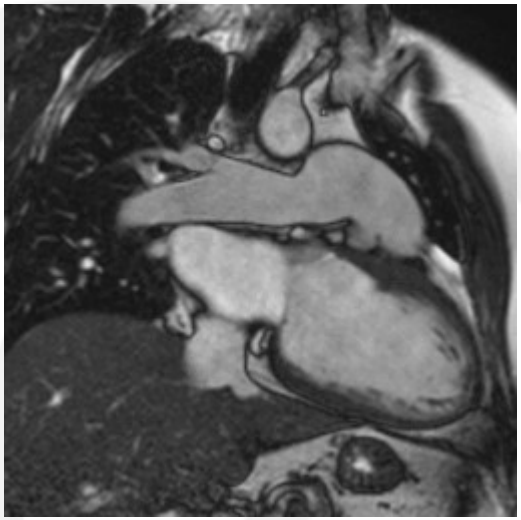
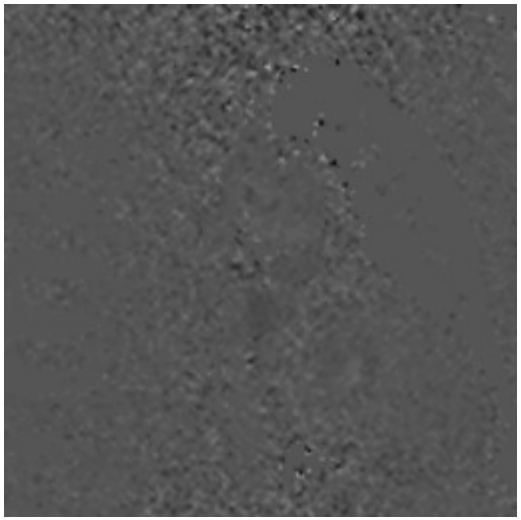
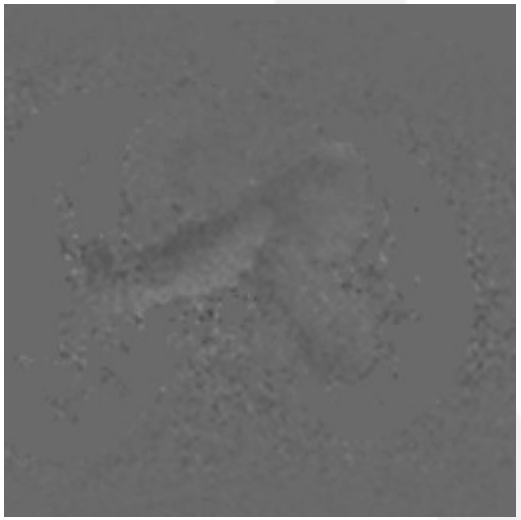
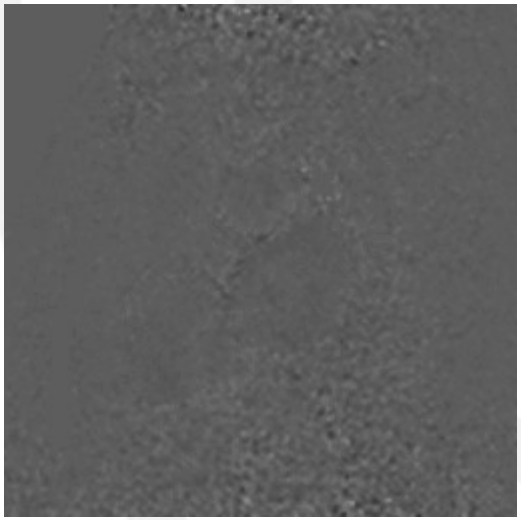




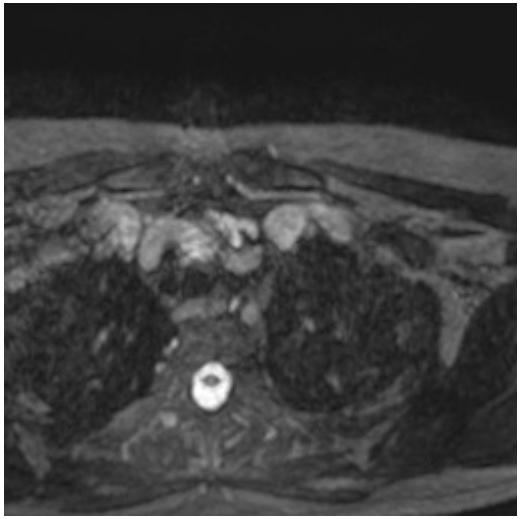
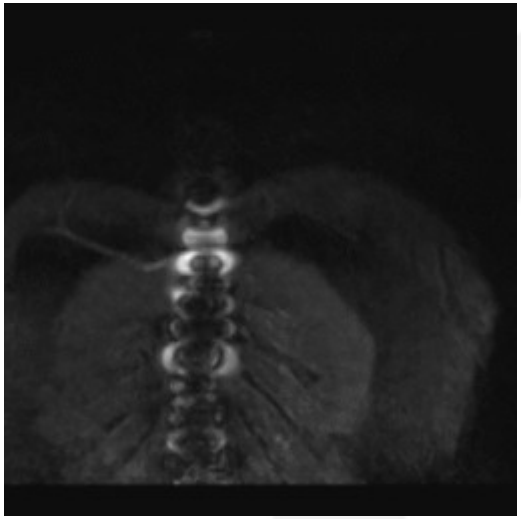
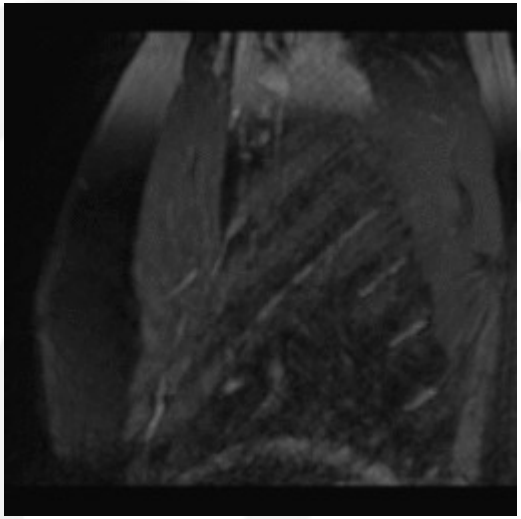
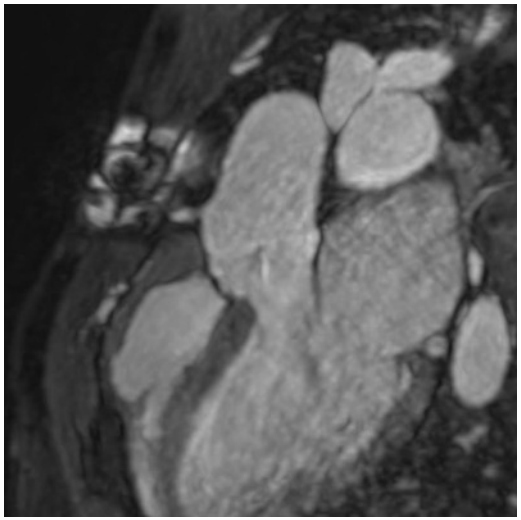
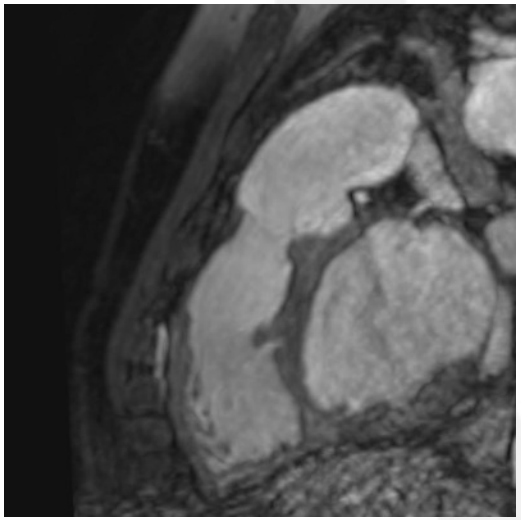
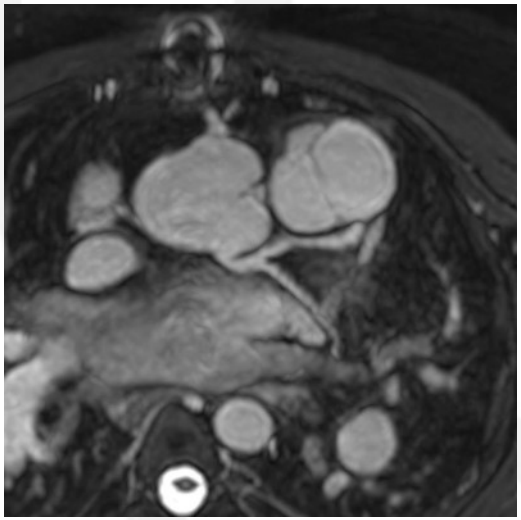
PA 253 16 3, AO 94 2 12, Qp/Qs: 2,27!

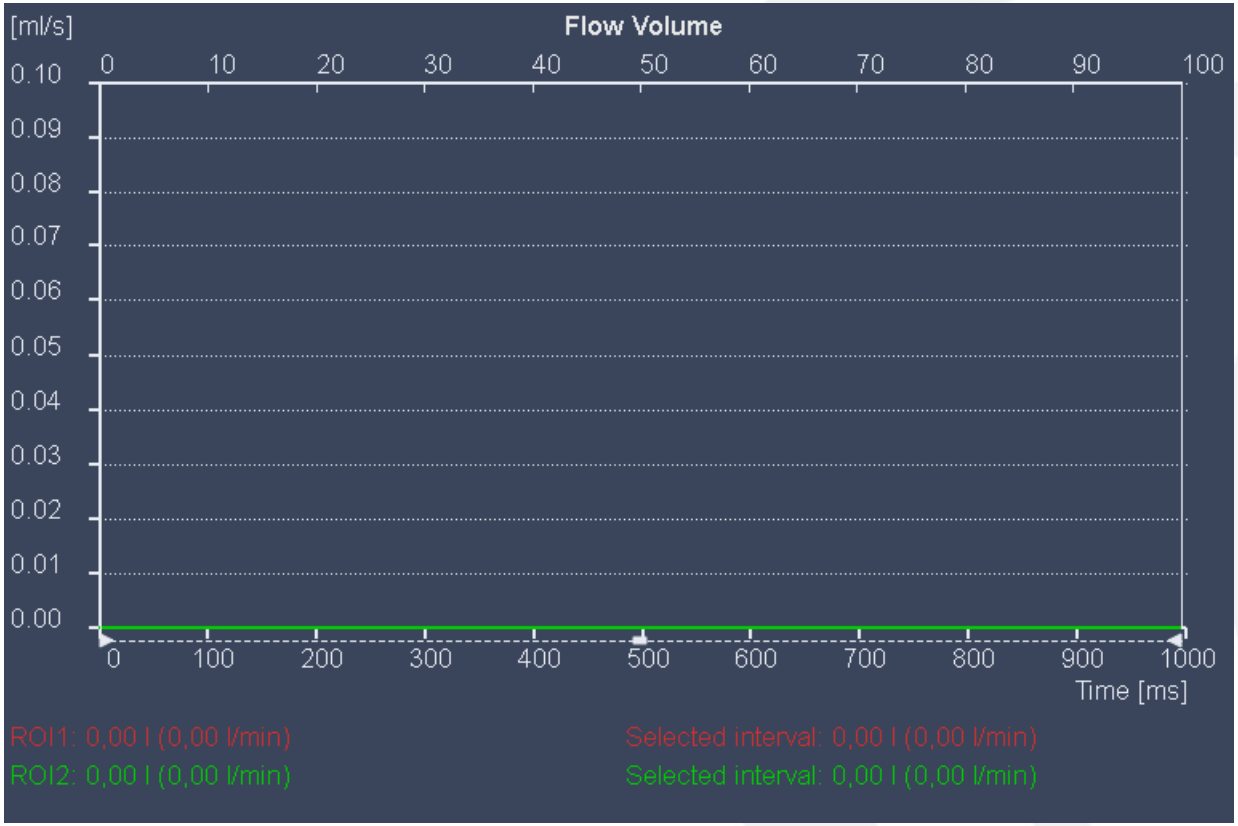
J: 106 2 0, B: 146 9 5, R-L: 54-46%

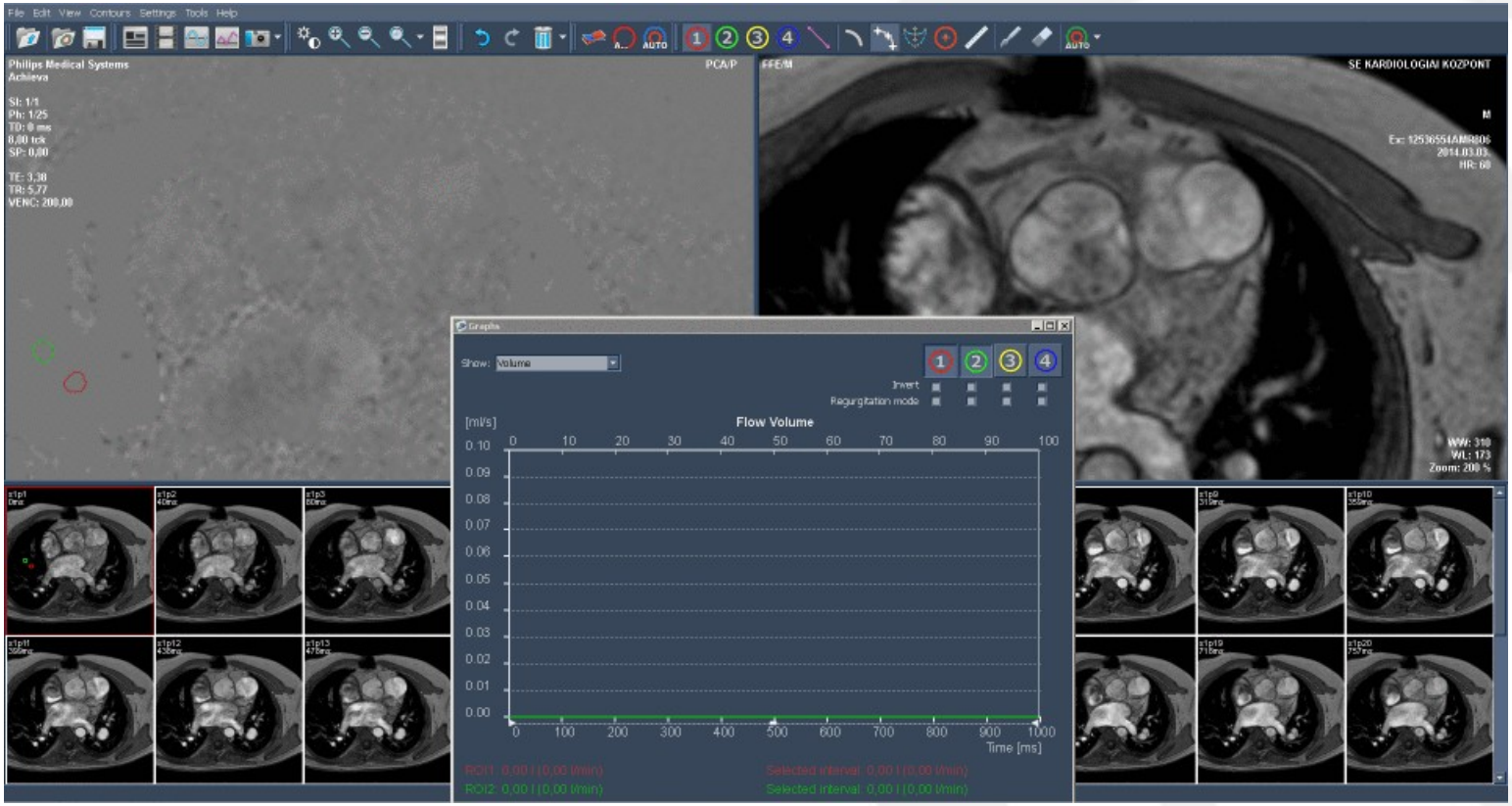
3D NAV MRA

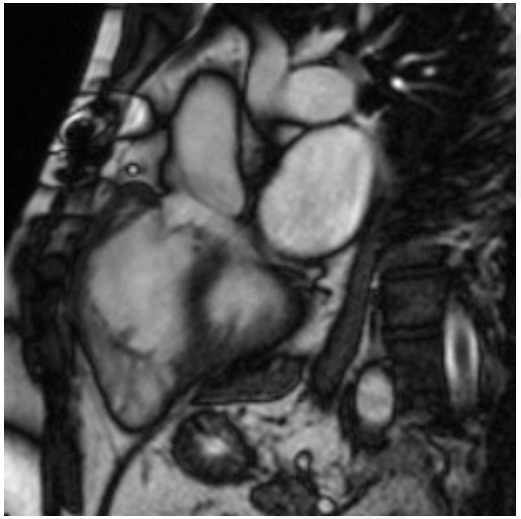
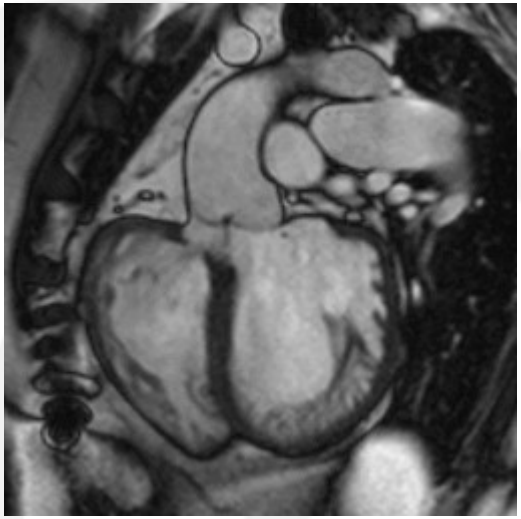
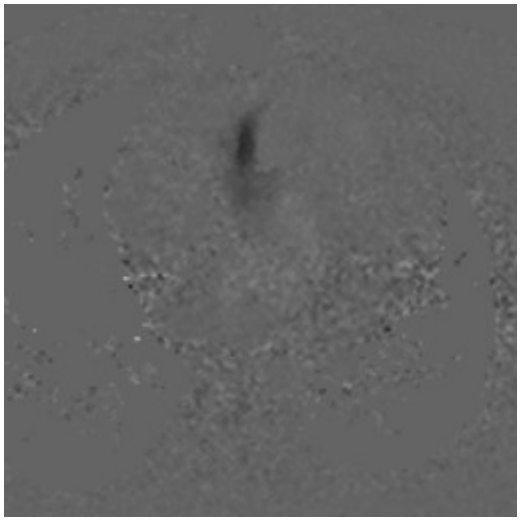
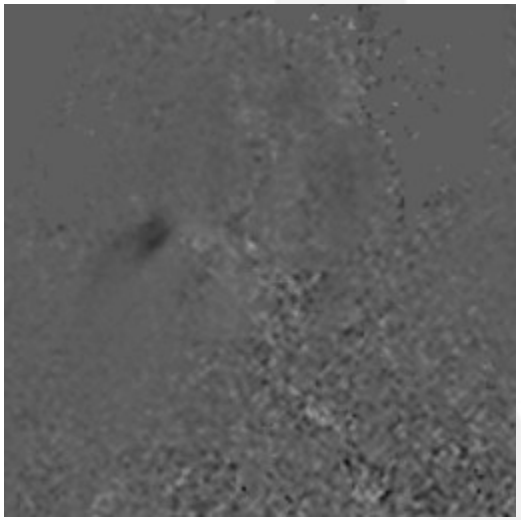
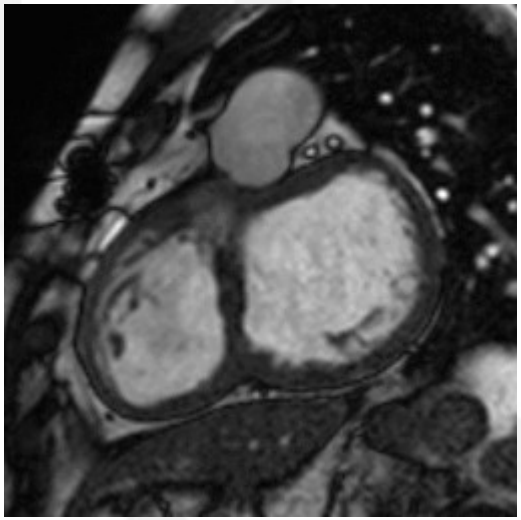
Flow quantification



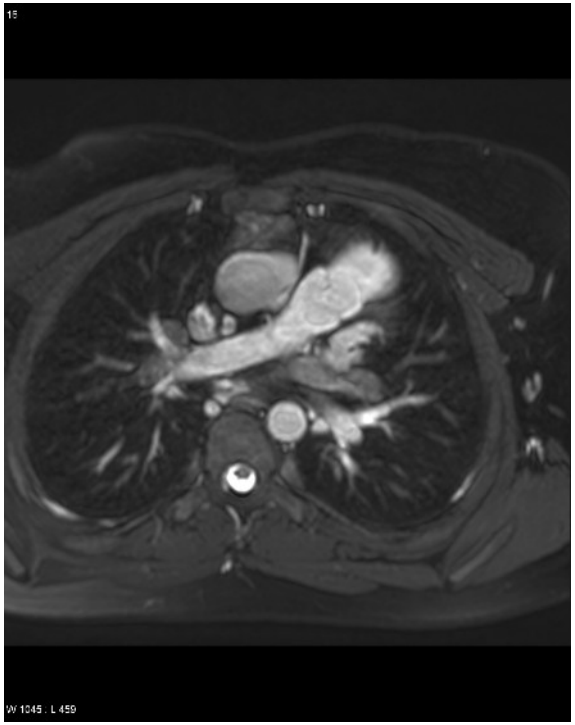
Flow quantification

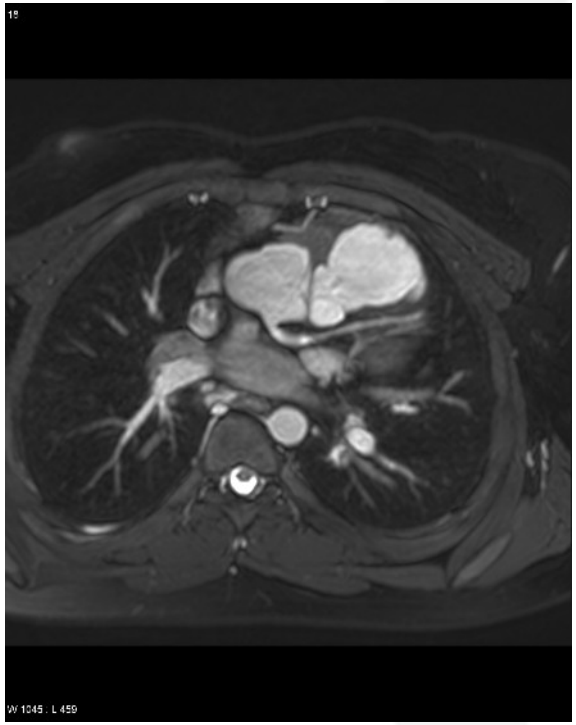


VSD

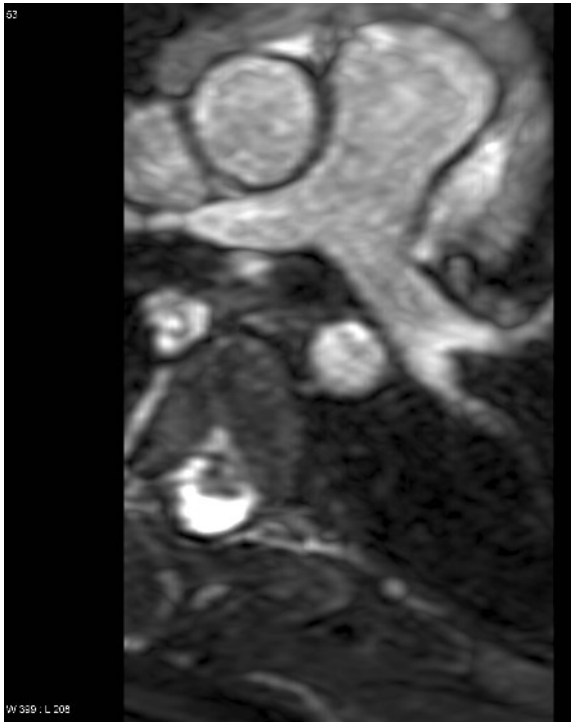
Navigated 3D

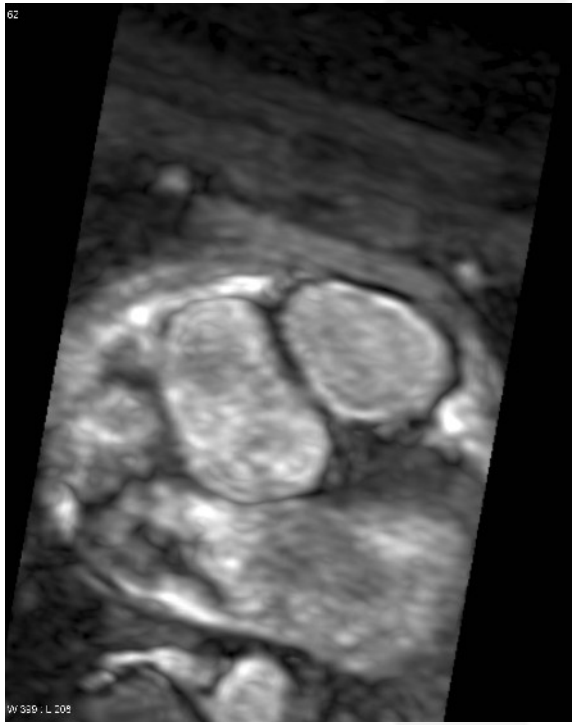




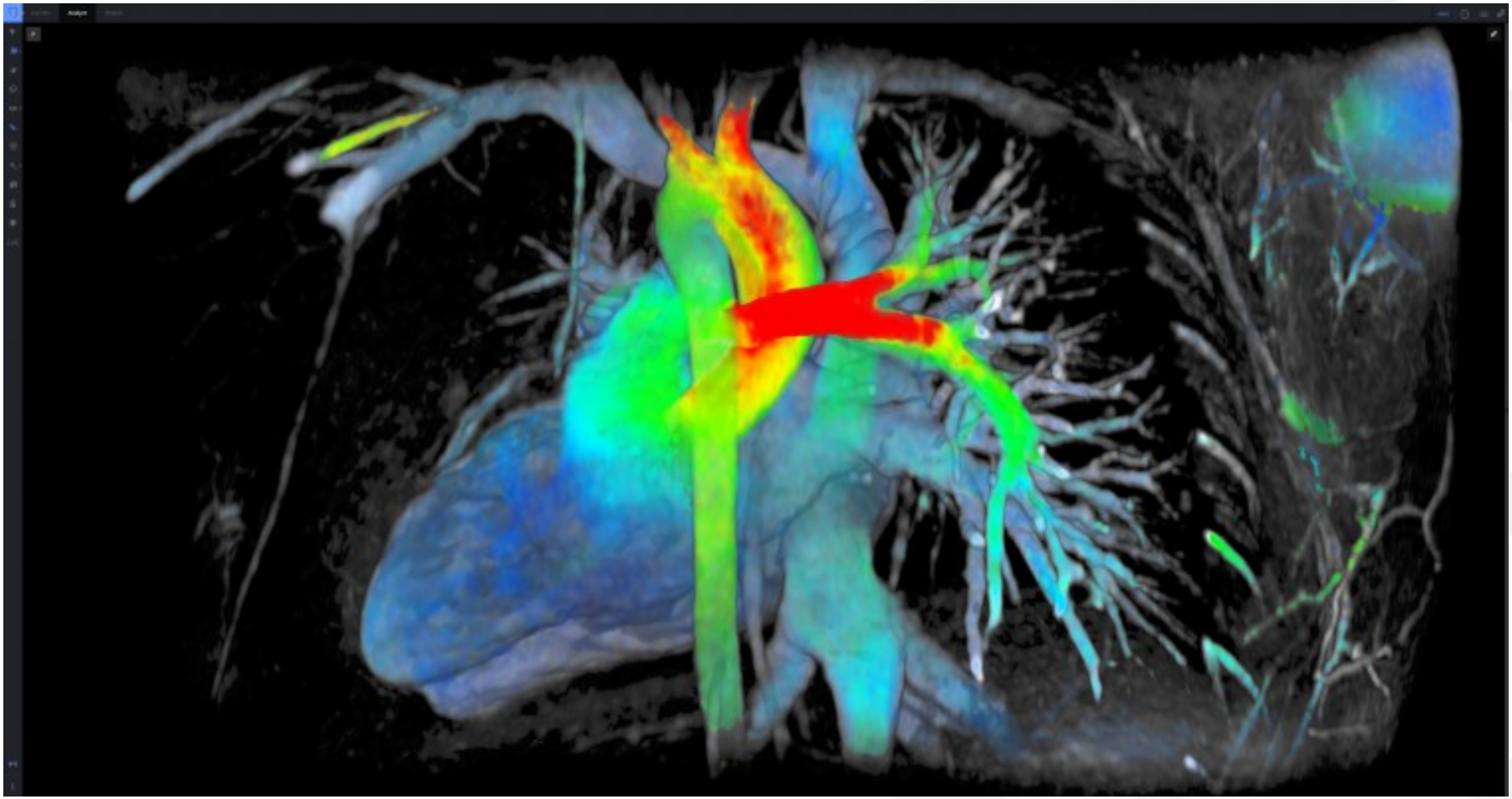
3D navigated MRA reconstructions

Further postprocessing



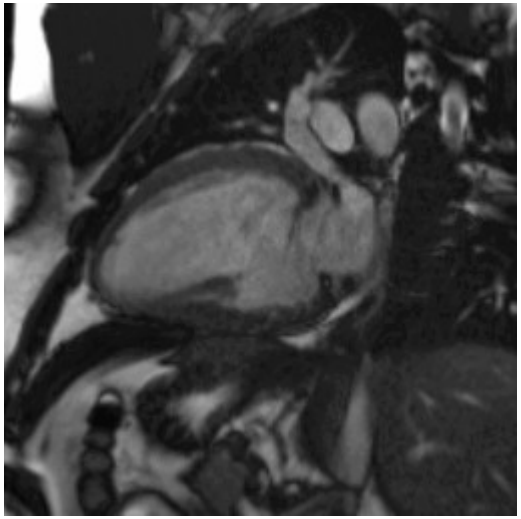


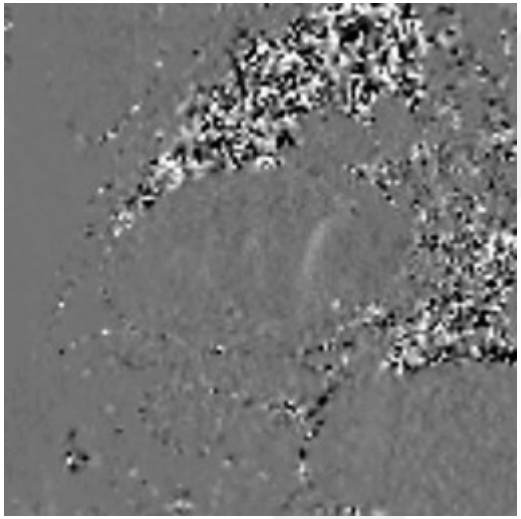
4D flow becoming increasingly popular

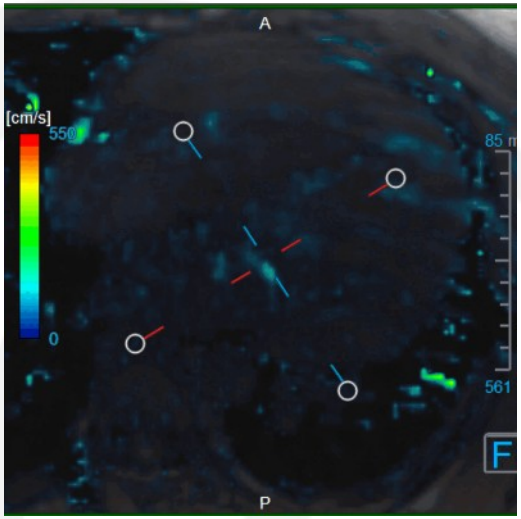


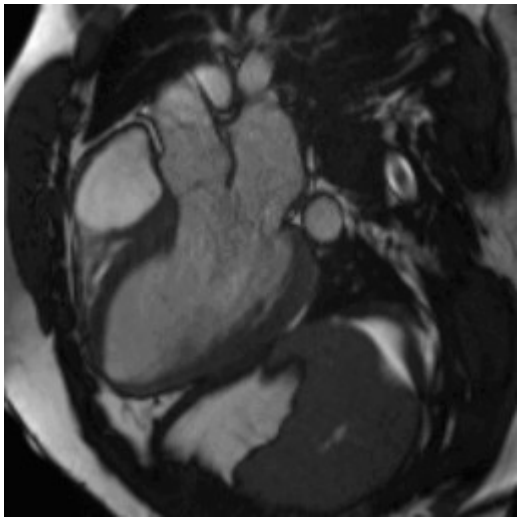
Arterys: ViosWorks

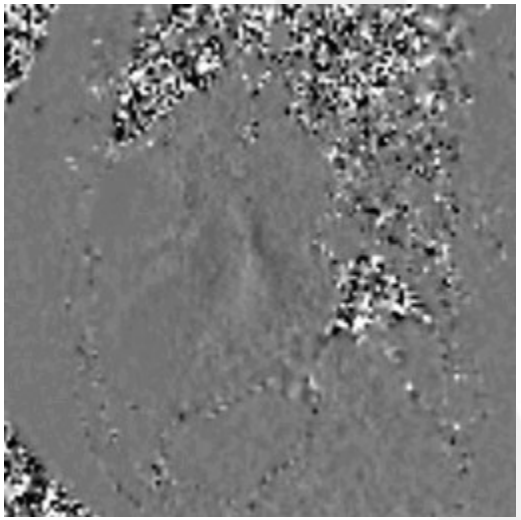
Mitral insuff.: 44%, 468cm/s, 88/38Hgmm

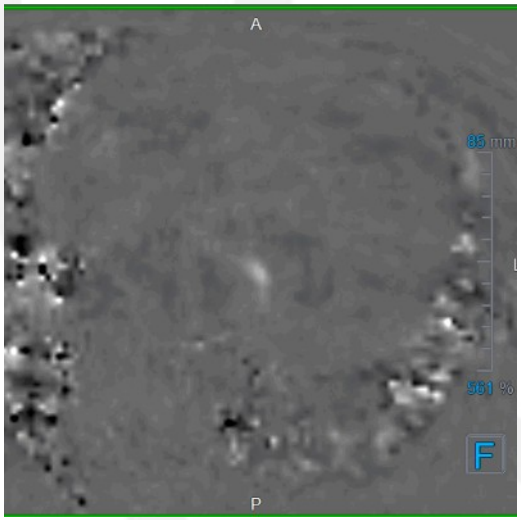






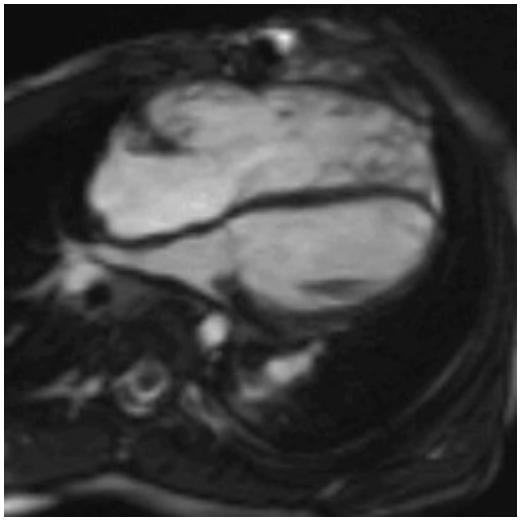


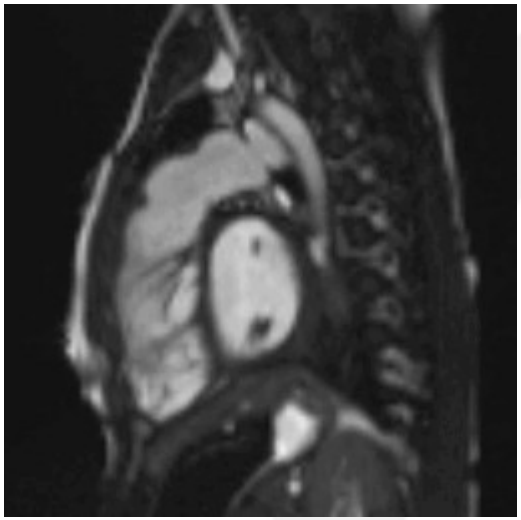


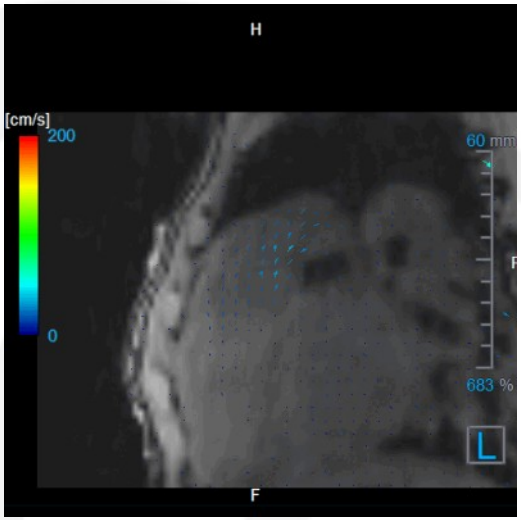


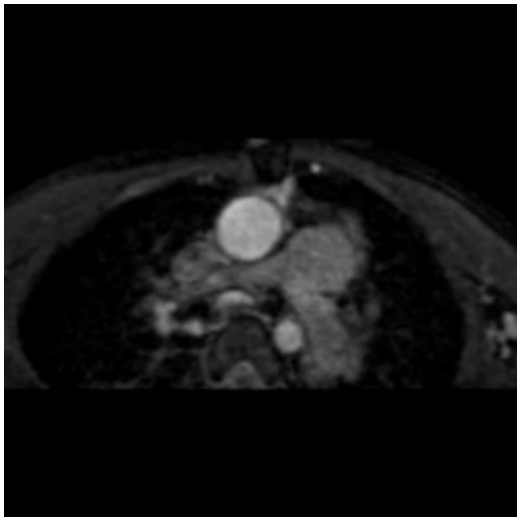
LV: EF 62[69], ESVi 61[40], EDVi 160[128], SVi 99[88], Mi 123[168]
RV: EF 50[54], ESVi 60[42], EDVi 122[92], SVi 61[49], Mi 24[62]

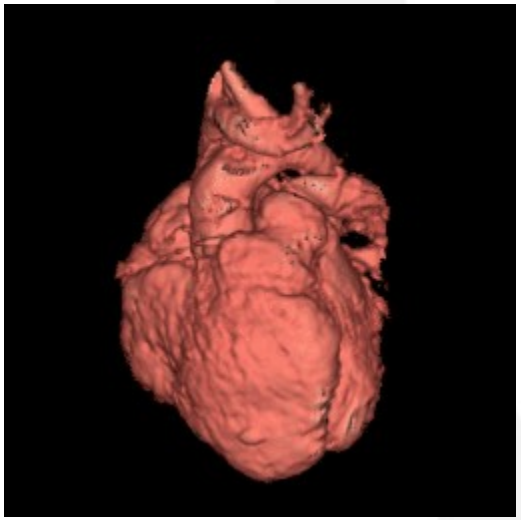
FIV, PA Rf: 64%, iNAV MRA, 4D-Flow

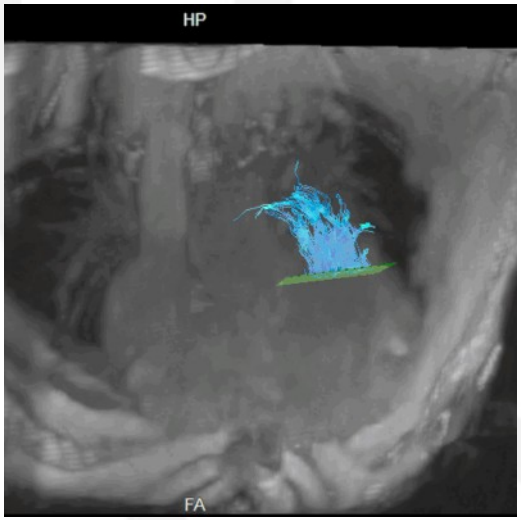






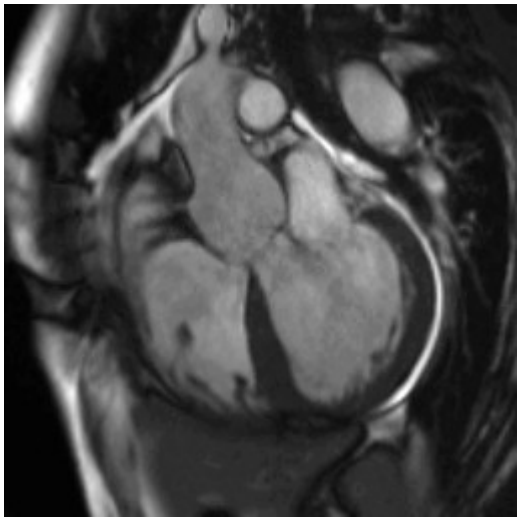


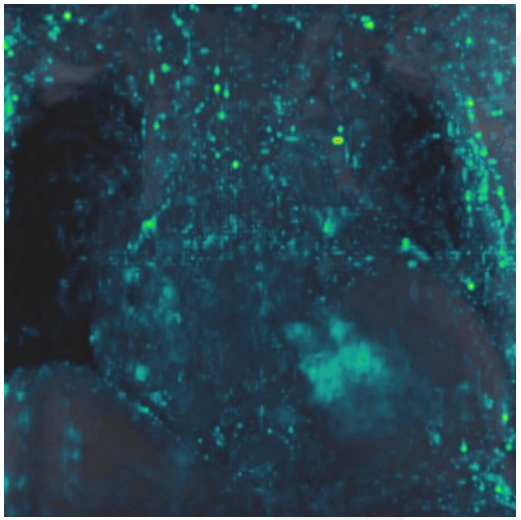


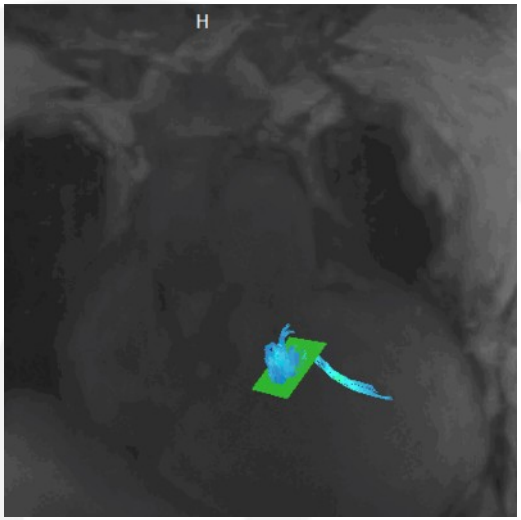


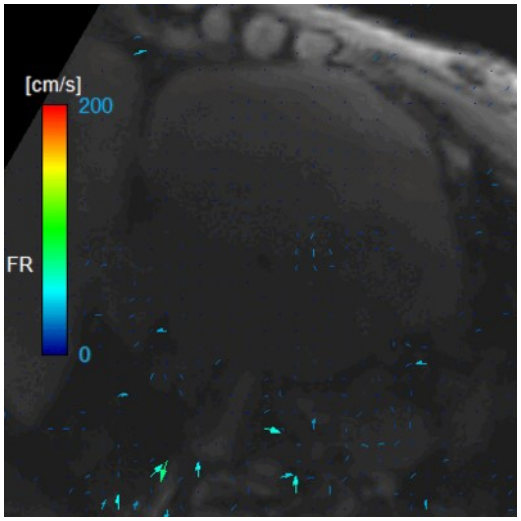
LV: EF 55[62], ESVi 33[23], EDVi 74[62], SVi 41[39], Mi 45[57]
RV: EF 52[59], ESVi 75[49], EDVi 156[118], SVi 80[69], Mi 40[79]

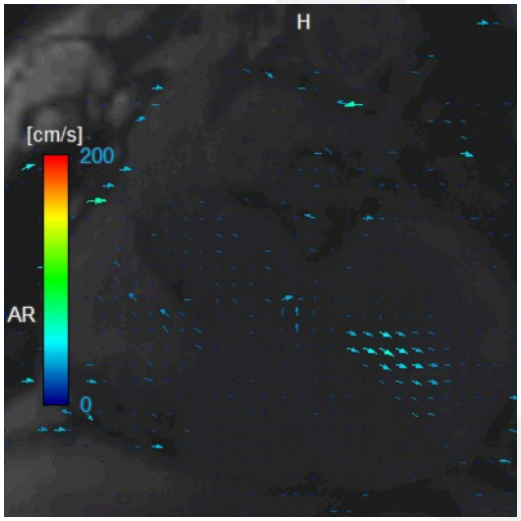
CoA, BAV, AOI, Ebstein-, AO Rf: 49%











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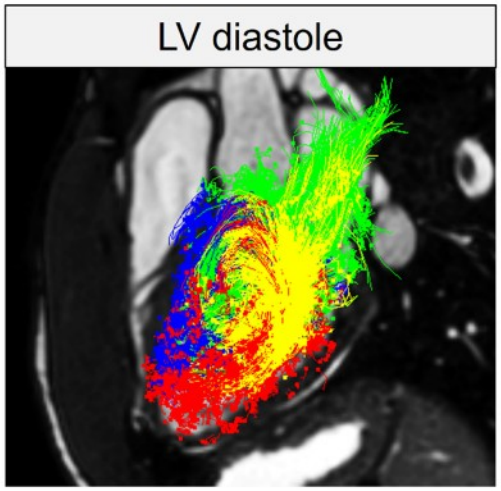
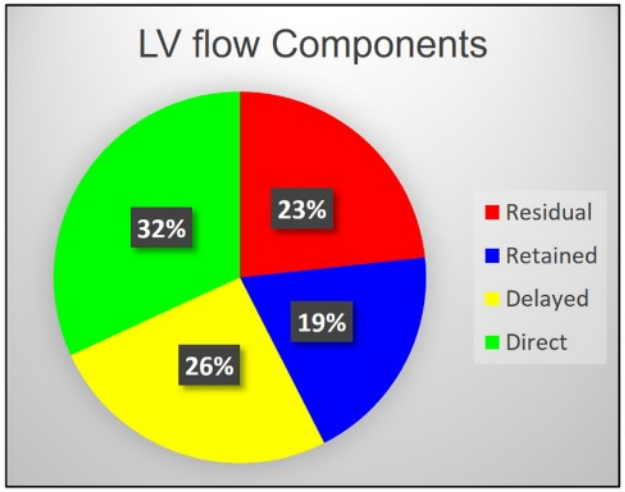
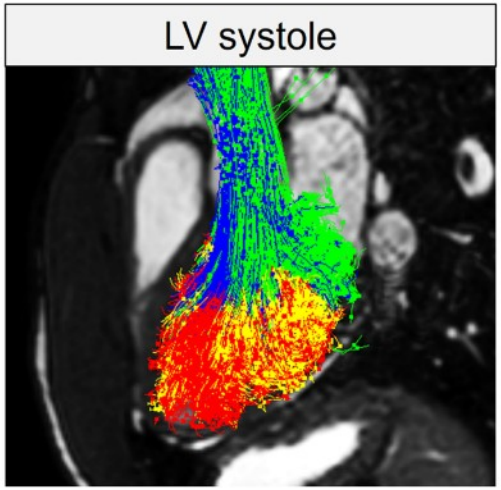
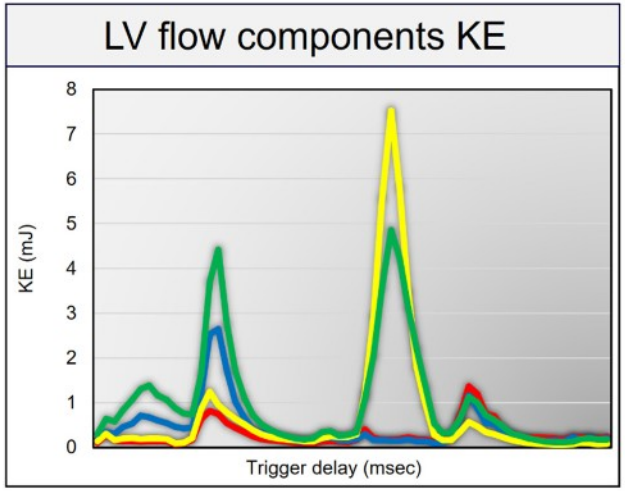
LV: EF 34[41], EDVi 152[127], SVi 52[52], Mi 123[150]
RV: EF 27[27], EDVi 149[110], SVi 40[33], Mi 54[96]

4D-Flow: Kinetic Energy

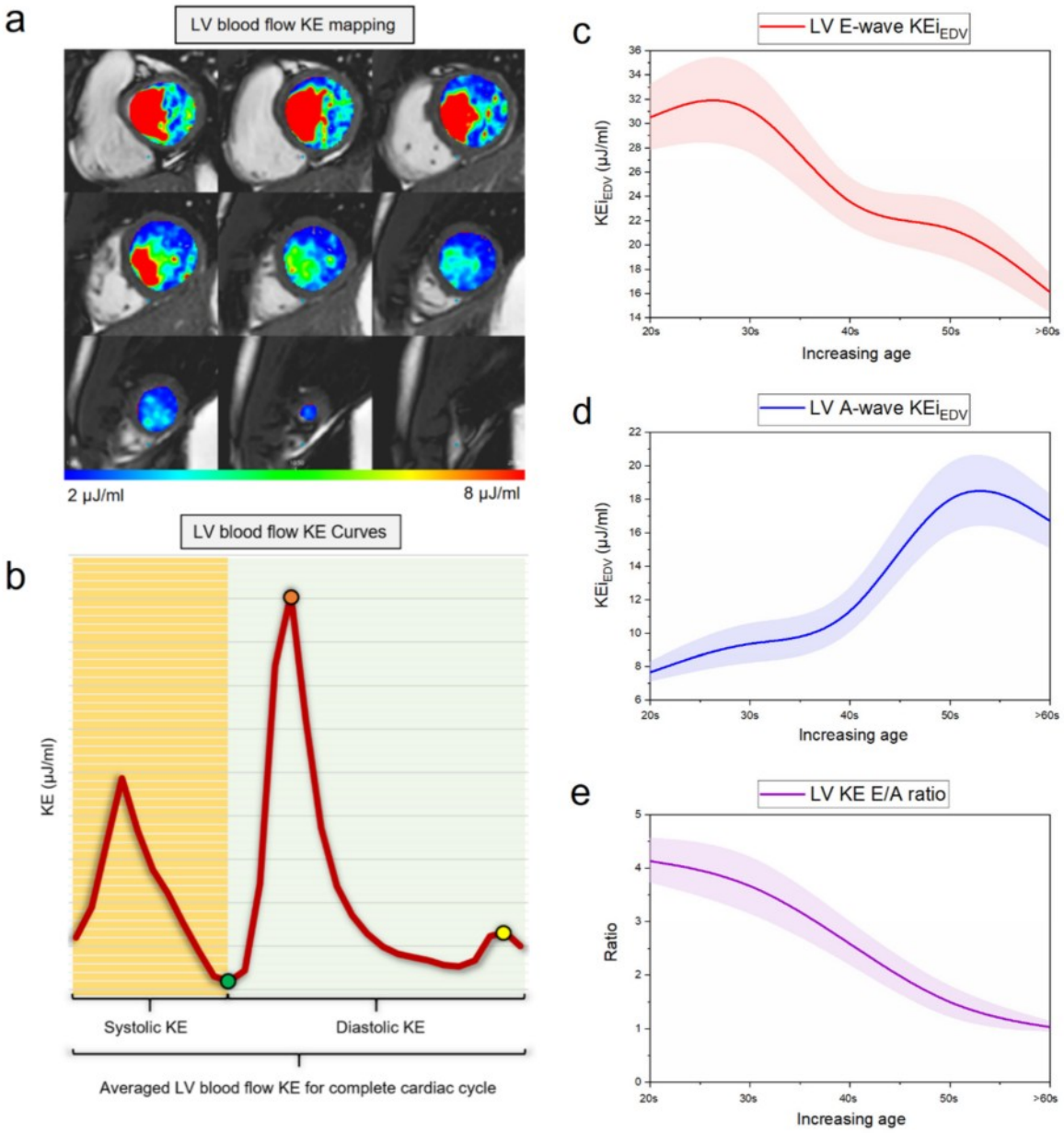




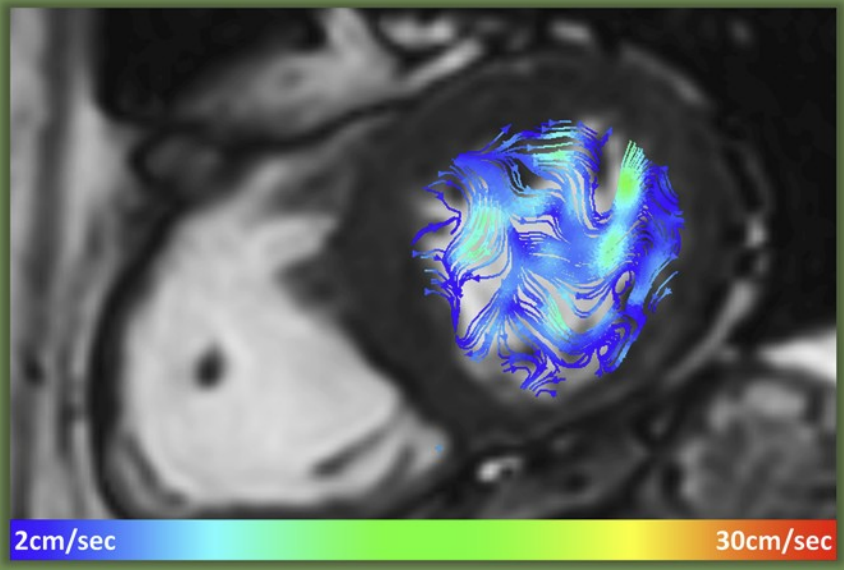


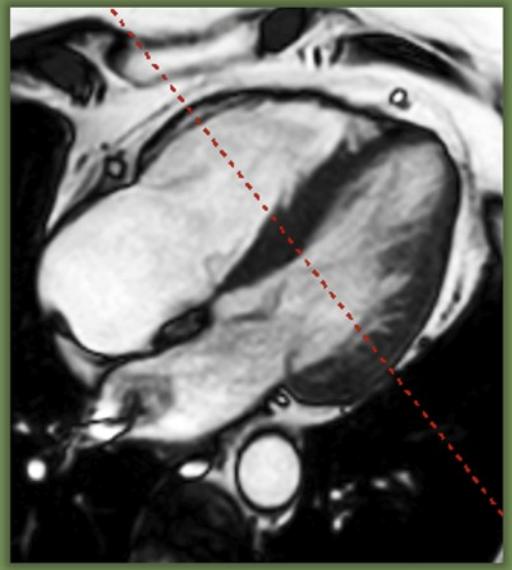


doi: 10.3390/jcdd7030037 J Cardiovasc Dev Dis 7(3):37 (2020)



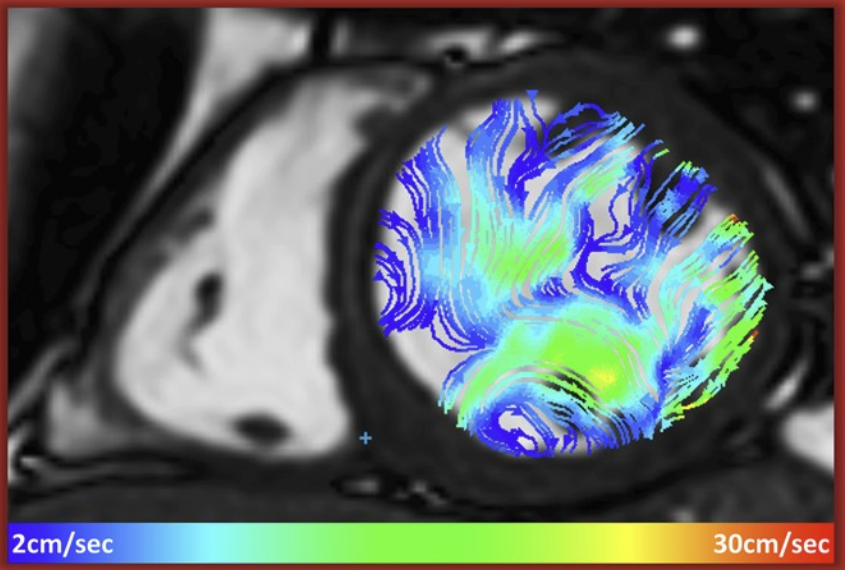
doi: 10.3390/jcdd7030037 J Cardiovasc Dev Dis 7(3):37 (2020)

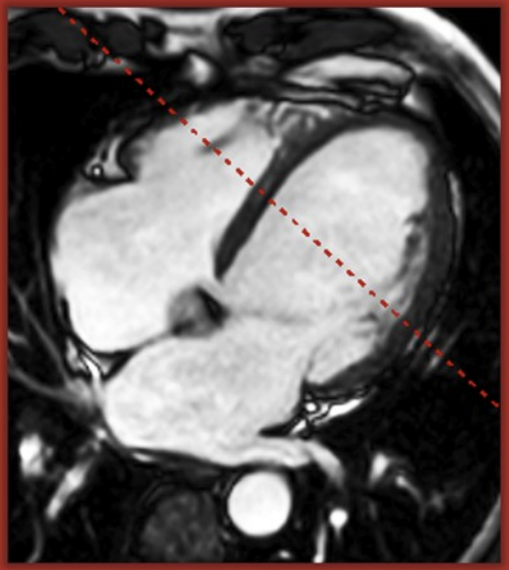




EF=60%
In-plane KE=23%

A





EF=32%
In-plane KE=45%

B

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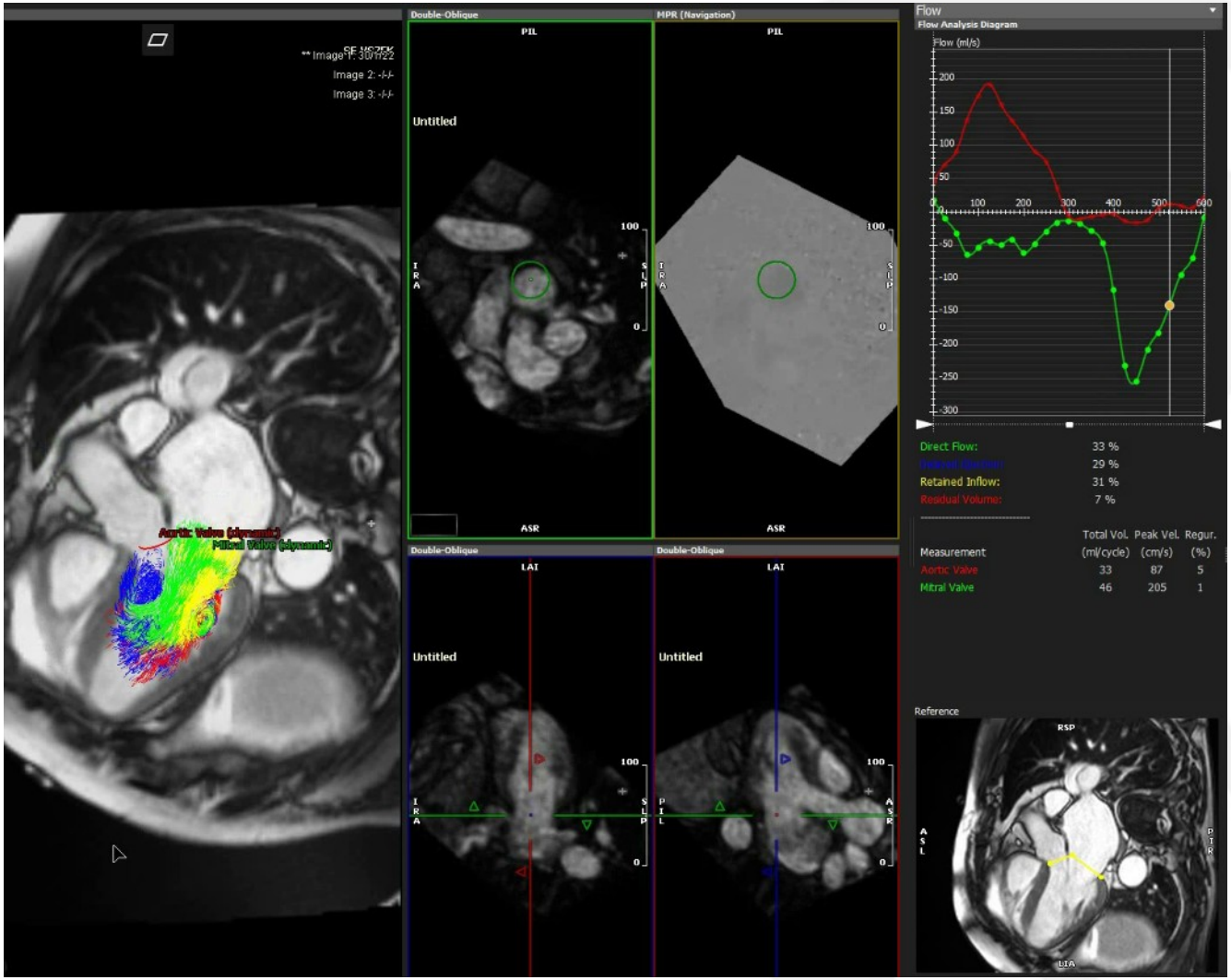
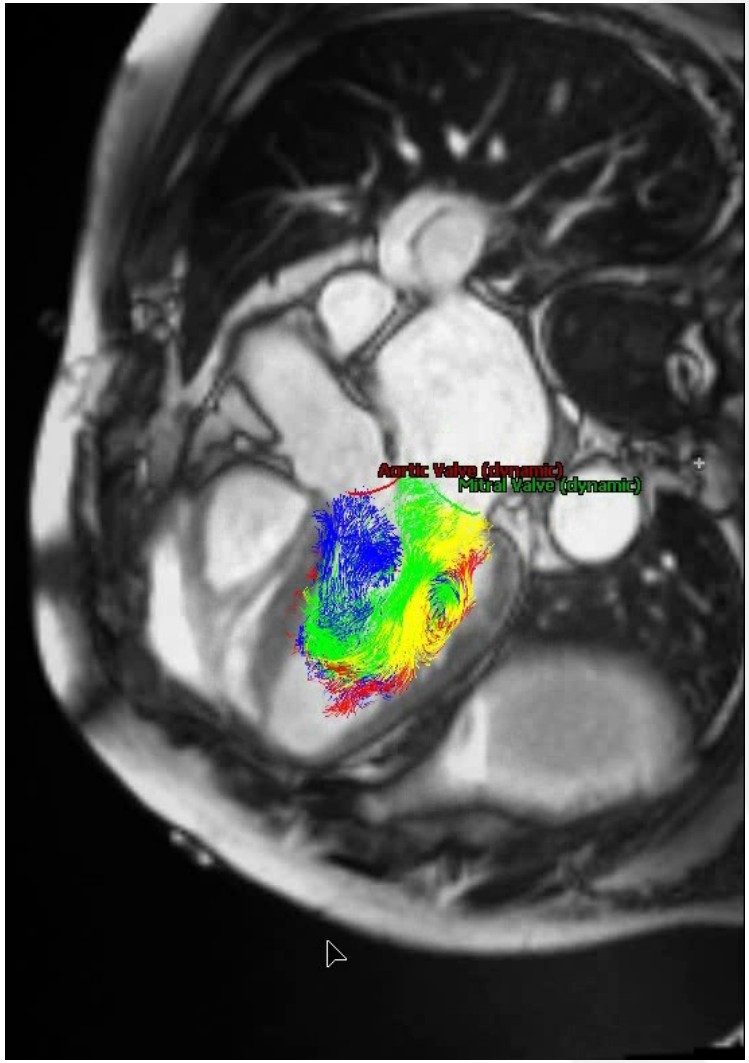
Garg et al. JCMR 20:61 (2018)
doi: 10.1186/s12968-018-0483-6

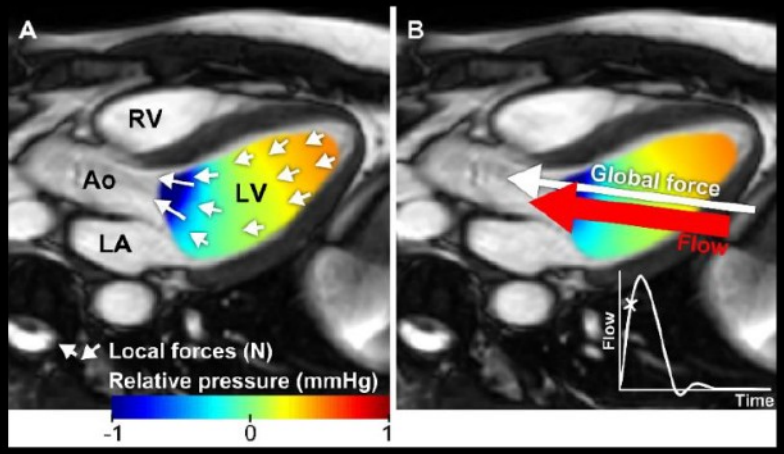
In-house experience



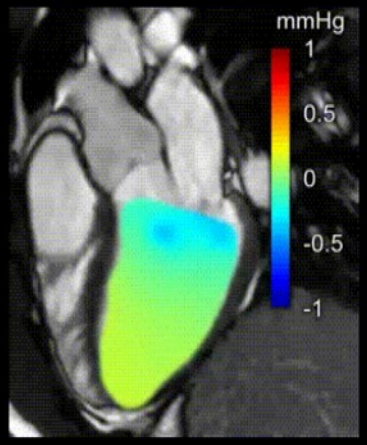
In-house experience

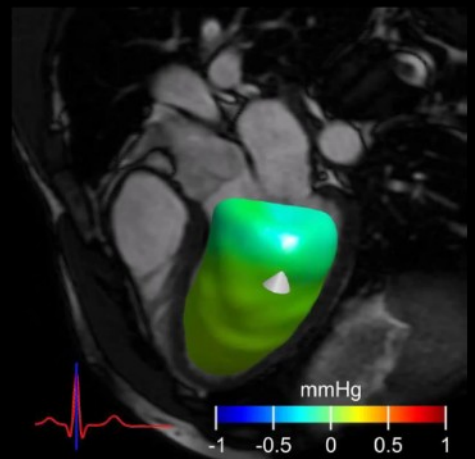


Hemodynamic Forces From 2D - 4D MRI Flow

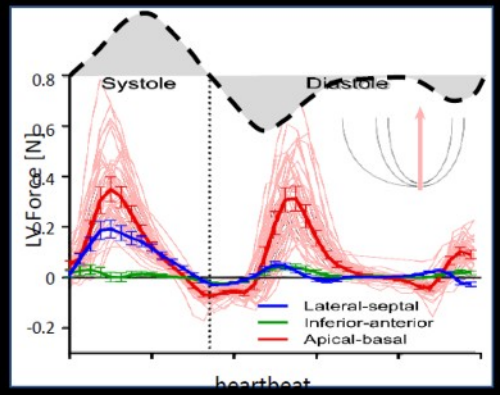


Arvidsson et al, AJP, 2016





Arvidsson et al. AJP Heart 312(2):H314, 2017



Hemodynamic forces (intra-LV pressure gradients) are **normally directed *Base-to-apex* with a highly reproducible pattern** with little variability among subjects

Semmelweis Egyetem
KARDIOLÓGIAI KÖZPONT

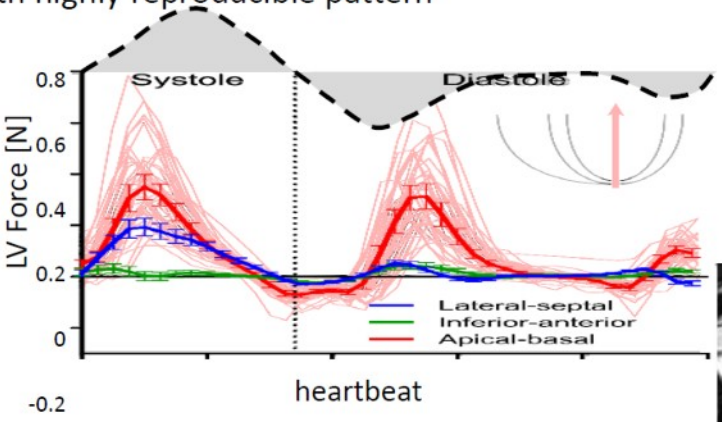
Giovanni Tonti, Senior lecturer
Cardiology Institute, G. D'Annunzio University, Chieti, Italy

What Hemodynamic Forces tell us (Observations)

CONFIRMATIONS BY 4D MR FLOW

NORMAL SUBJECTS

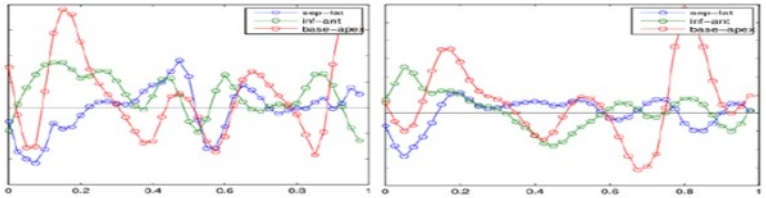
Hemodynamic forces are directed *Base-to-apex*
With highly reproducible pattern

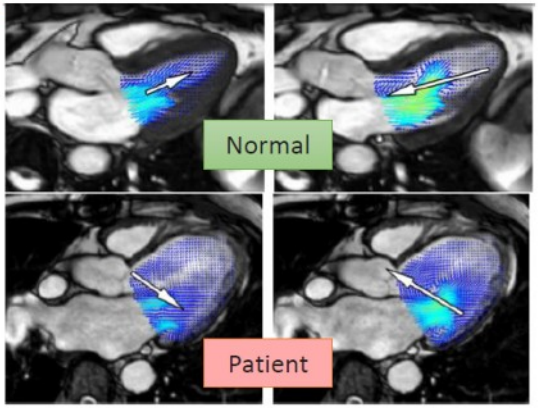


- **Ardvisson et al.** 2016
- **Toger et al.** 2018

PATHOLOGICAL SUBJECTS

Appearance of significant transversal components, alteration of timings, with high variability among subjects





Ardvisson et al. 2016
Eriksson et al. 2017 SCIENTIFIC REPORTS
Ardvisson et al. 2018

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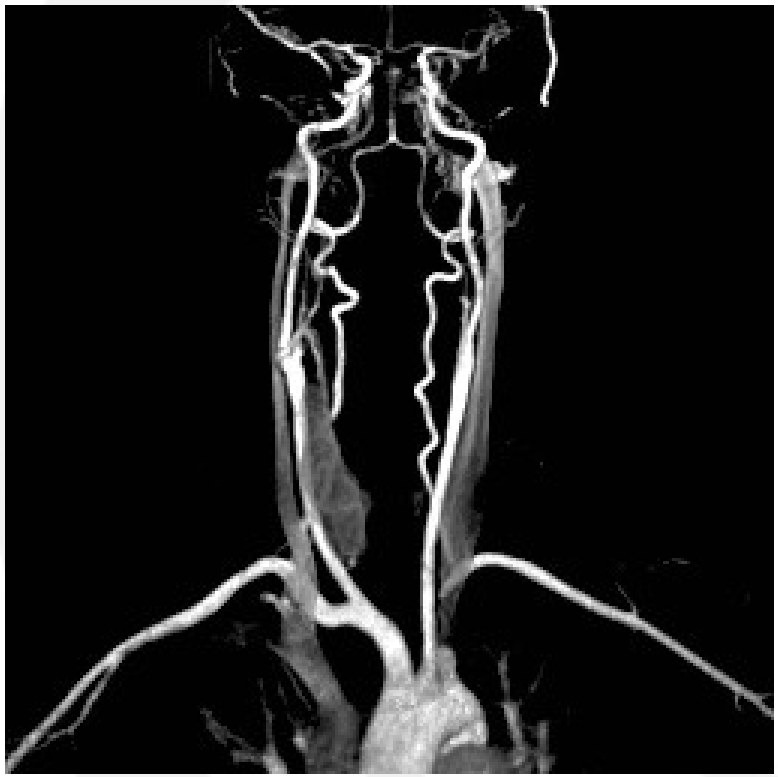
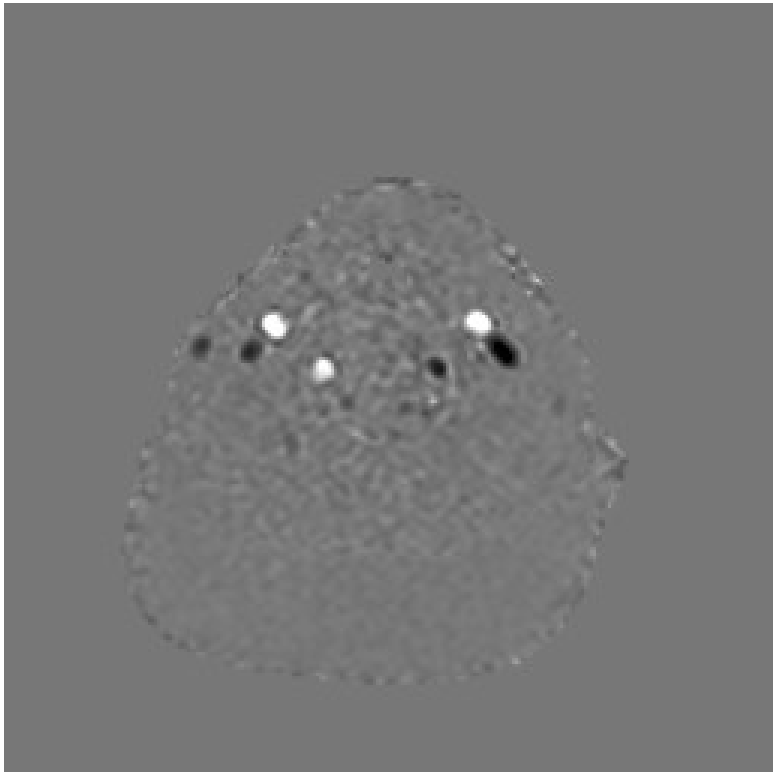
Giovanni Tonti, Senior lecturer
Cardiology Institute, G. D'Annunzio University, Chieti, Italy

CE-MRA



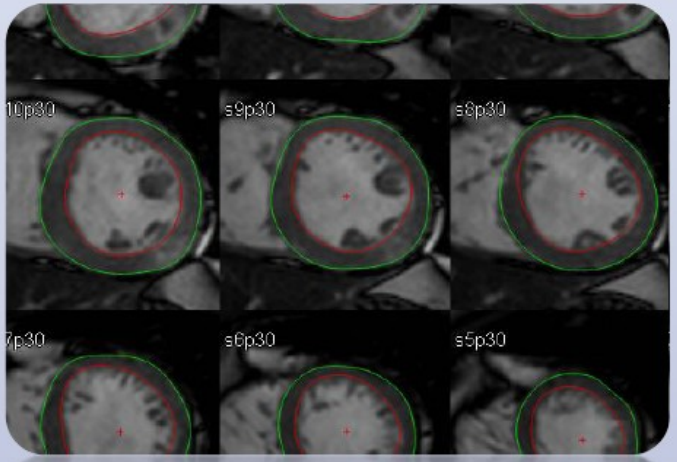
Flow measurement



Didn't go into details

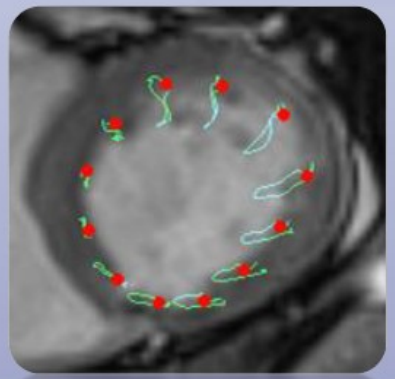
- Tagging
  - Top Magn Reson Imag 11(6):359-371 (2000)
  - Radiology 214(2):453-466 (2000)
  - J Cardiovasc Magn Reson 4(3):341-351 (2002)
  - J Magn Reson Imag 24(6):1432-1438 (2006)
  - J Magn Reson Imag 29(1):99-105 (2009)

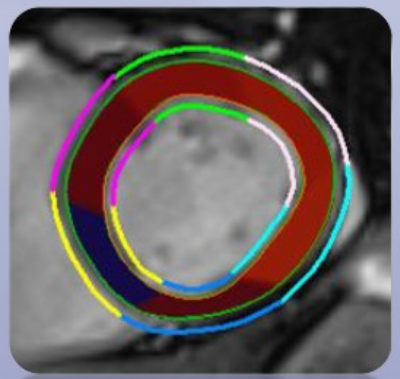
Medis QStrain



Works on SSFP cines
Cutting edge FT-MR
LV, RV and LA

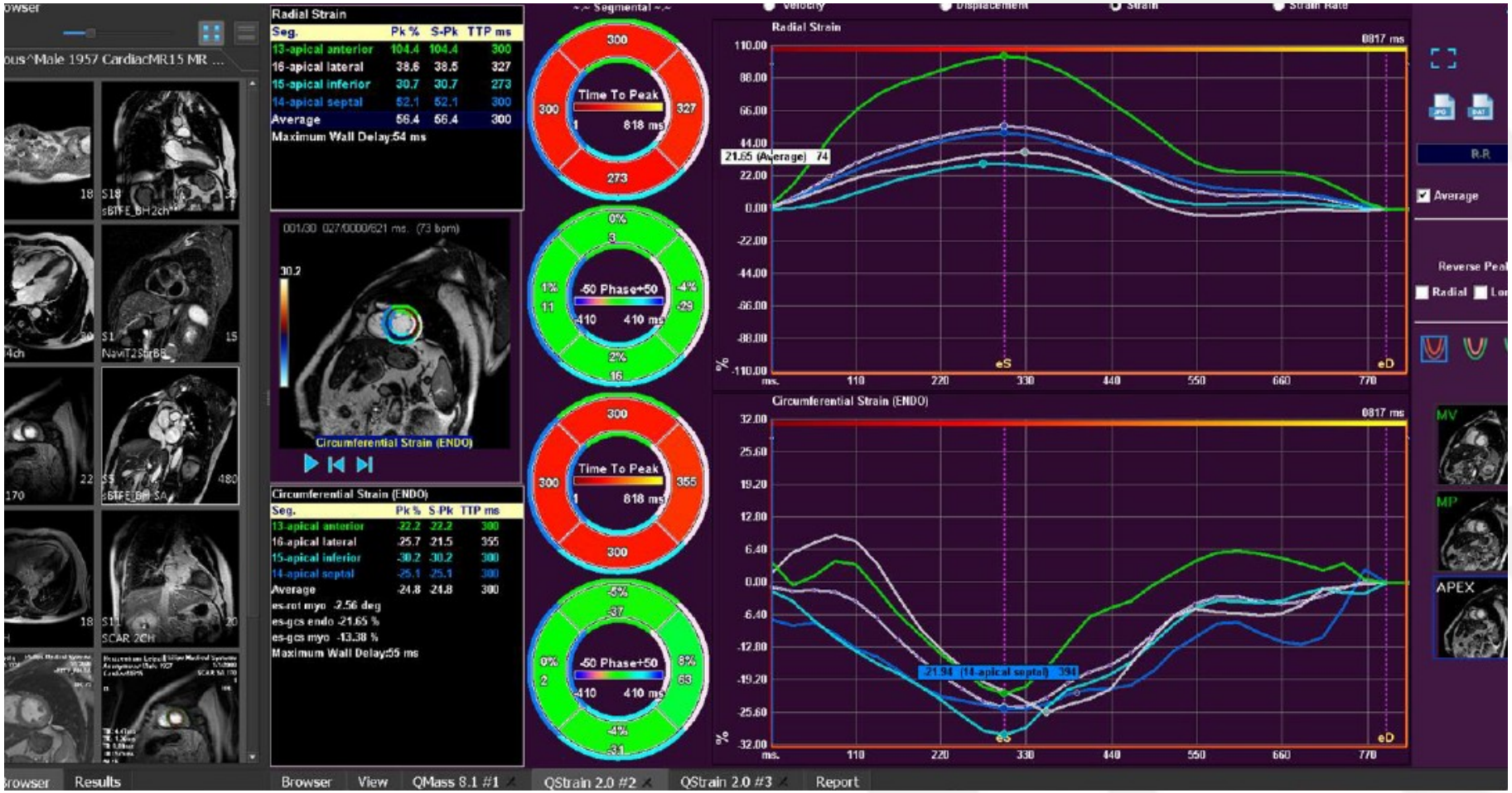
…When you have access to cutting edge, Feature Tracking MR algorithms…





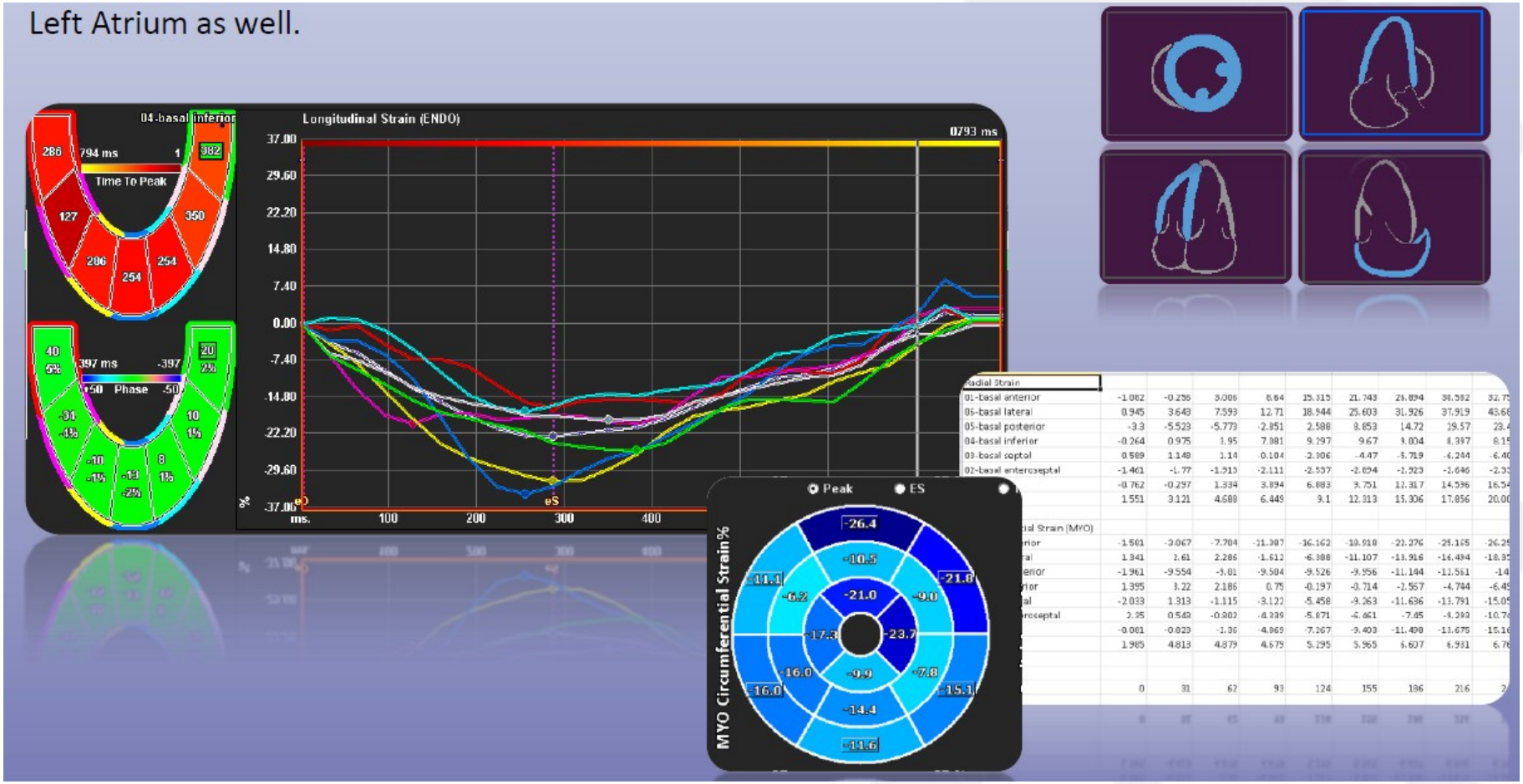
….to obtain a wealth of information with your existing data…

Medis QStrain

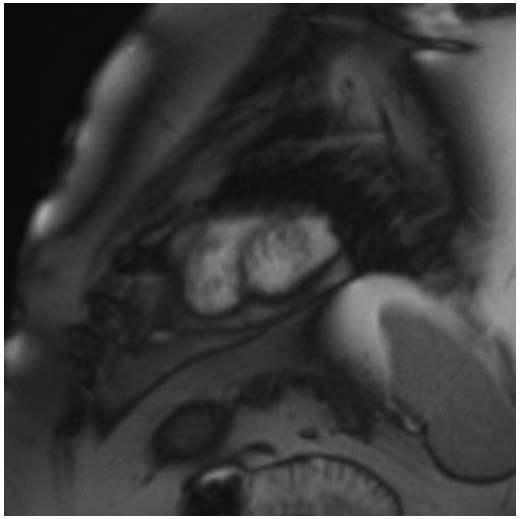
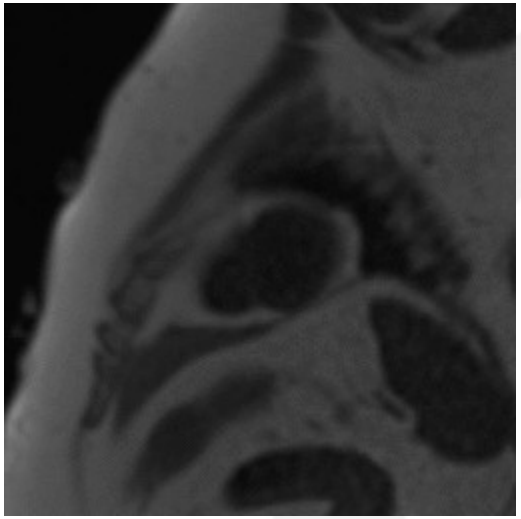
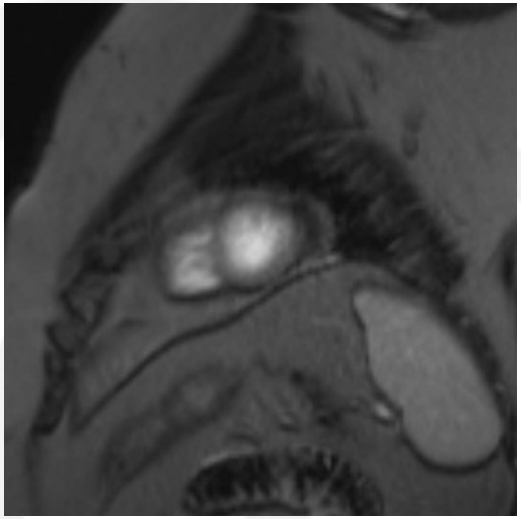
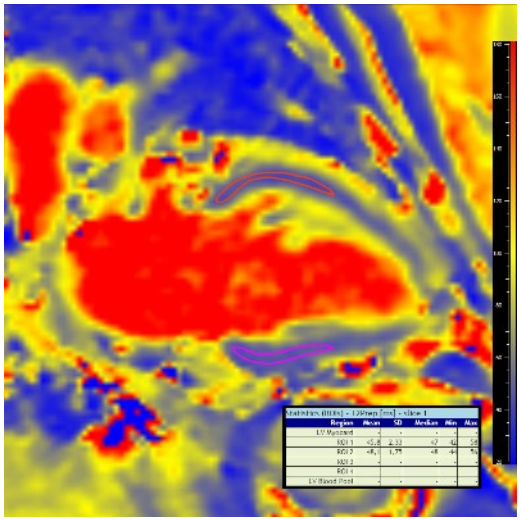
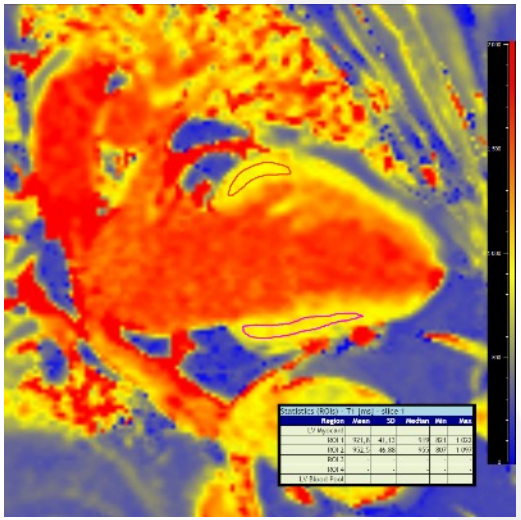
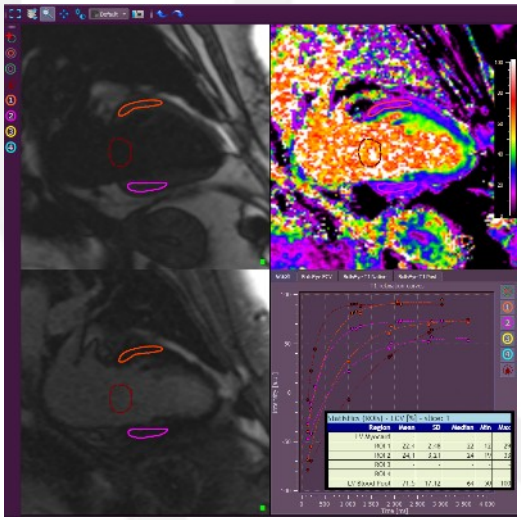


Medis QStrain

Left Atrium as well.



MM: thrombus-, GLS -26%, T2 45ms

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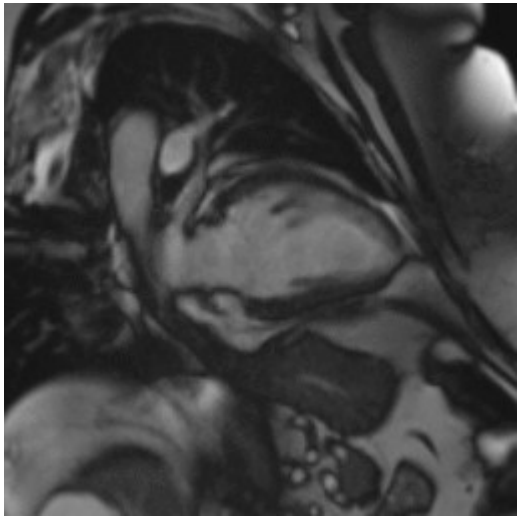
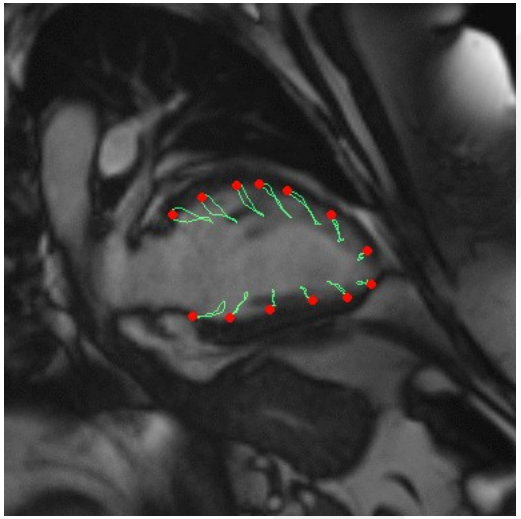
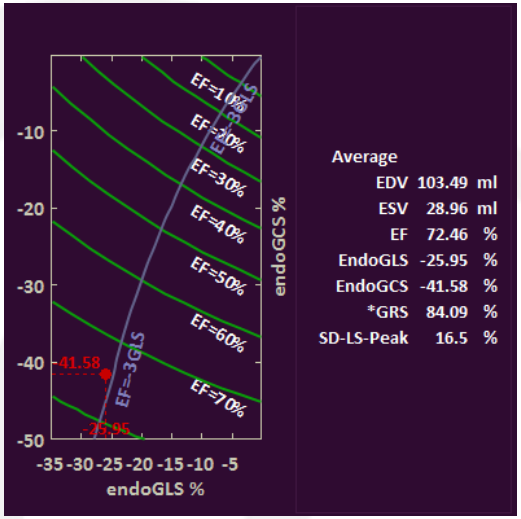
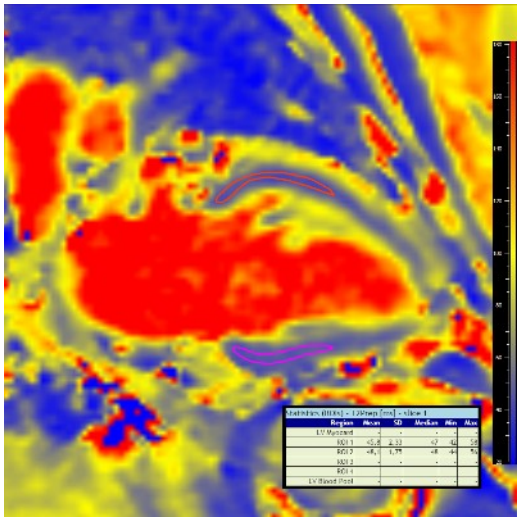
LV: EF 60[66], ESVi 22[15], EDVi 56[44], SVi 34[29], Mi 37[53]
RV: EF 57[63], ESVi 22[17], EDVi 52[46], SVi 29[29], Mi 13[22]

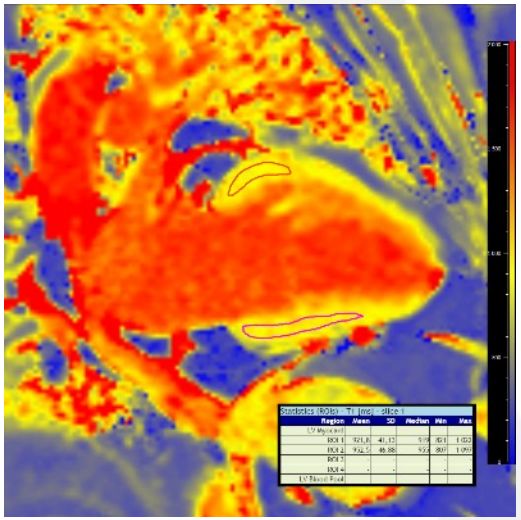
MM: thrombus-, GLS -26%, T2 45ms

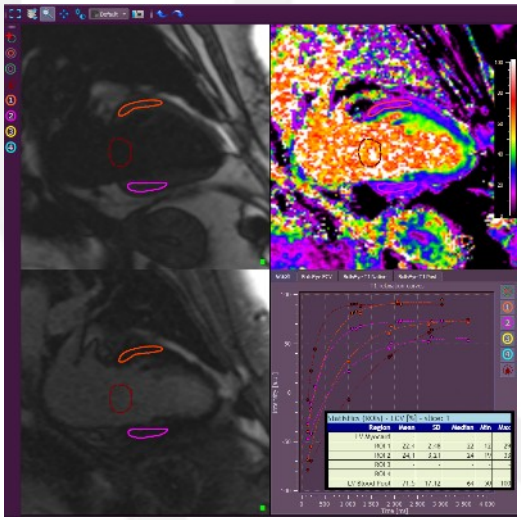












Semmelweis Egyetem
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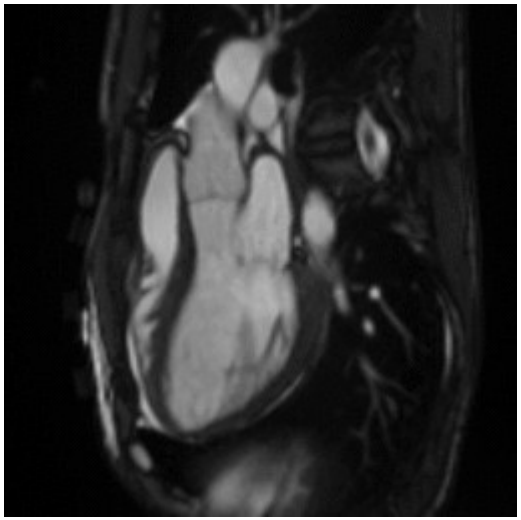
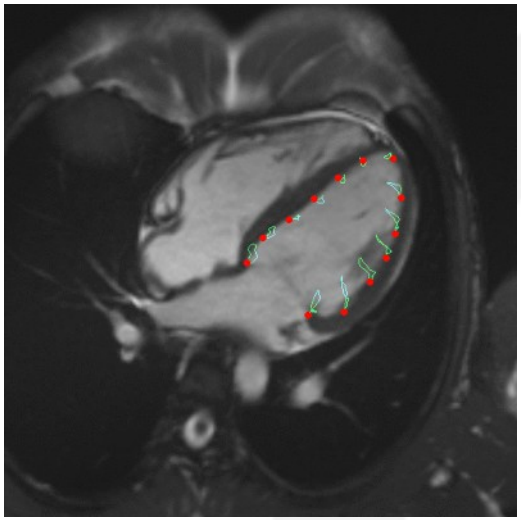
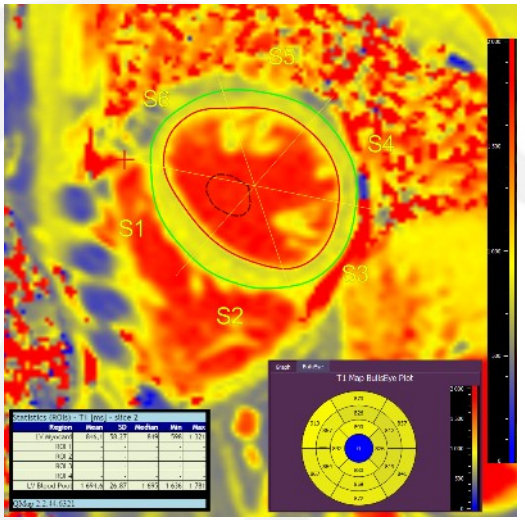
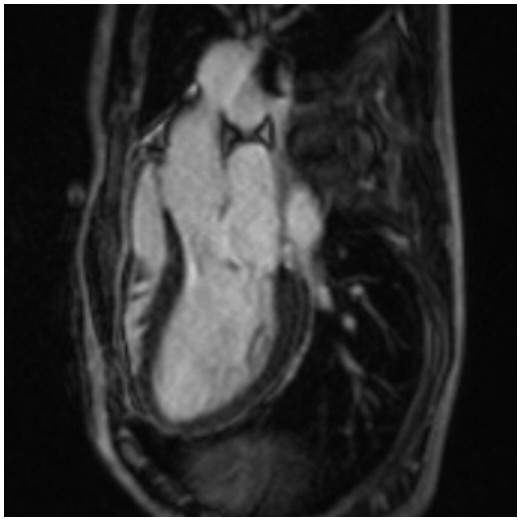
LV: EF 60[66], ESVi 22[15], EDVi 56[44], SVi 34[29], Mi 37[53]
RV: EF 57[63], ESVi 22[17], EDVi 52[46], SVi 29[29], Mi 13[22]

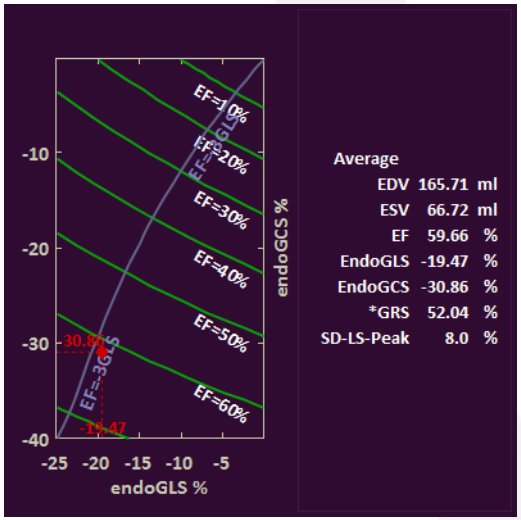
Anderson-Fabry, QStrain, QMap, LGE-

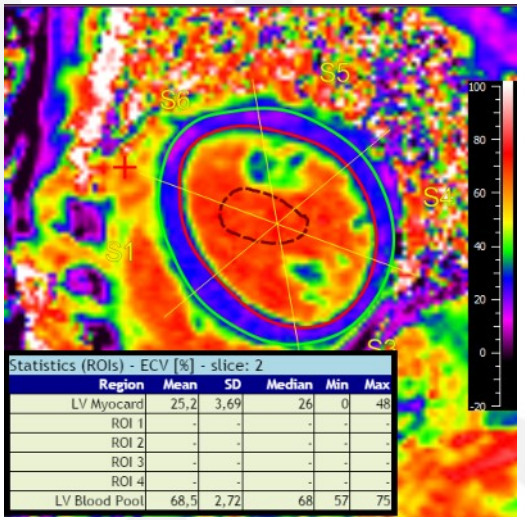






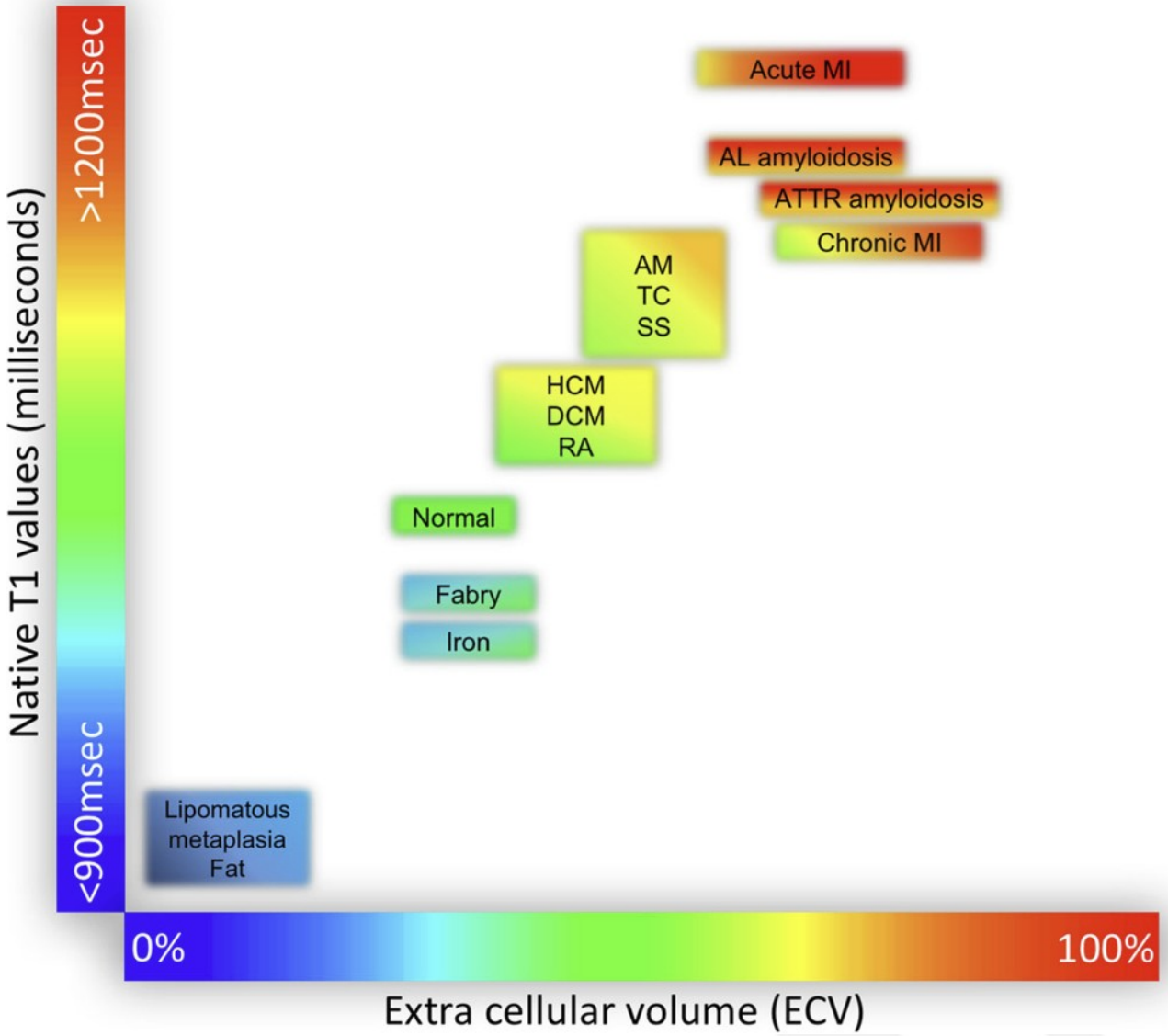






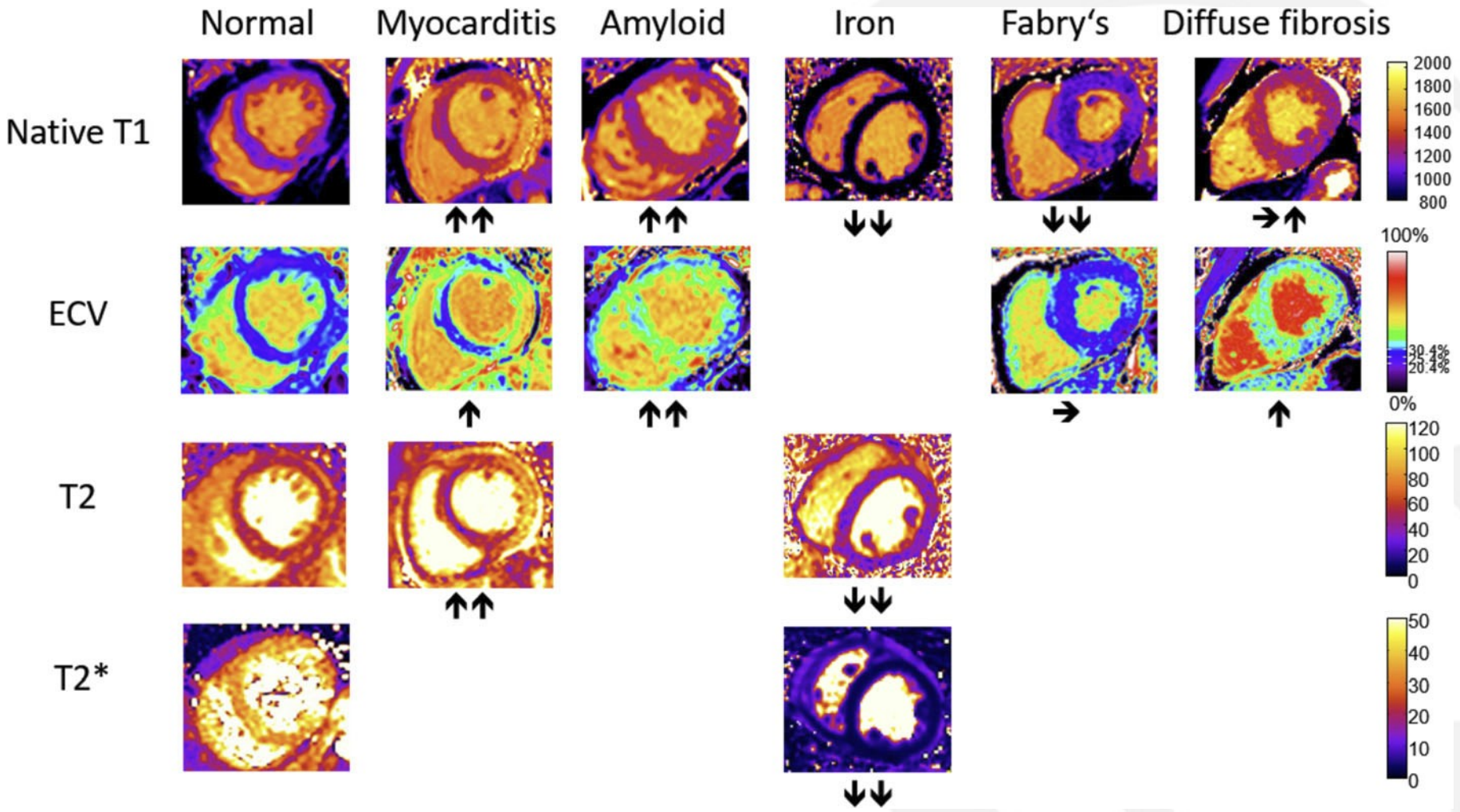
LV: EF 57[66], EDVi 122[96], Mi 87[109], 12mm, index 0.098, 1.09
RV: EF 52[61], EDVi 133[108], Mi 37[57]

T1 Mapping and ECV in clinical practice



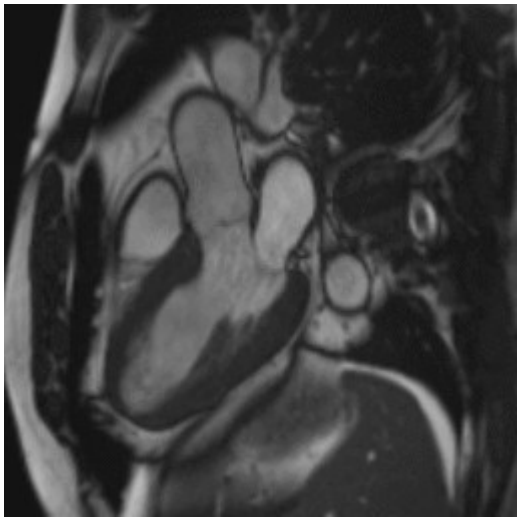
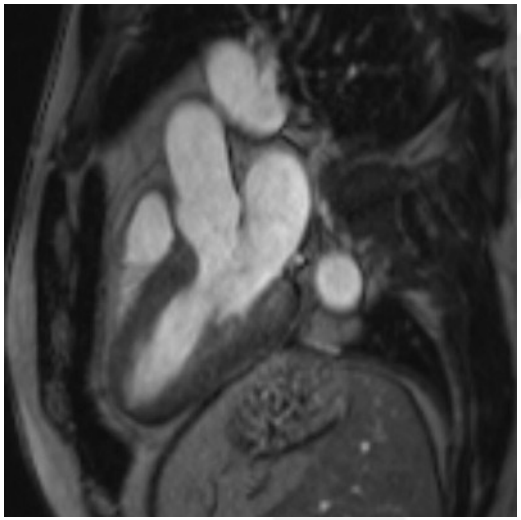
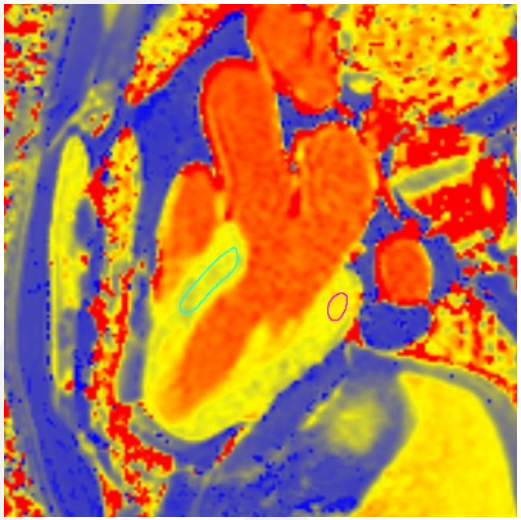
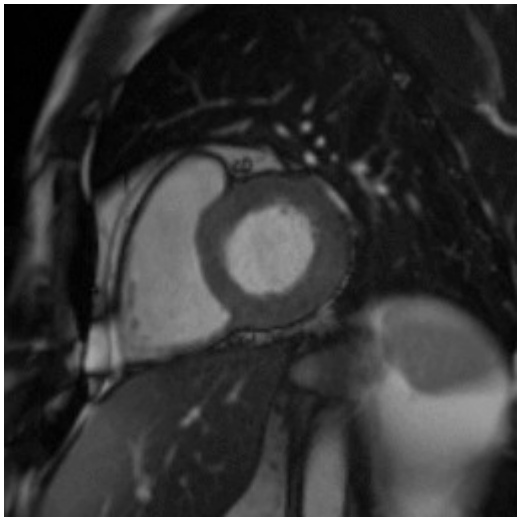
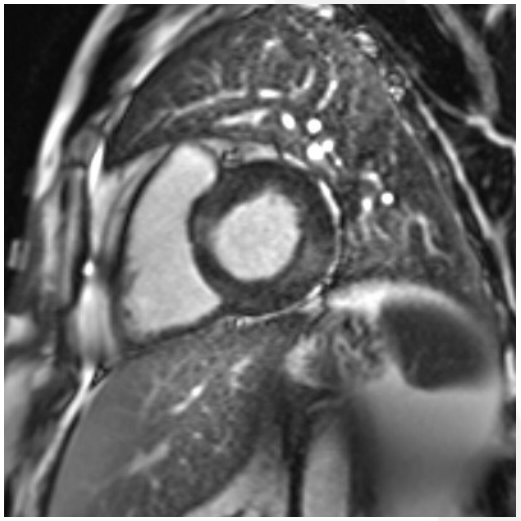
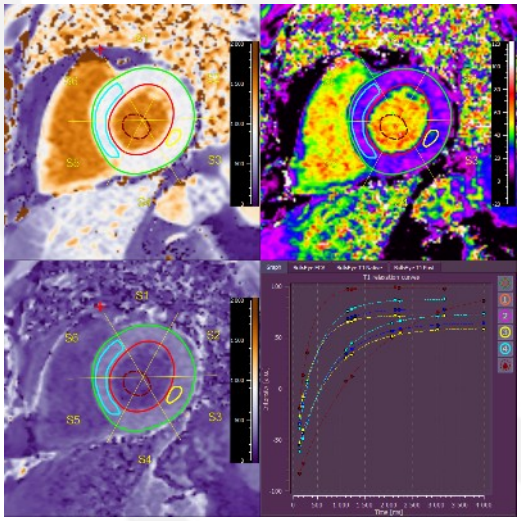
Messroghli et al. JCMR 19:75 (2017)
DOI: 10.1186/s12968-017-0389-8

$$ECV = (1 - haematocrit)\frac{\frac{1}{post\ contrast\ T1\ myo} - \frac{1}{native\ T1\ myo}}{\frac{1}{post\ contrast\ T1\ blood} - \frac{1}{native\ T1\ blood}}$$



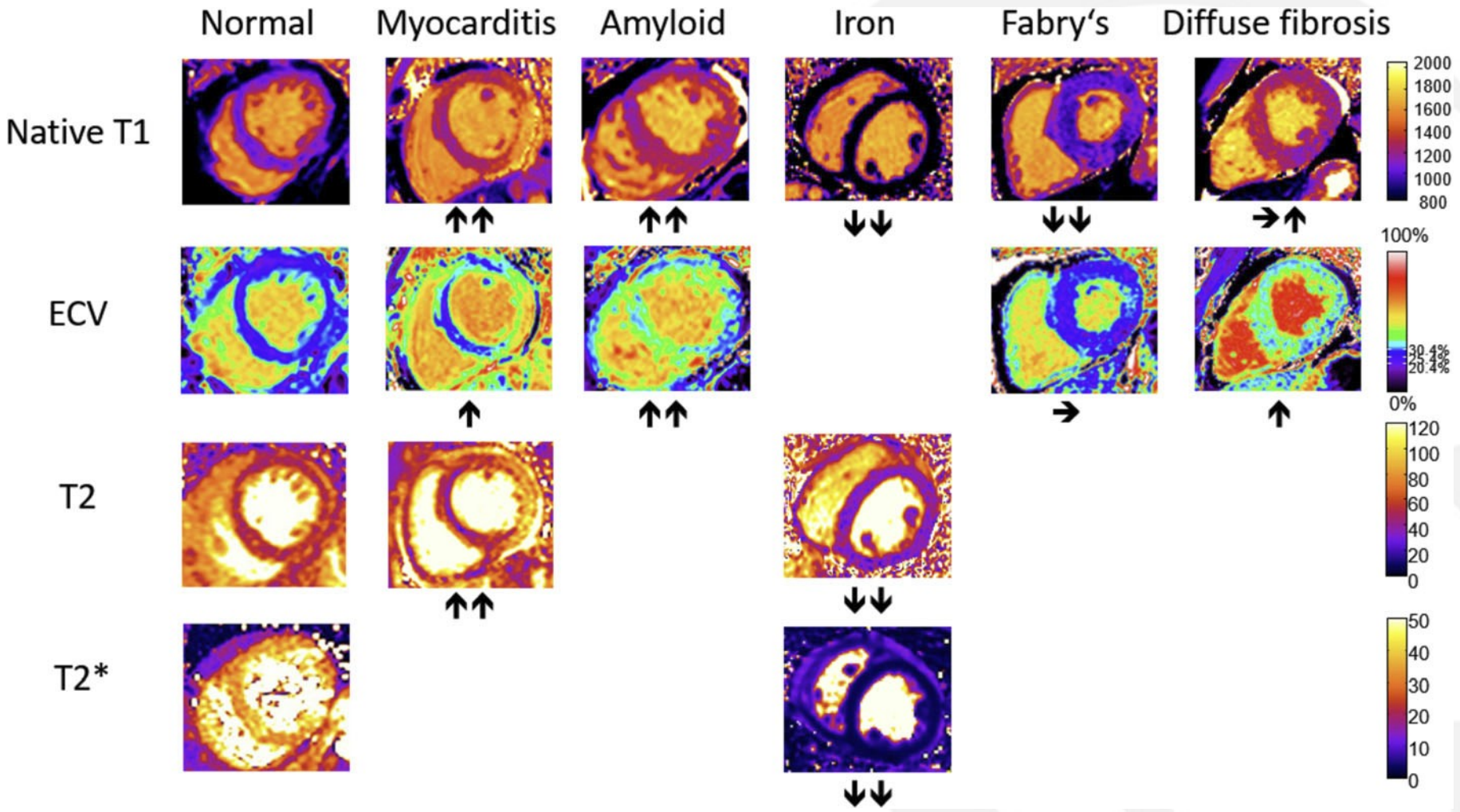
Messroghli et al. JCMR 19:75 (2017)
DOI: 10.1186/s12968-017-0389-8

Anderson-Fabry: 828/967 ms, 23/33 %

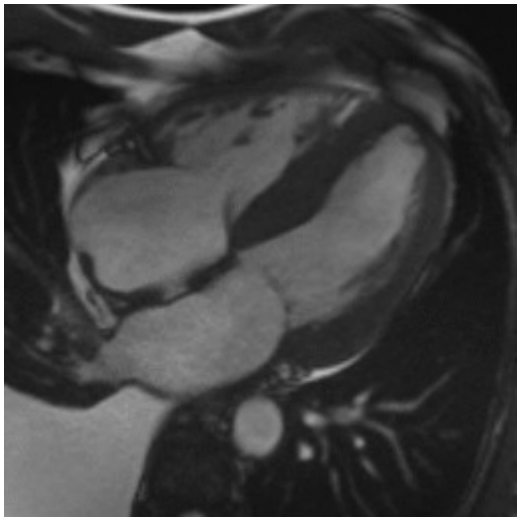
LV: EF 62[73], ESVi 26[13], EDVi 69[48], SVi 43[35], Mi 77[102]
RV: EF 58[65], ESVi 32[22], EDVi 74[65], SVi 43[42], Mi 21[33]

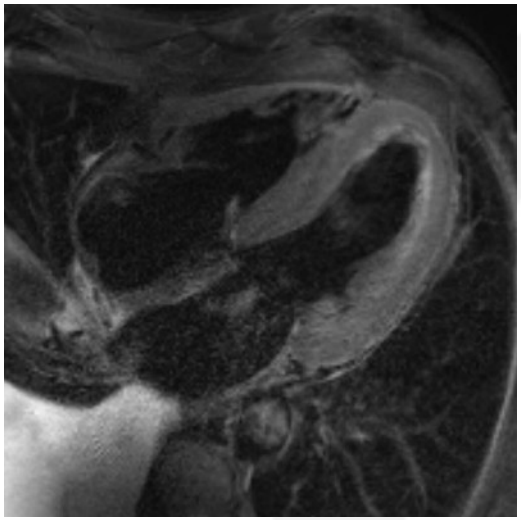
$$ECV = (1 - haematocrit)\frac{\frac{1}{post\ contrast\ T1\ myo} - \frac{1}{native\ T1\ myo}}{\frac{1}{post\ contrast\ T1\ blood} - \frac{1}{native\ T1\ blood}}$$

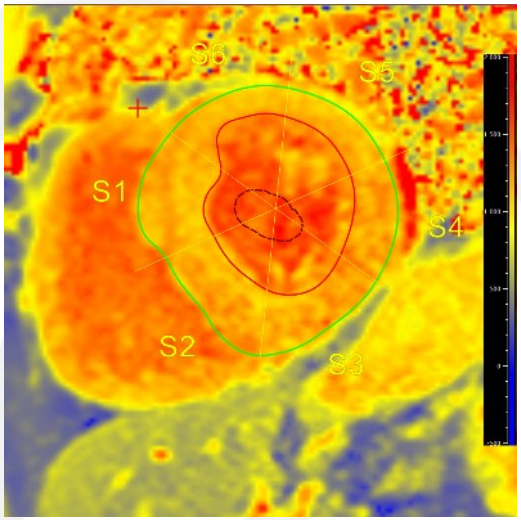


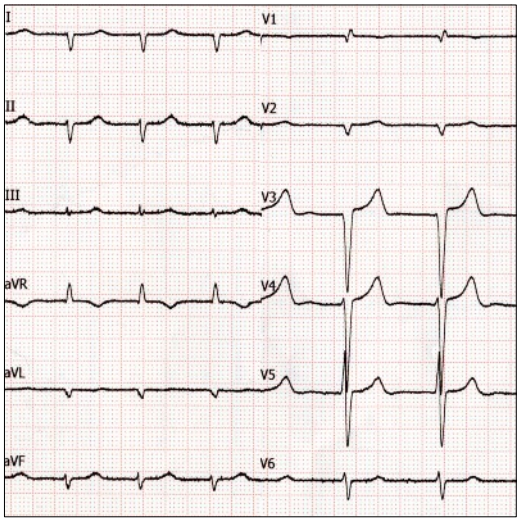
Messroghli et al. JCMR 19:75 (2017)
DOI: 10.1186/s12968-017-0389-8

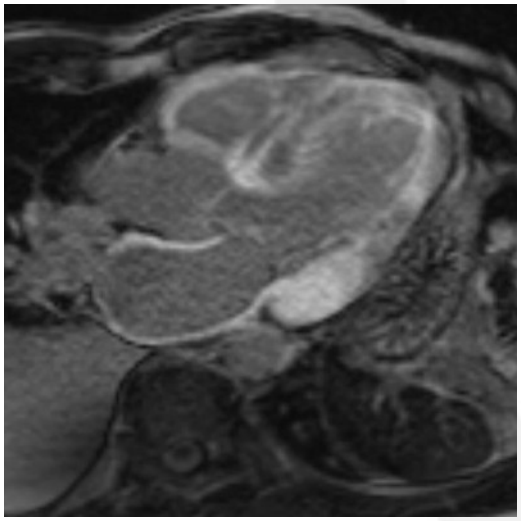
Amyloidosis – T1: 1166ms, ECV: 65%

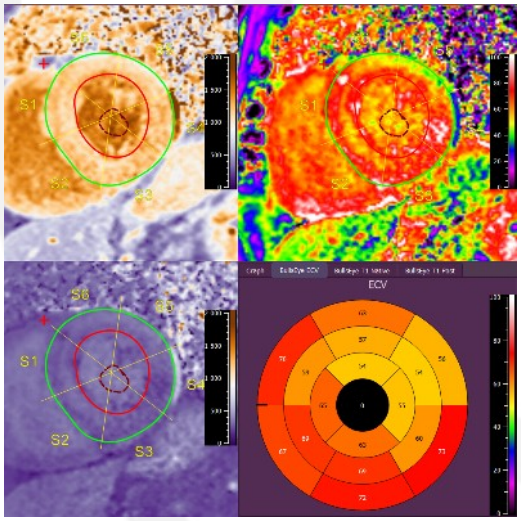






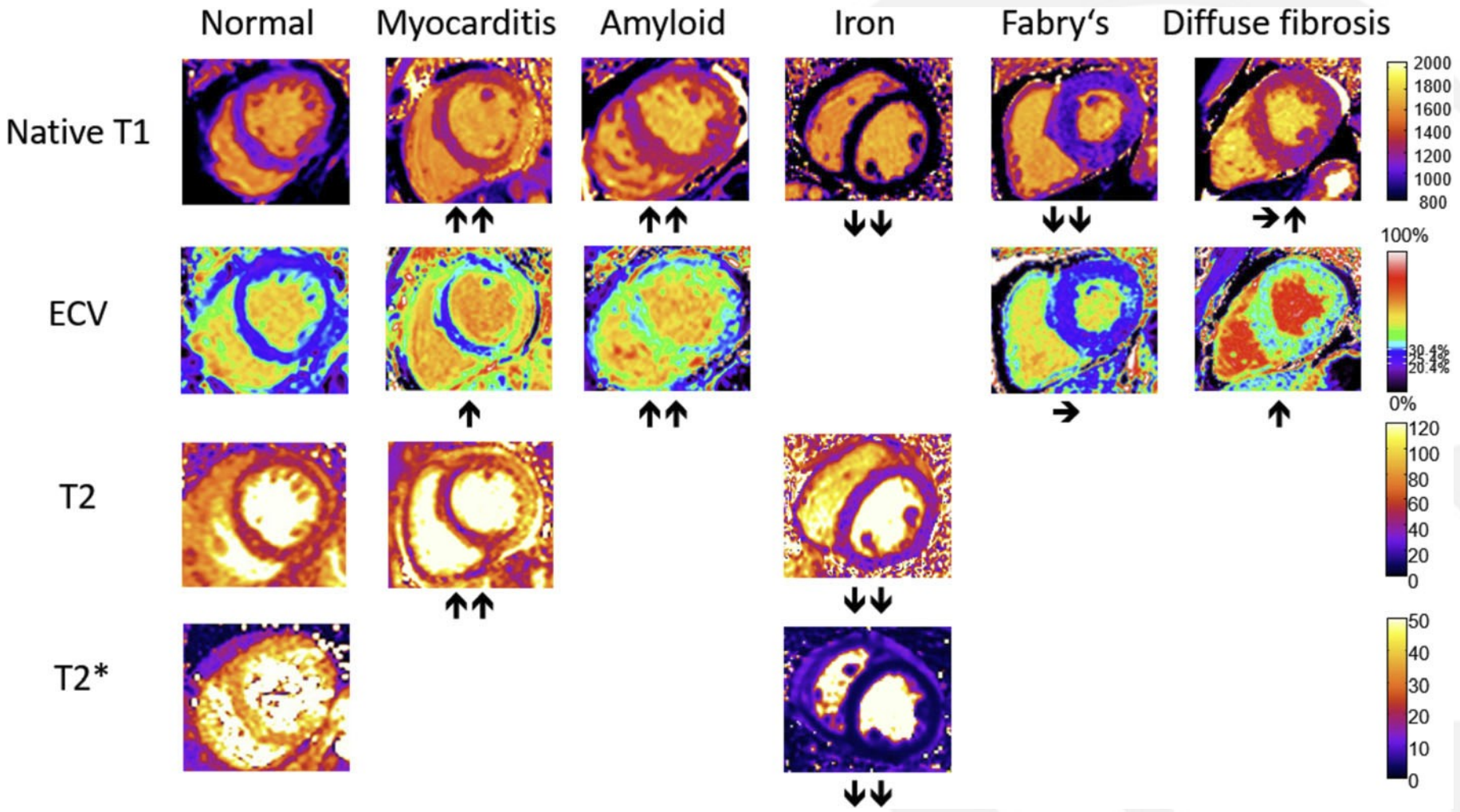






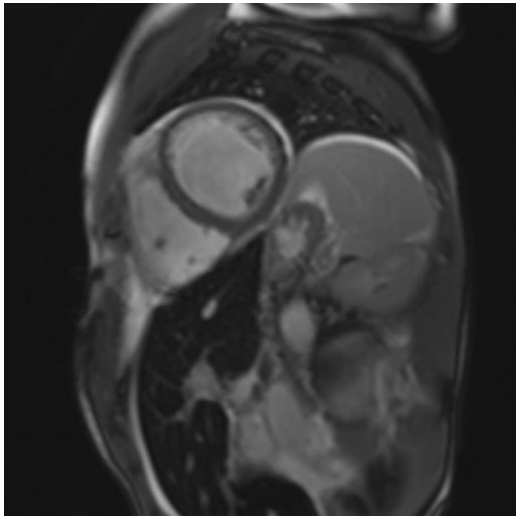
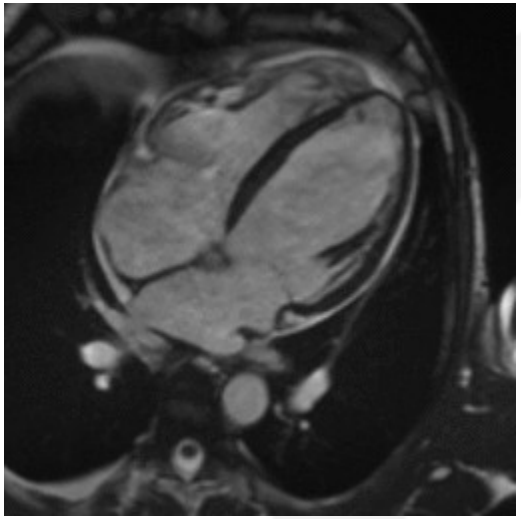
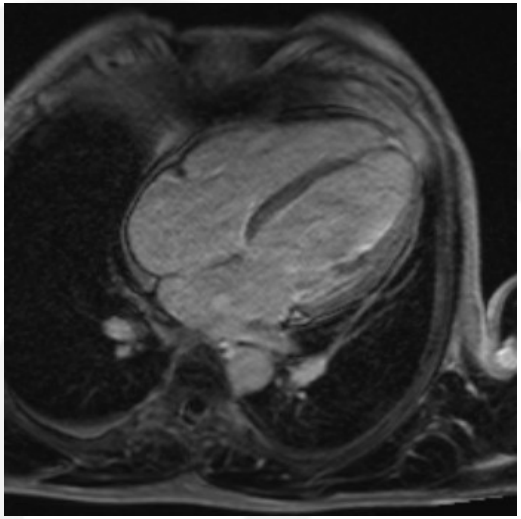
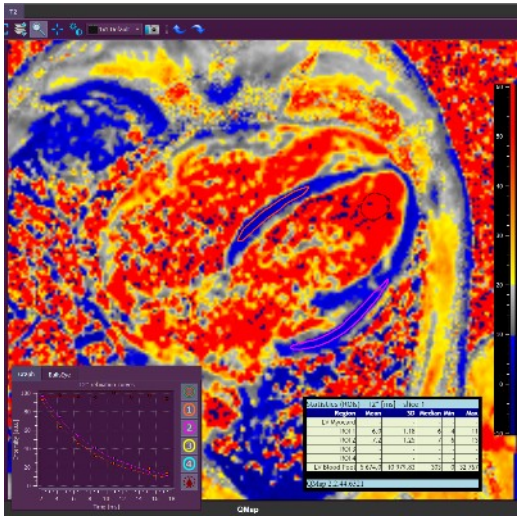
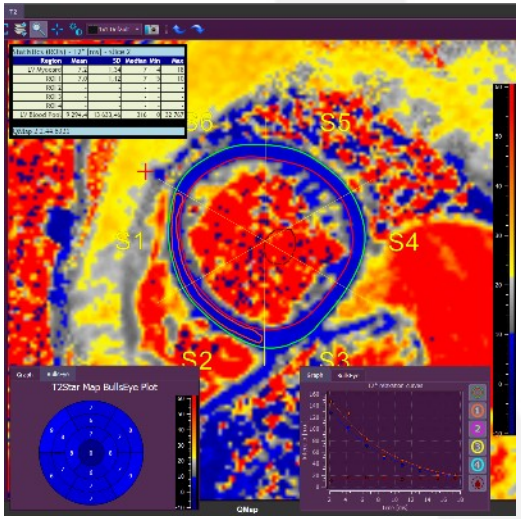
LV: EF 43[50], EDVi 107[72], Mi 141[181], mDWT: 25mm
RV: EF 39[47], EDVi 105[66], Mi 42[85]

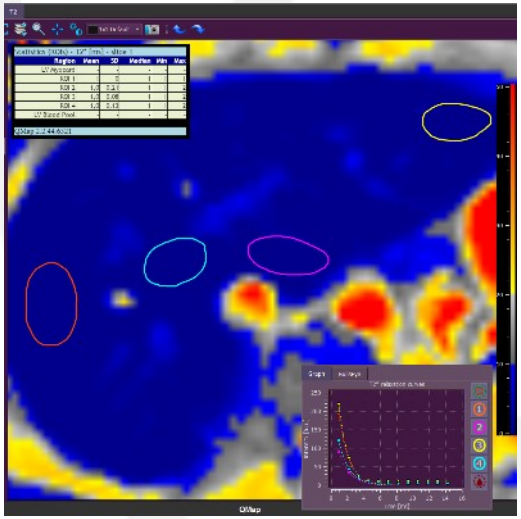
$$ECV = (1 - haematocrit)\frac{\frac{1}{post\ contrast\ T1\ myo} - \frac{1}{native\ T1\ myo}}{\frac{1}{post\ contrast\ T1\ blood} - \frac{1}{native\ T1\ blood}}$$



Messroghli et al. JCMR 19:75 (2017)
DOI: 10.1186/s12968-017-0389-8

Hemochromatosis: T2* 7ms, liver 1ms



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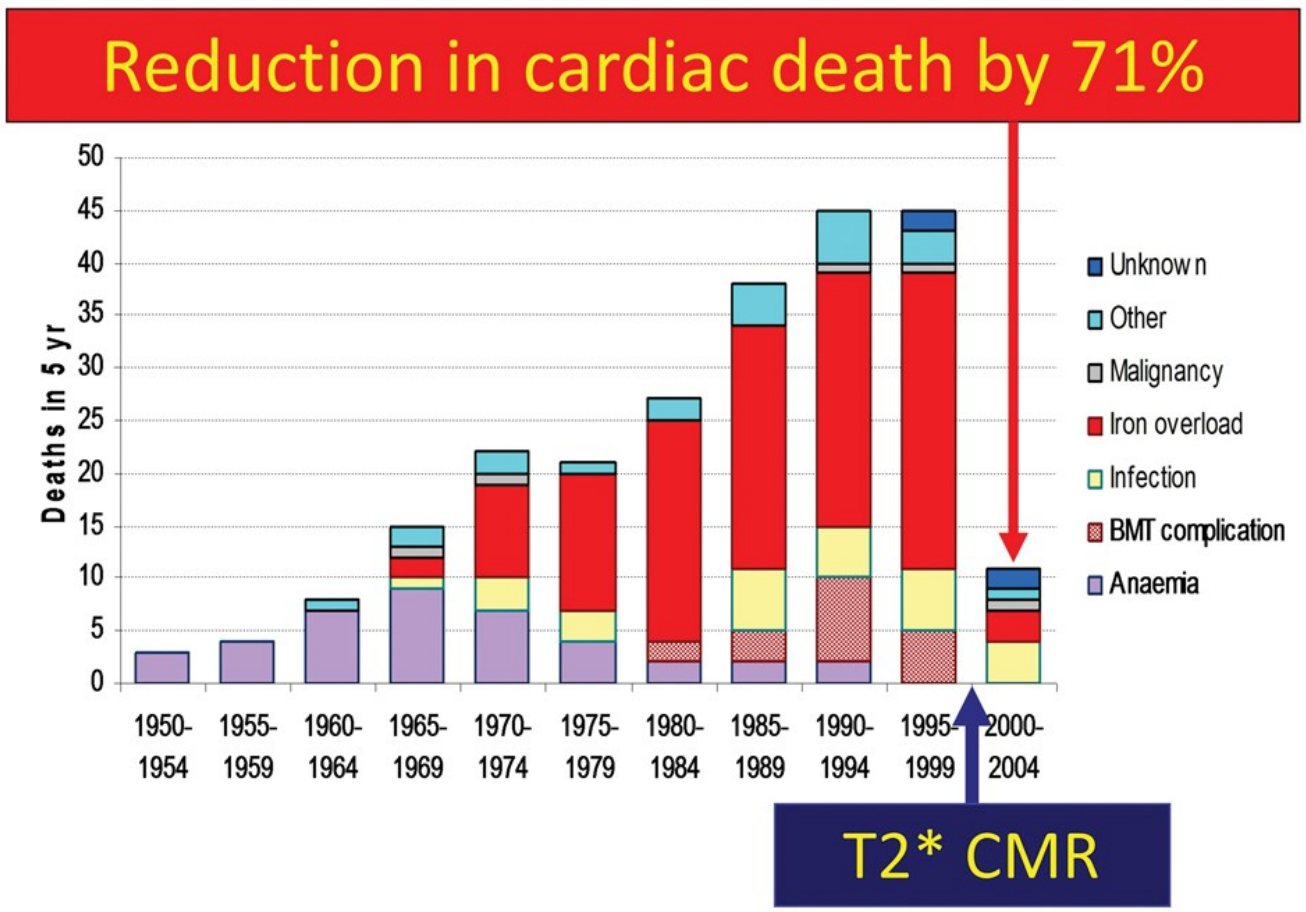
LV: EF 29, ESVi 221[117], EDVi 312[164], SVi 90[47], Mi 146[77]
RV: EF 39, ESVi 169[89], EDVi 278[147], SVi 109[57], Mi -

Survival: 71% reduction!

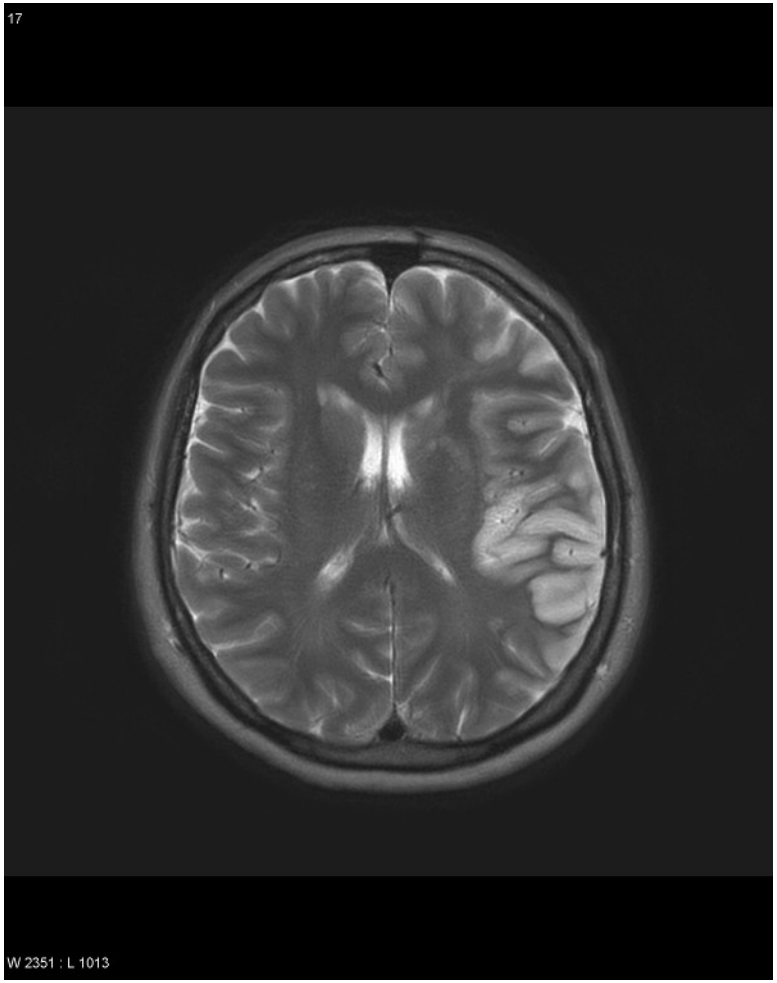


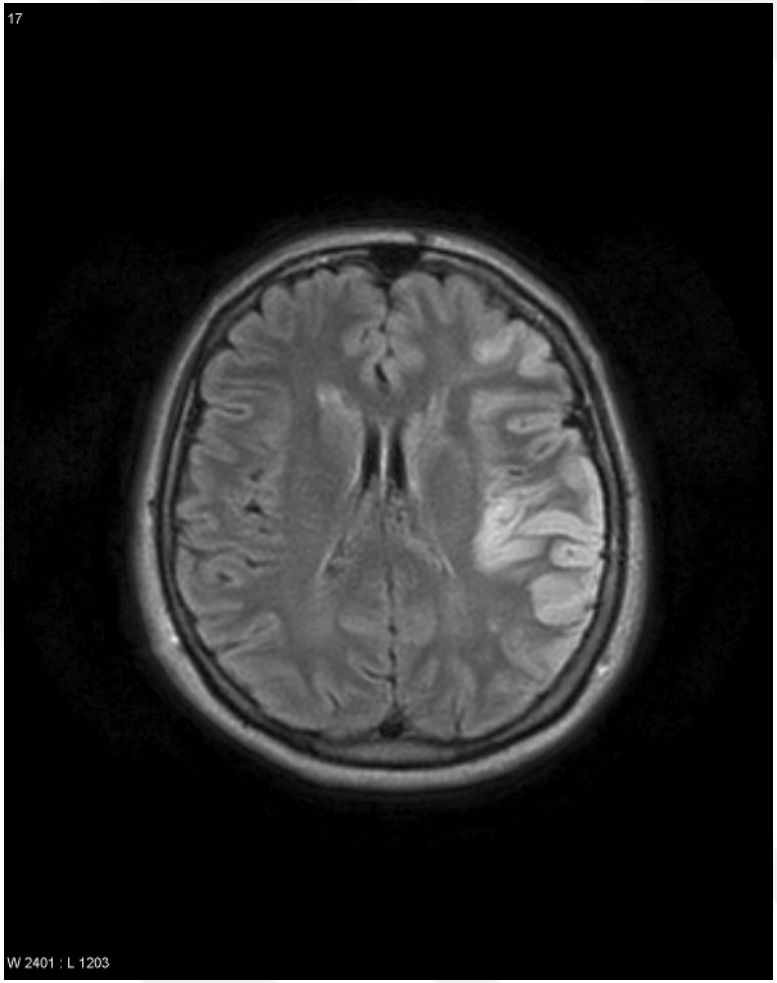
Modell. J Cardiovasc MR 2008: 42

Didn't go into details

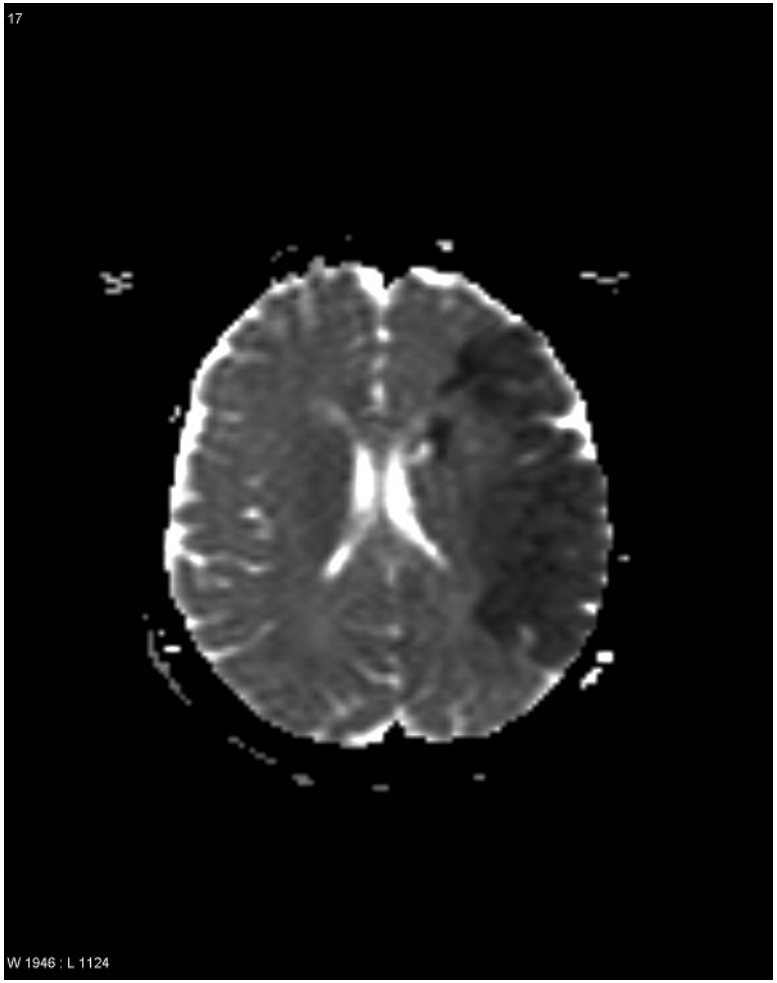
- Magnetic resonance spectroscopy
  - ^{1}H, ^{31}P, ^{23}Na, ^{13}C
  - MAGMA 11(1-2):44-46 (2000)
  - Heart Lung Circ 12(1):25-30 (2003)
  - Nat Clin Pract Cardiovasc Med 5:S49 (2008)

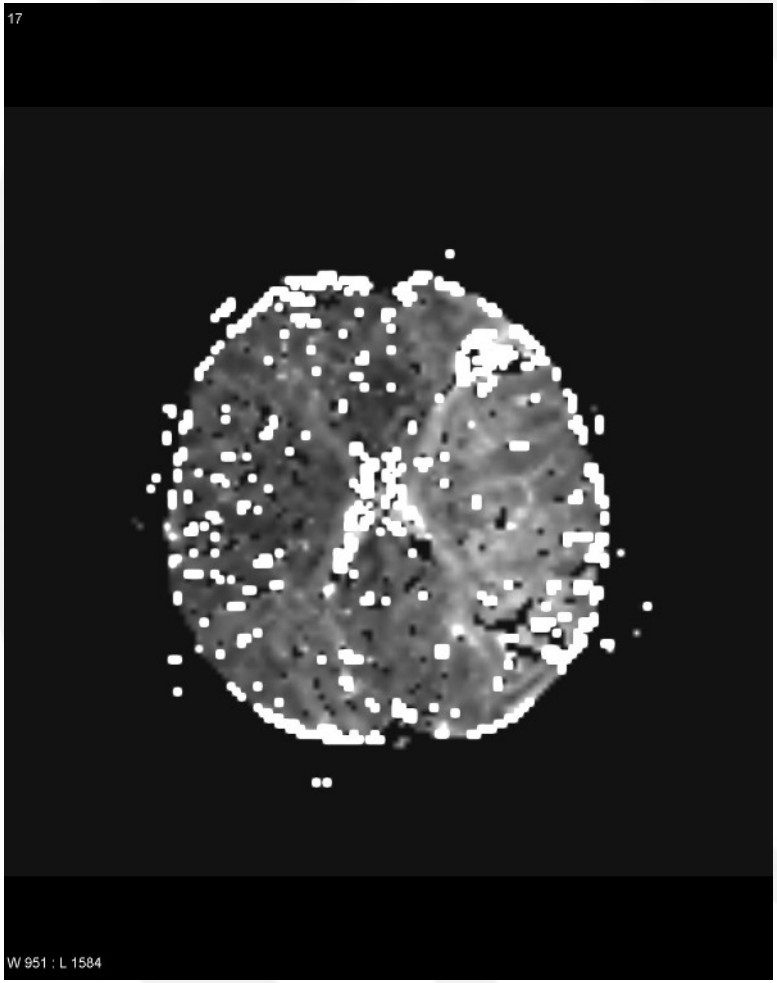
T2w and FLAIR



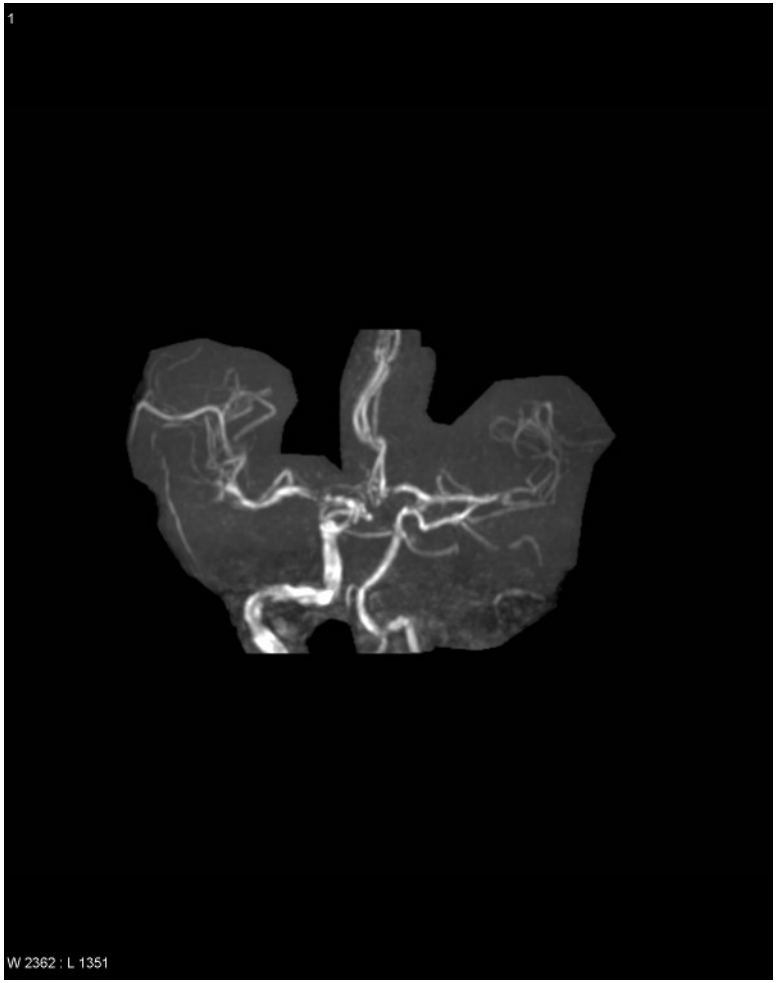


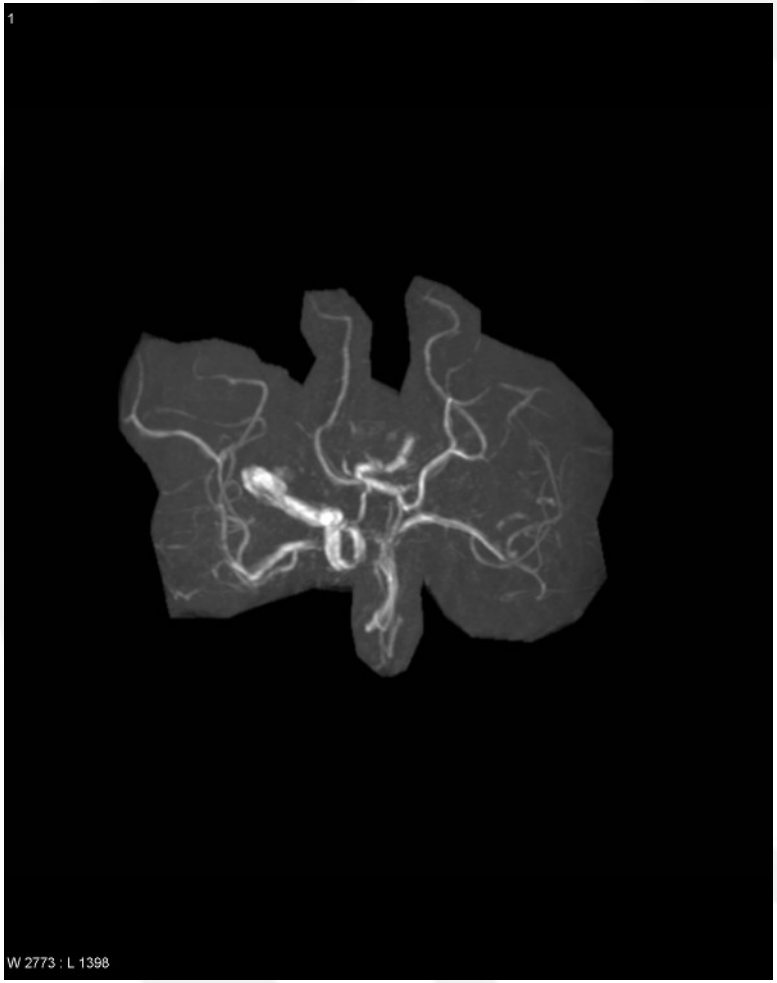
ADC and MTT



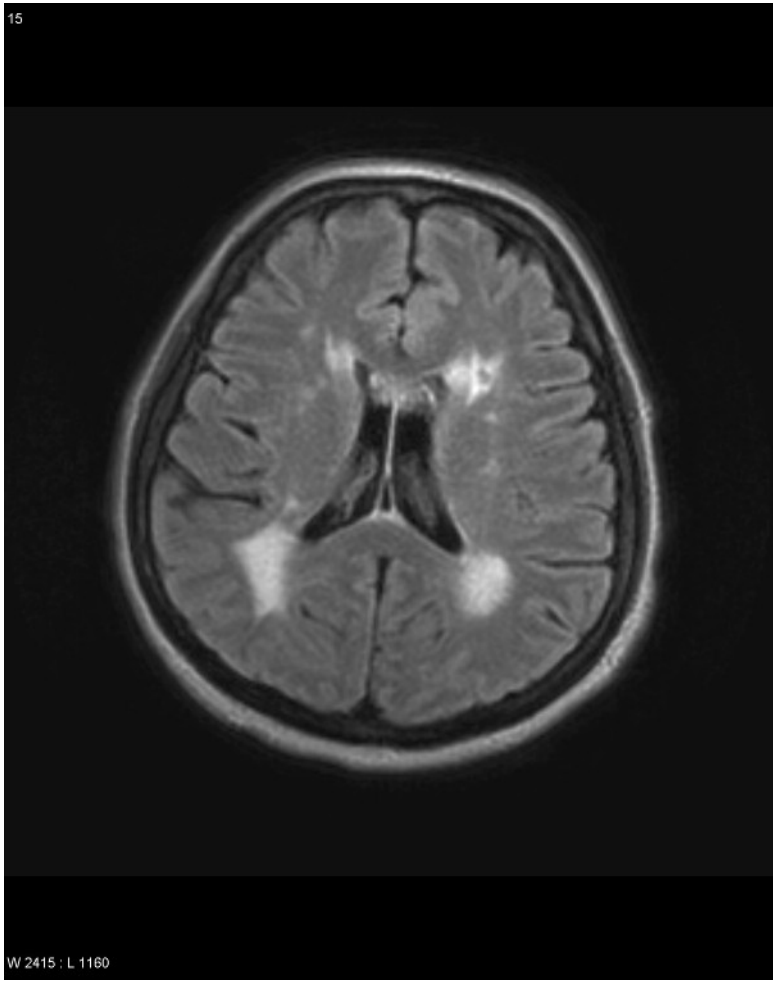


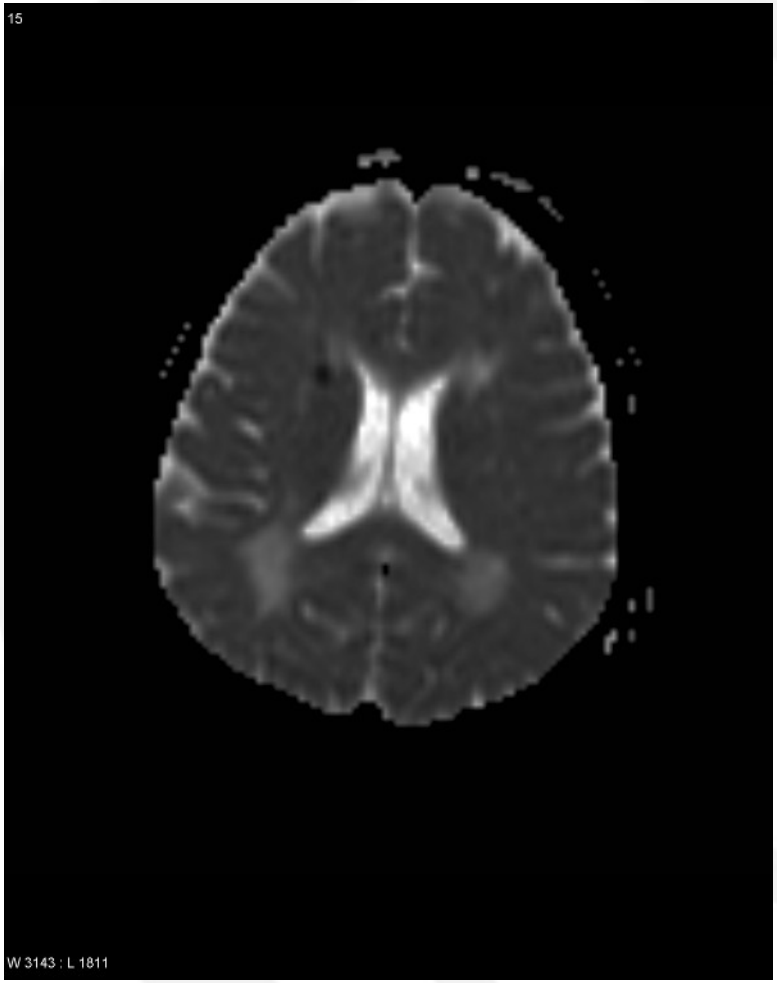
TOF MRA



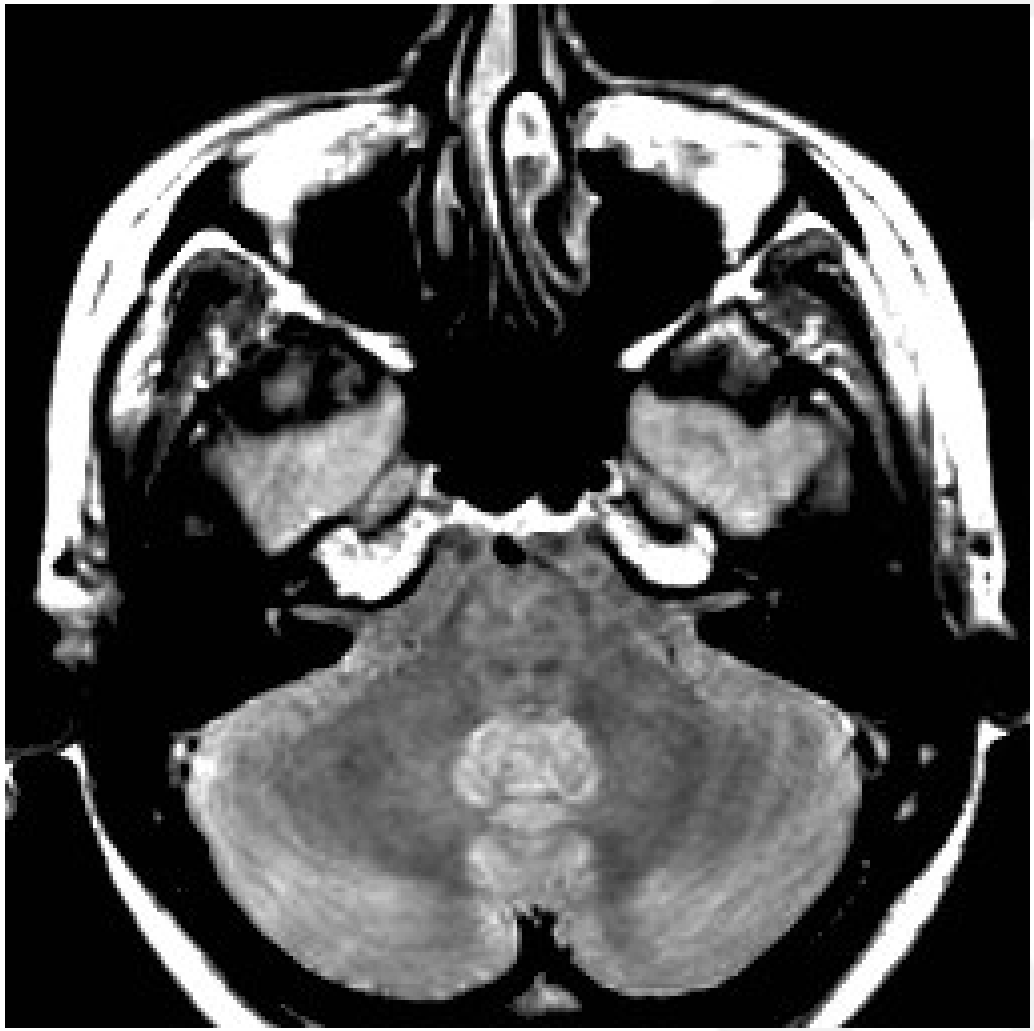


Lesion: FLAIR and ADC





Patron saint



Featured literature and links

- Prof Kovács J Sándor
  - **http://www.kardiologia.hu/symposium/73-21334.php**
  - **http://cbl1.wustl.edu**
- MR Physics:
  - Magnetic Resonance Imaging
    - **Vlaardingerbroek, ISBN: 3540436812**
- Cardiac MRI:
  - Clinical Cardiac MRI
    - **Taylor, ISBN: 3540262172**

Thanks goes to

- Merkely Béla
- Simor Tamás
- Hüttl Kálmán
- Vágó Hajnalka
- Balázs György
- Referring physicians – GOKI
- http://atoth.sote.hu/radiol