Perfusion MRI

Cardiac: Stress MRI

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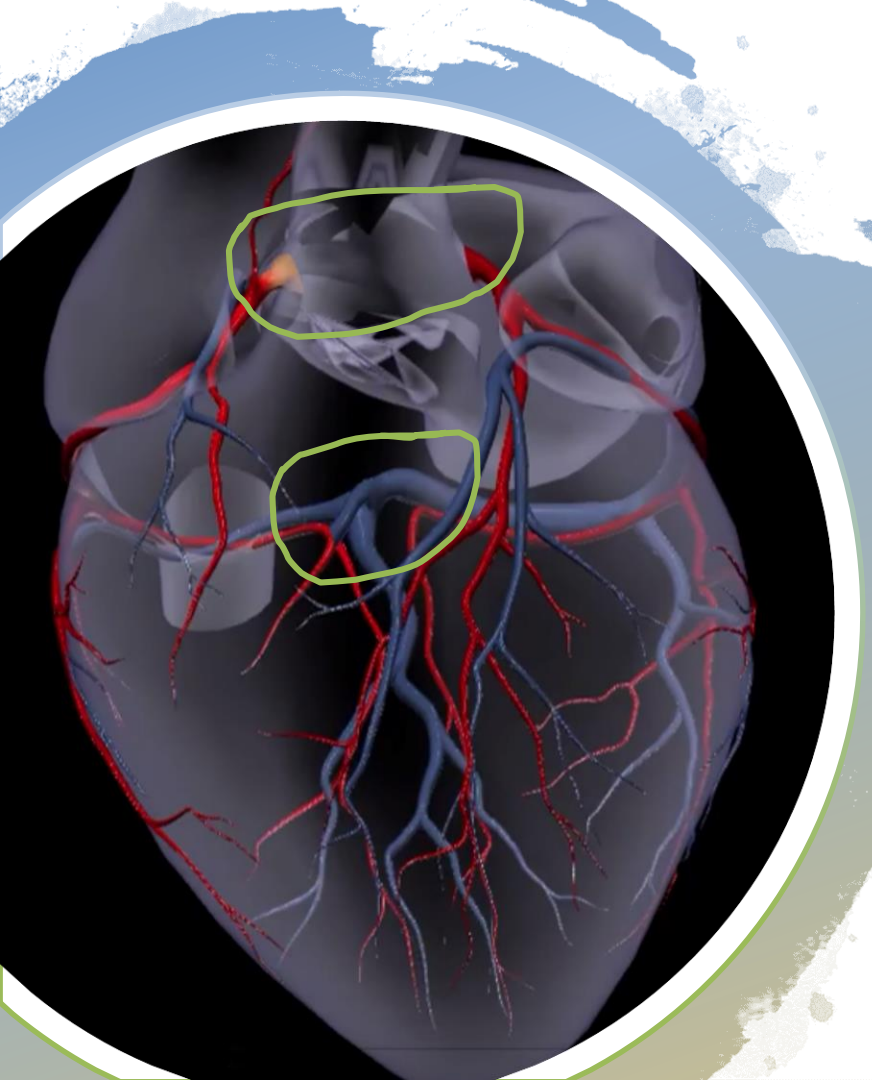


Coronary flow

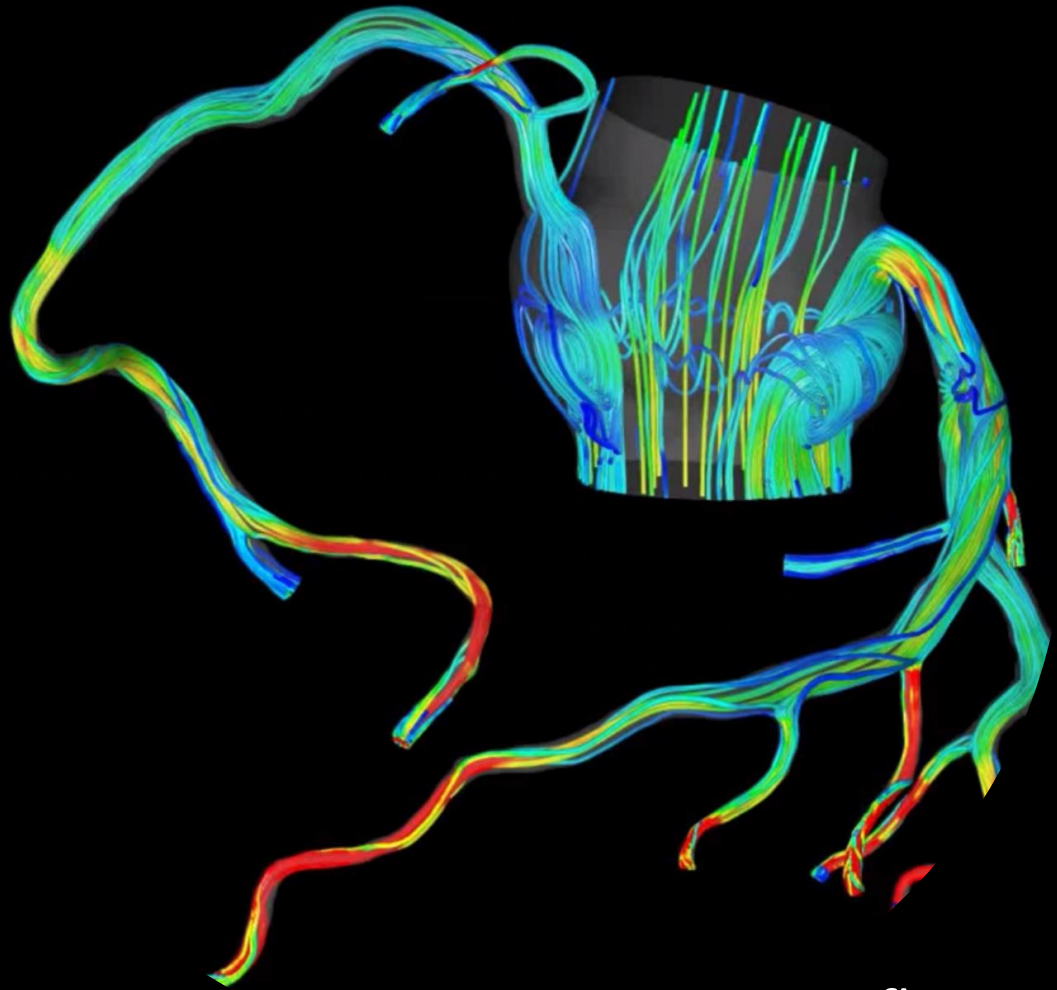
Blood pressure in the aortic root

—

Blood pressure in the right atrium

↓

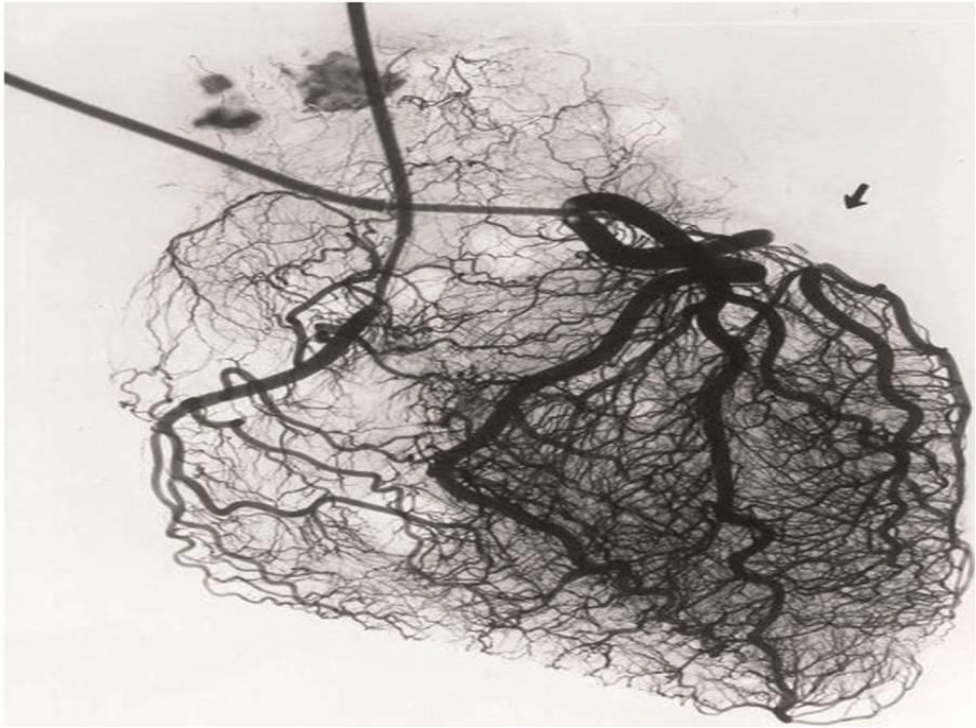
Pressure gradient driving flow across the myocardium

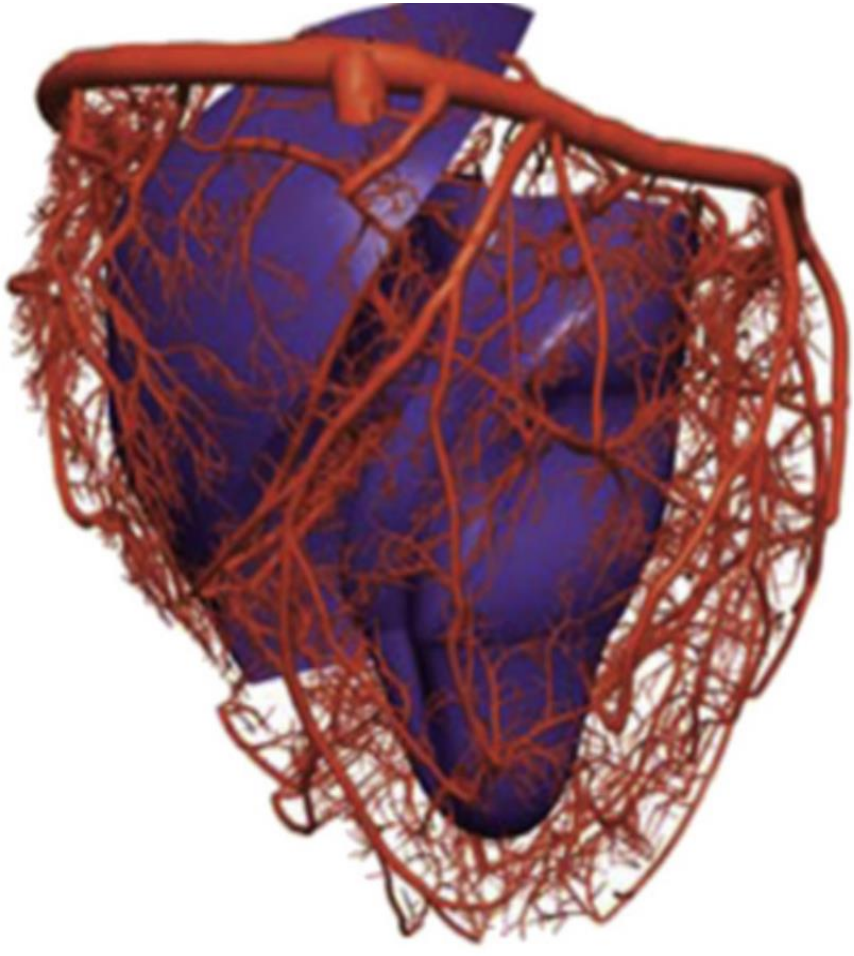


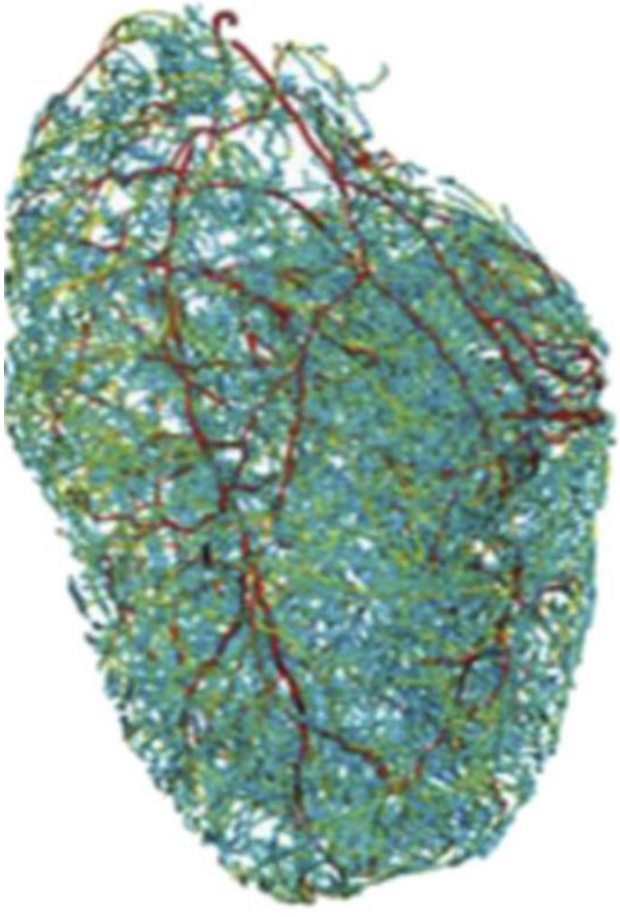
Coronary flow

What you see . . .

What you don't see . . .





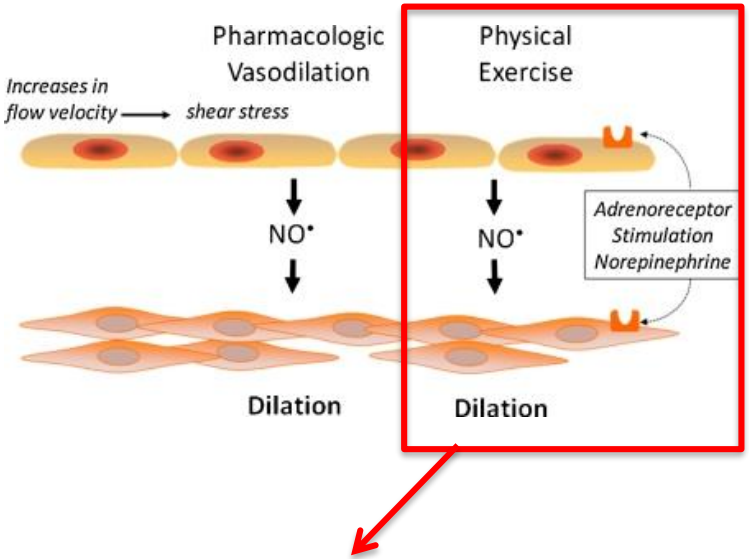


from 300 µm in the small arteries to less than 100 µm in the arteriolar vessels

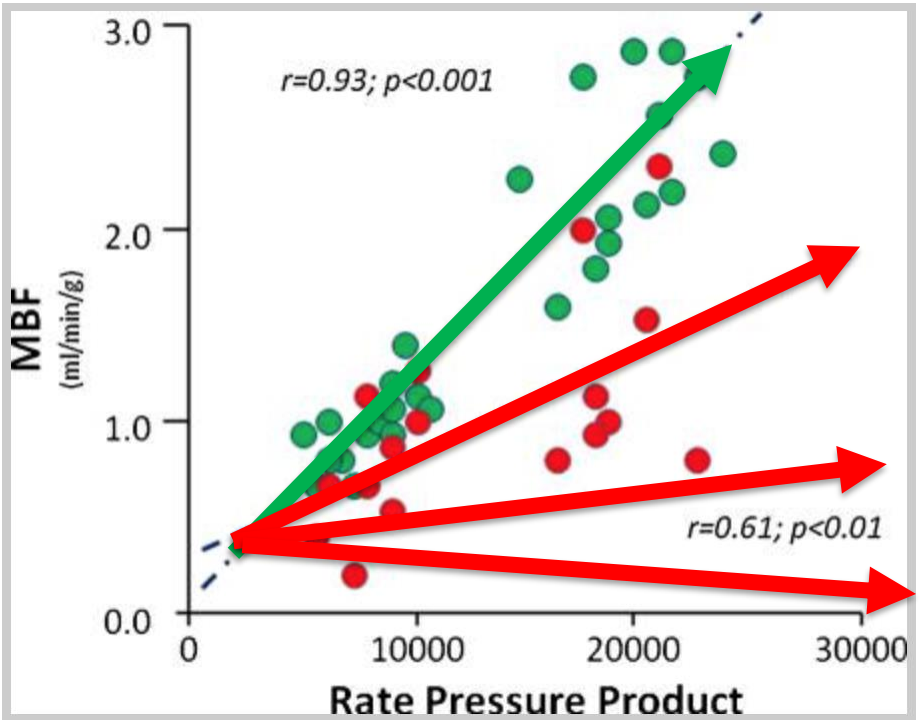
Pressure decline

Sarah L. Waters a Jordi Alastruey b , Daniel A. Beard et al Progress in Biophysics and Molecular Biology 104 (2011) 49e76

Coronary reserve

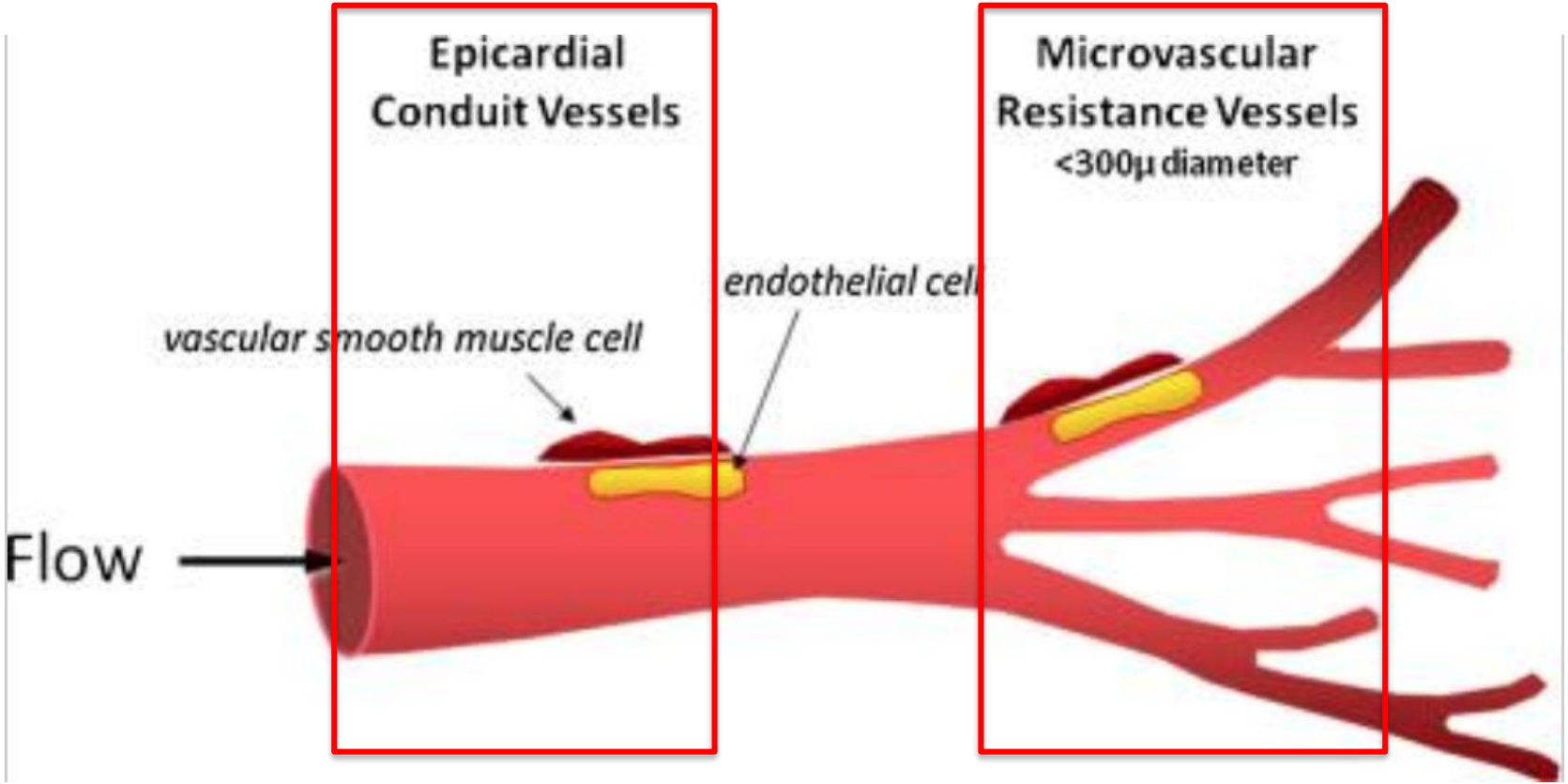


decrease in microvascular resistance

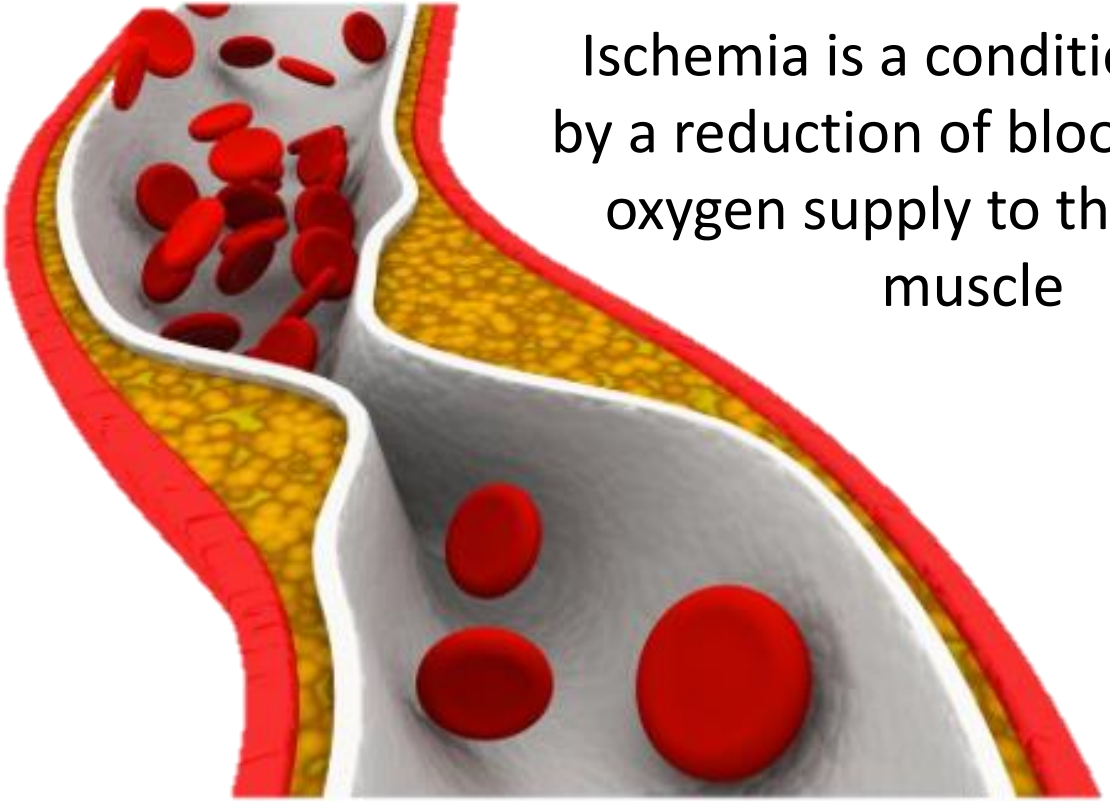


Krivokapich J, Czernin J, Schelbert HR J Am Coll Cardiol. 1996 Sep; 28(3):565-72.

Reduced coronary flow reserve

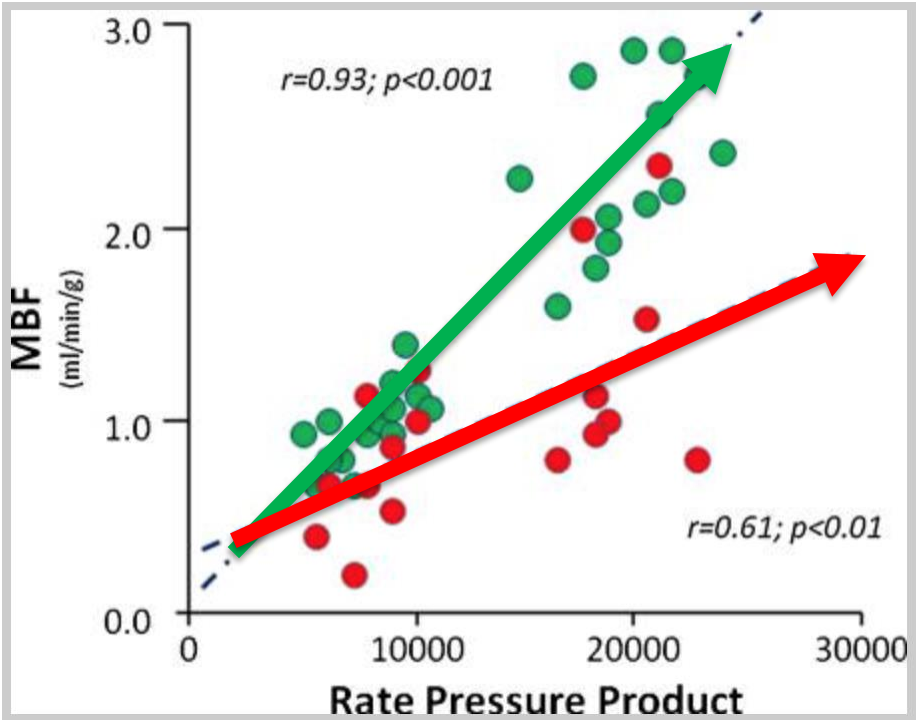


Epicardial critical stenosis

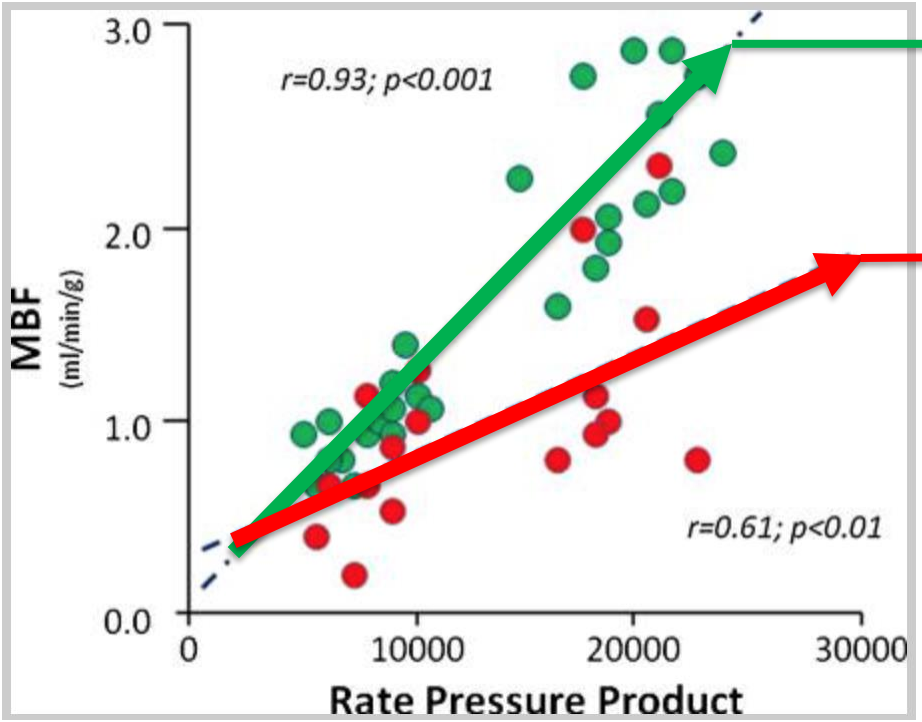


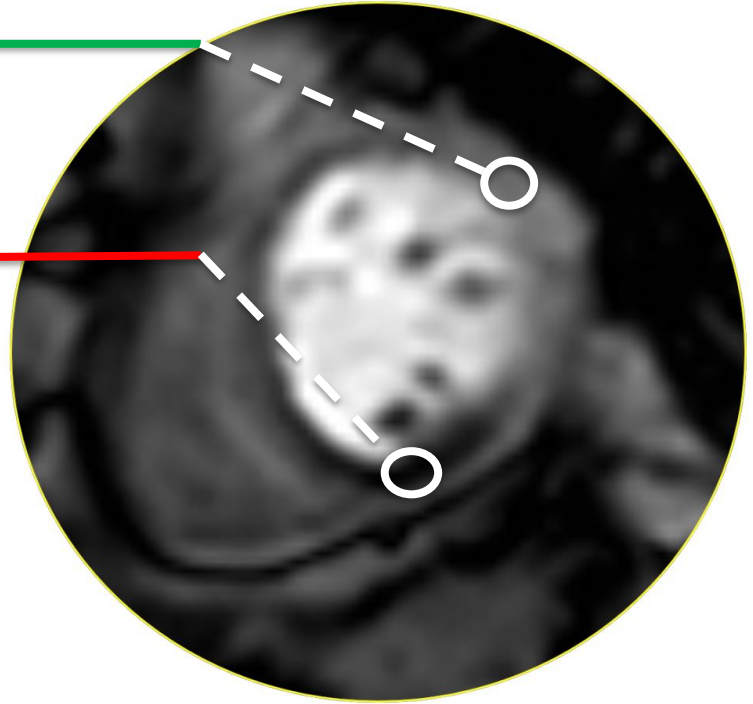
Ischemia is a condition caused by a reduction of blood flow and oxygen supply to the cardiac muscle

Detection of ischemia

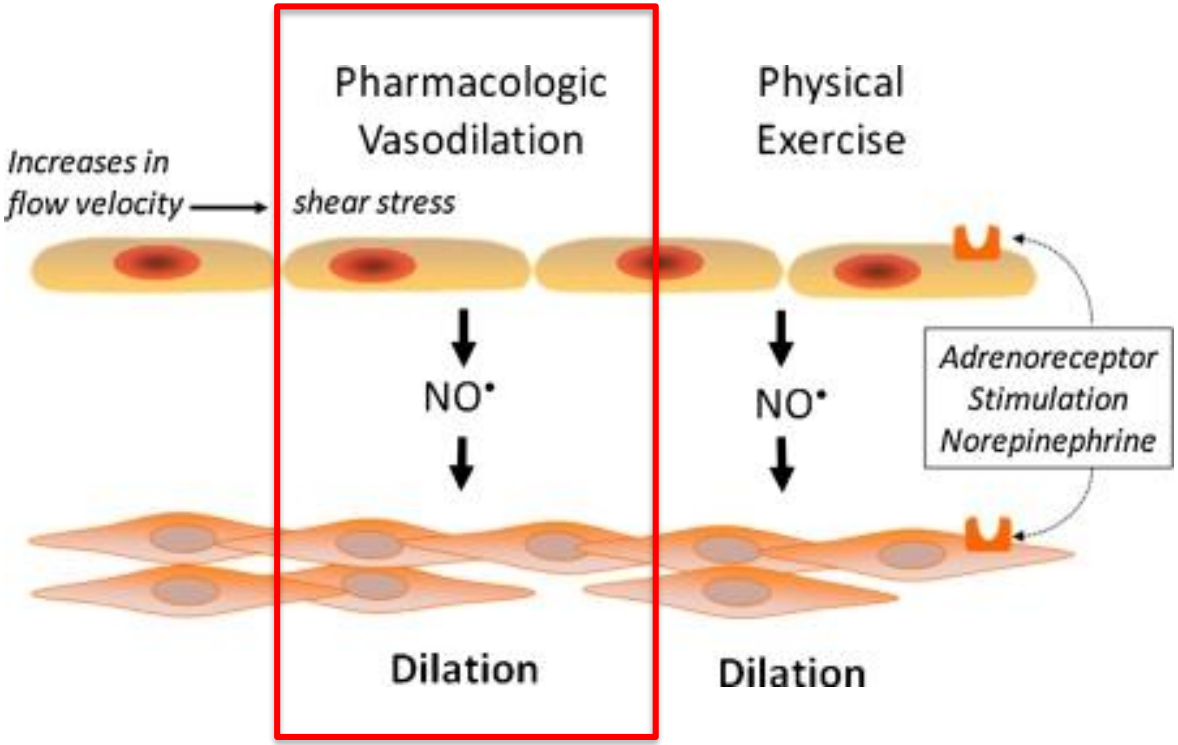


Detection of ischemia





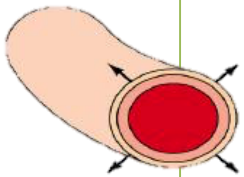
Stress induction

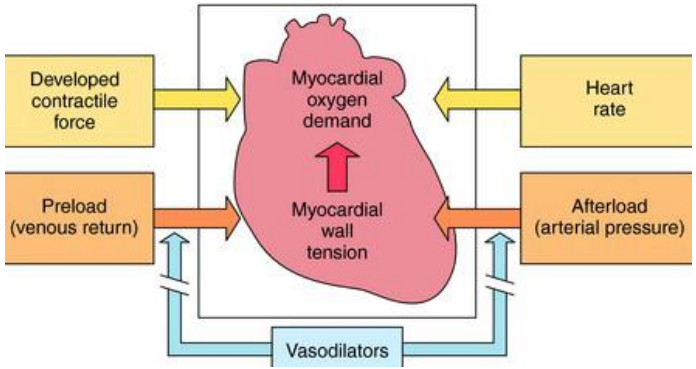


Pharmacological Stress

Vasodilators

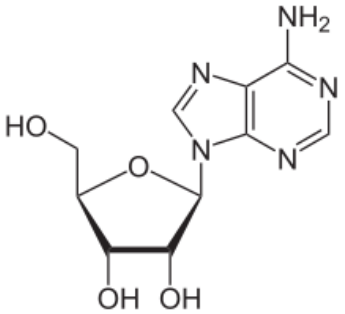
- Adenosine
- Dypiridamole
- Regadenoson



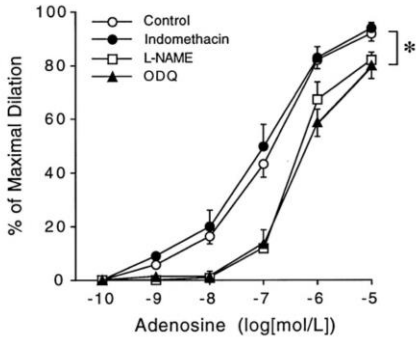


Adenosine

- 140 µg/kg per minute through a peripheral vein for 3 minutes
- short half-life of <10 s
- requires continuous infusion during the imaging procedure.
- Direct coronary vasodilatation



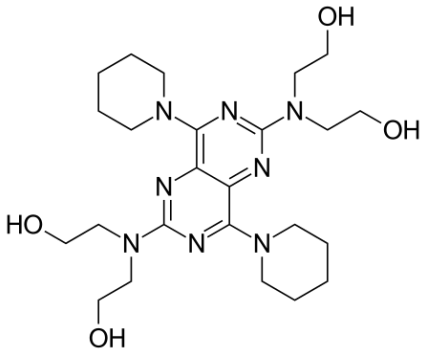
- Advantages:
- - brief duration of potential side effects
- - measure function and rest perfusion soon after the stress scan
- Controindication:
- - active broncospasm
- - more than first grade heart block
- - caffeine and aminophylline



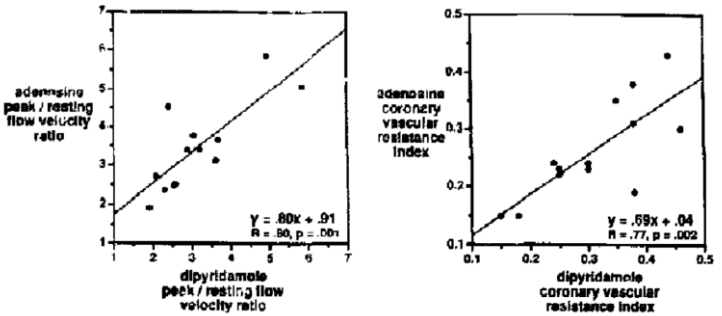
Travis W. Hein, Lih Kuo. Circ Res. 1999;85:634-642

Dipyridamole

- Dose 0.56 mg/Kg over 4 minutes
- half-life longer than adenosine
- **Indirect** coronary vasodilatation that works increasing intravascular adenosine level thought the inhibition of intracellular uptake and deamination of adenosine



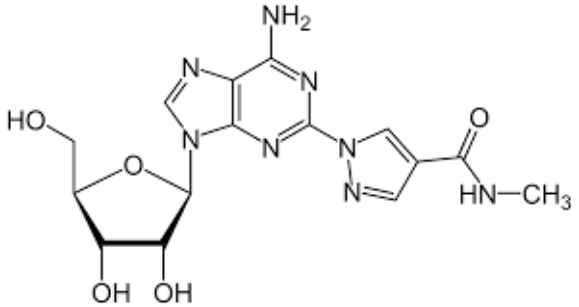
- <u>Advantages:</u>
  - bolus administration
  - much lower cost than adenosine
- <u>Disadvantages:</u>
  - **increase in blood flow less predictable than adenosine**
  - need of inhibitor for resting function and perfusion
- <u>Controindication:</u>
  - active broncospasm
  - more than first grade heart block
  - caffeine and aminophylline
  - SBP <90 mmHg



ROSSEN JD et al. J Am Coll Cardiol 1991;18:485-91

Regadenoson

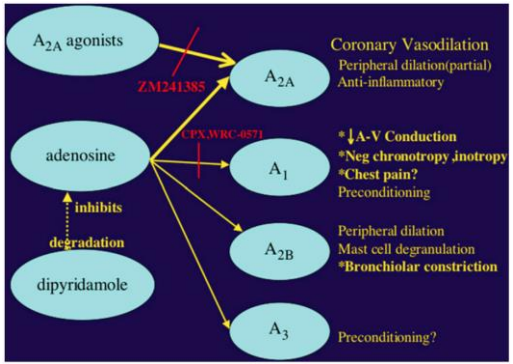
- Single non–weight-based dose
- Bolus administration
- Longer half-life than adenosine
- **Analogous of adenosine**

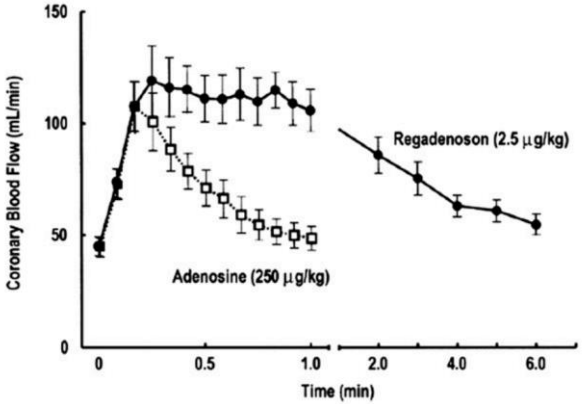


- <u>Advantages:</u>
  - single bolus administration
  - predictable vasodilatation
  - Higher affinity for A2A receptors, lower for A1, A2b and A3 receptors –> less P-R prolongation – less bronchospasm

- <u>Disadvantages:</u>
  - expensive

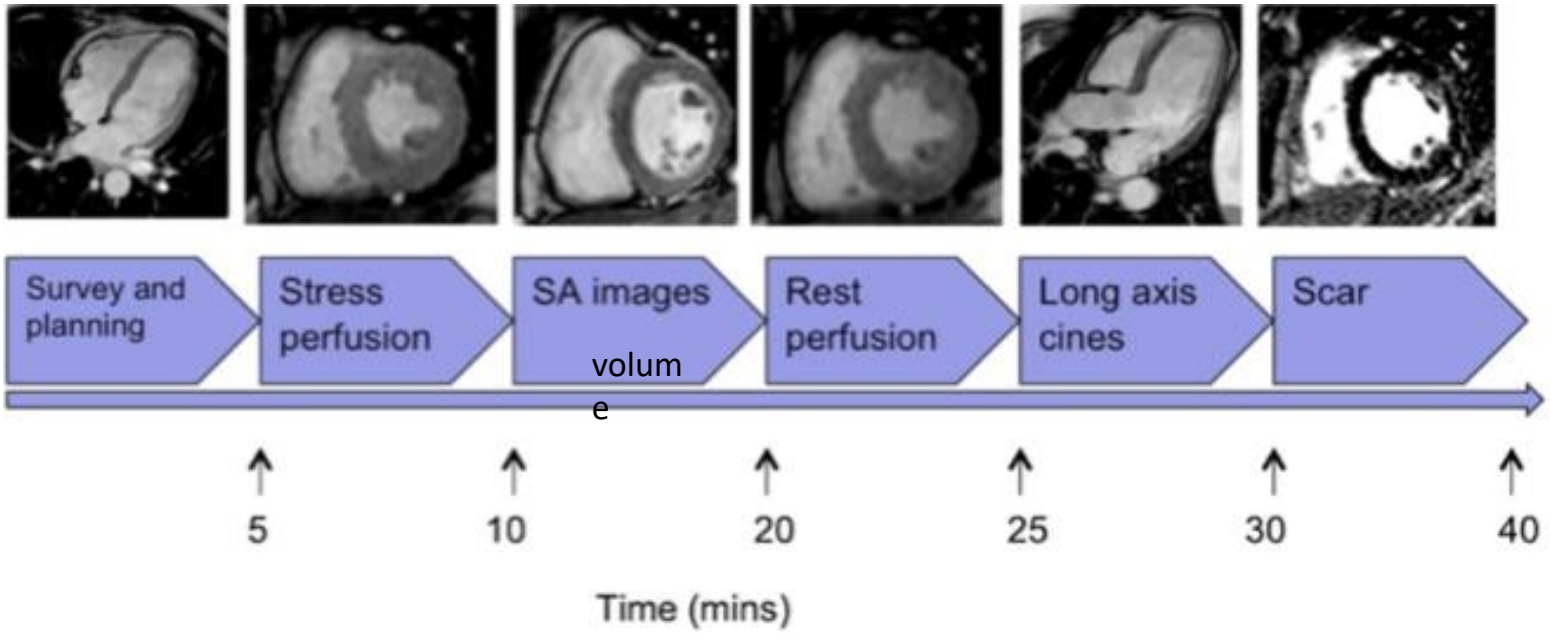
- <u>Controindication (same for adenosine):</u>
  - active bronchospasm, asthma
  - more than first grade heart block
  - caffeine and aminophylline

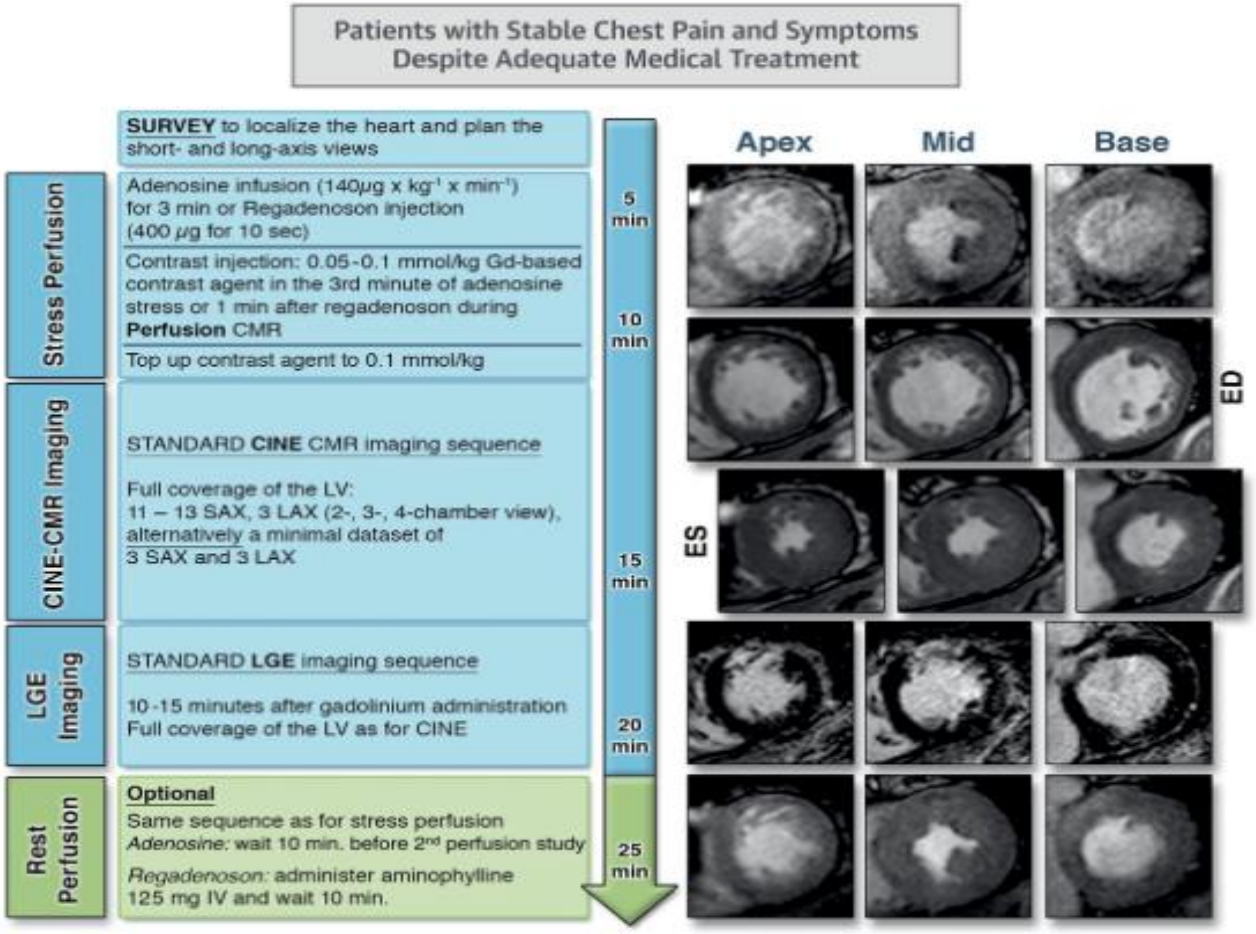




Elias H. Botvinick JOURNAL OF NUCLEAR MEDICINE TECHNOLOGY • Vol. 37 • No. 1 • March 2009

Stress CMR protocol





Hendel, R.C. et al. J Am Coll Cardiol Img. 2016;9(11):1338–48.

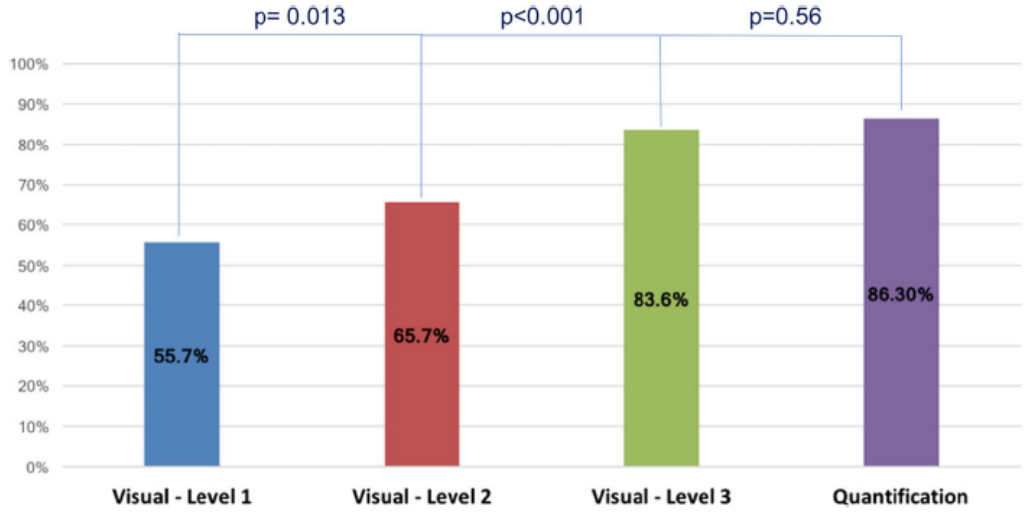
Villa et al. Journal of Cardiovascular Magnetic Resonance (2018) 20:74
https://doi.org/10.1186/s12968-018-0493-4

Journal of Cardiovascular Magnetic Resonance

RESEARCH Open Access

Importance of operator training and rest perfusion on the diagnostic accuracy of stress perfusion cardiovascular magnetic resonance

Adriana D. M. Villa[1†], Laura Corsinovi[1,2†], Ioannis Ntalas[1,3], Xenios Milidonis[1], Cian Scannell[1], Gabriella Di Giovine[1],



Operator training and experience had a significant impact on diagnostic accuracy.

Rest perfusion

significantly **higher confidence** of the operators in their reports

regardless of the level of training.

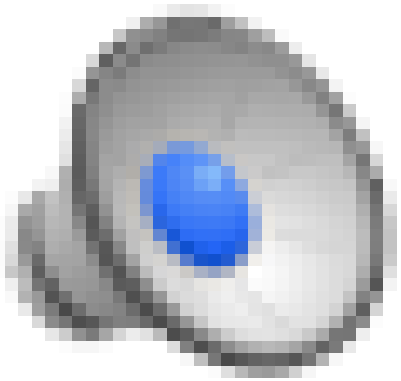
Efficacy of pharmacological stress

False negitive from 5-10% for caffeine and administration error

- Avoid caffeine
- Heart rate increase > 10 bpm
- A systolic blood pressure drop > 10 mmHg
- Chest pain
- Splenic switch-off?

Karamitsos TD, et al . Feasibility and safety of high-dose adenosine perfusion cardiovascular magnetic resonance. J Cardiovasc Magn Reson 2010;12:66.

Splenic switch-off

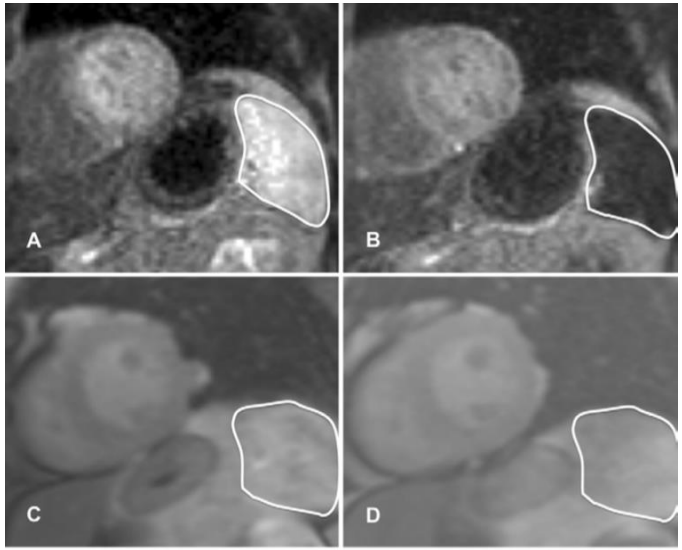


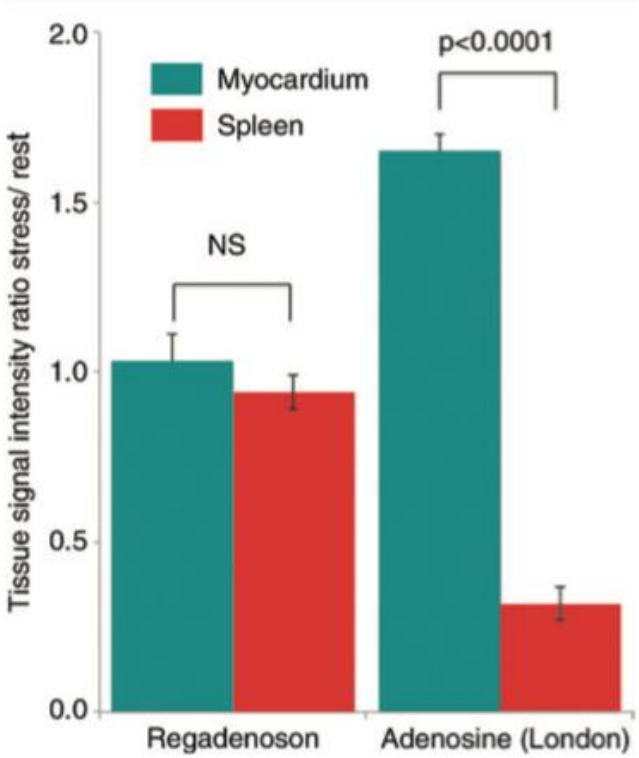
Manisty C et al.**Splenic Switch-off: A Tool to Assess Stress Adequacy in Adenosine Perfusion Cardiac MR Imaging.** Radiology. 2015 Sep;276(3):732-40

Splenic switch-off

Adenosine

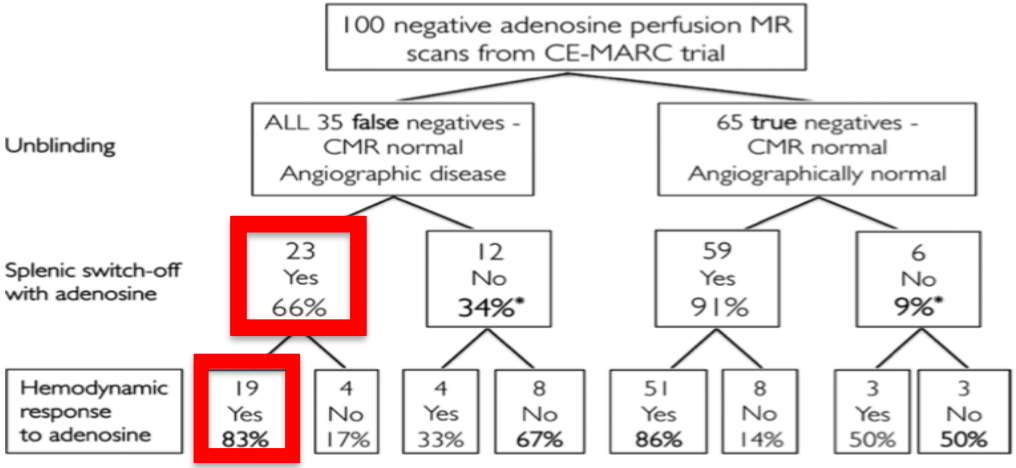
Regadenoson





Splenic switch-off

- Failed splenic switch-off may be a better marker than poor heart rate response to detect inadequate pharmacologic stress with adenosine
- Splenic perfusion via A1 and/or A2B adenosine receptors
- Coronary vasodilatation is mediated via the adenosine A2A receptor. Regadenoson as selective coronary A2A receptor agonist no discernable effect on splenic perfusion during stress



Manisty C et al. **Splenic Switch-off: A Tool to Assess Stress Adequacy in Adenosine Perfusion Cardiac MR Imaging.** Radiology. 2015 Sep;276(3):732-40.

Visual assessment

- Based on the differences of contrast between normal perfused myocardium respect to myocardium supplied by stenotic coronary artery
- Hypoperfused-ischemic area appears as hypointensity persisting for at least three frames after the arrival of contrast in the LV cavity, and persisting for at least four dynamics in the absence of post-infarction scar on LGE

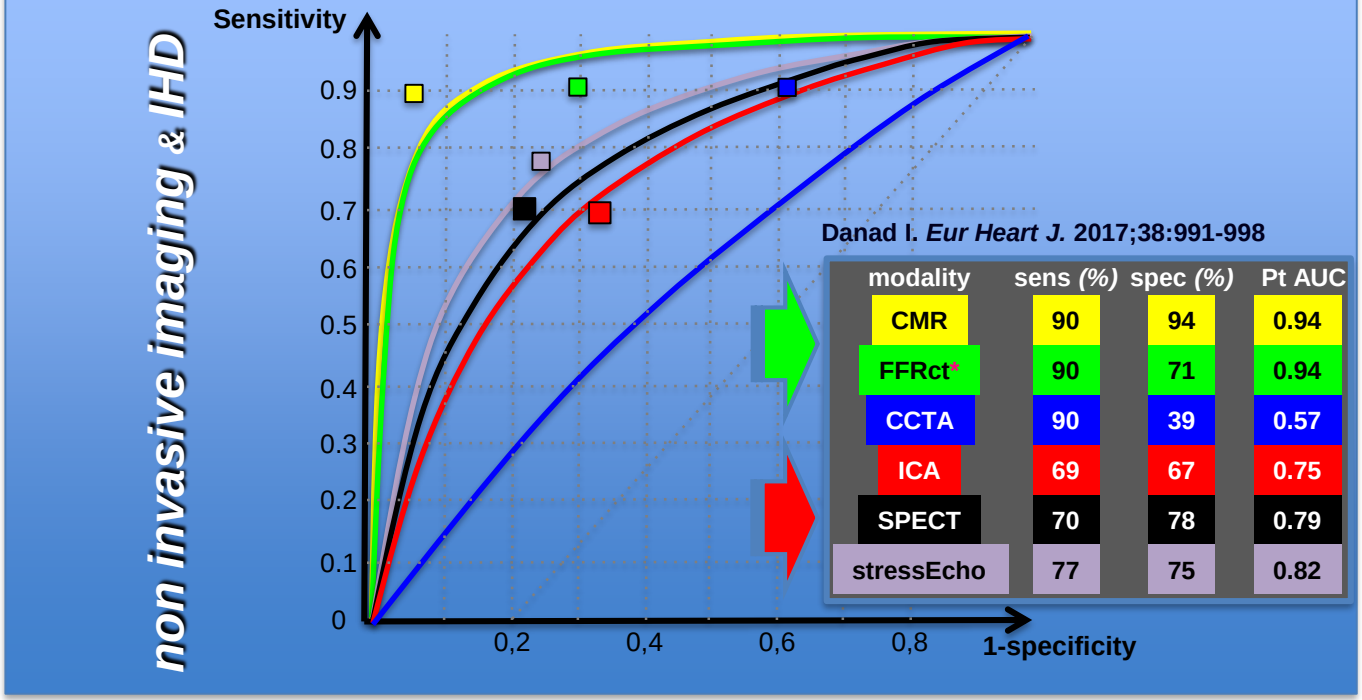
Transmural pattern

1. **<25%**
2. **25-50%**
3. **50-75%**
4. **>75%**

Hussain ST, et al . Design and rationale of the MR-INFORM study: stress perfusion cardiovascular magnetic resonance imaging to guide the management of patients with stable coronary artery disease. J Cardiovasc Magn Reson. 2012 Sep 19;14:65.

What is the best imaging approach?

Meta-analysis of performance of Cardiac Imaging tool *vs* invasive FFR



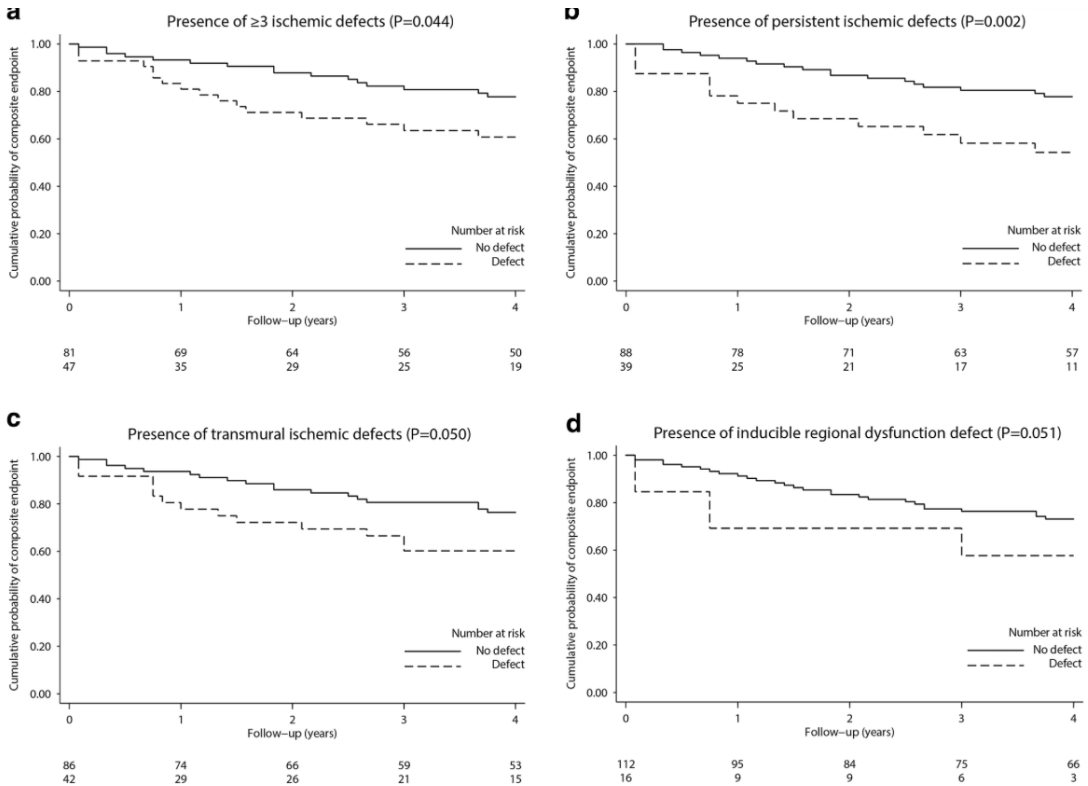
Stress CMR

- High temporal resolution (>1 image/s, 1RR-2RR)
- High spatial resolution (in-plane <3mm)
- High contrast resolution

Small subepicardial ischemia
Higher accuracy in balanced ischemia

- Panoramic evaluation (>3 slices; 3D images) → Whole LV coverage
- Standardized short and simple protocols
- Time-efficient (25- to 30-min session)

Prognostic value of inducible ischemia



Gómez-Revelles S et al. **Prognostic value of a new semiquantitative score system for adenosine stress myocardial perfusion by CMR.** Eur Radiol. 2018 Nov 7. doi: 10.1007/s00330-018-5774-7

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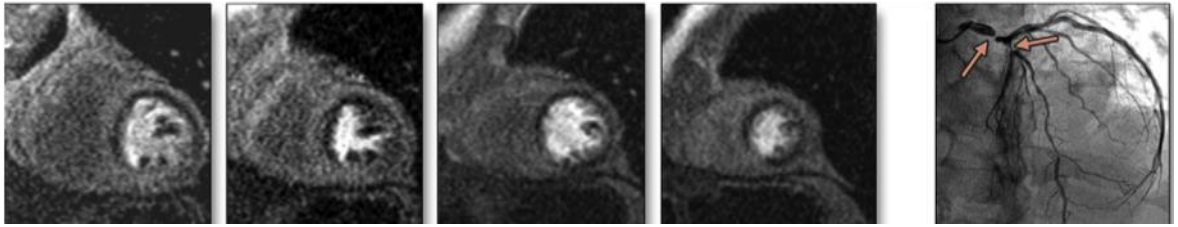
Stress Perfusion CMR in Patients With Known and Suspected CAD

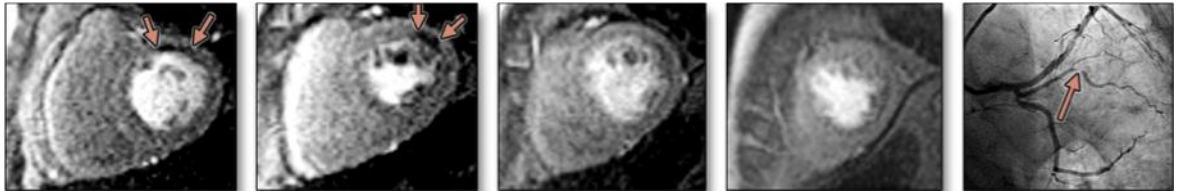
Prognostic Value and Optimal Ischemic Threshold for Revascularization

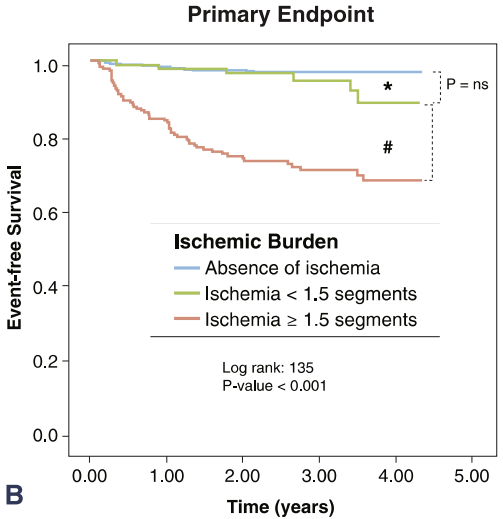
Gabriella Vincenti, MD,[a,b] Pier Giorgio Masci, MD, PhD,[a,b] Pierre Monney, MD,[a,b] Tobias Rutz, MD,[a,b] Sarah Hugelshofer, MD,[a] Mirdita Gaxherri, MD,[a] Olivier Muller, MD, PhD,[a] Juan F. Iglesias, MD,[a] Eric Eeckhout, MD, PhD,[a] Valentina Lorenzoni, PhD,[c] Cyril Pellaton, MD,[b,d] Christophe Sierro, MD,[a,b,e] Juerg Schwitter, MD[a,b]

LARGE PERFUSION DEFECT

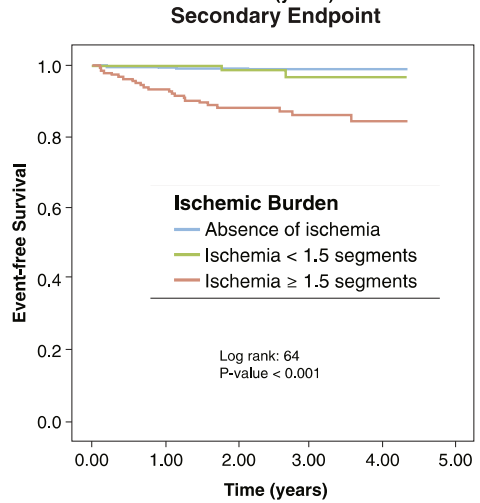


SMALL PERFUSION DEFECT

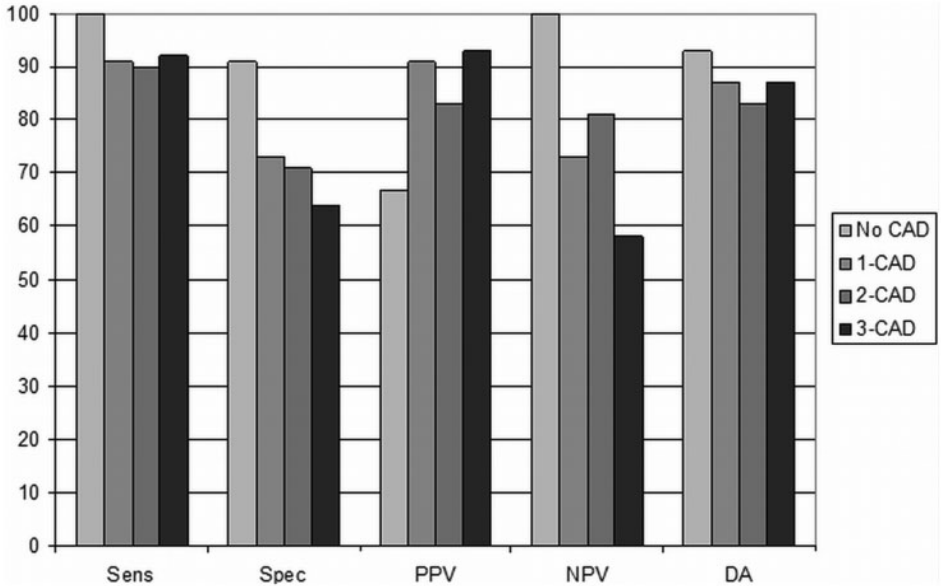




B



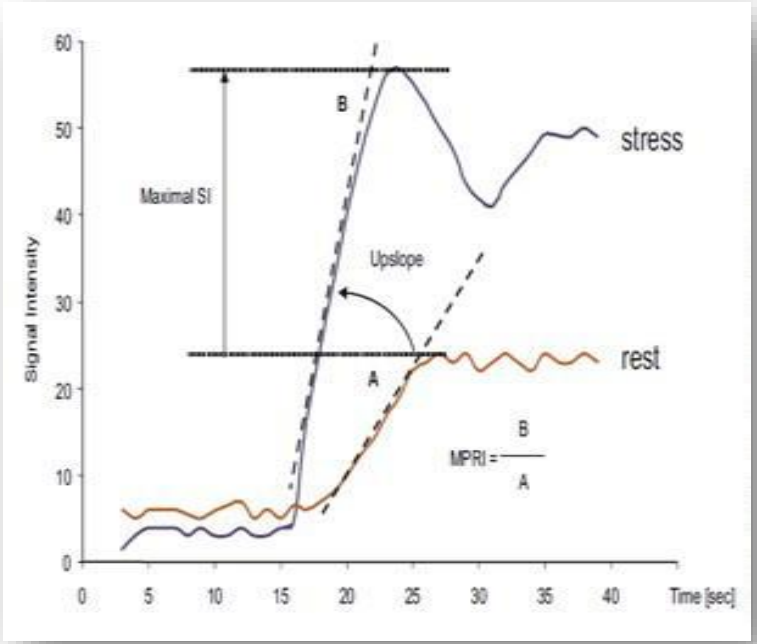
Visual assessment: three vessels coronary artery disease



IN FALSE NEGATIVE PATIENT MPRI WAS SIGNIFICANTLY REDUCED AT 1.76 IN 3-VESSEL CAD COMPARED TO 2.87 ($P < 0.05$) IN PATIENT WITHOUT CAD

Klumpp B et al. Acta Radiologica 2015; 56(2):143-151

Myocardial Perfusion Reserve Index



Myocardial perfusion Reserve Index (MPRI)

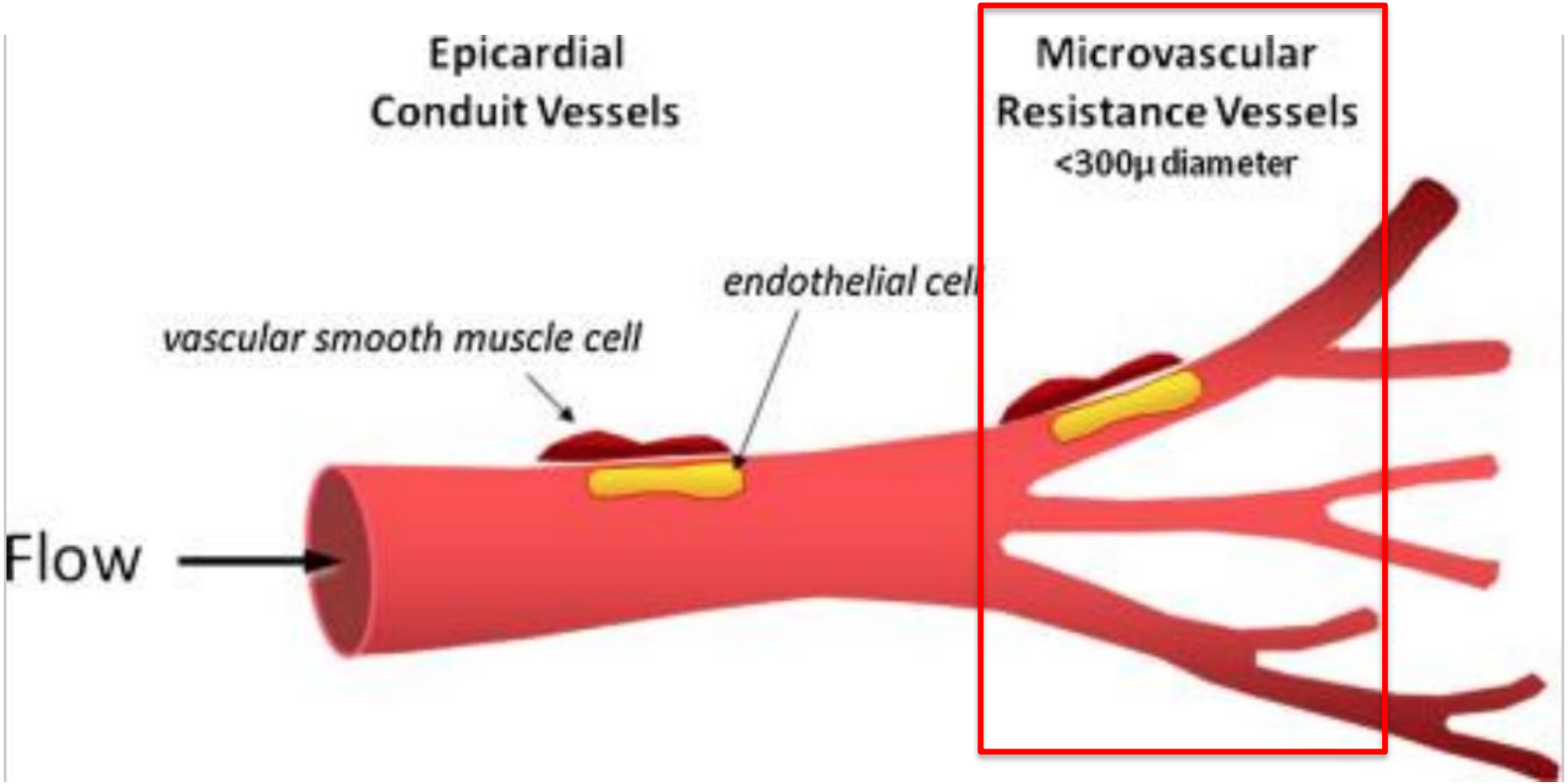
=

$$\frac{\text{Relative Upslop stress}}{\text{Relative Upslop rest}}$$

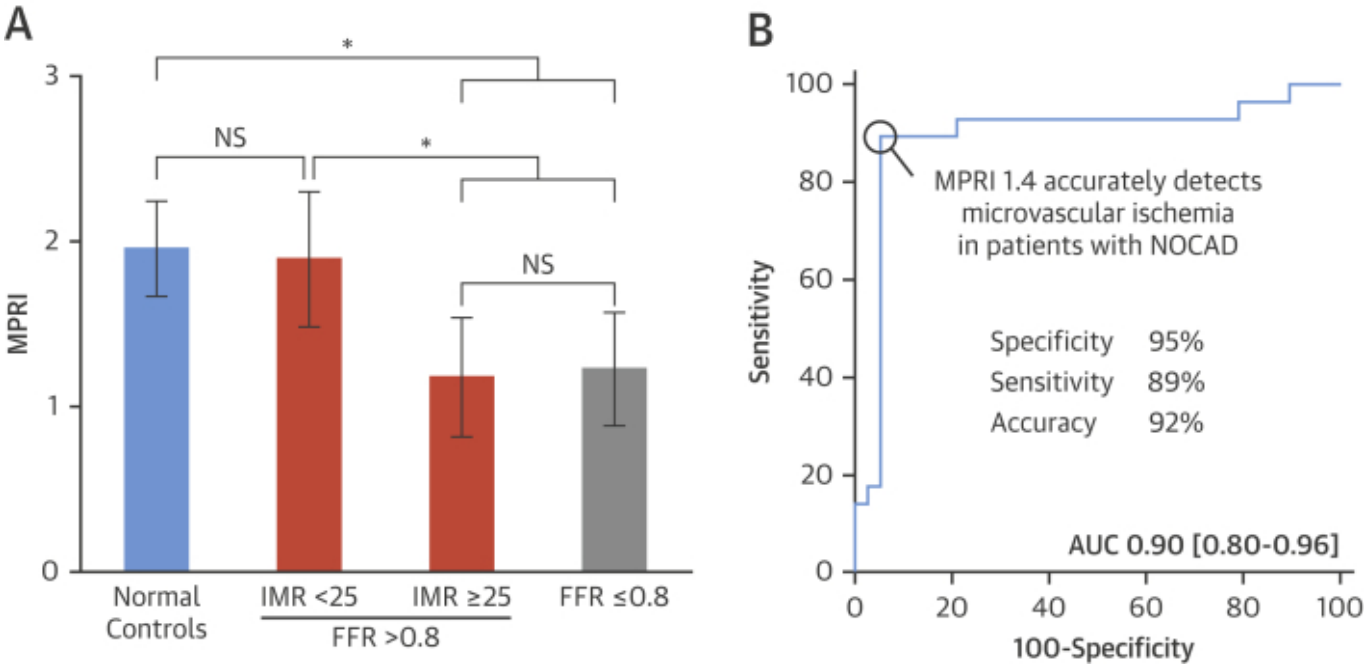
v.n >2*

Al-Saadi N, Nagel E, Gross M, et al. Noninvasive detection of myocardial ischemia from perfusion reserve based on cardiovascular magnetic resonance. Circulation 2000;101:1379–83

Reduced coronary flow reserve



Stress-rest CMR perfusion: high diagnostic accuracy for microvascular angina

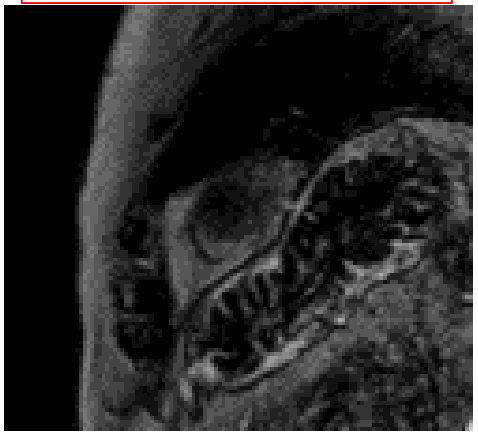


Liu A, Wijesurendra RS, Liu JM, Forfar JC, Channon KM, Jerosch-Herold M, Piechnik SK, Neubauer S, Kharbanda RK, Ferreira VM. J Am Coll Cardiol. 2018 Mar 6;71(9):969-979.

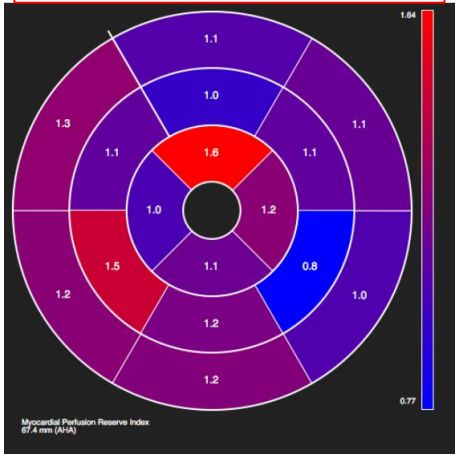
Stress perfusion

Rest perfusion

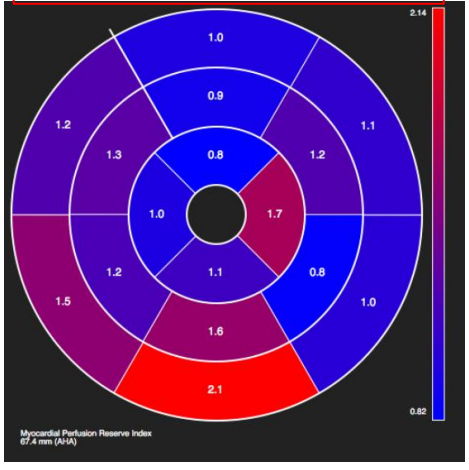
LGE



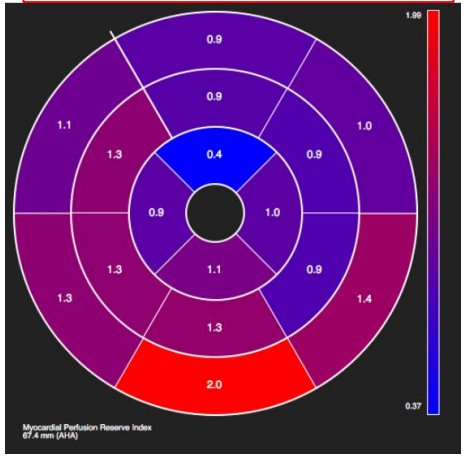
Endocardial MPRI



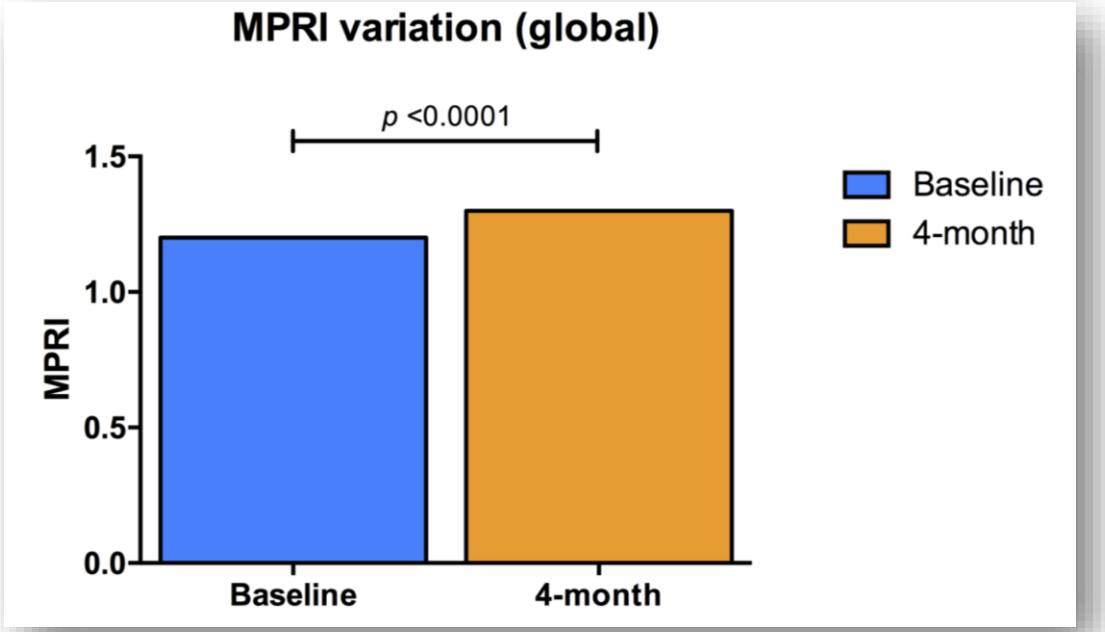
Mesocardial MPRI



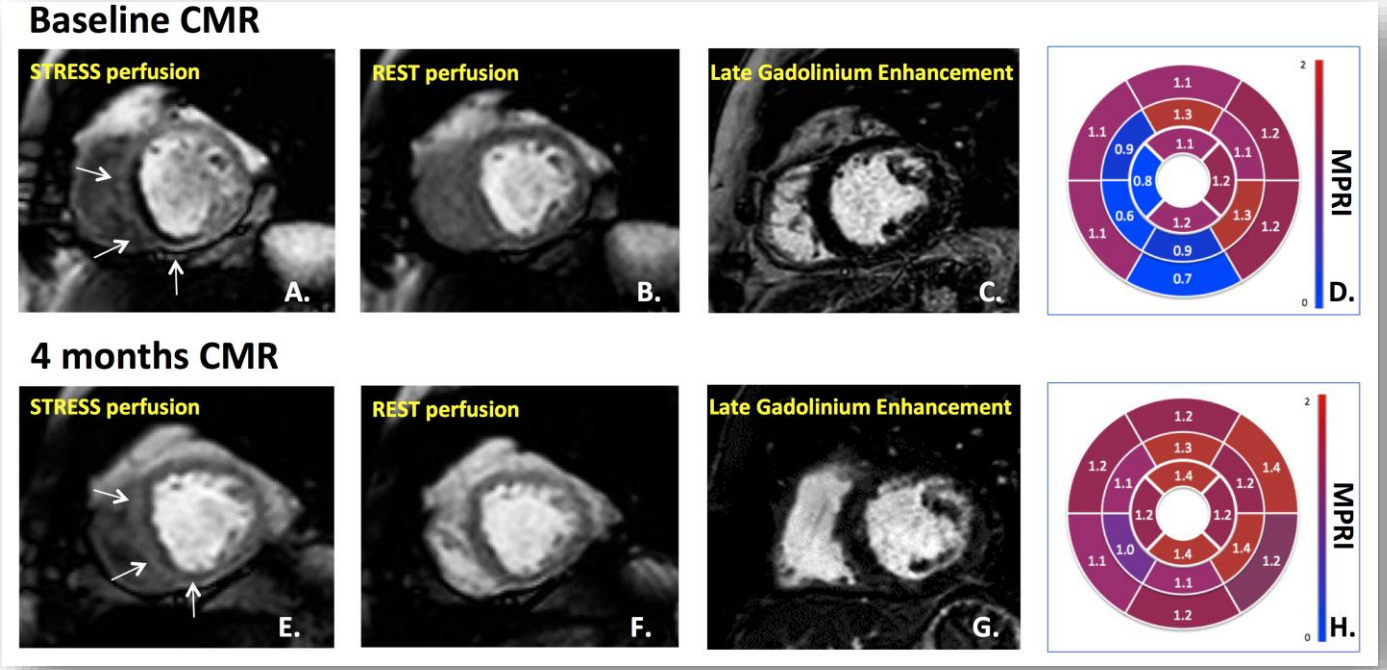
Epicardial MPRI



Myocardial Perfusion Reserve index



Clinical case



Non-Contrast myocardial blood perfusion quantification

Arterial Spin Labeling (ASL)

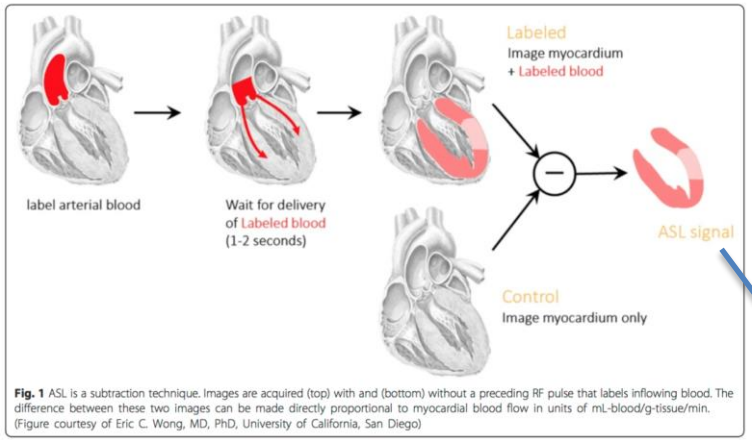
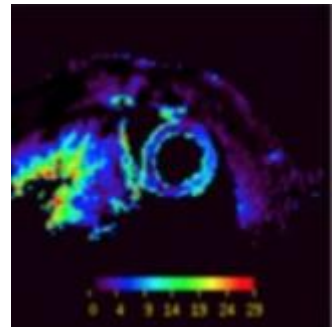


Fig. 1 ASL is a subtraction technique. Images are acquired (top) with and (bottom) without a preceding RF pulse that labels inflowing blood. The difference between these two images can be made directly proportional to myocardial blood flow in units of mL-blood/g-tissue/min. (Figure courtesy of Eric C. Wong, MD, PhD, University of California, San Diego)



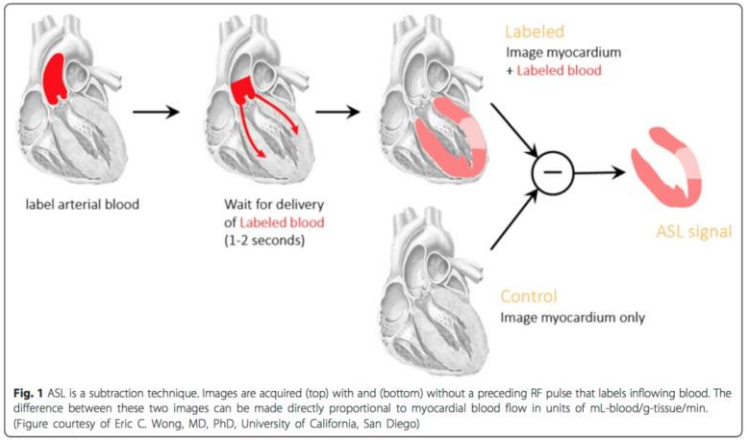
MBF map (ml/gr/min)

myocardial tissue magnetization difference created by magnetic blood labeling is lower than 4 % in humans

Kober et al. Journal of Cardiovascular Magnetic Resonance (2016) 18:22

Non-Contrast myocardial blood perfusion quantification

Arterial Spin Labeling (ASL)



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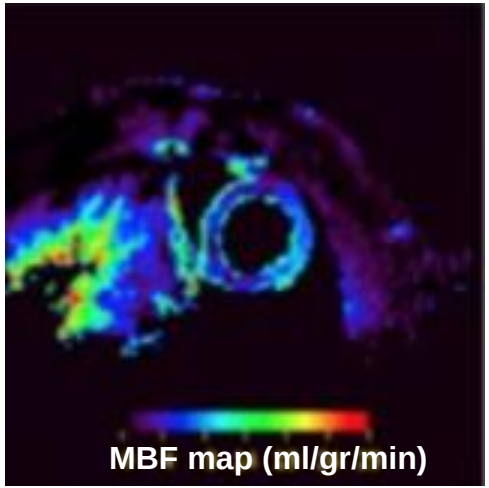

Magnetic field > 3T

SNR gain + ⇧T1 → ⇧life time of magnetic labeling

Double potential benefit from higher field

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Arterial Spin Labeling

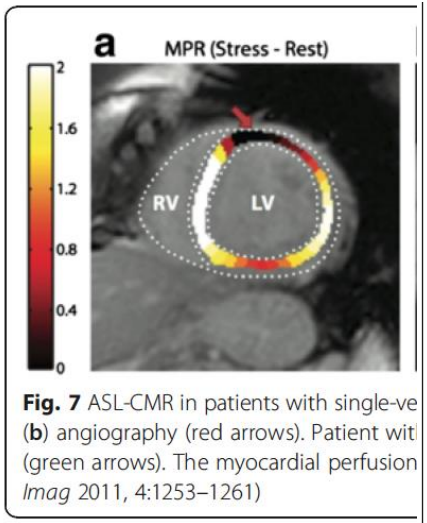

Fig. 7 ASL-CMR in patients with single-ve
(**b**) angiography (red arrows). Patient wit
(green arrows). The myocardial perfusion
Imag 2011, 4:1253–1261)

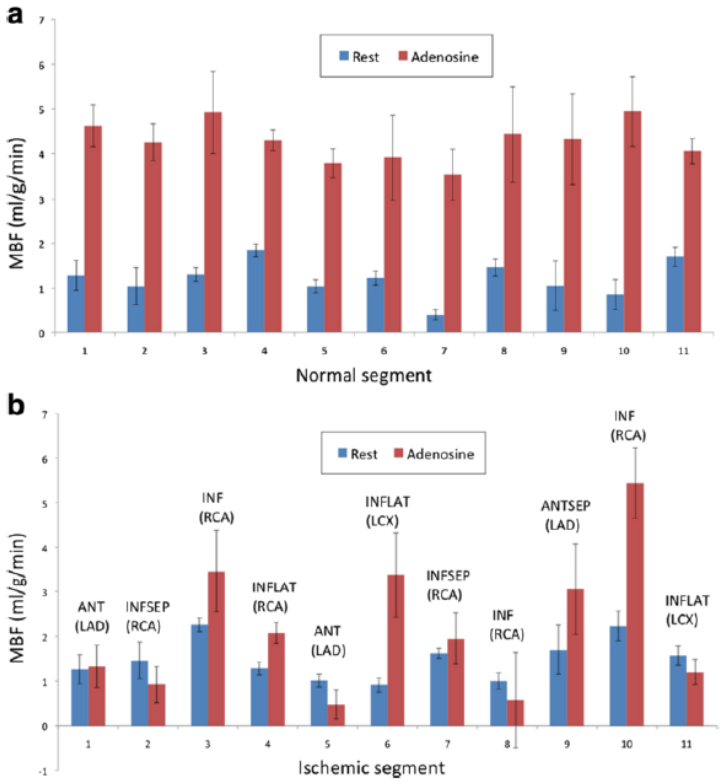

Fig. 8 ASL-CMR pilot study in patients with suspected CAD demonstrated that ASL detected clinically relevant increases in MBF associated with vasodilation in (**a**) normal myocardium, and was able to differentiate those from (**b**) segments that were most ischemic based on coronary angiography. (Data from Zun Z, et al. *JACC: Cardiovasc Imag* 2011, 4:1253–1261)

Conclusion

- High diagnostic accuracy
  - Epicardial coronary arteries disease
  - Microvascular disfunction

- Safe
- Stress efficacy

Scanner avaibility - training