Physics of cardiac MRI

By ;
Tamer Elwasify

- The most important part of the MRI machine is the magnet.
- The strength of the magnet is given in Tesla =10000Gauss
- High field 3 tesla and ultra high field magnets are recently used.
- The stronger the magnet the better the MR signal but more associated with technical problems and image artifacts.
- Types of magnets

1-permanent magnets: (kids magnet)

its disadvantage is thermal instability and limited strength as a 0.3 T may weigh 100 tons.

2-resistive magnets : electrical current passing through a loop of wire generating magnetic field

- only magnetic as long as the electricity passing through.
- usually get warm and have to be cooled
- achieve higher field strength .

3-super conducting magnets

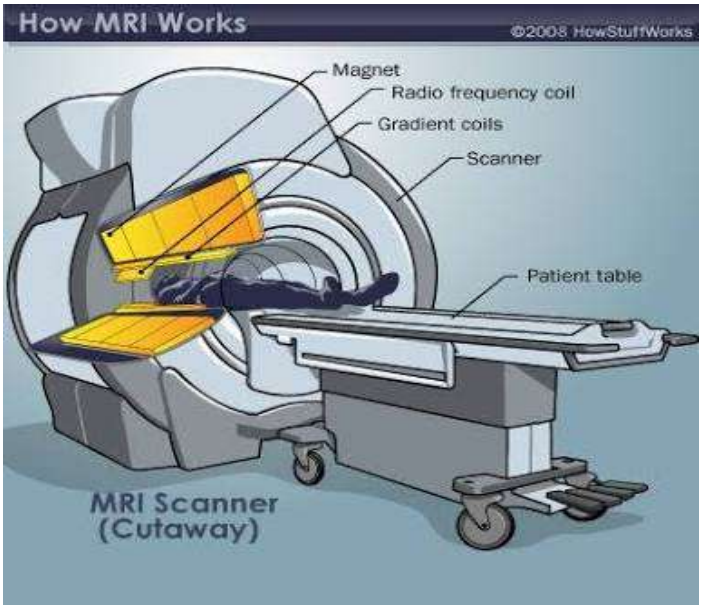
- widely used in MR machines nowadays
- also use electricity using special conducting material that loses its resistance at the superconducting

temperature -270 c , Helium and Nitrogen are used for cooling

when the temp rises above the superconducting temp it it leads to sudden resistance and rapid heat production which causes the cryogen to boil and leave the quench lines.

--higher field strength allows better resolution and faster examination

--lower field strength fields provide better tissue contrast and cheaper in price



- **Coil** sends an RF impulse to excite the protons and receive resulting signal

1-volume coils :surround the part to be examined .
2-body coil :permanent part of the scanner ,surrounds the body , used for all types of examinations .
3-gradient coil: produce additional linear magnetic field ,they are the cause of the noise we hear during MR test
4-surface coil : usually act as receiver coils ,they cant get signals from the deeper structures.
5-shim coil : for better magnetic field homogeneity

in abbreviation

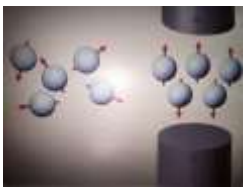
- The patient is placed in the magnet.
- A radio wave is sent.
- The radio wave is turned off
- The patient emits a signal which is received and used for reconstruction of the picture.

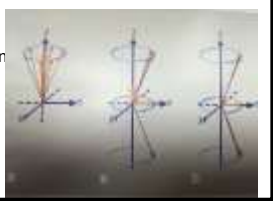
Requirements for the MRI unit

- Keep all metallic objects away as the machine can transform them into projectiles.
- Keep electronic devices away coz it may harm these devices
- The whole field should be shielded by a faraday cage to prevent interference between the outside radio waves and that from the machine.
- Larger metallic subjects especially when moving (cars – electric stairs) may influence the magnetic field


Swami Ramaiah, 35
Techinician
Oxygen Cylinder
Sunil Jadhav, 28
Ward boy
© Central European News

- Atoms consist of nucleus and shell of negative electrons.
- Protons are positively charged particles present inside the nucleus.
- Protons become aligned in parallel or antiparallel manner to the external magnetic field.
- The protons spin around there axis under normal conditions producing a magnetic field.
- When exposed to a magnetic field ,they start to wobble in a cone shape called precession
- Precession rate and frequency depend upon the strength of the magnetic field.
- When a person is put in a strong magnetic field , he becomes himself a magnet called longitudinal magnetization.
- Radiofrequency pulse is an electromagnetic wave within the frequency range of our radio waves sufficient to increase the energy level of protons to transfer them to higher energy state and transverse magnetization
- Transverse magnetization is responsible for the production of an electric and magnetic field of the proton.
- When the RF force stops , the transverse magnetization disappears and transverse relaxation occurs and longitudinal magnetization goes on again.
- The transverse magnetization component is the responsible for signal induction
- TR time less than 500 ms is considered short and more than 1500ms is considered long.
- TE less than20ms is considered short and more than 80 ms is long.





- T1 weighted images are mainly used for structural assessment and tissue differentiation.
- T2 weighted images are the mostly used in delayed enhancement and functional assessment and MRA.
- We get T1 weighted images by decreasing TR and get T2 weighted image by increasing the TE.
- If the fluid is white its T2 weighted image and if black its T1 weighted image.

MRI contrast agents

are a group of contrast media that improve the visibility and differentiation of body tissues.

- **Gadolinium** is the most commonly used paramagnetic substance .
- Its an extracellular fluid agent.
- Its chelates don't pass the blood tissue barrier unless compromised , and initially remains in circulation and diifuses in the interstitial spaces or eliminated by kidneys
- A rare earth metal which is toxic in its free state ,so its usually used bound to other chemicals (chelation).
- It shortens the relaxation time and has a great effect on the signal intensity we get from T1 and T2 weighted images.
- T1 weighted images are better to be used after contrast injection.
- We have to ask our selves 5 questions .

  1-age >60?
  2-hypertensive?
  3-diabetic?
  4-hx of renal disease?
  5-immediate post operative period <1 month or post period of liver transplant?

  if the answer is yes , we should eGFR for not more than 6 months period.
- **The absolute contraindication** for gadolinium is previous or preexisting nephrogenic systemic fibrosis
- **The relative contraindications are**

  - anaphylactic reaction to gadolinium containing agents
  -pregnancy.
  - eGFR<30ml/min/1.73m2
  -unstable renal impairment
  - hepatorenal syndrome ,chronic liver imp
  - breast feeding

- **side effects of gadolinium include**

  -headache , nausea ,dizziness,
  - anaphylactic reaction , contrast extra vasation
  -nephrogenic systemic fibrosis.

Types of gadolinium

1-extracellular agents:

gadoterate (dotarem)
gadodiamide(omniscan)
gadobutrol (gadavist in USA)

2-blood pool agents:

albumen bound (gadosovest)or vasovist

3-hepatobiliary agents

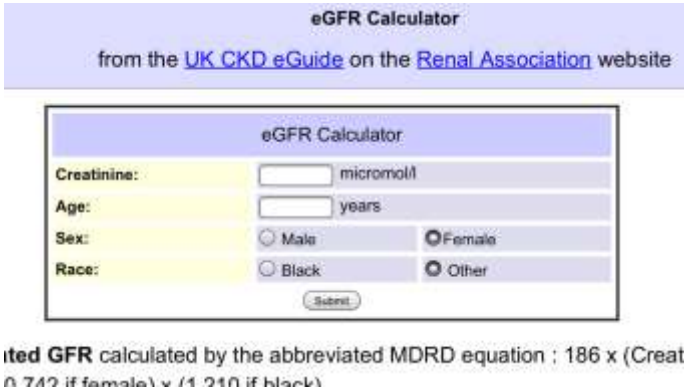
Euvist :50%taken up by liver and 50%by lidneys

- **9 gad chelates are approved by FDA including:**
  -gadoterate (dotarem)
  -gadodiamide(omniscan)
  -gadobutrol(gadavist)
- **Safety of gadolinium contrast agents:**
  they are nephro and neuro toxic coz at least 1% of the dose is retained in its free toxic state.
  when administered in the chelated form the LD50 is increased by a factor of 100

- **Guidelines recommend the followings for high risk patients:**

- using the minimum adequate dose 0.1 m mol/kg and avoid repeated scans
- consider immediate post scan hemodialysis 75%-93%and 98%removal after 3rd session
  use contrast agents with lowest risk
- We must assess the risk benefit of the high risk group eGFR<30ml/min/1.73m2
- We must take history of exposure to factors that increase incidence of NSF like metabolic acidosis ,vascular surgery and recent thrombotic events
- a written consent should be obtained from the high risk group.
- Schedule gadolinium immediately before hemodialysis and consider an extra dialysis session.

- Creatinine clearance estimate by Cockroft-Gault equation
  =sex*((140-age)/(serum creat))*(weight/72)
  male 1 , female 0.85



- Cardiac MRI provides a non invasive assessment of the structural and functional changes of the myocardium, pericardium , cardiac valves and great arteries
- It may work as a stand alone imaging modality or as a complement to coventional ECHO and angiography.
- It requires an adequate ECG tracing for adequate timed image acquisition .
- The ideal ECG tracing is regular and has a tall R wave.

Indications of cardiac MRI

- To separate ischemic from non ischemic cardiomyopathy ,for follow up of patients with myocarditis.
- Diagnosis and follow up of ptients with congenital HDs.
- In valvular heart diseases , however ECHO remains the ideal imaging modality.
- The most accurate modality for description of MI in acute and chronic phases
- Assessment of pericardial diseases and tumours.
- MSCT remains the better imaging modality for the noninvasive assessment of the coronaries
- MRI provides a competitive alternative to SPECT in the assessment of myocardial perfusion

Disadvantages to cardiac MRI

- Time consuming
- Dependent upon image acquisition during breath hold for 5-10 seconds.
- Patients with pacemakers and cardiac devices face the problem of heating of the tips of the leads and there's an increasing focus on these problems among producers.
- In contrast to devices , neither coronary stents nor valves are considered contraindications to MRI.
- Highly irregular arrhythmias is a challenge to the image quality ,despite getting new arrhythmia rejection programs

Pulse sequences used in cardiac MRI

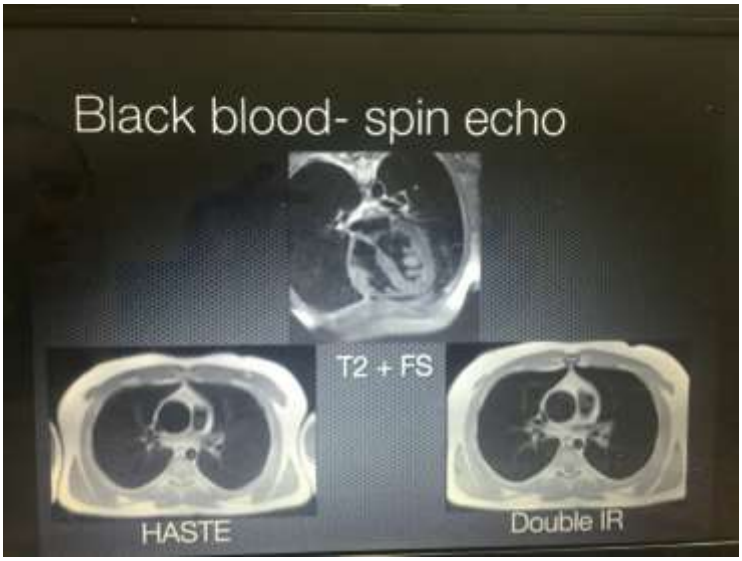
- Black blood . Used mainly for anatomy.
  (spin Echo)
- Bright blood .used for dynamic images and angiography
  (gradient Echo)
- Phase contrast images used to quantify flow.
- First pass perfusion followed by Delayed enhancement (infarction-inflammation-infiltration)
- Gadolinium assisted MRA-angiography .
- Tagging or physiological assessment .

Black blood images

- **Traditional T1 and T2 weighted images.**
  -T1 has a short TE and a short TR
  -T2 has a long TE and long TR.
  -called fast or turbo spin Echo.

- **Double inversion recovery.**
  - provides better blood suppression

- **Triple inversion recovery**
  -fat suppressed .
  -poor signal.
  -DIR is preferred with fat suppression.
- **Haste**
  -single shot fast spin Echo ,mostly T2 weighted.



Bright blood or gradient Echo

- **Flash** (fast low angle shot)

-signal is influenced by flow velocity

-works mainly on 3 T

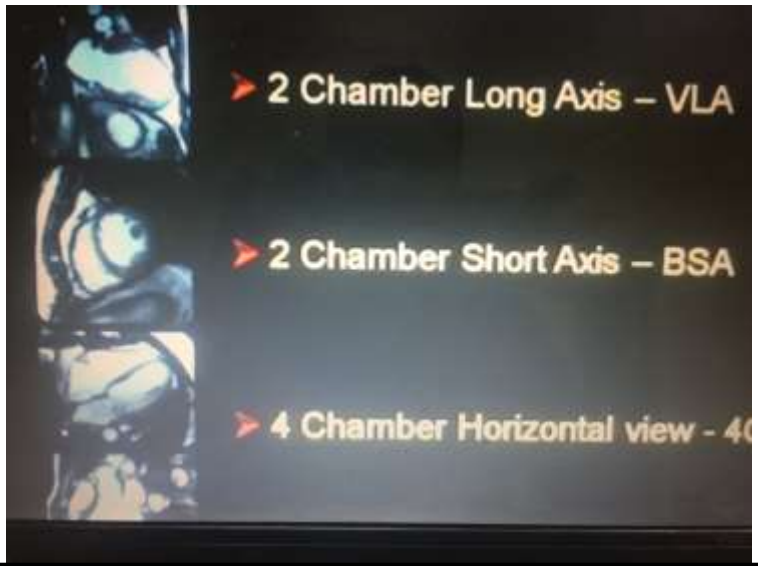
- **True FISP** (fast image with steady state precession)

-not affected by flow velocity.

-works on 1.5T

- **the image may be cine image or single shot**

Imaging planes in cardiac MRI


2 Chamber Long Axis – VLA
2 Chamber Short Axis – BSA
4 Chamber Horizontal view - 4

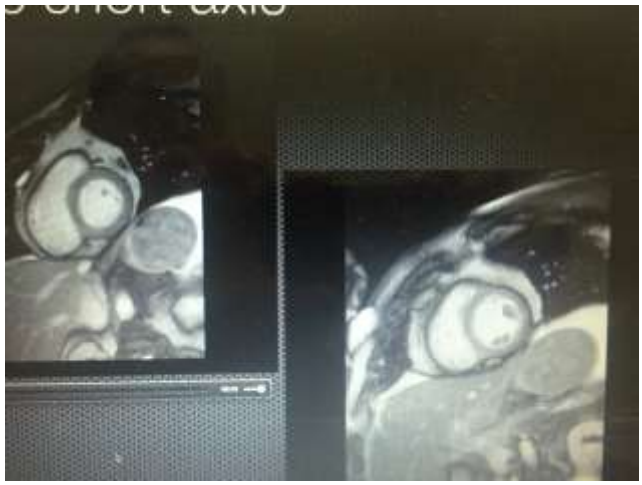

2 Chamber
Planned off of axial images- usually HASTE


Pseudo short axis
Planned off 2 chamber cine


Pseudo short axis

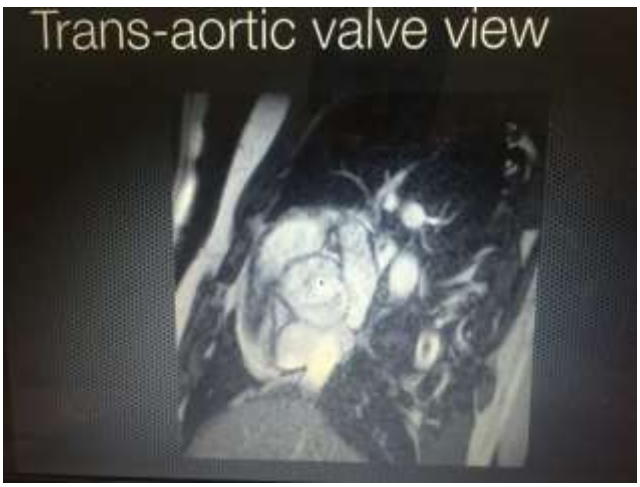

4 chamber
Planned off Pseudo SA and 2 Chamber


4 chamber




LVOT
▪ Planned off of pseudo SA


LVOT1 and LVOT2


Trans-aortic valve view


Trans-aortic valve view


Candycane
Planned off axials using 3 point tool

Candycane

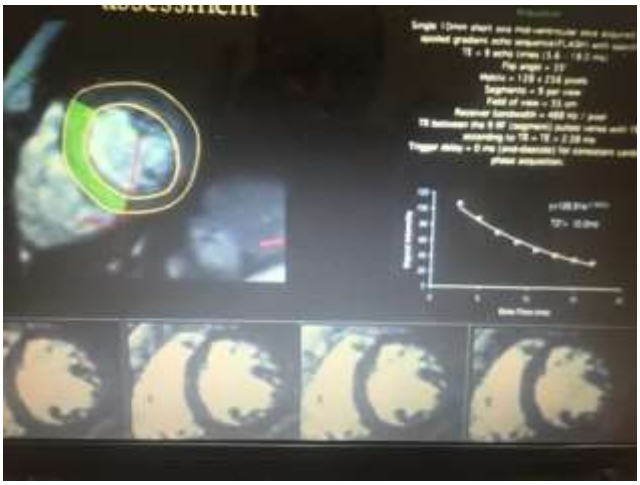
- Planned off axials using 3 point tool

Candycane

Tagging

- Used for physiological evaluation.
- In the form of grid or lines , but usually lines are used .

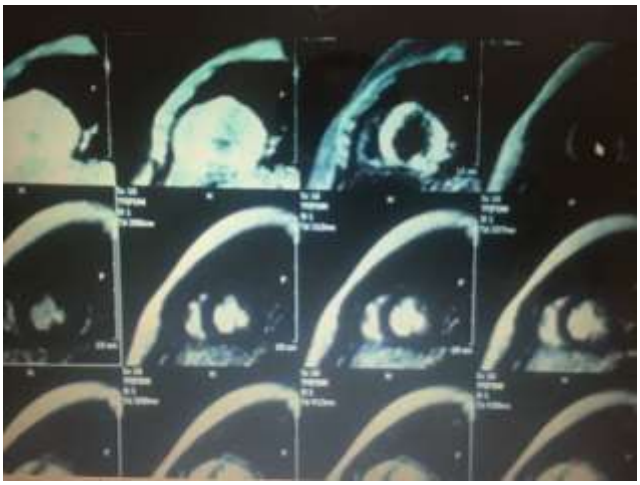
T2 star imaging



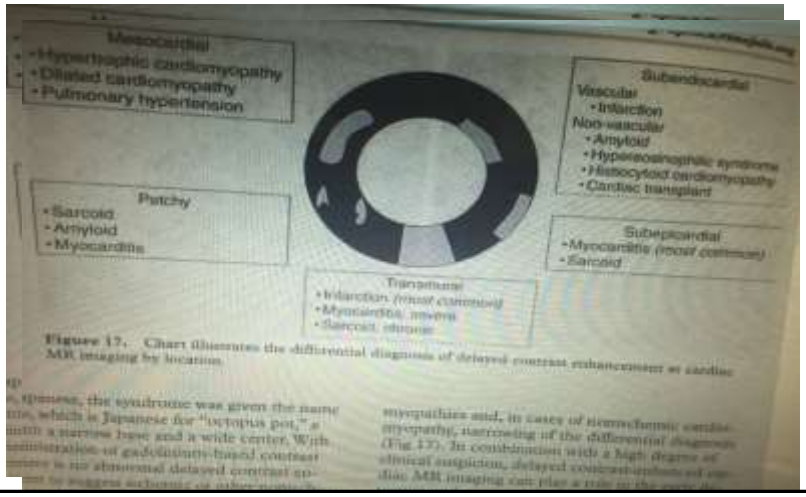
Myocardial perfusion imaging

- MRI is a promising tool in the functional assessment of the patients with known or suspected CAD.
- Perfusion imaging may be helpful to distinguish patients with symptoms of ischemia with normal anatomy.
- Serial perfusion imaging are useful to evaluate changes in the myocardial perfusion following conventional or novel strategies is useful tool in clinical and research settings.
- Perfusion imaging is enhanced by the addition of cardiac stress either physical or pharmacological.
- Perfusion deficits may be categorized as either reversible(present in stress testing alone) or irreversible(present on stress and rest)
- It easily demonstrates the abnormal patterns of ischemia like subendocardial type and syndrome X.
- Prognosis of future coronary events afterMI and before non cardiac surgery.
- Evaluation of the effects of collateral circulation.
- Follow up after medical or interventional ttt.
- No use of radiation , no use of iodinated materials , good functional assessment, high specificity 60-100% , sensitivity is 60-90%

- Gadolinium is used in 2 steps in cardiac MRI , the first one is the first pass perfusion done in the short axis in the resting or stress to differentiate the ischemic myocardium which appears black in color before wash out



- Then delayed enhancement MR is done 15 minutes from the first pass perfusion depending mainly in its mechanism of action on the delayed washout of gad from the injured myocardium compared to the normal ones
- Used to evaluate the scar in cases of ICM and non ischemic causes of heart failure
- Types of delayed enhancement



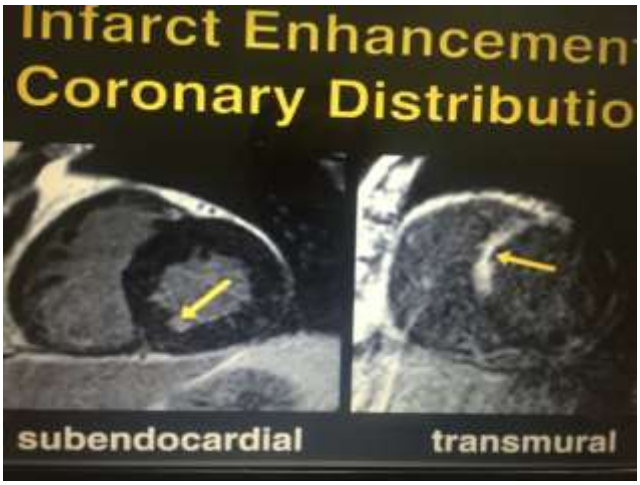
cardiomyopathy

- Ischemic cardiomyopathy
- Non ischemic cardiomyopathy

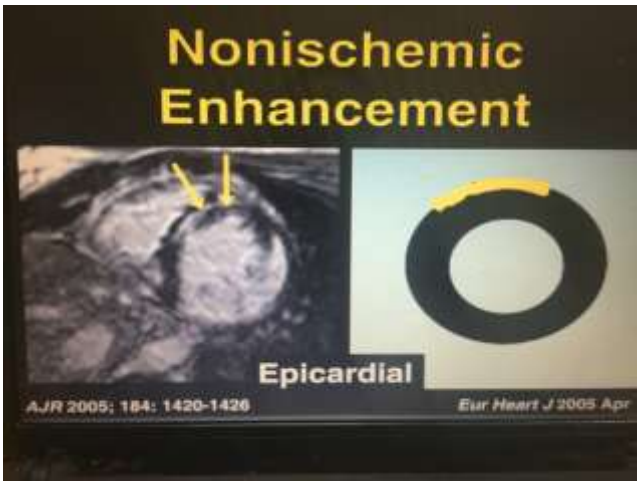
-Dilated CM.
-LV non compaction.
-Hypertrophic CM.
-ARVD.
-Infiltrative CM.
-Inflammatory CM

Comparison between SPECT and CMR

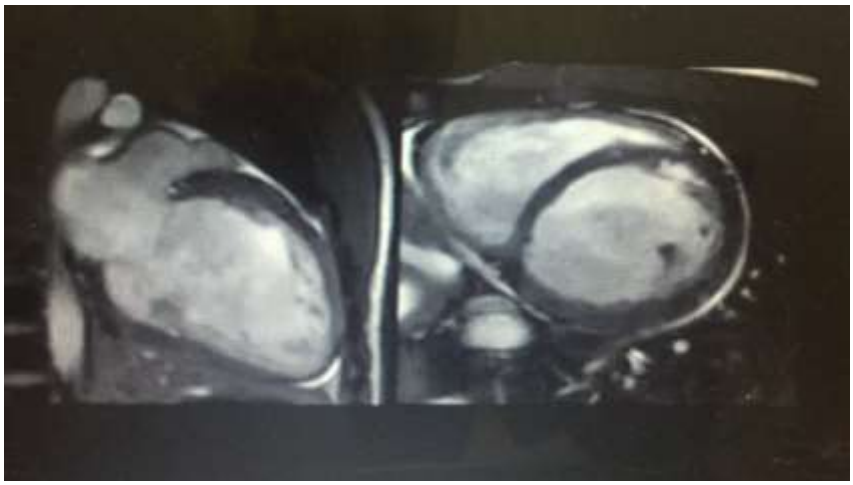
SPECT	CMR
-only detect significant lesions	-can detect any lesions
-always miss sub -endocardial infarctions	-can DD sub -endocardial from tranmural
-false +ve female breast shadow	-no false +ve.
-false –ve in MVD	-no false –ve.
-radiation dose is about 20msv	-no radiation.

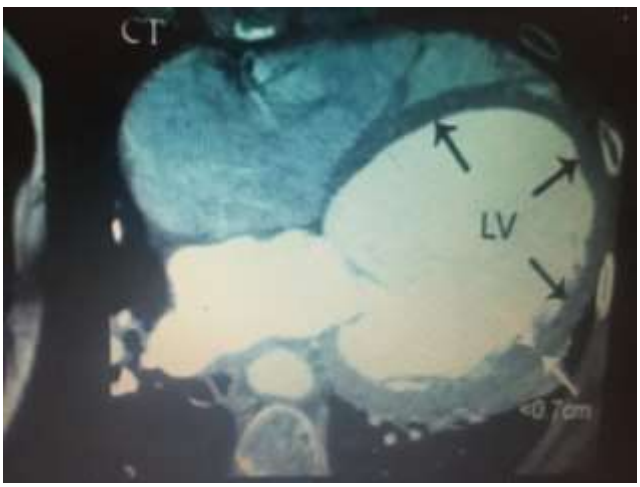

Infarct Enhancemen
Coronary Distributio
subendocardial
transmural


Nonischemic
Enhancement
Mid-myocardial
AJR 2005; 184: 1420-1426
Eur Heart J 200

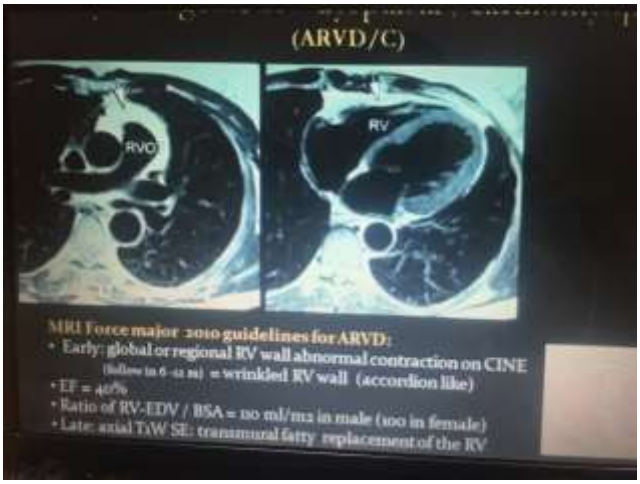

Nonischemic
Enhancement
Epicardial
AJR 2005; 184: 1420-1426
Eur Heart J 2005 Apr

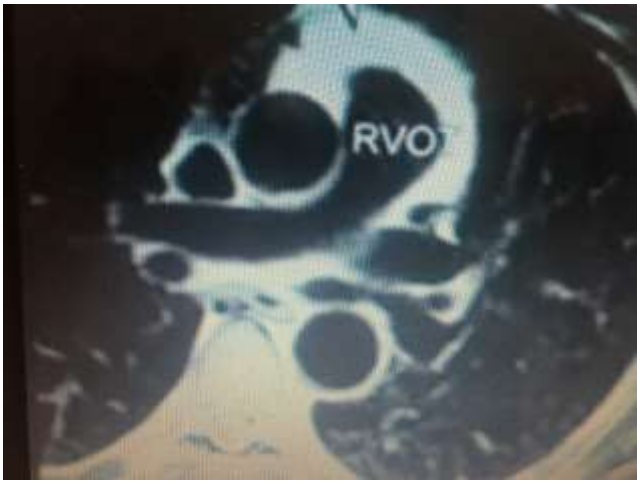

Nonischemic
Enhancement
Diffuse
JR 2005; 184: 1420-1426
Eur Heart J 2005

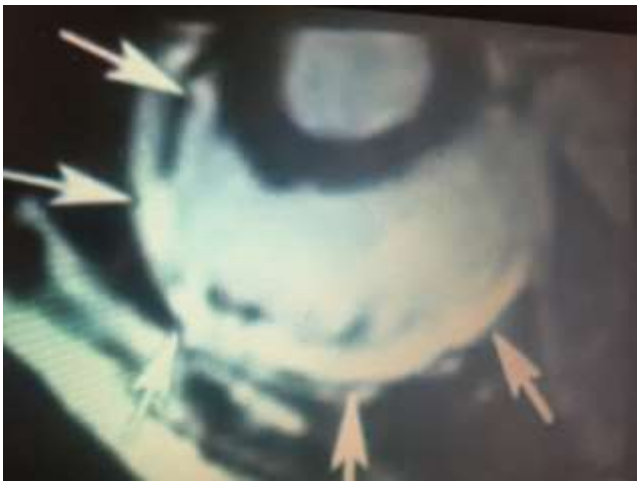


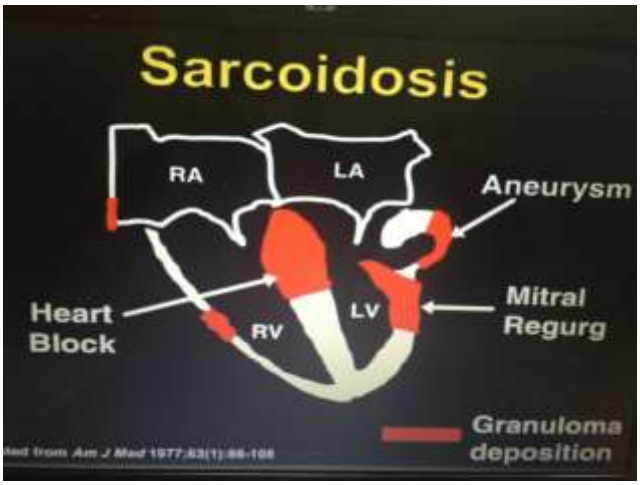

CT
LV
0.7cm

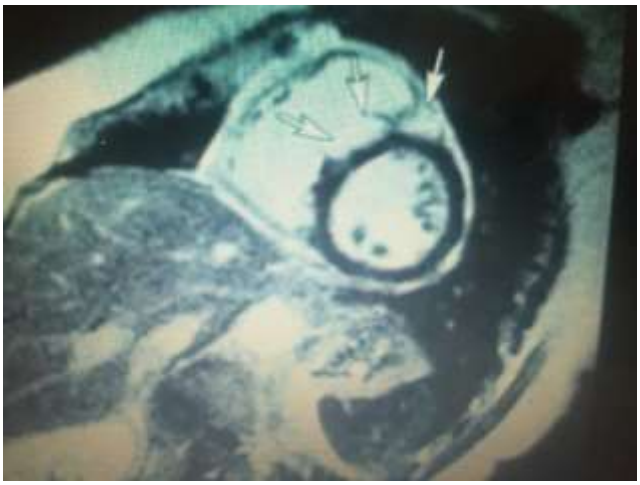

3- Hypertrophic cardiomyopathy (HCM

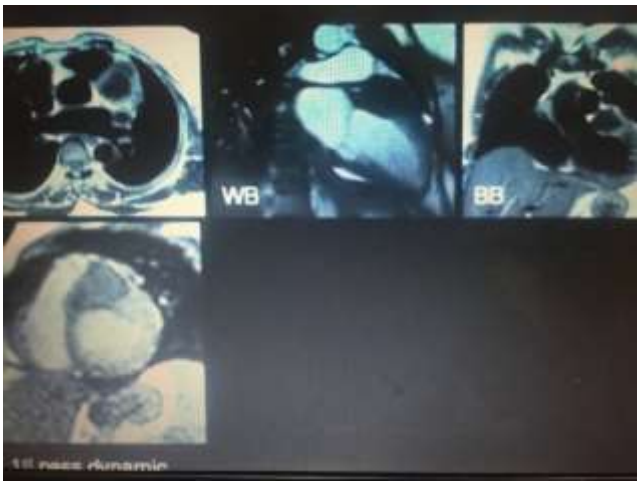

(ARVD/C)
RVO
RV
MRI Force major 2010 guidelines for ARVD:
• Early: global or regional RV wall abnormal contraction on CINE
(follow in 6-12 m) = wrinkled RV wall (accordion like)
• EF = 40%
• Ratio of RV-EDV / BSA = 110 ml/m2 in male (100 in female)
• Late: axial T1W SE: transmural fatty replacement of the RV


RVO




Sarcoidosis
RA
LA
Aneurysm
Heart Block
RV
LV
Mitral Regurg
Granuloma deposition




WB
BB

Thank you