Cardiac MRI; Core Concepts and Cases

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Disclosures

Bayer
Overall Aims

- Give you an introduction to what we do in CMR and why it continues to inspire me
- To show you the good and the limitations of CMR
- To cover what you need for the KBA (ESC guideline based)
Case based interactive discussion

Encourage debate

Email correspondence (danielsado@nhs.net) for anything you might want to ask

You are welcome to come and watch a CMR list with me at King’s College Hospital
Why does CMR inspire me?

- Many reasons...
- One of which is working with some fantastic healthcare professionals
- But also...
Whatever he told you about me isn’t true!

Graham Cole (@drgraham...)
twitter.com
4. Cardiac Magnetic Resonance (Core)

To have a basic understanding of the role of CMR and its capabilities, including its indications.
To have a basic understanding of how the procedures are carried out, in particular the safety issues.
To have a basic understanding of image analysis, post-processing and interpretation of images and data with emphasis on patient management.

<table>
<thead>
<tr>
<th>Knowledge</th>
<th>Possible Assessment Methods</th>
<th>GMP</th>
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<tbody>
<tr>
<td>Demonstrate knowledge of:</td>
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<tr>
<td>the indications and contra-indications to CMR</td>
<td>Exam, CBD, MCR</td>
<td>1</td>
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<tr>
<td>the basics of CMR safety</td>
<td>Exam, CBD, MCR</td>
<td>1</td>
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<tr>
<td>the basics of CMR image acquisition and image processing</td>
<td>Exam, CBD, MCR</td>
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<td>the basics of CMR imaging protocols (anatomical imaging and functional imaging)</td>
<td>Exam, CBD, MCR</td>
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<tr>
<td>The limitations of CMR</td>
<td>Exam, CBD, MCR</td>
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<table>
<thead>
<tr>
<th>Skills</th>
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<tr>
<td>Demonstrate the ability to:</td>
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<tr>
<td>plan and supervise the pre and post investigation management of CMR patients</td>
<td>mini-CEX, CBD, MCR</td>
<td>1,2</td>
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<td>interpret clinical information and the results of other investigations to decide what information must be acquired by CMR</td>
<td>mini-CEX, CBD, MCR</td>
<td>1,2</td>
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<tr>
<td>interpret images from basic CMR sequences</td>
<td>mini-CEX, CBD, MCR</td>
<td>1,2</td>
</tr>
<tr>
<td>interpret CMR reports and their application to clinical management</td>
<td>mini-CEX, CBD, MCR</td>
<td>1,2</td>
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<th>Behaviours</th>
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<tr>
<td>Demonstrate:</td>
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<tr>
<td>awareness of the limitations of non-invasive imaging</td>
<td>MSF, FS, MCR</td>
<td>1</td>
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<tr>
<td>appreciation of the importance of understanding cardiac anatomy in 3D</td>
<td>MSF, FS, MCR</td>
<td>1</td>
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<td>an appropriate threshold for seeking expert advice</td>
<td>MSF, FS, MCR</td>
<td>1.3</td>
</tr>
<tr>
<td>appreciation of the importance of providing detailed information about the procedure and its potential complications to patients</td>
<td>MSF, FS, MCR</td>
<td>1.3,4</td>
</tr>
<tr>
<td>appreciation of the importance of team work with radiologists, technologists and technical staff</td>
<td>MSF, FS, MCR</td>
<td>1.3</td>
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</tbody>
</table>
Cardiovascular Magnetic Resonance (CMR)

- Has only become a mainstream clinical test in the last 10-15 years. Why did this take so long to achieve?

  1) *No one thought the heart was very interesting to study?*

  2) *Cardiologists already got all the info they needed from existing tests?*

  3) *There are unique MRI physics challenges to scanning the heart?*

  4) *Cardiologists already had magnetic personalities (this was my SpRs suggestion)*

  5) *Electrophysiologists didn’t like the ECG quality obtained from in the magnetic field?*
CMR – Challenges

- The Heart Moves!
  - With Respiration
  - Intrinsically

- Therefore...
  - Sequences ideally need to be short
  - Cardiac ECG gating needs to be used
  - Patient ideally needs to be able to breath-hold for periods of around 5-10 seconds
What Cardiac Diseases go Through an CMR Scanner – A Year at King's College

![Bar Chart showing percentage of different cardiac diseases](chart.png)

- Normal
- Non Ischaemic Cardiomyopathy
- Dilated Cardiomyopathy
- Ischaemic Cardiomyopathy
- Myocarditis
- Myocardial Infarction
- Inherited Heart Disease
- Aortopathy
- Extra-cardiac Anatomy
- Ischaemic Heart Disease
- Rheumatological Heart Disease
- Others
- Cardiac Amyloidosis
- Valve Disease
- Sarcoidosis
- Adult Congenital Heart Disease
- Pericardial Disease
- Pulmonary Hypertension
How Much of a Difference does Clinical CMR make at KCH?

- New and unexpected diagnosis: N=23% (9% in EuroCMR Registry)
- Change in patient management: N=62% (62% in EuroCMR Registry)
- Showing normality where it was not expected: N=11% (not directly assessed in EuroCMR Registry)
Mr Zao – 25 year old man

Attending a Cuban gene therapy clinic to change his identity

Occupation: North Korean terrorist

Current state – awaiting an MRI scan and being chased by James Bond (Die another day)

Spot the errors in the following movie clip...
Potential Problems

- Metal curtain frame
- Non MRI ECG electrodes
- Gun
- Metal drip stand
- Metal Defib
- Metal Fridge
- Non MRI ECG electrodes
All fine until Bond turns the MRI scanner on?
MRI is one of the safest tests we do

BUT...

The magnet is ALWAYS on!

Ferromagnetic objects in the scanner are extremely dangerous
MRI Safety

Please circle correct answers

Have you had an MRI scan before?

YES  NO

If so, when and where was your last MRI scan done? [HOSPITAL 2011]

1. Do you have a CARDIAC PACEMAKER, DEFIBRILLATOR or any DEVICE in your Chest?

YES  NO

2. Have you ever had surgery to your HEAD or SPINE before?

YES  NO

Details ____________________________________________________________________________

3. Have you had any surgery within the last 6 weeks?

YES  NO

4. Do you have any metal clips, pins, screws or other devices inside your body?

YES  NO

5. Is there any possibility of having a metal fragment in your eye?

YES  NO

6. Do you have a hearing aid or implant?

YES  NO

7. Do you have diabetes, renal conditions?

YES  NO

8. FEMALE PATIENTS

Is there any possibility of being pregnant?

YES  NO

Are you breastfeeding?

YES  NO

__________________________________________________________________________________

To be completed upon arrival

Would you be happy for us to use your anonymised images & image data for future research?

YES  NO

Would you be happy for a 5-10 minute additional picture to be performed?

YES  NO

BEFORE GOING INTO THE MRI SCANNER

Please ensure that you have removed watches, mobile phones, magnetic swipe cards, e.g. Bank/Credit cards, travel cards, rail tickets and any loose metallic objects, e.g. coins, jewellery, hair grips.

Patient Signature: ___________________________ Date: ___________________________ Radiographer: ___________________________
What is the Risk of Gadolinium Administration in Patients with eGFR < 30?

1) Contrast nephropathy
2) Renal stone
3) Budd Chiari Syndrome
4) Nephrogenic systemic fibrosis
5) All of the above
Limitations of CMR

1) Claustrophobia
2) Limited temporal resolution
3) eGFR < 30ml/min for contrast studies
4) Cost?
5) Severe asthma for Adenosine stress perfusion
6) Availability (not such an issue in the UK)
7) Contraindications to an MRI study
8) Safe ferromagnetic implants that cause artefact (e.g. some aortic stents)
9) Ivory Tower mentality
How Does MRI Work?
What Body Constituents does Clinical MRI Image?

1) Calcium
2) Oxygen
3) Hydrogen
4) Nitrogen
5) All of the above
How does MRI work?

- Powerful magnetic field (1.5 or 3 Tesla)
- Protons in the body will align with direction of the magnetic field
- Radiofrequency pulses “excite” protons
How does MRI work?

- The protons then “relax” back to their starting state and release energy.
- This energy can be measured and transformed into a picture.
- $T_1$ is longitudinal relaxation.
- $T_2$ is transverse relaxation.
A Typical CMR Study

- For most studies we do the following....

1) Localiser single shots – To find out how exactly the heart lies in the chest

2) Black and white blood transverse stack of single shot images through the thorax – to look at extracardiac anatomy

3) Long and short axis cine imaging

4) Late gadolinium enhancement
Anatomical Imaging – Normal Axial Stack
What is the Abnormality?
High Spatial Resolution / Any Imaging Plane / Large Contrast between myocardium and blood pool..... Gold Standard for cardiac anatomy, ventricular EF and volume and mass assessment as a result.
Gadolinium is an *extracellular* tracer

In areas of extracellular volume (ECV) expansion it will accumulate in higher concentrations...

Increased ECV can be caused by:
- Fibrosis
- Oedema
- Infiltration (e.g. with Amyloid)
Gadolinium Kinetics inside and outside of Infarction

- **Gd-DTPA Bolus**

- Normal Myocardium

- Infarcted Myocardium

Time (mins):
- 1-3
- 10-20

Contrast
• Gadolinium potently decreases tissue T₁

• T₁ sensitive sequences bring out the change in gadolinium concentrations

• Focal areas of ECV expansion appear white on a background of surrounding “normal” black myocardium...
Aetiology: Ischaemic Vs Non Ischaemic LGE

**Ischaemic – Subendocardium involved**

LAD Territory Infarction

**Non - Ischaemic – Subendocardium not involved**

Previous Myocarditis
Some Different Disease Patterns of Late Enhancement

- **LAD Infarct – Non Viable**
- **RCA Infarct – Viable**
- **Myocarditis**
- **Sarcoidosis – Differing LGE Patterns**
- **Amyloidosis – Dark Blood pool and zebra stripe LGE in septum**
- **Hypertrophic Cardiomyopathy – Patchy LGE in the septum**
Main uses of CMR:

1) EF and Wall motion abnormality
2) Inducible Ischaemia
3) Myocardial Infarction / Viability
4) Differential Diagnoses
Offer non-invasive functional imaging (see section 1.3.6) for myocardial ischaemia if 64-slice (or above) CT coronary angiography has shown CAD of uncertain functional significance or is non-diagnostic. [2016]
CMR in Ischaemic Heart Disease

- NICE:
  - 1.3.6 Use of non-invasive functional testing for myocardial ischaemia
  - 1.3.6.1 When offering non-invasive functional imaging for myocardial ischaemia use:
    - Myocardial perfusion scintigraphy with single photon emission computed tomography (MPS with SPECT) or
    - Stress echocardiography or
    - First-pass contrast-enhanced magnetic resonance (MR) perfusion or
    - MR imaging for stress-induced wall motion abnormalities
    - Take account of locally available technology and expertise, the person and their preferences, and any contraindications (for example, disabilities, frailty, limited ability to exercise) when deciding on the imaging method
CMR Stress Perfusion

- Uses adenosine usually over a 4 min infusion at 140 mcg / kg / min
- Gadolinium for contrast
- Care in asthma, patient needs to avoid caffeine for 12 hours before the test
Case 2

- 75 year old gentleman
- Hypertension / Diabetes (type 2)
- 2009 – Angina and had PCI to RCA
- 2010 – Still had angina. On angiography, had severe mid LAD disease
- 2010 – CABG – LIMA to LAD only
2011: Still getting angina
Perfusion Imaging

Post Adenosine Stress

Rest

Basal Short Axis  Mid Short Axis  Apical Short Axis
Conclusion

- Thinning and akinetic wall motion of the inferolateral wall
- Some hypokinesis of the inferior wall
- Ischaemia in the inferolateral wall
What next?

- Repeat angiogram
- Subtotal Circumflex occlusion opened
Viability

- In segments with wall motion abnormality as a result of coronary artery disease, will revascularisation return normal/improved function to that segment?

- Does it matter even if the RWMA does get better?
CMR Viability

- Late enhancement technique
- <25% transmural infarction – Viable
- 25-50% transmural infarction – Grey Zone
- >75% transmural infarction – Not Viable

Infarction and Viability

Viable

Not Viable
Can administer low dose dobutamine and see if contraction improves
Case 3: All not what it seems?

- 26-yr-old gentleman – chest pain
- Past Medical history and Family history: Nil of note
- No risk factors for coronary artery disease
- Denied any illicit drug use
- Clinical examination unremarkable
ECG
Echocardiogram

- Normal

- What would you do at this point (it is 8pm in the evening)?
  1) Discharge
  2) Angiogram
  3) CTCA
  4) CMR
  5) None of the above
What Happened Next

- Patient had a VF arrest about 1 hour later
- Back to sinus rhythm with one shock
STIR (T2 Weighted Oedema Imaging)
Late Gadolinium Enhancement (LGE)
Diagnosis

- Acute Myocarditis
Management

- ICD inserted
- No shocks from this 6 weeks after
Heart Failure
60 yr old with HIV and SOB. No conventional CAD RF and no chest pain. What is the aetiology for the LV impairment?
Ischaemic Cardiomyopathy
Case 4: 30 Year old with SOB and no chest pain or CAD RF – Aetiology of the LV Impairment?
Case 4: Non Ischaemic Late Enhancement
### ESC Heart Failure Failure Guidelines

<table>
<thead>
<tr>
<th>Recommendations</th>
<th>Class</th>
<th>Level</th>
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<tbody>
<tr>
<td>TTE is recommended for the assessment of myocardial structure and function in subjects with suspected HF in order to establish a diagnosis of either HFrEF, HfmrEF or HfPEF.</td>
<td>I</td>
<td>C</td>
</tr>
<tr>
<td>TTE is recommended to assess LVEF in order to identify patients with HF who would be suitable for evidence-based pharmacological and device (ICD, CRT) treatment recommended for HFrEF.</td>
<td>I</td>
<td>C</td>
</tr>
<tr>
<td>TTE is recommended for the assessment of valve disease, right ventricular function and pulmonary arterial pressure in patients with an already established diagnosis of either HFrEF, HfmrEF or HfPEF in order to identify those suitable for correction of valve disease.</td>
<td>I</td>
<td>C</td>
</tr>
<tr>
<td>TTE is recommended for the assessment of myocardial structure and function in subjects to be exposed to treatment which potentially can damage myocardium (e.g., chemotherapy).</td>
<td>I</td>
<td>C</td>
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<tr>
<td>Other techniques (including systolic tissue Doppler velocities and deformation indices, i.e., strain and strain rate) should be considered in a TTE protocol in subjects at risk of developing HF in order to identify myocardial dysfunction at the preclinical stage.</td>
<td>Ila</td>
<td>C</td>
</tr>
<tr>
<td>CMR is recommended for the assessment of myocardial structure and function (including right heart) in subjects with poor acoustic window and patients with complex congenital heart diseases (taking account of cautions/contra-indications to CMR).</td>
<td>I</td>
<td>C</td>
</tr>
<tr>
<td>CMR with LGE should be considered in patients with dilated cardiomyopathy in order to distinguish between ischaemic and non-ischaemic myocardial damage in case of equivocal clinical and other imaging data (taking account of cautions/contra-indications to CMR).</td>
<td>Ila</td>
<td>C</td>
</tr>
<tr>
<td>CMR is recommended for the characterization of myocardial tissue in case of suspected myocarditis, amyloidosis, sarcoidosis, Chagas disease, Fabry disease non-compaction cardiomyopathy, and haemochromatosis (taking account of cautions/contra-indications to CMR).</td>
<td>I</td>
<td>C</td>
</tr>
<tr>
<td>Non-invasive stress imaging (CMR, stress echocardiography, SPECT, PET) may be considered for the assessment of myocardial ischaemia and viability in patients with HF and CAD (considered suitable for coronary revascularization) before the decision on revascularization.</td>
<td>Ilb</td>
<td>B</td>
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</table>
Inherited Heart Disease
31 year old with VT while cycling. No FHx of inherited heart disease. RVEDVi is 120ml/m2 and RV EF is 32%. What is the diagnosis?

1) LV Non Compaction
2) RV Non Compaction
3) Secundum ASD
4) ARVC
5) Pulmonary Hypertension
42 Yr old with FHx of DCM. Normal EF and LV EDV. What is the Diagnosis?

1) LV Non Compaction
2) RV Non Compaction
3) Secundum ASD
4) ARVC
5) Pulmonary Hypertension
50 Year Old male with hypertension and FHx of Sudden Death. Normal EF with septal wall thickness of 25mm. What is the Diagnosis?

1) LV Non Compaction
2) DCM
3) Hypertensive Heart Disease
4) Hypertrophic Cardiomyopathy
5) ARVC
Unusual Forms of LVH: Localised
Apical Predominant HCM
Guiding Myectomy
Fibrosis can:

1) Be a nidus for ventricular arrhythmia
2) Result in decrease contractility

Therefore, there has been much interest in assessing fibrosis using CMR
### ESC HCM Guidelines for HCM

<table>
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<tr>
<th>Recommendations</th>
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<th>Level</th>
<th>Ref.</th>
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<tbody>
<tr>
<td>It is recommended that CMR studies be performed and interpreted by teams</td>
<td>I</td>
<td>C</td>
<td>148,149</td>
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<td>studied in cardiac imaging and in the evaluation of heart muscle disease.</td>
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<tr>
<td>In the absence of contraindications, CMR with LGE is recommended in patients</td>
<td>I</td>
<td>B</td>
<td>126,127</td>
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<td>with suspected HCM who have inadequate echocardiographic windows, in order to</td>
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<td>confirm the diagnosis.</td>
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<tr>
<td>In the absence of contraindications, CMR with LGE should be considered in</td>
<td>IIa</td>
<td>B</td>
<td>124,126,127,130,136,138–143</td>
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<td>patients fulfilling diagnostic criteria for HCM, to assess cardiac anatomy,</td>
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<td>ventricular function, and the presence and extent of myocardial fibrosis.</td>
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<tr>
<td>CMR with LGE imaging should be considered in patients with suspected apical</td>
<td>IIa</td>
<td>C</td>
<td>127,129</td>
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<td>hypertrophy or aneurysm.</td>
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<tr>
<td>CMR with LGE imaging should be considered in patients with suspected cardiac</td>
<td>IIa</td>
<td>C</td>
<td>22,147</td>
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<td>amyloidosis.</td>
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<tr>
<td>CMR with LGE may be considered before septal alcohol ablation or myectomy, to</td>
<td>IIb</td>
<td>C</td>
<td>150,151</td>
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<tr>
<td>assess the extent and distribution of hypertrophy and myocardial fibrosis.</td>
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</table>
ESC Task force criteria for ARVC

By MRI:
- Regional RV akinesia or dyskinesia or dyssynchronous RV contraction
- and 1 of the following:
  - Ratio of RV end-diastolic volume to BSA ≥110 mL/m² (male) or ≥100 mL/m² (female)
  - or RV ejection fraction <40%

By MRI:
- Regional RV akinesia or dyskinesia or dyssynchronous RV contraction
- and 1 of the following:
  - Ratio of RV end-diastolic volume to BSA ≥100 to <110 mL/m² (male) or ≥90 to <100 mL/m² (female)
  - or RV ejection fraction >40% to ≤45%
Case 7: 28 yr old professional footballer with SOB
What is the Diagnosis

1) Restrictive Cardiomyopathy
2) Constrictive Pericarditis
3) Myocarditis
4) Myocardial infarction
5) Sarcoidosis
25 yr old professional footballer with SOB
Over the years, CMR has shifted from a morphologic imaging modality towards a comprehensive one, allowing visualization and tissue characterization of the pericardium (and heart) in patients with pericardial disease and appraisal of the consequences of pericardial abnormalities on cardiac function and filling patterns. As such, it is probably the preferred imaging modality to optimally assess pericardial disease.
Last Words – For Everyday Practice and not the KBA...
Which Imaging Modality is the Best in Cardiology?
What determines how good an imaging modality is?

- Ability of the referrer
- Physics of the technique
- Equipment you use
- Ability of the person doing the scan
- Ability of the person reporting the scan
- The leadership, management and team ethic of those delivering the care
Dan Sado and Graham Cole in reality
Conclusions

- Cardiac MRI is now widely used in the UK and serves patients from all cardiological subspecialties

- With good referral practice, 1/3 of scans find something completely unexpected, 2/3 changes patient management and 1/10 show “normality” where it was not expected

- CMR is now in ESC guidelines for heart failure / IHD / ACHD / pericardial disease / Ventricular arrhythmia / HCM / ARVC
And Finally

- Do email me any questions (danielsado@nhs.net)

- You are welcome to come to King’s College Hospital to watch some studies / reports being done if you would like to