Strengthening the Application of Nuclear Medicine in the Management of Cardiovascular Diseases
Cardiac Imaging

CT and MR

Prof Lin Tun Tun
Head of Department of Radiology
University of Medicine (1)
Yangon General Hospital
CARDIAC CT
Advances in CT Technology

• Increased image quality

• Improvements in hardware and software such as refined image reconstruction methods.

• lower radiation exposure of cardiac CT especially for coronary CTA
INDICATIONS FOR CARDIAC CT

• Chest pain with intermediate pretest probability of CAD

• Acute coronary syndrome with intermediate pretest probability of CAD (no ECG changes and negative serial enzymes negative) Evaluation of bypass grafts and coronary anatomy

• Evaluation of complex congenital heart disease (anomalies of coronary circulation, great vessels, and cardiac chambers and valves)

• Evaluation of cardiac masses or pericardial conditions

• Evaluation of pulmonary vein anatomy before radiofrequency ablation, coronary vein

• Evaluation of suspected aortic dissection, aortic aneurysm, or pulmonary embolism.
History

- **EBCT** – mid 1990 – 1.5 to 3mm slice thickness

- **4 MSCT** -2000- 1mm slice thickness (30 heart beats minimum over all image-acquisition time)

- **4-16-64 MSCT** - 2004 -0.5 to 0.75 mm (4-8 heart beats)
DATA ACQUISITION SYSTEM
continuous acquisition of CT data
up to 140 levels in 15 seconds

ELECTRON GUN
permits 640 mA of x-ray power
for fast, low-noise studies

TARGET-RING
comprised of multiple targets for optimal
single-slice or multi-slice scanning modes

PRECISE, HIGH-SPEED
Couch Motion
makes continuous volume
scanning possible

ELECTRON BEAM
allows millisecond
scanning

SELF-CONTAINED
INTERNAL COOLING SYSTEM
eliminates interscan delay, permits
higher throughput, longer volume studies
EBCT- Electron Beam CT

Electron source
Focusing coil
Deflection coil
Data acquisition system (DAS)

12 Detectors
A B C D

e-Speed
Data Acquisition
Evolution of CT - 40 years

- First CT: Slip Ring
- Spiral CT, Twin detector
- MSCT, DSCT, DSCT/DECT
- New detector technologies
- Multidetector, Multisource CT
- Data Handling, Dose management

40 years timeline from 1972 to 2012
Dual source CT
2005- Dual Source CT

2 X-ray sources and 2 detectors

Faster than every beating heart

DSCT became available around the year 2005, with 2 64 simultaneously acquired slices and a rotation time of 33 milliseconds and

More recently, with 2 128 simultaneously acquired slices and a gantry rotation time of 0.28 seconds.

Capable of imaging full cardiac detail

As much as 50 percent less radiation exposure compared to traditional CT scans
256 slice CT

Breath holding time is reduced. The entire heart can be covered in a single rotation.
<table>
<thead>
<tr>
<th>Resolution/Coverage</th>
<th>64-Slice (Multiple Vendors)</th>
<th>256-Slice (Philips)</th>
<th>320-Slice (Toshiba)</th>
<th>Dual-Source with 128 × 2-Slice (Siemens)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporal resolution (ms)</td>
<td>165–200</td>
<td>135</td>
<td>175</td>
<td>75</td>
</tr>
<tr>
<td>Spatial resolution (mm)</td>
<td>0.5–0.625</td>
<td>0.625</td>
<td>0.5</td>
<td>0.6</td>
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<tr>
<td>z-Axis coverage (mm)</td>
<td>32–40</td>
<td>80</td>
<td>160</td>
<td>38.4</td>
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</table>
An 18-year-old man who presented with chest pain. Prospective ECG-gated axial images of the heart were obtained. Asc aorta, ascending aorta; Desc aorta, descending aorta; LA, left atrium; LAA, left atrial appendage; LAD, left anterior descending; LCX, left circumflex; LIMA, left internal mammary artery; LPV, left pulmonary vein; RA, right atrium; RCA, right coronary artery; RI, ramus intermedius; RIMA, right internal mammary artery; RPV, right pulmonary vein; RVOT, right ventricular outflow tract.
Synchronization With Cardiac Cycle
MIP rendering Technique Normal coronary arteries
MIP – normal left MCA, LAD and several diagonal branches
Curved MPR
The vessel can be seen in long length
2 reconstructions of the same image:
VR does not well distinguish calcification from the lumen
MIP is more transparent and overlapping vessels become more problematic
MIP–LIMA: small diameter <1.5 mm and clips make interpretation difficult. Multiple views may be necessary.
By-pass surgery 10 yrs ago: All 4 vessels are patent
• Coronary CTA images acquired with the most recent CT hardware. (A) A 320-slice CT, (B) high-pitch spiral acquisition with dual-source CT.
Reduction of image noise through **iterative reconstruction**. A coronary CT angiogram was acquired using 80 kV tube voltage (effective dose, 0.32 mSv) in a patient with a body weight of 93 kg. Conventional filtered back projection (top) shows considerable image noise. Through iterative reconstruction (below), image noise can be reduced substantially.
Dual-Energy CT

- The subtraction of x-ray data obtained at different energy levels may, therefore, substantially increase contrast between these materials and all surrounding structures.

- Dual-energy CT can be achieved by simultaneous acquisition with 2 tubes and 2 detectors (DSCT) by extremely rapid switching of the emitted x-rays between different energy levels or by the design of detectors, which combine different elements with varying sensitivity to discrete kilovolt levels.

- Potential clinical applications in cardiovascular imaging include, for example, the improved delineation of vascular calcium (and its separation from the contrast enhanced lumen) and improved visualization of differences in myocardial contrast enhancement when myocardial perfusion is studied during exercise or at rest.
Clinical Applications

- Coronary Calcium
- Coronary CTA
- LV Function
- Evaluation of CABG
- Evaluation Stent
- Assessment of Myocardial Viability
Coronary CT Angiography

- Conventional coronary angiography is currently the gold standard and routine procedure for evaluating the extent of stenosis.

- Recent studies suggest that 64-slice coronary CT angiography (CTA) is highly accurate for exclusion of significant coronary artery stenosis (50% luminal narrowing), with a sensitivity range of 79% to 99% and specificity between 95% and 97%.

- The high negative predictive value associated with 64-slice scanners (98%–99%) in comparison with invasive coronary angiography enables the exclusion of obstructive CAD following a normal CTA with a high degree of certainty, obviating invasive cardiac catheterization, particularly in patients with low to intermediate risk of relevant stenoses.
Calcium Scoring: CAC score 1872 Significant CAC in all coronary arteries
• (A) Calcium scoring by Agatston method 5 0 in a 43-year-old woman presenting with chest pain. (B) Calcium scoring by Agatston method 5 1217 in a 56-year-old woman presenting with chest pain
Calcium scoring

- Calcium Score: Presence of Coronary Artery Disease (CAD)
  - 0: No evidence of CAD
  - 1–10: Minimal evidence of CAD
  - 11–100: Mild evidence of CAD
  - 101–400: Moderate evidence of CAD
  - >400: Extensive evidence of CAD
Anomalous coronary artery

Origin of left circumflex coronary artery from the right coronary ostium and course distal to the aortic root toward the left coronary groove
VR Technique:

Need to evaluate the images from multiple views as any given artery cannot be fully visualized from any angle.
A 46-year-old woman who presented with chest pain. Curved MPR image of the RCA and LM with branches. Acute marg, acute marginal branch; D1, diagonal branch; LAD, left anterior descending; LCX, left circumflex; LM, left main; OM, obtuse marginal branch; RCA, right coronary artery.
Multidetector CT images show acute thrombotic occlusion of the left circumflex artery.
A 57-year-old male patient with CT-verified vulnerable plaque who subsequently developed ACS. CTA revealed a 50% stenotic lesion with positive remodeling, low-attenuation plaque, napkin ring sign, and spotty calcification within the proximal left anterior descending artery (A). Emergency coronary angiography revealed a 90% stenotic lesion at the site corresponding to the CT-verified vulnerable plaque in the proximal left anterior descending artery (B).
EVALUATION OF CABG

• Conventional angiography remains the gold standard in evaluating the patency of coronary bypass grafts; however, in recent years improvements in MDCT technology have enabled accurate and noninvasive visualization of grafts.

• Recent literature on 64-slice CT reports sensitivity and specificity ranges of 93.3% to 100% and 91.4% to 100%, respectively, in assessing CABG occlusion and significant stenosis (50%).

• The sensitivity, specificity, positive and negative predictive values, and accuracy for detecting graft stenosis were 93%, 98%, 93%, 98%, and 97%, respectively.

• For graft occlusion the comparative values were 96.4%, 98.1%, 96.4%, 98.1%, and 97.6%, respectively.
MIP showing patent LIMA graft
Evaluation of Stents

- to visualize and accurately assess stent patency, restenosis, or neointimal hyperplasia

- But is limited in its ability to evaluate stent patency in coronary arteries.

- The diagnostic accuracy of MDCT in evaluating stent patency depends on various factors, including stent diameter, material, and design.

- Metallic struts in stents can create a blooming artifact, which can result in the appearance of a thicker strut and underestimation of lumen diameter.

- In addition, characterization of contrast enhancement patterns is vital in the analysis of stent patency.
VR - Stent in mid-left anterior descending artery
EBCT--- MIP –the patent stent
MIP 64 MSCT Stent patency cannot be reliable as scan artifact from stent struts
Contrast is well visualised inside the stent allowing assessment of stent patency.

Coronary stents are considered occluded when no contrast is visible inside the stent lumen, with decreased or loss of distal runoff, indicating significant re-stenosis. Visualization of contrast in the vessel distal to the stent alone does not necessarily indicate patency, because this may be the result of retrograde filling of the vessels.
Ultra-high resolution Images from 64 MSCT of a stent mounted on a vessel model
64 MSCT Images of 3 stents – which appear patent
Patent stent in the distal right coronary artery in vivo
Left Ventricular Function

- Accurate assessment of left ventricular (LV) function has both prognostic and therapeutic value in patients with coronary disease.

- Retrospective contrast-enhanced ECG-gated MDCT enables the acquisition of data within a cardiac cycle, which can be reformatted and used to determine LV volume and global function.

- Although MDCT is not the primary modality for functional analysis, it provides additional useful information in patients undergoing MDCT coronary angiography for detection of coronary artery obstruction, without the need for further imaging studies or additional radiation exposure.

- Cine magnetic resonance (MR) imaging is currently regarded as the gold standard for the assessment of global and regional cardiac function.
Images at ED and ES phases allowing EF and volume calculation
Assessment of Myocardial Viability

- Coronary revascularization by percutaneous coronary intervention (PCI) in patients with acute myocardial infarction may improve survival with the identification and restoration of viable myocardium.

- The evaluation of myocardial viability using contrast-enhanced MR imaging has been well established.

- However, recent preliminary studies have demonstrated the potential of cardiac MDCT in assessing myocardial perfusion as an alternative technique.

- Habis and colleagues performed cardiac CT imaging immediately after coronary angiography without contrast reinjection and demonstrated a promising technique in early assessment of myocardial viability.
• 75-year-old man with stable angina.
• reversible perfusion defects of anteroseptal wall of left ventricle; these findings suggest ischemia. CT images show good correlation with SPECT images:
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• reversible perfusion defects of anteroseptal wall of left ventricle; these findings suggest ischemia. CT images show good correlation with SPECT images:
A 45-year-old man with recent infarction of inferior left ventricle wall and stent in, undergoing dual-energy CT and SPECT before coronary artery bypass grafting. A and B, Coronary CT angiography images show long segment of occlusion in proximal LAD (LAD) (arrow, A), and patent stent in RCA (arrow, B). C and D, On SPECT horizontal stress (C) and rest (D) long-axis images, there is reversible perfusion defect of anteroseptal wall (arrows, C). E and F, Corresponding views for stress (E) and rest (F) dual-energy CT show reversible perfusion defect of anteroseptal wall (arrows, E). G, Volume-rendered dual-energy CT image shows perfusion defect of anterior left ventricle wall within context of entire thorax.
Venous Mapping for Atrial Fibrillation

• Ectopic arrhythmic foci originating within the pulmonary veins are a cause of both paroxysmal and persistent atrial fibrillation.

• Radiofrequency catheter ablation (RFCA) of the distal pulmonary veins and posterior left atrium is effective as a treatment for paroxysmal atrial fibrillation in patients with refractory atrial fibrillation or resistant to pharmacologic therapy or cardioversion.

• Multidetector CT of the pulmonary veins provides important anatomic information including the number, location, size, and orientation of pulmonary veins and their ostial branches noninvasively.

• Preprocedural mapping has been shown to decrease radiofrequency ablation procedure time.
Radiation Dose

• A combination of prospective triggering with low voltage settings is an effective measure for reducing the ED of coronary CTA to values of **2-4 mSv** independent of scanner system.

• Further dose reduction to nearly **1 mSv** can be achieved with high-pitch prospectively triggered coronary CTA.
CT Dose Reduction

- Prospective ECG Gating
- Retrospective ECG Gating
- Tube current modulation
- Iterative Reconstruction
Assessment of Cardiac Structure and Function
Pedunculated LV
Apical thrombus

left atrial appendage thrombus
Apical thrombus

Left atrial myxoma
Bicuspid aortic valve
Pericardial calcification

Myocardial (subendocardial Infarction)
Multiple pulmonary emboli
Cardiac CT in Emergency Department

- CAD
- Pulmonary Embolism
- Aortic Dissection
Limitations and pitfalls of coronary CTA

- feasible in patients with a stable heart rhythm, able to breath-hold for 20 seconds.

- The image quality is degraded by irregular heart rhythms; atrial fibrillation is a contraindication for MSCT imaging.

- Well known pitfalls of MSCT coronary angiography include motion artefacts and severe coronary calcification.

- One of the most serious problems is that the presence of severe calcification in the coronary arteries reduces diagnostic accuracy, and it may even be impossible to assess some coronary segments if extremely severe calcification is present.
Evaluation of plaque Morphology by CTA

- Plaques characterized by positive remodeling, low attenuation, and napkin ring circular enhancement on contrast-enhanced coronary CTA have been regarded as **rupture-prone vulnerable plaques**, which account for about 60% of all vulnerable lesions and may be precursors of plaque rupture.
- Recently it demonstrated that the distribution and prevalence of computed tomography (CT)-verified vulnerable plaques were approximately similar to that of **thin-cap fibroatheroma (TCFA)** reported in autopsy cases,
- Coronary artery calcium score (CACS) alone may not be as useful for exclusion of a risk of acute coronary syndrome (ACS).
- Coronary CTA needs to demonstrate incremental prognostic value beyond the Framingham Risk Score (FRS) and other prognostic markers.
- The clinical usefulness of CT-based detection of vulnerable plaque remains to be demonstrated.
- **CT-derived plaque features** were demonstrated to predict the occurrence of slow-flow complications during percutaneous coronary interventions (PCIs), which opens a further potential field for coronary CTA.
Evaluation of plaque characteristics using new plaque analyzing software (Plaque Labeling Method). Atypical chest pain, underwent coronary CTA revealed 25% stenotic lesion at the left main trunk. One year later, revealed a progressive 75% stenotic lesion at the left main trunk.

Plaque characteristics - area and plaque area and plaque characteristics (red, necrotic core; blue, fibrous and/or fibrofatty; yellow, calcification) could be evaluated. The results showed that the necrotic core area (red area) progressed remarkably after 1 year.
Future – CTA

- Single breath hold to reduce respiratory motion
- Higher spatial resolution
- Reduced slice thickness
- Increased no of detectors
- Reduced overall-imaging time
- Reductions in contrast requirement
- Rapidity and ease with coronary CTA - CT will be the preferred method for most applications in the absence of renal insufficiency or contrast allergy
- Better workstations for ease of use and diagnostic capabilities
- Multisector reconstruction
- Reduced radiation exposure
CARDIAC MR
MRI

• Multi-parametric cardiac magnetic resonance (CMR) (stress perfusion, rest perfusion, and late gadolinium enhancement) has higher sensitivity and negative predictive value (NPV) for the diagnosis of CAD.

• Delayed enhancement CMR (DEMCR), one of the most common examinations for tissue characterization both in ischemic and non-ischemic myocardial diseases, has become the gold standard for visualization and quantification of infarcted myocardium and scar tissues as well as for the detection of infiltrative diseases of the heart.
Magnetic Resonance Myocardial Perfusion Imaging

- CMR has evolved significantly in the past decade.

- CMR is able to assess multiple aspects of cardiovascular pathology in a single examination, including myocardial and coronary artery anatomy, ventricular function, myocardial perfusion, and viability.

- First-pass contrast-enhanced MR imaging has emerged as an excellent alternative imaging modality for the assessment of myocardial perfusion.

- Because **perfusion abnormalities proceed systolic dysfunction**, there is no surprise that direct perfusion imaging has higher sensitivity than indirect imaging (eg, wall motion dysfunction) for detection of ischemia, a concept described as “ischemic cascade”.
• The **ischemic cascade** refers to the temporal sequence of events that develop over time when there is a progressive imbalance between myocardial oxygen demand and supply with abnormal myocardial perfusion being the first detectable event.
Potential mechanisms of hyperenhancement. In the acute and chronic infarct settings, hyperenhancement is hypothesized to directly result from consequences of myocyte cell death, with associated increase in extracellular volume of distribution for gadolinium-based contrast agents.
CMR images (upper panel) and corresponding histologic slices (lower panel) showing the exact match between the hyperenhanced area and the necrotic region defined by histology in the setting of acute myocardial infarction.

Multicomponent CMR stress testing protocol

The multicomponent approach to CMR stress testing includes the following:

1. **Cine MRI** for the assessment of cardiac morphology and regional and global systolic function at baseline

2. **Stress perfusion MRI** to visualize regions of myocardial hypoperfusion during vasodilation (eg, with adenosine infusion)

3. **Rest perfusion MRI** to aid in distinguishing true perfusion defects from image artifacts

4. **DE-MRI** for the determination of myocardial infarction (MI)
Images from a typical patient scan. **Cine and delayed-enhancement** images are acquired at six to eight short axis locations and at two to three long-axis locations during repeated breath holds. Images are interpreted with the cine images (cine-MRI) immediately adjacent to the delayed-enhancement images (DE-MRI). In this patient example, DE-MRI demonstrates a myocardial infarction involving the inferior wall and inferoseptum of the left ventricle.
MR Viability Imaging Procedure

- Insert peripheral IV
- Place patient in scanner
- Obtain scout images
- Obtain cine images
- Inject gadolinium (0.1-0.2 mmol/kg)
- Wait 10 minutes
- Obtain delayed enhancement images
  (segmented GRE with inversion prepulse)
Diagram illustrating the difference between the DE observed in ischemic and nonischemic diseases. Ischemic disease presents a vascular territory distribution and characteristically involves the endocardium. In non-ischemic conditions, the abnormal DE may be midwall, patchy, epicardial, or global subendocardial.
MI in a 50-year-old man. Viability study in short axis (A) and horizontal long axis (B) demonstrates subendocardial enhancement of the interventricular septum with some focal areas of transmural infarction. Based on the MRI findings, surgical revascularization was performed with significant improvement of the left ventricular function.
Viability MR in a 55-year-old male patient with history of CAD and percutaneous intervention considered for revascularization surgery. Contrast-enhanced MR demonstrates extensive DE (arrows) and left ventricular dilation consistent with transmural infarction with true left ventricular aneurysm.
CMR

- Identification of specific patterns of myocardial DE that occur in a variety of non-ischemic diseases, such as myocarditis, sarcoidosis, hypertrophic cardiomyopathy, and amyloidosis, has further extended the clinical applications of contrast-enhanced CMR imaging.
Dilated cardiomyopathy in a 60-year-old man. Delayed images after contrast injection in short axis (A) and horizontal long axis (B) demonstrate abnormal late gadolinium enhancement in the midventricular wall, with a nonvascular distribution (arrows).
Hypertrophic cardiomyopathy in a 53-year-old male. Irregular areas of contrast enhancement are appreciated in this short axis delayed images after contrast injection (arrows).
MRCA

- **Coronary artery magnetic resonance (MR) angiography** is useful for identifying coronary artery anomalies, in particular in younger individuals, without exposure to ionizing radiation or iodinated contrast medium.

- Only **limited multicenter MRCA experience** is available and there are still no data on the prognostic value of coronary MR imaging.

- Technical challenges that need to be addressed are further improvements in motion suppression and abbreviated scanning times aimed at improving spatial resolution and patient comfort.

- The development of **new and specific contrast agents**, **high-field MR imaging** with **improved spatial resolution**, and continued progress in MR imaging methods development will undoubtedly lead to further progress.
MR coronary angiography in a young female athlete with exercise-induced chest pain. Free breathing 3-D noncontrast turbo field-echo images demonstrate normal origin and course of the proximal right and left coronary arteries (arrows).
Future Cardiovascular MRI

MR cardiovascular imaging

For

– Greater definition of tissue characteristics
– Perfusion
– Valvular function
– Lack of X-ray radiation
– Lack of need for contrast media

Against

Limited temporal and spatial resolution
partial volume artifacts due to slice thickness limitations
reliance on multiple breath holds
Poor visualization of left main coronary artery
FUTURE DEVELOPMENTS

• Undoubtedly, both hardware and software for cardiac imaging will continue to be improved.

• Higher spatial and temporal resolution requires a substantially higher radiation dose to avoid excessive image noise.

• Close collaboration between clinicians, imaging researchers, hardware engineers, and software developers will, hence, be necessary to guide the further development to make full use of its potential.
Thank You !