Basic Cardiac CT; 
Assessment of cardiac function

By;
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Cairo University
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How the Air Force guys relax..!!
Overview

• Cardiac function analysis:
  – Global and Regional
  – Methods of measurement
  – Tools of measurement
  • CT cardiac function analysis:
    – Technique: Acquisition, Image reconstruction, Analysis
    – Limitations
    – Clinical Considerations

Cardiac function analysis; Why?

• Analysis of left ventricular myocardial function is fundamental in patients with ischemic and non-ischemic cardiomyopathy to:
  – Establish diagnosis,
  – Disease stratification,
  – Treatment planning,
  – Estimation of prognosis

• Determination of global left ventricular function is the strongest determinant of pump failure and death due to myocardial infarction*

Cardiac function analysis; Global and regional

- **Global** LV function; represented by
  - EDV and ESV,
  - Stroke volume,
  - Ejection fraction,
  - Cardiac output,

- **Regional** LV function; represented by
  - Myocardial wall thickness,
  - Systolic wall thickening,
  - Systolic wall motion

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**Global** Cardiac function analysis; Measurement

- Determination of the end-diastole, the end-systole
- Different approaches to measure the *volume*;
  - The *area-length method*
  - The *Simpson’s method*
  - Threshold-based *direct volume measurement*
**Global** Cardiac function analysis; The *area-length method*

- Uses a vertical or horizontal *long-axis* view
- Developed for catheter angiography (limited number of available projections)
- Ventricular area (A) and length from apex to the mitral valve plane (L) are used to calculate the left ventricular volume (V) according to the formula:

\[ V = \frac{8}{3 \pi} \cdot \frac{A^2}{L} \]

**Global** Cardiac function analysis; The *Simpson’s method*

- Uses contiguous *short-axis* image sections of the LV
- Developed for CMR
- Cross sectional images have a certain section thickness (S),
- Left ventricular volume (V) is calculated by adding all cross-sectional areas (A) multiplied with the section thickness (S):

\[ V = \sum A_n \times S \]

Geometric assumptions → Errors in remodeled hearts

Does not rely on geometric assumptions
Global Cardiac function analysis; Direct volume measurement

- Developed for imaging modalities that depict signal-intensity differences between the myocardium and cardiac chambers.
- Signal difference can be produced by contrast-enhanced blood in the cardiac chambers.
- Total chamber volume equals the sum of all contiguous voxels exceeding a predefined attenuation threshold.

Does not rely on geometric assumptions.

Global Cardiac function analysis; Reference values

Global left ventricular (LV) and right ventricular (RV) function parameters adapted from cine magnetic resonance imaging data in healthy volunteers.*

<table>
<thead>
<tr>
<th></th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Left ventricle</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LV-EDV (ml)</td>
<td>102–235</td>
<td>95–174</td>
</tr>
<tr>
<td>LV-EDV/BSA (ml/m²)</td>
<td>55–112</td>
<td>56–59</td>
</tr>
<tr>
<td>LV-ESV (ml)</td>
<td>28–93</td>
<td>27–74</td>
</tr>
<tr>
<td>LV-ESV/BSA (ml/m²)</td>
<td>13–45</td>
<td>14–40</td>
</tr>
<tr>
<td>LV ejection fraction (%)</td>
<td>55–72</td>
<td>54–74</td>
</tr>
<tr>
<td>LV mass (g)</td>
<td>85–181</td>
<td>37–67</td>
</tr>
<tr>
<td>LV mass/BSA (g/m²)</td>
<td>46–82</td>
<td>–</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Right ventricle</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RV-EDV (ml)</td>
<td>111–243</td>
<td>83–178</td>
</tr>
<tr>
<td>RV-EDV/BSA (ml/m²)</td>
<td>111–243</td>
<td>48–103</td>
</tr>
<tr>
<td>RV-ESV (ml)</td>
<td>57–111</td>
<td>52–73</td>
</tr>
<tr>
<td>RV-ESV/BSA (ml/m²)</td>
<td>25–53</td>
<td>18–42</td>
</tr>
<tr>
<td>RV-EF (%)</td>
<td>41–65</td>
<td>50–70</td>
</tr>
</tbody>
</table>

Regional Cardiac function analysis; Assessment

• Left ventricular myocardial wall thickness
  – between 6 and 8 mm in diastole
  – between 10 and 14 mm in systole.
  – Normal systolic thickening is approximately 5 mm

• Left ventricular myocardial wall motion
  – During rest
  – During stress (exercise, pharmacological)

Regional Cardiac function analysis; Assessment

• Systolic contraction requires functional muscle tissue and an adequate regional blood supply
  – Scar tissue does not contract
  – High-grade Coronary stenosis → RWMA at rest
  – Stress imaging requires serial measurements,
    • Achieved with cine echocardiography and CMR
    • Major limitation for CT; repeated contrast injections and radiation exposure
**Regional** Cardiac function analysis; Assessment

![Diagram showing left ventricular segmentation with regions labeled: 1. basal anterior, 2. basal anterior septal, 3. basal inferior, 4. basal inferior lateral, 5. basal inferolateral, 6. basal lateral, 7. mid anterior, 8. mid anterior septal, 9. mid inferior, 10. mid inferolateral, 11. mid inferolateral, 12. mid lateral, 13. apical anterior, 14. apical septal, 15. apical inferior, 16. apical inferolateral, 17. apex.](image)

**Reference values**

- Regional LV function parameters adapted from CMR data in healthy volunteers*

<table>
<thead>
<tr>
<th></th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left ventricle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EDWT (mm)</td>
<td>7.6 ± 1.4</td>
<td>6.3 ± 1.0</td>
</tr>
<tr>
<td>ESWT (mm)</td>
<td>13.2 ± 1.8</td>
<td>12.2 ± 1.6</td>
</tr>
<tr>
<td>SWT (mm)</td>
<td>5.5 ± 0.8</td>
<td>5.8 ± 1.2</td>
</tr>
<tr>
<td>SWTH (%)</td>
<td>75 ± 16</td>
<td>96 ± 24</td>
</tr>
</tbody>
</table>

Cardiac function analysis; Tools for measurement

- Echocardiography
- Cardiac catheterization
- Scintigraphy; Gated SPECT

Cardiac MRI

- Excellent temporal and spatial resolution,
- Allows image acquisition in any desired plane
- High degree of accuracy and reproducibility*

Currently considered the Reference standard in assessment of cardiac function**


Cardiac CT

- Pure ventricular function analysis is not the focus of MSCT,
- Other non-invasive imaging modalities, which do not require ionizing radiation or potentially nephrotoxic contrast media
- In most cases, functional assessment will be carried out complementary to coronary CTA

Cardiac CT function analysis; Acquisition

- Virtually any cardiac phase is contained in an ECG-gated MSCT spiral data set,
- Images from ES and ED phases can be retrospectively produced
Cardiac CT function analysis; Acquisition

ECG Dose Modulation / “Pulsing”

- Prospective gating; “Step and Shoot”
- Low-dose scan: 3.5mSv
- You *cannot* do cardiac function analysis
**Cardiac CT function analysis; Reconstruction**

- **Basic steps are:**
  - *Axial CT slice*: connect the LV apex with the mitral valve (A).
  - A *two-chamber view* is generated (B).
  - Again connect the LV apex with the mitral valve, to identify the individual *double-oblique cardiac long axes*. A *four-chamber view* is generated (C).
  - True *cardiac short-axis slices* are created by further reformations orthogonal to the interventricular septum (D,E,F).
  - *ED* and *ES* images are generated.

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**Cardiac CT function analysis; Regional function analysis**

<table>
<thead>
<tr>
<th>Segment no.</th>
<th>Location</th>
<th>Segment name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Basal</td>
<td>Anterior</td>
</tr>
<tr>
<td>2</td>
<td>Anteroapical</td>
<td>Inferoapical</td>
</tr>
<tr>
<td>3</td>
<td>Inferoapical</td>
<td>Inferoapical</td>
</tr>
<tr>
<td>4</td>
<td>Inferoapical</td>
<td>Anterolateral</td>
</tr>
<tr>
<td>5</td>
<td>Anterolateral</td>
<td>Anterolateral</td>
</tr>
<tr>
<td>6</td>
<td>Anterolateral</td>
<td>Anterolateral</td>
</tr>
<tr>
<td>7</td>
<td>Mid-Cavity</td>
<td>Anterior</td>
</tr>
<tr>
<td>8</td>
<td>Anteroapical</td>
<td>Inferoapical</td>
</tr>
<tr>
<td>9</td>
<td>Inferoapical</td>
<td>Inferoapical</td>
</tr>
<tr>
<td>10</td>
<td>Inferoapical</td>
<td>Inferoapical</td>
</tr>
<tr>
<td>11</td>
<td>Inferoapical</td>
<td>Inferoapical</td>
</tr>
<tr>
<td>12</td>
<td>Anterolateral</td>
<td>Anterolateral</td>
</tr>
<tr>
<td>13</td>
<td>Apical</td>
<td>Anterior</td>
</tr>
<tr>
<td>14</td>
<td>Septal</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Inferoapical</td>
<td>Inferoapical</td>
</tr>
<tr>
<td>16</td>
<td>Infrapapical</td>
<td>Infrapapical</td>
</tr>
<tr>
<td>17</td>
<td>Apical</td>
<td>Apex</td>
</tr>
</tbody>
</table>

*MRI segmentation published in 2002 by Compte et al.*
Cardiac CT function analysis; Analysis

• Most commercially available software can do automatic reconstruction and analysis to determine global and regional function.

Cardiac CT function analysis; Clinical considerations

<table>
<thead>
<tr>
<th>Author</th>
<th>N</th>
<th>Modality compared to MSCT</th>
<th>LV-EDV</th>
<th>LV-ESV</th>
<th>LV-EF</th>
<th>LV-EF: MSCT vs. other modality (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Juergens 2002</td>
<td>22</td>
<td>CVG</td>
<td>–</td>
<td>–</td>
<td>0.80</td>
<td>–11.5 ± 3.7</td>
</tr>
<tr>
<td>Humdy 2002</td>
<td>30</td>
<td>CVG</td>
<td>0.72</td>
<td>0.88</td>
<td>0.76</td>
<td>13.3 ± 11</td>
</tr>
<tr>
<td>Heuschmid 2003</td>
<td>25</td>
<td>CVG</td>
<td>0.59</td>
<td>0.82</td>
<td>0.88</td>
<td>–17 ± 9</td>
</tr>
<tr>
<td>Boehm 2004</td>
<td>20</td>
<td>CVG</td>
<td>–</td>
<td>–</td>
<td>0.83</td>
<td>–4.7 ± 7.1</td>
</tr>
<tr>
<td>Dirksen 2002</td>
<td>15</td>
<td>2D-echo</td>
<td>–</td>
<td>–</td>
<td>0.93</td>
<td>–1.3 ± 4.5</td>
</tr>
<tr>
<td>Grude 2003</td>
<td>28</td>
<td>TGrE-CMR</td>
<td>0.92</td>
<td>0.90</td>
<td>0.90</td>
<td>–7.9 ± 5.6</td>
</tr>
<tr>
<td>Mahren 2003</td>
<td>16</td>
<td>SSFP-CMR</td>
<td>0.99</td>
<td>0.99</td>
<td>0.98</td>
<td>–0.9 ± 3.6</td>
</tr>
<tr>
<td>Juergens 2004</td>
<td>30</td>
<td>SSFP-CMR</td>
<td>0.93</td>
<td>0.94</td>
<td>0.89</td>
<td>–0.25 ± 4.9</td>
</tr>
</tbody>
</table>

• Comparison of LV-EDV and LV-ESV determined from cardiac CT to cine-ventriculography (CVG), 2D-echocardiography (2D-Echo), and CMR using turbo-gradient echo (TGrE) and steady-state free precession (SSFP) cine sequences.
Cardiac CT function analysis; Clinical considerations

Comparison between MSCT and CMR

- Only a few studies have used MSCT to focus on the detection and quantification of regional myocardial dysfunction*, **
- Areas of impaired motion were identified with good reliability compared to echocardiography and CMR

**Mahnken AH, et al. Radiol 2003;604–611
# Cardiac CT function analysis: Clinical considerations

## ACCF/ACR/SCCT/SCMR/ASNC/NASCI/SCAI/SIR Appropriateness Criteria

**Cardiac CT function analysis; Clinical considerations**

A Report of the American College of Cardiology Foundation Quality Strategic Directions Committee Appropriateness Criteria Working Group, American College of Radiology, Society of Cardiovascular Computed Tomography, Society for Cardiovascular Magnetic Resonance, American Society of Nuclear Cardiology, North American Society for Cardiac Imaging, Society for Cardiovascular Angiography and Interventions, and Society of Interventional Radiology

**CCT/CMR WRITING GROUP**

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Manesh R. Patel, MD
Christopher M. Kramer, MD, FACC
Michael Pevn, MD, FACC

### Table 8: Structure and Function

<table>
<thead>
<tr>
<th>Indication</th>
<th>Appropriateness Criteria (Median Score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morphology (Use of C.Angiography)</td>
<td></td>
</tr>
<tr>
<td>28. Assessment of complex congenital heart disease including anomalies of coronary circulation, great vessels, and cardiac chambers and valves</td>
<td>A (F)</td>
</tr>
<tr>
<td>29. Evaluation of myocardial function in patients with poor ventricular function or even failure</td>
<td>A (F)</td>
</tr>
</tbody>
</table>

**Evaluation of Ventricular and Valvular Function (Use of C.Angiography)**

| 30. Evaluation of LV function following myocardial infarction or heart failure patients | A (F) |
| 31. Evaluation of LV function following myocardial infarction or heart failure patients | A (F) |
| 32. Characterization of native and prosthetic cardiac valves | A (F) |

**Evaluation of Juxta- and Extra-Cardiac Structures (Use of C.Angiography)**

| 33. Evaluation of cardiac mass (e.g., tumor or thrombus) | A (F) |
| 34. Evaluation of pericardial conditions (pericardial mass, constrains pericardial, or complications of cardiac surgery) | A (F) |
| 35. Evaluation of pulmonary vein anatomy prior to invasive radiofrequency ablation for atrial fibrillation | A (F) |
| 36. Noninvasive coronary vein mapping prior to placement of hemodialysis catheter | A (F) |
| 37. Noninvasive coronary vein mapping, including formal coronary venography for repeat cardiac surgical reintervention | A (F) |

**Evaluation of Aortic and Pulmonary Valve (Use of C.Angiography)**

| 38. Evaluation of repaired aortic dissection or thoracic aortic aneurysm | A (F) |
| 39. Evaluation of repaired pulmonary embolism | A (F) |

*As assigned, CT angiograms which has a sufficiently high yield for these specific indications.*
Cardiac CT function analysis; Clinical considerations

Cardiac computed tomography: indications, applications, limitations, and training requirements

Report of a Writing Group deployed by the Working Group Nuclear Cardiology and Cardiac CT of the European Society of Cardiology and the European Council of Nuclear Cardiology

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Cardiac CT function analysis; Clinical considerations

Non-coronary imaging

Left and right ventricular function

Clinical implications and recommendations

Although CT imaging allows accurate assessment of left and right ventricular function, CT examinations will in most cases not be performed specifically for that purpose. Other diagnostic tests without radiation exposure or the need for contrast injection (i.e. echocardiography) are the methods of choice. However, it should be noted that ventricular function is adjacent information that can be obtained from standard coronary CT angiography investigations without altering the image acquisition protocol, and the ability of CT to provide accurate right ventricular assessment might be useful in several clinical conditions including congenital heart disease, carcinoid heart disease, or prior to lung transplantation.
Cardiac CT function analysis; Viability

- Detection of LV myocardial viability or damage is important in patients with coronary artery disease,
- Revascularization can lead to improvement in left ventricular function and patient survival
- “Late or delayed enhancement” phenomenon;
  - Initially described for cardiac CT
  - Cornerstone for detection of myocardial scar tissue and assessment of myocardial viability with CMR.
  - Recently re-transferred to MSCT


Cardiac CT function analysis; Viability

- Delayed enhancement MSCT images demonstrated accurate measurement of infarct size in AMI in animals* and humans**

Cardiac CT function analysis; Viability

- MSCT delayed enhancement requires *large volumes of contrast material*
- Larger infarct sizes following primary PCI correlated with increased LV remodelling and HF at 6 months follow up*


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Cardiac CT function analysis; Clinical considerations

- Advantages of cardiac CT function analysis are apparent:
  1. Does not rely on geometric assumptions; *direct voxel-based volumetry* can be applied;
  2. Outstanding *spatial resolution*,
  3. Rapid data acquisition in a *single breath-hold*, and *cardiac implants* do not represent a contraindication;
  4. Cardiac function data are contained in any coronary artery CT study
Cardiac CT function analysis; Clinical considerations

- Cardiac CT becoming the *first-line modality* for pure cardiac function evaluation?

→ Probably, this will *NEVER* happen, due to:
  - Availability of the many competing imaging modalities,
  - Radiation exposure
  - Iodinated contrast material

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Thank You