Cardiac PET/CT

Erick Alexanderson M.D.
Morphology Detection of Coronary involvement

Anatomy

Physiology

Perfusion Cardiac physiology Miocardial Blood Flow
Application of PET/CT in cardiology

- Myocardial Perfusion
- Endothelial Function
- Computed Angiotomography
- Myocardial Viability
- Cardiac Function
- Inflammation of the atherosclerotic plaque
- Myocardial Blood Flow
- Molecular Imaging
Application of PET/CT in cardiology

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ISCHEMIA

NORMAL

MILD

MODERATED

SEVERE
Myocardial Perfusion

Radiotracers:

- $^{82}$Rubidium
- $^{15}$O-Water
- $^{11}$C-Acetate
- $^{13}$N-Ammonia

PET $^{13}$N Ammonia
PET $^{13}$N Ammonia
PET/CT Experience in Mexico

- Unidad PET/CT Ciclotrón.
- Facultad de Medicina.
- Universidad Nacional Autónoma de México.

588 STUDIES

2003 - July 2010
PET/CT Experience in Mexico

STUDIES

NH (BS) CT

NH (BS) CPT

NH (BS)

N = 588
PET/CT Experience in Mexico

- Previous Infarction: 19%
- No Previous Infarction: 81%

N = 588
PET/CT Experience in Mexico

Sex

FEMALE 35%

MALE 65%

N = 588
Application of PET/CT in cardiology

- Myocardial Perfusion
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- Cardiac Function
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- Myocardial Blood Flow
- Molecular Imaging
Computed Angiotomography
Computed Angiotomography
Computed Angiography
Computed Angiometryography
Plaque Calcification

- Calcified
- Non calcified
- Mild Calcified
COLLATERAL CIRCULATION
<table>
<thead>
<tr>
<th>CCTA</th>
<th>Patients n = 181</th>
<th>Non ischemia by PET</th>
<th>Ischemia by PET</th>
<th>Extent of ischemia by PET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Significant coronary stenosis</td>
<td>54 (30%)</td>
<td>3 (6%)</td>
<td>51 (94%)</td>
<td>Mild: 14, Moderate: 11, Severe: 26</td>
</tr>
<tr>
<td>Non significant stenosis</td>
<td>42 (23%)</td>
<td>5 (12%)</td>
<td>37 (88%)</td>
<td>Mild: 22, Moderate: 6, Severe: 9</td>
</tr>
<tr>
<td>Normal coronary arteries</td>
<td>85 (47%)</td>
<td>50 (59%)</td>
<td>35 (41%)</td>
<td>Mild: 25, Moderate: 5, Severe: 5</td>
</tr>
</tbody>
</table>
Applications of PET/CT in Cardiology

- Myocardial Perfusion
- Computed Angiotomography
- Cardiac Function
- Myocardial Blood Flow
- Endothelial Function
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- Inflammation of the atherosclerotic plaque
- Molecular Imaging
Gated PET/CT

- LVEF STRESS: 73%
- LVEF REST: 69%

NORMAL
Gated PET/CT

**Stress NH3:** 04/08/2006
- **EF** = 70% (R0)
- **EDV** = 60 ml
- ** ESV** = 18 ml
- **SV** = 42 ml
- **Mass** = 88 gm

**Estimated % Thickening**
- > 40%
- 25% -> 40
- 10% -> 25
- 0% -> 10
- -10% -> 0
- <-10%

**Rest NH3:** 04/08/2006
- **EF** = 65% (R0)
- **EDV** = 54 ml
- **ESV** = 19 ml
- **SV** = 35 ml
- **Mass** = 88 gm
Gated PET/CT

Stress NH3: 08/04/2006
EF = 53% (RD)
EDV = 88 ml
ESV = 41 ml
SV = 47 ml
Mass = 129 gm

gates in cine: 8

Estimated % Thickening
> 40%
25% => 40%
10% => 25%
0% => 10%
-10% => 0%
<= -10%

Rest NH3: 08/04/2006
EF = 54% (RD)
EDV = 83 ml
ESV = 38 ml
SV = 45 ml
Mass = 129 gm
LVEF Rest – Stress
Normal Patients

REST

STRES

64.6 ± 7.5%

70 ± 7.1%

Alexánderson E. Presentado en ICNC 8, Praga 2007
LVEF Rest – Stress
Ischemic Patients

56.9 ± 5% [REST]
49.8 ± 8.1% [STRESS]

n = 12, p < 0.001

Alexánderson E. Presentado en ICNC 8, Praga 2007
$\triangle \text{LVEF}$ and extend of affected myocardium

Dorbala et al. J Nucl Med 2007;48
Applications of PET/CT in Cardiology

- Myocardial Perfusion
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Quantification of Myocardial Blood Flow

EARLY DETECTION

CAD

Isquemic

Accurated Diagnosis

Functional Impact

Obstruction

STRESS

REST
Quantification of Myocardial Blood Flow

17 healthy controls

13 patients with CAD by Angiography

$^{13}$N-Ammonia Myocardial Perfusion

Quantification of Myocardial Blood Flow

Compared with Angiography
Quantification of Myocardial Blood Flow

Increases the diagnosis of myocardial ischemia.

PET-Cyclotron Unit, UNAM, Mexico
Relation between Coronary Flow and Coronary Stenosis
Relation between coronary stenosis and Endothelium – Dependent Vasodilatation Index
Clinical Case

- Female patient, 62 years of age with diabetes and longstanding hypertension.

- A year with progressive dyspnea, NYHA III, associated with diaphoresis, and chest tightness.

- On this occasion with typical chest pain, so she went to ER.
ER EKG
Type: OGS Stress
Study: MIPI SUPINE
Dataset: STRESS_FBP(G)
Date: 2009-01-14 13:52:50
Volume: 45ml [4]
EDV: 77ml [8]
ESV: 45ml [4]
EF: 41%
Area: 99cm² [4]
Mot Ext: 60%, 60cm² [4]
Thk Ext: 44%, 44cm² [4]
Matrix: 64x64 x 27(z) x 8(t)
Mm/Vox: 6.78 x 6.78 x 6.78
Applications of PET/CT in Cardiology

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Coronary Flow $[^{13}\text{N}]$ – ammonia PET

![Image of images showing coronary flow at rest, CPT, and stress]

<table>
<thead>
<tr>
<th>Extent</th>
<th>Severity</th>
<th>Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAD</td>
<td>77.71</td>
<td>0.187</td>
</tr>
<tr>
<td>LCX</td>
<td>34.65</td>
<td>0.502</td>
</tr>
<tr>
<td>RCA</td>
<td>20.55</td>
<td>0.416</td>
</tr>
<tr>
<td>LV</td>
<td>47.85</td>
<td>0.459</td>
</tr>
</tbody>
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<tr>
<td>LAD</td>
<td>80.26</td>
<td>0.211</td>
</tr>
<tr>
<td>LCX</td>
<td>24.66</td>
<td>0.790</td>
</tr>
<tr>
<td>RCA</td>
<td>25.90</td>
<td>0.908</td>
</tr>
<tr>
<td>LV</td>
<td>49.63</td>
<td>0.849</td>
</tr>
</tbody>
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<td>49.63</td>
<td>1.849</td>
</tr>
</tbody>
</table>

EDVI

CFR

IVED ≥ 1.5

CFR ≥ 3.0

Alexánderson E. Arch Cardiol Mex. 2005
Quantification of myocardial flow

• Detection of endothelial dysfunction
  – DM: CFR
  – Hypertension: EDVI
  – AFS: EDVI
  – Normal perfusion

• Screening of patients in treatment

• Diagnosis of vascular disease
CORONARY DYSFUNCTION SCREENED WITH PET

Glucose metabolism alterations


- CFR
  - HEALTHY: 3.20±0.66
  - INSUL R: 2.75±0.50 2.77±0.63
  - GLUC INTOL: 2.57±0.36
  - DM2: 1.65±0.41

p< 0.05 vs control
Endothelial Dysfunction in DM

Endothelial Dysfunction associated with smoke

$p = \text{ns}$

$p < 0.001$

Czernin et al. Circulation 1995;91:2891
Effect of ezetimibe-simvastatine over endothelial dysfunction in dyslipidemic patients: Assessment by $^{13}$N-ammonia positron emission tomography

Erick Alexanderson, a,b Leonardo García-Rojas, a Moisés Jiménez, b Rodrigo Jácome, a Rodrigo Calleja, a Alfonso Martínez, a Juan M. Ochoa, a Aloha Meave, a,b and Graciela Alexanderson c

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Acceptad in Journal of Nuclear Cardiology 2010
doi:10.1007/s12350-010-9273-8
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Goals of Viability Imaging

IDENTIFY
Patients with low cardiac function.
Revascularization may improve:

• **Left Ventricular function**
• **Symptoms**
• **Survival**
Viability Criteria with PET

DISCORDANT

CONCORDANT

Ammonia

18-FDG

Circulation 1983; 67: 766-78
18F-FDG

13N-ammonia

18F-FDG

13N-ammonia

18F-FDG

13N-ammonia
Viability

18FDG  13N Amonnia
Long term prognosis in patients with LV dysfunction and viability with PET + received therapy

With Mismatch

Without Mismatch

Revascularization

Medical

Survival Rate

Time (months)

P = 0.007

P = 0.12

Di Carli et al. JTCVS 1998
Applications of PET/CT in Cardiology

- Myocardial Perfusion
- Computed Angiotomography
- Cardiac Function
- Myocardial Blood Flow
- Endothelial Function
- Myocardial Viability
- Inflammation of the atherosclerotic plaque
- Molecular Imaging
Inflammation of the atheroesclerotic plaque

Uptake of FDG in the carotid arteries.
Inflammation of the atheroesclerotic plaque

<table>
<thead>
<tr>
<th>Factor</th>
<th>Strong uptake (SUV ≥ 2.7), N = 11</th>
<th>Weak uptake (SUV 1.2 to 2.3), N = 2</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>3</td>
<td>1</td>
<td>1.0</td>
</tr>
<tr>
<td>Age, mean ± S.D.</td>
<td>66.2 ± 102</td>
<td>66.5 ± 16.2</td>
<td>0.9</td>
</tr>
<tr>
<td>Hypertension</td>
<td>8</td>
<td>1</td>
<td>1.0</td>
</tr>
<tr>
<td>Diabetes</td>
<td>2</td>
<td>1</td>
<td>0.4</td>
</tr>
<tr>
<td>Hyperlipidemia</td>
<td>6</td>
<td>2</td>
<td>0.4</td>
</tr>
<tr>
<td>Good outcome Rankin 0–2</td>
<td>4</td>
<td>1</td>
<td>0.7</td>
</tr>
<tr>
<td>Stenosis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate 50–69%</td>
<td>3</td>
<td>2</td>
<td>0.052</td>
</tr>
<tr>
<td>Significant 70–89%</td>
<td>5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Severe ≥90%</td>
<td>3</td>
<td>0</td>
<td>0.052</td>
</tr>
<tr>
<td>Presence of primary endpoint</td>
<td>8</td>
<td>0</td>
<td>0.3</td>
</tr>
</tbody>
</table>
Inflammation of the atheroesclerotic plaque

Uptake of FDG in the Aorta.
A. Before treatment  
B. After treatment

Alexánderson E, et al. *Tex Heart Inst J* 2007;34:466-
Detection of the inflammatory activity in patients with Takayasu’s Arteritis with PET

<table>
<thead>
<tr>
<th></th>
<th>PET +/- clinical +</th>
<th>PET +/-clinical -</th>
<th>PET -/clinical +</th>
<th>PET -/clinical -</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basal</td>
<td>33%</td>
<td>28%</td>
<td>6%</td>
<td>33%</td>
<td>66%</td>
</tr>
<tr>
<td>3rd month</td>
<td>33%</td>
<td>67%</td>
<td>0%</td>
<td>0%</td>
<td>33%</td>
</tr>
<tr>
<td>6th month</td>
<td>13%</td>
<td>50%</td>
<td>0%</td>
<td>38%</td>
<td>50%</td>
</tr>
<tr>
<td>9th month</td>
<td>0%</td>
<td>64%</td>
<td>7%</td>
<td>29%</td>
<td>29%</td>
</tr>
<tr>
<td>Means</td>
<td>20%</td>
<td>52%</td>
<td>3%</td>
<td>25%</td>
<td>45%</td>
</tr>
</tbody>
</table>

Alexanderson E, accepted ESC 2009, Barcelona España
Detection of the inflammatory activity in patients with Takayasu’s Arteritis with PET

Conclusions

- $^{18}$F-FDG detects inflammatory activity in clinically inactive patients
- The findings with PET seem to correlate with the histopathological results, in which inflammatory activity kept present beside being clinically inactive
- $^{18}$F-FDG PET may identify inflammatory activity by a no – invasive way in patients with Takayasu’s Arteritis, even in those patients that do not account clinical criteria
- Therefore, the PET is a useful method that can evaluate and establish an adequate treatment in these patients

Alexanderson E, accepted ESC 2009, Barcelona España
Applications of PET/CT in Cardiology

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- Molecular Imaging
Molecular Imaging

- \(^{11}\text{C Palmitato}\)
- IPPA
- BMIPP
- \(^{18}\text{FDG}\)
- Glucose
- Glycogen
- \(^{11}\text{C Glucose-6-P}\)
- Glucose-6-P
- Glycolysis
- Pyruvate
- Lactate
- \(^{13}\text{C Acetate}\)
- \(^{15}\text{O}_2\)
- \(^{11}\text{C Homocystein}\)
- Adenosine
- ATP
- Krebs
- \(^{15}\text{O}_2\)
- Oxidative phosphorylation
- Lipid storage
- AGL-CoA
- ATP
- ADP
- K+
- Na+
- [O\(_2\)]

- \(^{201}\text{Tl+}\)
- \(^{82}\text{Rb+}\)
- Misonidazole

- \(^{11}\text{C-HED}\)
- Dopamine
- \(^{18}\text{F-NF}\)
<table>
<thead>
<tr>
<th>Innervation</th>
<th>Biological target</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-18 Fluorodopamine</td>
<td>Sympathetic presynaptic function</td>
</tr>
<tr>
<td>C-11 Hydroxyephedrine</td>
<td>Catecholamine presynaptic uptake</td>
</tr>
<tr>
<td>C-11 epinephrine</td>
<td>Presynaptic uptake and storage of catecholamines</td>
</tr>
<tr>
<td>C-11 fenilepinephrine</td>
<td>Presynaptic uptake and metabolism of catecholamines</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Receptors</th>
<th>Biological target</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-11 CGP12177</td>
<td>Beta-adrenergic Receptor</td>
</tr>
<tr>
<td>C-11_MQNB</td>
<td>Muscarinic Receptor</td>
</tr>
<tr>
<td>Molecular probes</td>
<td>Biological target</td>
</tr>
<tr>
<td>F-18 peptide RGD</td>
<td>Integrin αv β3</td>
</tr>
<tr>
<td>F-18 annexin</td>
<td>Apoptosis</td>
</tr>
</tbody>
</table>
Applications of PET/CT in Cardiology

CONCLUSIONS

- New.
- Non invasive.
- Gives us anatomical and physiological information of the heart (coronary and cardiac anatomy, calcification and characteristics of the plaque, perfusion and ventricular function)
- Pending to determine the diagnostic and prognostic value of the method
  - Which patients may benefit with both tests?
  - Which sequence of tests?
  - Improves the treatment?
- The major dose of radiation and the high cost make the study LOW appropriate for a Check up
- The combination of perfusion and CT is the best method to predict cardiovascular results
CARDIAC MRI
Ischemic Heart Disease

- Anatomy – Ventricular Function
- Myocardial perfusion
- Late Reinforcement
- Microvascular obstruction
- T2 -------- Edema
- Difference between acute heart attack – old heart attack
- RV Infarction
- Acute chest pain
- Complications
Ischemic Heart Disease

- Anatomy – Ventricular Function
- Myocardial perfusion
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- Microvascular obstruction
- T2 -------- Edema
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- Complications
Morphology

- Characteristics and dimensions of the cardiac cavities.
- Diastolic diameter of the LV and RV
- Systolic diameter of the LV and RV
- Thickness of the ventricular walls
- Atrial dimensions
- Valvular Morphology
- Aortic root dimensions
- Intracavitary thrombus exclusion
Function

- Systolic function of the LV and RV
- Diastolic function of the LV

Bellenger NG, Pennell DJ, Eur Heart J 2000, 21:1387-1396
Function

- LV EF
- EDV and ESV
- SV
- Mass

<table>
<thead>
<tr>
<th>Cine Imaging (rest/stress)</th>
<th>T2-Weighted Imaging</th>
<th>First Pass Perfusion (rest/stress)</th>
<th>Early Gadolinium Enhancement</th>
<th>Late Gadolinium Enhancement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contractile function</td>
<td>Tissue edema</td>
<td>Regional myocardial blood flow</td>
<td>Microvascular integrity</td>
<td>Myocardial necrosis/fibrosis</td>
</tr>
<tr>
<td>LV function/ischemia/viability</td>
<td>Infarct age/myocardial salvage</td>
<td>MVO/ischemia</td>
<td>No reflow/MVO</td>
<td>Infarct size/viability</td>
</tr>
</tbody>
</table>

Contemporary Reviews in Cardiovascular Medicine

Use of Cardiovascular Magnetic Resonance Imaging in Acute Coronary Syndromes

Tim Lodge, MD, PhD

Circulation 2009;119:1671-1681
Ischemic Heart Disease

- Anatomy – Ventricular Function
- Myocardial perfusion
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PERFUSION

Dypiridamol .56mg/Kg
(4min / in minute 7 Gd)
Adenosine 140gammas/Kg/min
(6min / in min 3 Gd)

Stress perfusion
Rest perfusion
Late reinforcement

Morphology
LV-RV Function
15´
Morphological complement

• Subendocardic persistent defect that remains more than 10 seconds
• It’s observed in two short axis
Diagnose

ISCHEMIA

Stress

Rest
Subendocardic Ischemia
Perfusion

Sensitivity 91%
Specificity 94%

Coronary angiography

Shwitter J, Circulation 2001;103:2230-2235
Ischemic Heart Disease

- Anatomy – Ventricular Function
- Myocardial perfusion
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- Microvascular obstruction
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- Acute chest pain
- Complications
Late Reinforcement

Contrast material distribution

→

Extracellular space
Late Reinforcement
Late Reinforcement
Late Reinforcement

Morphology

STRESS

REST

Late Reinforcement


Simonetti OP, Radiology 2001; 218:215-23
Late Reinforcement

Normal

Non transmural

Transmural
Non Transmural

Transmural
Non transmural
transmural
Late Reinforcement

• Arrhythmogenic risk predictor
• Myocardial scar, subtract for ventricular arrhythmias
• Size and morphology of the scar

Fieno DS JACC 2000; 36: 1985-91
Amado LC JACC 2004; 44:2383-9
Viability diagnose

Dobutamine 10gammas/Kg/min (in minute 10)

Morphology
Function
Function
Late Reinforcement

REST
STRESS
Gd
First pass

Thickness and movility
All segments dysfunctional

Segments with severe hypokinesia, diskinesia and akinesia

Segments with akinesia and diskinesia

Transmural extension in late reinforcement

n = 153

Meave A. Arch Cardiol Mex 2005; 75: 71-78.
Ischemic Hearth Disease

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- Complications
Contrast-Enhanced Cardiovascular Magnetic Resonance Imaging of Right Ventricular Infarction

Andreas Kumar, MD,*† Hassan Abdel-Ary, MBBCit, MSc,*† Ilka Kriedemann,† Jeanette Schulz-Menger, MD,*† C. Michael Gross, MD,*† Rainer Dietz, MD,*† Matthias G. Friedrich, MD, FESC*†

Calgary, Alberta, Canada; and Berlin, Germany
Ischemic Heart Disease

- Anatomy – Ventricular Function
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- Microvascular obstruction
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- Acute chest pain
- Complications
Microvascular Obstruction and the No-Reflow Phenomenon After Percutaneous Coronary Intervention

Ronen Jaffe, MD; Thierry Charron, MD; Geoffrey Paley, MD; Alexandre Dick, MD; Bradley H. Strauss, MD, PhD

Circulation 2008; 117:3152-3156
Microvascular Obstruction

- Embolism, platelets activation.
- No reflux phenomenon
- Extended infarction, major cardiac remodeling.
- Low prognosis

Acute Heart Attack

• Chest pain in the ER
• Difference between new and old cardiac infarction
Acute heart attack
Ischemic Heart Disease

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- Late Reinforcement
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Ischemic Heart Disease

- Anatomy – Ventricular Function
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- Late Reinforcement
- RV Infarction
- Microvascular obstruction
- T2 -------- Edema
- **Difference between acute heart attack – old heart attack**
- Acute chest pain
- Complications
18 dogs (15-25Kg), LDA occlusion.

Baseline
Occluded
Reperfusion

2 dogs with prolonged occlusion
9 dogs euthanasia

Edema as a Very Early Marker for Acute Myocardial Ischemia

A Cardiovascular Magnetic Resonance Study

Hassan Abdel-Aty, MD,* Myra Cocker, BSc,* Cheryl Meek, RN,† John V. Tyberg, MD, PhD,† Matthias G. Friedrich, MD*

Calgary, Alberta, Canada

JACC 2009;53:1194-1201
Reperfusion 90 minutes ischemia
Male, 45 years old, chest pain, positive markers, ST elevation.
Male, 45 years old, chest pain, positive markers, ST elevation.
Male, 52 years old, chest pain, ST elevation in EKG, CVMR post primary angioplasty
Male, 52 years old, chest pain, ST elevation in EKG, CVMR post primary angioplasty
Male, 52 years old, chest pain, ST elevation in EKG, CVMR post primary angioplasty
Male, 52 years old, chest pain, ST elevation in EKG, CVMR post primary angioplasty

Three months follow up
Female, 56 years old
Ischemic Heart Disease

- Anatomy – Ventricular Function
- Myocardial perfusion
- Late Reinforcement
- RV Infarction
- Microvascular obstruction
- T2 -------- Edema
- Difference between acute heart attack – old heart attack
- Acute chest pain
- Complications
Male, 29 years old, chest pain, ST elevation in EKG, positive blood markers.
Male, 29 years old, chest pain, ST elevation in EKG, positive blood markers.
Male, 29 years old, chest pain, ST elevation in EKG, positive blood markers.

Inferior Infarction?
Male, 29 years old, chest pain, ST elevation in EKG, positive blood markers.
Male, 29 years old, chest pain, ST elevation in EKG, positive blood markers.
Male, 29 years old, chest pain, ST elevation in EKG, positive blood markers.
Late reinforcement patterns

Myocarditis

Modified Raymond Kim
Male, 29 years old, chest pain, ST elevation in EKG, positive blood markers.
Male, 29 years old, chest pain, ST elevation in EKG, positive blood markers.

Myocarditis
Ischemic Heart Disease

- Anatomy – Ventricular Function
- Myocardial perfusion
- Late Reinforcement
- RV Infarction
- Microvascular obstruction
- T2 -------- Edema
- Difference between acute heart attack – old heart attack
- Acute chest pain
- Complications
MRI Conclusion

- Single exploration → integral evaluation
- Approximated time 40 min.
- Morphology, qualitative and quantitative function, myocardial perfusion (ischemia), myocardial edema, extension and severity of the infarction, viability
- Prognostic value
- No need for Iodated contrast material nor radiation.