Coronary CT Angiography: introduction

Contrast, drugs, technique optimization
Overview

- Coronary CT angiography
  - Basic protocol

- Contrast
  - General principles
  - Bolus types

- Drugs
  - Beta blockers
  - Nitroglycerin

- Optimize technique
  - Dose
Coronary CT Angiography

Basic 64 channel single source protocol
Coronary CT Angiography

Basic protocol
- Localizers
- Timing bolus in ascending thoracic aorta
- Contrast administration
- Diagnostic scan
- Image post-processing

AP and lateral localizers of the chest
Coronary CT Angiography

**Basic protocol**
- Localizers
- **Timing bolus in ascending thoracic aorta**
- Contrast administration
- Diagnostic scan
- Image post-processing

**Timing bolus in ascending thoracic aorta**
- Location below carina
- Inject 20 cc contrast + 20 cc saline @ 5 cc/s
- 6 sec delay
- Interscan delay 2 sec
- Repeat scan till contrast bolus passes through asc. TA

- ROI in ascending thoracic aorta
- Time-attenuation curve
- Contrast arrival time
**Coronary CT Angiography**

※ **Basic protocol**
  - Localizers
  - **Timing bolus in ascending thoracic aorta**
  - Contrast administration
  - Diagnostic scan
  - Image post-processing

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※ ROI in ascending thoracic aorta

※ Time-attenuation curve

※ Contrast arrival time
Coronary CT Angiography

* Basic protocol
  - Localizers
  - Timing bolus in ascending thoracic aorta
  - Contrast administration
  - Diagnostic scan
  - Image post-processing

Contrast saline

- 50 cc 5 cc/s
- 30 cc 5 cc/s
- 20 cc 5 cc/s
- 50 cc 5 cc/s
Coronary CT Angiography

* Basic protocol
  * Localizers
  * Timing bolus in ascending thoracic aorta
  * Contrast administration
  * Diagnostic scan
  * Image post-processing

RG Helical, pitch 0.2

Prospective triggered, step-and-shoot
Scan Acquisition

- Timing bolus at aortic root
- Triphasic contrast injection with dual syringe injector
- Scan acquisition at timing bolus peak + 5 sec
  - Cranial – caudal
  - 2 cm above root through heart
Patient preparation

• Beta-blockers
  • 50 – 100 mg PO
  • 40 – 60 minutes
  • Target HR < 65 bpm

• Nitroglycerin
  • 1 SL spray
  • 4 – 6 minutes
Contrast for coronary CTA
Contrast for coronary CTA

- Target coronary attenuation
- General principles of contrast enhancement
- Contrast concentration
- Bolus types
- Saline chaser
Target coronary artery enhancement

- Desired result of contrast bolus
- Allow visualization of the coronary artery lumen, wall, disease

- Lumen attenuation too low
  - Low contrast to noise
  - Overestimate degree of stenosis

- Lumen attenuation too high
  - Limit differentiation of lumen from mural calcification
Target coronary artery enhancement

- Desired result of contrast bolus
- Allow visualization of the coronary artery lumen, wall, disease

- Lumen attenuation too low
  - Low contrast-to-noise
  - Higher error rates

- Lumen attenuation too high
  - Limit differentiation of lumen from mural calcification
Target coronary artery enhancement

* Desired degree of arterial enhancement (300-350 HU)*

< 200 HU inadequate visualization

> 350 HU can make distinction of lumen from mural calcification difficult, underestimate stenosis.

> 500 HU lumen attenuation can compromise accuracy of lumen stenosis detection with noncalcified plaques as well.

> 500 HU decreases plaque detectability.

Johnson PT, AJR 2009;192:w214

Calcifications in proximal LAD

Ao attn

156 HU
Target coronary artery enhancement

Ao attn

156 HU

Ao attn

364 HU
Target coronary artery enhancement

* Desired degree of arterial enhancement (300-350 HU)*

  < 200 HU inadequate visualization

  With pulsating coronary phantom:

  > 350 HU can make distinction of lumen from mural calcification difficult, underestimate stenosis.

  > 500 HU lumen attenuation
    ➢ can compromise accuracy of lumen stenosis detection with noncalcified plaques as well.
    ➢ decreases plaque detectability.

* Reports with higher attenuation, upper limit maybe higher

Johnson PT, AJR 2009;192:w214
Contrast enhancement: general principles

- Degree of contrast enhancement
  - Amount of iodine
  - Tube voltage

- Increases proportionally with iodine concentration for a given tube voltage
  - Increase iodine concentration by 1 mg iodine / mL
    - 26 HU enhancement at 120 kVp
    - increases with lower kVp (for 1 mg/mL iodine)
      - 30 HU enhancement at 100 kVp
      - 40 HU enhancement at 80 kVp

<table>
<thead>
<tr>
<th>80 kVp</th>
<th>100 kVp</th>
<th>120 kVp</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 HU</td>
<td>30 HU</td>
<td>26 HU</td>
</tr>
</tbody>
</table>

Bae KT, Radiology, 2010;256(1):32
Contrast agents

*Contrast media concentration*

- Commercially available in wide range of concentrations
  - 240 – 370 mg Iodine per mL (US)

- Higher iodine load = higher mean coronary attenuation
- Any concentration of contrast can achieve the g l/s to achieve predetermined levels of coronary artery attenuation.
- Contrast volumes in general < 100 mL for 64-MDCT

<table>
<thead>
<tr>
<th>Concentration mg Iodine/mL</th>
<th>Mean volume mL</th>
<th>Range mL</th>
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</thead>
<tbody>
<tr>
<td>320</td>
<td>93</td>
<td>60 - 150</td>
</tr>
<tr>
<td>350</td>
<td>89</td>
<td>60 - 125</td>
</tr>
<tr>
<td>370</td>
<td>91</td>
<td>60 - 150</td>
</tr>
</tbody>
</table>

Bae KT, Radiology 2010;256:32. Johnson PT, AJR 2009;192:w214
Bolus types

• Uniphasic
  • Contrast only

• Biphasic
  • Contrast + saline flush

• Triphasic
  • Contrast + blend + saline flush
Bolus types

- **Uniphasic**
  - Contrast only

- **Biphasic**
  - Contrast + saline flush

- **Triphasic**
  - Contrast + blend + saline flush

**Advantages**
- Simple
- Don’t need dual head injector

**Disadvantages**
- Higher contrast volumes
- Highest frequency of streak artifacts

Jin-guo L, Eur J Rad, 2009, May
Streak artifacts from right heart

Lowess smooth plot – probability of streak artifact increases with right-heart attenuation

Mitsumori LM, AJR 2010;194:w263
Streak artifacts from right heart

Right heart attenuation
406.9 ± 117.9 HU

Right heart attenuation
272.7 ± 55.2 HU
Bolus types

* **Uniphasic**
  - Contrast only

* **Biphasic**
  - Contrast + saline flush

* **Triphasic**
  - Contrast + blend + saline flush

**Advantages**
- Lower contrast amounts
- Higher attenuation of coronary arteries
- Low frequency of streak artifacts

**Disadvantage**
- Poor visualization of right heart structures

Jin-guo L, Eur J Rad, 2009, May
Poor visualization of right heart structures

Coronal aorta, AV

HLA and SAX mpr heart
Bolus types

- **Uniphasic**
  - Contrast only

- **Biphasic**
  - Contrast + saline flush

- **Triphasic**
  - Contrast + blend + saline flush

**Advantages**
- Lower contrast volume
  - Similar to amt of biphasic
- Less streak artifacts
- Intermediate attenuation in right heart (TRO)

**Disadvantages**
- Need dual head injector
- Variable blend percentages

Jin-guo L, Eur J Rad, 2009, May
Contrast Administration

- **Timing bolus at aortic root**
- **Triphasic contrast injection with dual syringe injector**
  - Phase 1 — 50 mL 100% iodixanol at 5 cc/s
  - Phase 2 — 50 mL blend 60% iodixanol with 40% saline at 5 cc/s
  - Phase 3 — 50 mL saline at 5 cc/s.
- **Scan acquisition at timing bolus peak + 5 sec**

Shuman WP, Radiology 2008;248(2):431
Intermediate attenuation in right heart to minimize contrast related streak artifacts but allow visualization of right heart structures.
Triple rule out CTA: contrast bolus

- simultaneously opacify three separate vascular territories
  - PA – CA – Thoracic aorta
  - Reflect both right and left heart circulations
Example clinical TRO case: diagnostic opacification of PA, Coronary arteries, and Aorta with relative clearing of the Right heart.

Mitsumori LM, AJR 2010;194:w263
Cardiac function
Saline Chaser

- Saline chaser widely used with coronary CTA

  - **Improves contrast efficiency**
    - Pushing contrast within IV tubing and peripheral veins into the central blood volume (12 – 20 cc in veins, 10 cc in tubing)
    - Increases iodine load and enhancement

  - **Clear contrast from SVC and right heart**
    - Reduces streak and beam-hardening artifact

Bae KT, Radiology 2010;256:32. 
Johnson PT, AJR 2009;192:w214
Coronary CT angiography
introduction

Drugs – metoprolol and NTG
Optimizing patient’s heart rate to minimize motion artifacts

Cardioselective β-blocker
- Used to lower heart rate
- Rhythm more regular

Effects of oral dose seen within 1 hr, peak plasma concentrations at 90 min
- Peak effect of IV dose occurs between 5 and 10 min
- Plasma half-life for oral and IV in healthy volunteers ranges 3 – 4 hrs

Pannu HK, AJR, 2006;186:s341
Coronary motion

- RCA higher velocities
- motion trough 60 – 70 % of R-R
- higher heart rates
  - increased coronary velocities
  - narrower trough

Husmann, Radiology 2007, 245:567
metoprolol

contraindications

- Sinus bradycardia (hr < 60 bpm)
- Systolic BP < 100 mmHg
- Allergy to the medication
- Decompensated heart failure
- Asthma or COPD on B-agonist inhalers, active bronchospasm
  - h/o childhood asthma, no current asthma, no meds given BB
- Second/third degree heart block

protocol

- Dedicated Radiology nurse
  - Vitals
  - History
  - Screen for contraindications

- HR > 65 bpm
  - Metoprolol 50 or 100 mg PO
  - Reassess 40 – 60 min
  - Repeat dose

Schoepf UJ, Radiology 2007;244:1.
Pannu HK, AJR, 2006;186:s341
**IV metoprolol**

- 2.5 mg IV over 1 min
- Hr > 65 bpm, second dose after 5 min
- If remains elevated, 5 mg x 2 over 1 min, 5 min between doses
- Upto max dose of 15 mg

**With contraindications to BB**
- Can attempt calcium channel blockers
  - Diltiazem 0.25 mg/kg IV
    - Upto 25 mg total
  - Oral regimen (Cardizem)
    - 30 mg regular release

2.5 – 2.5 – 5 – 5 mg at 5 min intervals

Schoepf UJ, Radiology 2007;244:1.
Pannu HK, AJR, 2006;186:s341
Nitroglycerin

- **Vasodilator**
  - Relaxes vascular smooth muscle
  - Widely used with invasive coronary angiography
    - Optimize enhancement and size of lumen and small branches
    - Intra-arterial administration
  
- **For coronary CT angiography**
  - Significantly increases the volume and diameter of epicardial coronary arteries
  - Improves visualization of branch vessels
  - Less effect on stenotic segments could enhance detection of obstructive disease
  - Better correlation with angiography and IVUS

- **Sublingual spray (0.4 mg)**
  - Maybe more efficacious and have less side effects

Decramer I, AJR 2008;190:219
nitroglycerin

Adverse events

- Hypotension
- Flushing
- Headache

Contraindications

- Recent use (24 hrs) of phosphodiesterase inhibitors
  - Viagra (sildenafil)
  - Cialis (tadalafil)
  - Levitra (vardenafil)
  - Side effects can include severe hypotension and death
- Early MI
- Severe anemia
- Increased intracranial pressure
- Hypersensitivity to NTG

Schoepf UJ, Radiology 2007;244:48
Coronary CT angiography

introduction

Optimization of technique
ECG synchronization

※ Prospective ECG triggered
  • Axial, half scan, step-and-shoot acquisition
  • Dose 60 to 80% less than RG

RG Helical, pitch 0.2

Prospective triggered, pitch 1.0

Shuman WP, Radiology 2008;248:431
Prospective ECG Triggering

**parameters**

- **Step-and-shoot technique**
  - **Manual mA value**
  - **Body size**
  - **Center frequency**
    - **Heart rate**
  - **Beam on time**
    - **HR variability**

**ranges and values**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
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<tbody>
<tr>
<td>mA</td>
<td>200 – 800 mA</td>
</tr>
<tr>
<td>Center frequency</td>
<td>0 – 100 %</td>
</tr>
<tr>
<td>HR variability</td>
<td>75%</td>
</tr>
<tr>
<td>Beam on time</td>
<td>0 – 200 mS</td>
</tr>
<tr>
<td></td>
<td>100 mS</td>
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</table>
64 channel CTA

- Timing bolus at aortic root
- Triphasic contrast injection with dual syringe injector
- Scan acquisition at timing bolus peak + 5 sec

<table>
<thead>
<tr>
<th>Weight Range</th>
<th>mA Selection</th>
</tr>
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<tbody>
<tr>
<td>&lt; 60 kg</td>
<td>400-450 mA</td>
</tr>
<tr>
<td>60 – 90 kg</td>
<td>500-550 mA</td>
</tr>
<tr>
<td>90 – 120 kg</td>
<td>600-650 mA</td>
</tr>
<tr>
<td>&gt; 120 kg</td>
<td>700-750 mA</td>
</tr>
</tbody>
</table>

- No AEC (chest)
- Weight based
topogram attenuation estimates

※ region specific patient attenuation differences !
  • not reflected by weight
  • men vs women
  • short vs tall

206 lbs topo -44.4 hu
199 lbs topo -27.1 hu
207 lbs topo 15.1 hu
200 lbs topo 42.5 hu

Menke J, Radiology 2005;236:565
mA look-up table

• NG helical exam (NI 30) prescribed first

• View mA look-up table
  • mAs
  • 1.4 to 1.6x mA for PT

<table>
<thead>
<tr>
<th>station</th>
<th>x axis</th>
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<tbody>
<tr>
<td>1</td>
<td>750</td>
</tr>
<tr>
<td>2</td>
<td>750</td>
</tr>
<tr>
<td>3</td>
<td>326</td>
</tr>
<tr>
<td>4</td>
<td>607</td>
</tr>
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<td>5</td>
<td>750</td>
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<td>7</td>
<td>750</td>
</tr>
<tr>
<td>8</td>
<td>750</td>
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<tr>
<td>avg</td>
<td>679.125</td>
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<table>
<thead>
<tr>
<th>Pitch</th>
<th>Helical NG</th>
<th>PT gated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.375</td>
<td>1.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rotation time (sec)</th>
<th>Eff mAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>mA*0.5</td>
</tr>
<tr>
<td></td>
<td>1.375</td>
</tr>
<tr>
<td></td>
<td>mA*0.227</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
</tr>
</tbody>
</table>
control set (n = 46), weight vs image noise

15/46 = 33%

\[ y = 0.0634x + 14.901 \]

\[ R^2 = 0.1589 \]

\[ R = 0.400 \]

Image noise (sd, hu)

Patient weight (lbs)

Median 25.2

IQ 25 = 21.6

IQ 75 = 28.9
test set (n = 30), weight vs image noise

\[ y = 0.0293x + 21.511 \]

\[ R^2 = 0.0665 \]

\[ R = 0.2579 \]

\[ \frac{4}{30} = 13\% \]

<table>
<thead>
<tr>
<th>IQ 25</th>
<th>IQ 75</th>
</tr>
</thead>
<tbody>
<tr>
<td>24.7</td>
<td>29.3</td>
</tr>
</tbody>
</table>

\[ \text{median} = 27.2 \]
example images – measured noise

19 hu
25.5 hu
30.1 hu

38.6 hu
41.3 hu
55.5 hu
Optimizing Dose

- Prospective triggering

- Padding
  - Longer period of beam-on time
  - Increases number of reconstructed phases
  - Linear increase in dose with padding duration
  - 0 vs 100 ms of padding = 45% reduction in dose

- Decrease padding when
  - HR variability < 5 bpm
  - HR < 65 bpm

- Tailored amount of padding can allow reduction in radiation exposure

LaBounty TM, AJR, 2010;194:933
Anomalous coronary arteries

Dose reduction
Anomalous RCA
ALARA

- Request in younger patients
- Need patient specific technique parameters
  - mA
  - kVp
  - Scan length
  - Minimize phases

Paul JF, Eur Radiology, 2007;17:30308
PT CTA: 0.4 mSv
15 yo M for anomalous coronary arteries
- 5’6” – 113 lbs (BMI 18)
- HR 64 bpm (bb)

80 kVp, mA 300
- DLP 25.3 mGy*cm
- k = 0.017*

No padding
- Single phase acquisition
- Steady heart rate
- Proximal coronary, tolerate some degree of motion

Topogram attenuation estimate to set mA
- Limitations of weight based mA selection

*Mayo JR, AJR 2009;192:646
# Radiation Dose

<table>
<thead>
<tr>
<th>Source</th>
<th>Range of Effective dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background radiation</td>
<td>3</td>
</tr>
<tr>
<td>Chest radiograph</td>
<td>0.05 – 0.24</td>
</tr>
<tr>
<td>CT chest</td>
<td>4 - 18</td>
</tr>
<tr>
<td>Diagnostic catheter angiography</td>
<td>2 - 16</td>
</tr>
<tr>
<td>NM sestamibi stress/rest Thallium stress/rest</td>
<td>9</td>
</tr>
<tr>
<td>64d Retrospective ECG gated cardiac CT</td>
<td>12 – 18</td>
</tr>
<tr>
<td>64d RG cardiac CT with ECG dose modulation</td>
<td>8 – 18</td>
</tr>
<tr>
<td>64d Prospective ECG Triggered cardiac CT</td>
<td>2 – 4</td>
</tr>
</tbody>
</table>

Thank You