CT Contrast Parameters for the Medical Physicist

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Conflict of Interest

- TPS supplies CT protocols to GE Healthcare under a licensing agreement, TPS is a consultant and on an advisory board to GE Healthcare, TPS receives research support from GE Healthcare
- TPS is on the MAB of Imalogix LLC
- TPS is a consultant to AstoCT LLC, and cybermed.ai (DBA RadFlow), AiDoc, iSchemaView
- TPS receives book royalties from Medical Physics Publishing
CT CONTRAST 101

No contrast

Positive Oral and IV contrast (parenchymal phase)

Negative Oral and IV contrast (liver arterial phase)

CT CONTRAST 101

CO2 gas contrast agent

Same pt no CO2

(a) (b)

(c) (d)

Note: the localizers even show the CO2

Both scans have positive oral agent

CT CONTRAST 101

Positive oral contrast introduced via Foley catheter

(arrow shows catheter, don’t confuse this with an artifact)


https://www.ausmed.com/cpd/articles/urinary-catheter
CT CONTRAST 101

Introducing contrast agent into the spinal column is called CT Myelography.

(Contents of the column is called arthrogram)

Positive contrast agent in spinal column

Native (non con) scan for comparison

CT CONTRAST 101

General Guidance

Patient with moderate or severe allergy to iodine based contrast

- Give these patients Barium Readical, or perform the scan without oral contrast. Consult the attending radiologist for guidance.
- If the patient is going to surgery post imaging, then give them lohexol; surgery prefers this, please consult the attending radiologist for approval.

Outpatients: 1 dose = 4mL of lohexol in 200 mL of clear liquid.

- Abd CT: 2 doses (400 mL of oral contrast)
- Abd/Pel CT: 4 doses (800 mL of oral contrast)
- Last dose on CT table: 8mL of lohexol in 200 mL of clear liquid.
  - X-Large cups = 800 mL (1x q 1 hour)
  - Large cups = 400 mL (2x q 30)
  - Small cups = 200 mL (4x q 15)
  - Patients have their choice of to mix the lohexol with lemonade or water.
  - Billing = All oral contrast (Including COT)

Inpatients: 1 dose = 4mL of lohexol in 200 mL of clear liquid.

- Abd CT: 2 doses q 30 minutes
- Abd/Pel CT: 4 doses q 30 minutes
- Billing = None (Patient is billed on the floor)

Bariatric Oral

- If the patient is a bariatric post-op patient they will not drink up on the floor. Rather, they will get one 2x concentrated dose on CT table: 8mL of lohexol in 200 mL of clear liquid. If you have questions please ask the protocoling radiologist.
- Billing = 8 mL of lohexol
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CT CONTRAST 101
Piston based pump... simple, the plunger pushes the agent out

Peristaltic pump, the rotating action pushes agent along a flexible tube

https://dienerprecisionpumps.com/positive-displacement-pumps/
CT CONTRAST 102

Air/CO2
Generates CT number ~-1000, “usually doesn’t get diluted”
Used for CTC

Iodine
Workhorse for CT. Usually it will always be diluted by blood (IVC administration) or water (oral) or urine (catheter injection)
Typical liver parenchymal enhancement is 20-80 HU enhancement.

- Veins between injection site and heard/lungs
- Arteries
```
<table>
<thead>
<tr>
<th>Material</th>
<th>80 kV</th>
<th>100 kV</th>
<th>120 kV</th>
<th>140 kV</th>
<th>N/A</th>
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<tbody>
<tr>
<td>Water</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>Air</td>
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<td>-1,000</td>
<td>-1,000</td>
<td>-1,000</td>
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<td>Fat</td>
<td>-152*</td>
<td>-111*</td>
<td>-89*</td>
<td>-69*</td>
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<td>Brain</td>
<td>47*</td>
<td>43*</td>
<td>39*</td>
<td>37*</td>
<td></td>
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<tr>
<td>Soft Tissue</td>
<td>62*</td>
<td>58*</td>
<td>54*</td>
<td>52*</td>
<td></td>
</tr>
<tr>
<td>Solid Cortical Bone</td>
<td>3,760*</td>
<td>2,590*</td>
<td>1,940*</td>
<td>1,330*</td>
<td>[-200 &gt; 1000]**</td>
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<tr>
<td>Pure Calcium</td>
<td>9,570*</td>
<td>5,960*</td>
<td>3,950*</td>
<td>2,090*</td>
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<td>Pure Iodine</td>
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<td>180,000*</td>
<td>93,200*</td>
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<td>Iodine Contract</td>
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<td>See footnote a</td>
<td>See footnote a</td>
<td>See footnote a</td>
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<td>Relative Iodine Enh.²</td>
<td>1.68</td>
<td>1.27</td>
<td>1</td>
<td>0.826</td>
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<td>1.70</td>
<td>1.28</td>
<td>1</td>
<td>0.81</td>
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<td>Kidney</td>
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<tr>
<td>Pancreas</td>
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<td>[30 - 50]**</td>
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<td>PMP</td>
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<td>-200***</td>
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<td></td>
<td></td>
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<td>120***</td>
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<tr>
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<td>990***</td>
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</table>
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Become familiar with these equations... and you can understand every “lower kV equals dose reduction for CTA” paper ever written.

\[ \mu(E) = a_1 \times \frac{1}{E^3} + a_2 \times f_{KN}(E) \]

\[ a_1(x, y) = C \times \rho_e \times Z^{n-1} \]

\[ a_2(x, y) = \rho_e \]

Z is 5-7 for soft tissue

Z is 53 for iodine
1. Inject via antecubital vein
1. Inject via antecubital vein

2. Blood goes into SVC and then into right atrium

3. Blood goes to right ventricle and goes out pulmonary artery to lungs

4. Returns via pulmonary vein and goes to left side of heart to be pushed out aorta via left ventricle.

5. First stop is supplying heart via coronaries. Then head via carotid and vertebral vessels.
Numbers increase with ROI locations via path blood follows from injection site → blood/I mix HU goes down as we move from site because of blood mixing diluting agent.
Contrast time of arrival will vary from person to person, but assuming an antecubital injection, values will generally be in the range of 7 to 10 seconds for the pulmonary artery, 12 to 15 seconds for the ascending aorta, 15 to 18 seconds for the abdominal aorta, and 30 to 40 seconds for hepatic parenchyma.


Intravenous Contrast Medium Administration and Scan Timing at CT: Considerations and Approaches

Kyongtae T. Bae

Published Online: Jul 1 2010 | https://doi.org/10.1148/radiol.10090908
 Longer and longer injections push CT enhancement up and delay peak enhancement.
Longer and longer injections push CT enhancement up and delay peak enhancement.

Bigger people have more blood... which dilutes contrast agent.
CT CONTRAST 104

Longer and longer injections push CT enhancement up and delay peak enhancement.

Bigger people have more blood... which dilutes contrast agent.

Arterial enhancement is “in and out” faster relative to parenchymal.
Equations Governing the Major Facets of Contrast Delivery

\[ \text{Volume}_{\text{arbitrary strength}} (\text{ml}) = \frac{\text{Strength}_{\text{reference}} (\text{mg I / ml})}{\text{Strength}_{\text{arbitrary}} (\text{mg I / ml})} \times \text{Volume}_{\text{reference strength}} (\text{ml}) \]  
[See Table 8.2]

\[ \text{Volume} (\text{ml}) = \text{Duration} (\text{s}) \times \text{Injection flow rate} (\text{ml / s}) \]  
[See Table 8.3]

Total iodine load (mg I) = Contrast concentration (mg I per ml) × Contrast volume (ml)

Scan delay = Time to optimal enhancement – \( \frac{1}{2} \) Scan duration

Scan speed (mm/s) = \( \frac{\text{Collimation} (\text{mm}) \times \text{Pitch}}{\text{Rotation time} (\text{s})} \)

Scan duration (s) = \( \frac{\text{Scan range} (\text{mm})}{\text{Scan speed} (\text{mm / s})} \)

= \( \frac{\text{Scan range} (\text{mm}) \times \text{Rotation time(s)}}{\text{Collimation} (\text{mm}) \times \text{Pitch}} \)

Contrast volume as a function of patient weight and contrast strength is shown in Table 8.3 for routine abdominal parenchymal enhancement.
CT CONTRAST 104

Equations Governing the Major Facets of Contrast Delivery

\[ \text{Volume}_{\text{arbitrary strength}} (\text{ml}) = \frac{\text{Strength}_{\text{reference}} (\text{mg I / ml})}{\text{Strength}_{\text{arbitrary}} (\text{mg I / ml})} \times \text{Volume}_{\text{reference strength}} (\text{ml}) \]  
\[ \text{Volume} (\text{ml}) = \text{Duration (s)} \times \text{Injection flow rate (ml / s)} \]  
\[ \text{Total iodine load (mg I)} = \text{Contrast concentration (mg I per ml)} \times \text{Contrast volume (ml)} \]

Iodine load versus contrast volume

All volumes are not created equal... a lower volume of high concentration agent can deliver the same total iodine as a larger volume of less concentrated agent

Want more enhancement?
Increasing volume can give more enhancement, but change contrast timing

Increasing concentration will increase enhancement and usually wont change timing
Scan delay = Time to optimal enhancement $- \frac{1}{2} \text{Scan duration}$
Scan delay = Time to optimal enhancement − \( \frac{1}{2} \) Scan duration

\[
\text{Scan speed (mm/s)} = \frac{\text{Collimation (mm)} \times \text{Pitch}}{\text{Rotation time (s)}}
\]

\[
\text{Scan duration (s)} = \frac{\text{Scan range (mm)}}{\text{Scan speed (mm/s)}} = \frac{\text{Scan range (mm)} \times \text{Rotation time (s)}}{\text{Collimation (mm)} \times \text{Pitch}}
\]
As a physicist, you should “own” scan duration. You can get scan length from dose report (DLP/CTDInvol).

- Yes I know about overscanning. It doesn’t matter here...
- As a physicist, you can suggest scanner specific scan delays differences based on scan speed.
  - Faster scanners usually need longer delays
- Physicists are good at multiplying and dividing numbers... so do site specific volume calcs for your sites having different strength agents.
CT Contrast 201...graduating to the clinic ;)

If every one gets 125 mls... big people see less enhancement.
Typical IV contrast prescription. Most sites around the world will have increases in I contrast with weight.

Example CTPA (PE) contrast prescription

**IV Contrast Parameters**

- **Patient weight < 140 kilos. (Less than 300 lbs.)**
  - 100 mL lohexol (Omnipaque) 300 MG/ML @ 5 mL/sec
  - 10 mL Sodium Chloride 0.9% @ 5 mL/sec

- **Patient weight 140-160 kilos. (300-350 lbs.)**
  - 100 mL iopamidol (Iovue 370) 370 mg/ml @ 5 mL/sec
  - 10 mL Sodium Chloride 0.9% @ 5 mL/sec

- **Patient weight > 160 kilos. (More than 350 lbs.)**
  - 150 mL iopamidol (Iovue 370) 370 mg/ml @ 5 mL/sec
  - 10 mL Sodium Chloride 0.9% @ 5 mL/sec

Example routine parenchymal phase torso contrast prescription

<table>
<thead>
<tr>
<th>Patient Weight (lbs)</th>
<th>Contrast Volume (ml or cc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>130 and less</td>
<td>80 (minimum amount to load)</td>
</tr>
<tr>
<td>140</td>
<td>86</td>
</tr>
<tr>
<td>150</td>
<td>92</td>
</tr>
<tr>
<td>160</td>
<td>98</td>
</tr>
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<td>165</td>
<td>101</td>
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<td>170</td>
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<td>175</td>
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<td>190</td>
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<td>200</td>
<td>122</td>
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<td>210</td>
<td>128</td>
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<td>220</td>
<td>135</td>
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<tr>
<td>230</td>
<td>141</td>
</tr>
<tr>
<td>240</td>
<td>147</td>
</tr>
<tr>
<td>250 and larger</td>
<td>150 (max amount to load)</td>
</tr>
</tbody>
</table>
Smaller people see big increase in enhancement (opposite effect and rationale for large people).

Within black lines we use weight based dosing.

Large patients see quick fall off in enhancement due to blood volume increase and beam hardening.
• Just due to beam hardening, we see a HUGE reduction in CT number with increasing patient size
  - 5 HU per cm of WED!

Parameterizing Size-Based Variations in CT Number
AAPM ePoster Library. Rose S. 07/12/20; 302594; BReP-SNAP-I-36 Topic: Multi-detector CT
BOLUS TRACKING

Allows for CT protocol acquisition tuned to patient specific cardiac output and flow dynamics

Administered 140.8 ml of 300 mg/ml using P3T Abdomen.

Bolus tracking time series
@Prof_TimStick’s Actionable information

• If your site isn’t using weight-based dosing...they will see large changes in enhancement with weight (and are probably wasting a lot of money)

• If your site isn’t using bolus tracking... also badness, not enough time today to get into that. But sick patients really benefit from BT as they usually need longer (tens of seconds) delays w.r.t. healthy people
Homework time!

- Go to PACS and figure out the scan timing as I have done on the following slides
- There will be site and vendor specific limitations and nuances you’ll need to understand...
Parenchymal liver scan

Baseline bolus tracking image

Scanner generated bolus tracking report

Dose slide. Series 200 on GE is the bolus tracking phase. (this study had a chest and a AP)
We have a story. At 1:11:26 the tech took the non contrast baseline image for ROI placement.

At 1:12:25 they started acquiring CINE images to monitor enhancement, taking an image every ~3-4 seconds… The pt hit enhancement threshold at 1:12:47.

It took ~7 seconds to move from bolus tracking position to start of scan (1:12:54-1:12:47)
I know we use a 40 second delay before acquiring the first bolus tracking image, so we started injection at 1:12:25 – 40 seconds.

1:11:45 was injection start

So time of scan from injection start was 1:12:54 – 1:11:45 = 69 seconds
Please feel free to reach out to me with questions
tszczykutowicz@uwhealth.org

@Prof_TimStick