Physiologic Basis of Contrast Medium Injection Strategies for Vascular, Neuro, and Abdominal CT

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Principles of CT – Angiography (Cardiovascular MDCT)

• fast, high resolution, volumetric CT Acquisition (+ EKG gating)
• strong arterial Contrast medium enhancement
• Post-processing 2D, 3D, (4D)

CT – Angiography Intracranial arteries

optimized 3D resolution
(0.5×0.5×0.3 mm)

Treatment planning of intracranial aneurysms

Balassy, Fleischmann, et al
Europ Radiol 2001

4 x 3 mm ICA Aneurysm

Relation to PcoA?
Relation to ant. clinoid?

4 x 3 mm ICA Aneurysm
CTA: 3D volume rendering

• video rendering (*.avi) simulating surgical view
• relation to anterior clinoid
• relation to carotid a.
• relation to PcoA

CTA Evolution

<table>
<thead>
<tr>
<th>Year</th>
<th>Equipment</th>
<th>Scan Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>SDCT</td>
<td>40 s</td>
</tr>
<tr>
<td>1999</td>
<td>4-MDCT</td>
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</tr>
<tr>
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Scan times for abd.aorta CTA
**Physiology and Pharmacokinetics**

Key Rules for CTA

.. to understand relationship between i.v. CM delivery and arterial enhancement (time-attenuation response)

**Early contrast dynamics (~ 1 min.)**

- i.v. contrast medium injection
- → r. heart → lung* → l. heart → arterial system
- → organs* → brain
- → kidney
- → spleen, intestines ...
- → liver
- → myocardium, muscles

*intravascular/interstitial

**Early Contrast Dynamics**

Key Rules for CTA

1. Arterial enhancement is proportional to iodine administration rates
2. Arterial enhancement increases ("cumulative") with longer injection duration

INPUT

- intravenous injection rate (mL/s)

OUTPUT

- arterial enhancement (ΔHU)

![Graphs showing contrast dynamics and enhancement response](image)

**INPUT**

- intravenous injection rate (mL/s)

**OUTPUT**

- arterial enhancement (ΔHU)

![Graph showing contrast dynamics and enhancement response](image)

**INPUT**

- intravenous injection rate (mL/s)

**OUTPUT**

- arterial enhancement (ΔHU)

![Graph showing contrast dynamics and enhancement response](image)
**INPUT**

- Intravenous injection rate (mL/s)
  - 4 mL/s
  - +16 mL
  - +4 mL
  - 128 mL

**OUTPUT**

- Arterial enhancement (ΔHU)

### Cardiac Output in CTEPH

- **Patient – Factor**
  - Arterial enhancement inversely related to:
    - Cardiac output (CO)
    - Central blood volume (CBV)
    - CO (and CBV) correlate with body weight
    - Usually unknown

  - 34 y.o. man
    - PAP: 63/12 (34)
    - CO: 5.4 L/min
    - CI: 2.5 L/min/m²
  - 59 y.o. woman
    - PAP: 67/23 (40)
    - CO: 3.4 L/min
    - CI: 1.7 L/min/m²

### Testbolus: 16 mL @ 4mL/s
**CTA Evolution**

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*Scan times for abd. aorta CTA*

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**Limitations of fast CTA Acquisition**

1. Short acquisitions (injections) give lower enhancement.
2. Increase the injection rate (iodine flux).
3. Increased risk of completely missing the bolus.
4. Risk of outrunning the bolus (aneurysms, peripheral CTA ...)

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**Abdominal 64-CTA (4s)**

- Bolus triggering in abd. aorta, without additional delay
- 302 HU

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**Abdominal 64-CTA (4s)**

- 64 HU
- Bolus triggering in abd. aorta, without additional delay

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**20-s scan**

- 5 ml/s for 20s
- 100 ml

**20-s scan**

- 5 ml/s for 20s
- 100 ml

---

**10-s scan**

- 5 ml/s for 10s
- 50 ml

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*Inj. rate (ml/s)*

*Delay (s)*

*Enhancement (HU)*

*Time (s)*
Integrated 'Design' of CTA Injection/Scanning Protocols

Traditional 'Design' of CTA Scanning/Injection Protocols

Scanning protocol

Injection protocol

Spatial resolution (z) vs. volume coverage

Arterial enhancement

Scan Time

try to scan as fast as possible

Integrated 'Design' of CTA Injection/Scanning Protocols

64 - channel CTA of the abdominal Aorta

Scantime: 10s for ALL patients (pitch variable) (automated tube current modulation)

Inj.duration: 18s for ALL patients

Delay: bolus trig. w/ 8s delay (t_{CMT}+8)

Integrated Scanning-Injection Protocols

64 - channel CTA of the abdominal Aorta

Scantime: 10s for ALL patients (pitch variable) (automated tube current modulation)

Inj.duration: 18s for ALL patients

Delay: bolus trig. w/ 8s delay (t_{CMT}+8)

Automated tube current modulation (Care-Dose 4D)

- q-ref.mAs: 250
- eff.mAs: 136
- mA: 318

81 y/o woman, AAA (161cm, 55 kg)

83 y/o man, AAA (173cm, 95 kg)

Weight

flow

volume

<35 kg

4.0 mL/s

72 mL

55–65

4.5 mL/s

81 mL

(average)

66–85

5.0 mL/s

90 mL

86–95

5.5 mL/s

99 mL

>95 kg

6.0 mL/s

108 mL

+ saline flush
Integrated Scanning-Injection Protocols

**64 - channel Lower Extremities**

- **Scantime:** 40s for all patients (pitch variable)
  - Automated tube current modulation
- **Inj. duration:** 35s for all patients
- **Delay:** Bolus triggering

<table>
<thead>
<tr>
<th>Weight</th>
<th>Biphasic Injection</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;55kg</td>
<td>20 mL (4.0mL/s) + 96 mL (3.2mL/s)</td>
</tr>
<tr>
<td>55kg</td>
<td>25 mL (5.0mL/s) + 120 mL (4.0mL/s)</td>
</tr>
<tr>
<td>&gt;85kg</td>
<td>28 mL (5.5mL/s) + 132 mL (4.4mL/s)</td>
</tr>
<tr>
<td>&gt;95kg</td>
<td>30 mL (6.0mL/s) + 144 mL (4.8mL/s)</td>
</tr>
</tbody>
</table>

Patient & Scan Specific Contrast Medium

**Dosing: How and Why?**

Current Stanford CTA injection strategy:
- Simple, weight based injection volumes and flow rates, combined with a fixed scan time.
- Automated bolus triggering.

Early contrast dynamics (~ 1 min.)

- i.v. contrast medium injection
  - r. heart → lung* → l.heart → arterial system
  - organs* → brain
  - → kidney
  - → spleen, intestines ...
  - → liver
  - → myocardium, muscles

Pharmacokinetic and physiologic principles

**Arterial enhancement (e.g. aorta)**
- Proportional to iodine flux
  - Inversely proportional to CO
- Increases with inj. duration

**Parenchymal enhancement (normal liver)**
- Proportional to total iodine dose,
  - Inversely proportional to BW

**Physiology and Pharmacokinetics**

All radiographic contrast media are extracellular fluid markers
- Intravascular space → arterial enhancement
- Interstitial space → parenchymal enhancement
Pharmacokinetic and physiologic principles

Arterial enhancement
• proportional to iodine flux
  \[ \text{flux (mg/s)} \times \text{duration (s)} \]
• inversely proportional to CO
• increases with inj. duration
• timing is critical
• CM volume not important

Parenchymal enhancement (normal liver)
• proportional to total iodine dose,
  \[ \text{iodine (mg)} \times \frac{1}{\text{BW (kg)}} \]

Blood Supply / Enhancement of the Liver
Enhancement of the (normal) liver
• proportional to total iodine dose
• inversely proportional to body weight
  \[ 600 \text{mg Iodine / kg BW} \]

Typical Protocols
Non Vascular, CM Enhanced
• Moderate volumes (based on body weight),
  depends on organ, lower flow rates, same injection duration (but not critical), fixed delay

Examples
• Neck: 1.0 mL/kg, in 30s, 40s delay
• Chest: 1.0 mL/kg, in 25s, 30s delay
• C/A/P: 1.6 mL/kg, in 40s, 70s delay
• CT V: 2.0 mL/kg, in 40s, 110+70 delay

Integrated Scanning-Injection Protocols
64-channel Biphasic Liver (Isovue 370)
Scantime: ~6s for patients (automated tube current modulation)
Inj.duration: 30s for ALL patients
Delay: \( t_{CM} + 16s \) (late art.), +34s (venous)

<table>
<thead>
<tr>
<th>Weight (kg)</th>
<th>Flow (mL/s)</th>
<th>Volume (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;55 kg</td>
<td>3.0 mL/s</td>
<td>88 mL</td>
</tr>
<tr>
<td>55–65</td>
<td>3.5 mL/s</td>
<td>104 mL</td>
</tr>
<tr>
<td>(average)</td>
<td>4.0 mL/s</td>
<td>120 mL</td>
</tr>
<tr>
<td>66–85</td>
<td>4.5 mL/s</td>
<td>136 mL</td>
</tr>
<tr>
<td>&gt;95 kg</td>
<td>5.0 mL/s</td>
<td>145 mL</td>
</tr>
</tbody>
</table>

6.22 CT VENOGRAPHY
CONTRAST: (Omni 350)
Injection (~1.8–2.0 mL/kgBW in 40s)
• <121 lbs (<55 kg): 100 mL @ 2.5 mL/s
• 121–143 (<65 kg): 120 mL @ 3.0 mL/s
• 143–187 (75 kg): 135 mL @ 3.5 mL/s
• 187–209 (>85 kg): 150 mL @ 4.0 mL/s
• >209 lbs (>95 kg): 175 mL @ 4.4 mL/s

Group 1: diaphragm to symphysis, Delay: 110s
Group 2: symphysis to below knees, Prep Group Delay: 70s

+ saline flush
Parenchymal enhancement:
• follows portal venous enh.
• lower & later (10-15s)
• proportional to \(I / \text{kg BW}\)

Hepatic MD-CT: Phase Separation

• follows arterial enhancement
• lower
• later (1-5s)

Hypervascular lesions:
• hypervasc. lesions
• (portal venous inflow ph.)

Parenchymal Phase (hepatic venous ph.):
• hypoattenuating lesions
• \(t_{\text{CMR}} + 40s\)
MD-CT: Hepatic Enhancement
MD-CT of the liver in patients with HCC

<table>
<thead>
<tr>
<th></th>
<th>Iopamidol 300mg/ml</th>
<th>Iopamidol 370mg/ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total J dose (average)</td>
<td>0.5 g/kg (31 g)</td>
<td>0.3 g/kg (31 g)</td>
</tr>
<tr>
<td>Injection rate (average)</td>
<td>3.3 ml/s</td>
<td>3.2 ml/s</td>
</tr>
<tr>
<td>Iodine Administration rate</td>
<td>17.3 mg/kg/s (1.0 g/s)</td>
<td>20.3 mg/kg/s (1.2 g/s)</td>
</tr>
<tr>
<td>Injection duration</td>
<td>30 s</td>
<td>25 s</td>
</tr>
<tr>
<td>Lesion to liver contrast</td>
<td>27.2 HU</td>
<td>40.9 HU</td>
</tr>
</tbody>
</table>

K. Awai, Radiology 2002; 224, 377

Contrast Delivery for Hepatic MDCT

- correct timing → relative to $t_{CMT}$
- suspected hypervascular lesions → maximum iodine administration rate, to maximize lesion/background contrast (mL/s per kg BW)
  - late arterial phase ($t_{CMT} + -10-15s$)
- parenchyma, hypoattenuating lesions → large iodine dose (~45g; 600mg/kg BW)
  - parenchymal phase ($t_{CMT} + -40s$)

THANK YOU!