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

Dominik Fleischmann
Department of Radiology
Stanford University

---

**Principles of CT – Angiography**

(Cardiovascular MDCT)

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

---

**CTA Evolution**

<table>
<thead>
<tr>
<th>Year</th>
<th>Technology</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>
<td>25 s</td>
</tr>
<tr>
<td>2002</td>
<td>16-MDCT</td>
<td>10 s</td>
</tr>
<tr>
<td>2004</td>
<td>64-MDCT</td>
<td>4 s</td>
</tr>
</tbody>
</table>

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

---

**INPUT**

intravenous injection rate (mL/s)

---

**OUTPUT**

arterial enhancement (ΔHU)

---

* i_CM: CM transit time
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

think about CTA injection protocols as

Flow × duration

- 120 mL @ 4mL/s
- 150 mL @ 5mL/s
- 60 mL @ 6 mL/s
"Patient – Factor"

arterial enhancement inversely related to:
- Cardiac output (CO)
- Central blood volume (CBV) 

CO (and CBV) correlate with body weight \(^1\)
at least in pts. with ~normal LVF

\(^1\) Hittmair & Fleischmann, JCAT 2001

**Cardiac Output in CTEPH**

- 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

**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)

**20-s scan**
- 5 ml/s for 20s
- 100 ml

**10-s scan**
- 5 ml/s for 10s
- 50 ml

**Integrated ‘Design’ of CTA Injection/Scanning Protocols**

- Scanning protocol: use fixed scan time
- Injection protocol: arterial enhancement

\(\rightarrow\) time (s)
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 ($t_{\text{CMT+8}}$)

---

**Automated tube current modulation** (CareDose-4D)

$q\text{-ref.mAs: } 250$

$\text{eff.mAs: } 136$

$m\text{A: } 282$

$q\text{-ref.mAs: } 250$

$\text{eff.mAs: } 270$

$m\text{A: } 318$

---

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

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

---

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

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

---

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

---

Integrated Scanning-Injection Protocols

64 - channel Biphasic Pancreas

**Scantime:**
- ~6s for patients
  (automated tube current modulation)

**Inj. duration:**
- 30s for ALL patients

**Delay:**
- $t_{\text{CMT+25s}}$ (panc.phase), +25s (venous)

---

**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

* intravascular/interstitial

---

**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 (e.g. aorta)**
  - • proportional to Iodine flux
  - • inversely proportional CO
  - • increases with inj. duration

- **Parenchymal enhancement (normal liver)**
  - • proportional to total Iodine dose,
  - • inversely proportional to 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

---

**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**
Blood Supply / Enhancement of the Liver

 Enhancement of the (normal) liver

 - proportional to total iodine dose
 - inversely proportional to body weight

→ 600mg iodine / kg BW

---

Integrated Scanning-Injection Protocols

64 - channel Biphasic Liver (Isovue 370)

- **Scantime:** ~6s for patients
- **Inj. duration:** 30s for ALL patients
- **Delay:** \( t_{CMT} + 16s \) (late art.), +34s (venous)

<table>
<thead>
<tr>
<th>weight</th>
<th>flow</th>
<th>volume</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) 66-85</td>
<td>4.0 mL/s</td>
<td>120 mL</td>
</tr>
<tr>
<td>86-95</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>

+ saline flush

---

MD-CT: Hepatic Enhancement

Parenchymal enhancement:
- follows portal venous enh.
- lower & later (~10s)
- proportional to I / kg BW

Hypervascular lesions:
- follows arterial enhancement
- lower
- later (~1-5s)

---

Hypervascular lesions:
- follows arterial enhancement
- lower
- later (~1-5s)
**MD-CT: Hepatic Enhancement**

### Arterial Phase
- CTA
- \( t_{CMT} \)

### Late Arterial Phase
- Portal venous inflow phase
- Hypervascular lesions
- \( t_{CMT} + 10-15 \text{s} \)

### Parenchymal Phase
- Hypoattenuating lesions
- \( t_{CMT} + 40 \text{s} \)

---

**Hepatic MD-CT: Phase Separation**

### (Early) Arterial Phase
- CTA
- \( t_{CMT} \)

### Late Arterial Phase
- Portal venous inflow phase
- Hypervascular lesions
- \( t_{CMT} + 15 \text{s} \)

### Parenchymal Phase
- Hypoattenuating lesions
- \( t_{CMT} + 40 \text{s} \)

---

**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 (\( t_{CMT} + \sim 10-15 \text{s} \))
- Parenchyma, hypoattenuating lesions → large iodine dose (~45g; 600mg/kg BW)
  - Parenchymal phase (\( t_{CMT} + \sim 40 \text{s} \))

---

**MD-CT: Hepatic Enhancement**

### Lesion-to-liver attenuation difference always greatest in portal venous inflow phase

---

**MD-CT of the liver in patients with HCC**

- Total J dose (average)
  - 0.5 g/kg (31 g)
  - 0.5g/kg (31 g)
- Injection rate (average)
  - 3.3 mL/s
  - 3.2 mL/s
- Iodine dose (~45g; 600mg/kg BW)
  - 17.3 mg/kg/s (1.0 g/s)
  - 20.3 mg/kg/s (1.2 g/s)
- Injection duration
  - 30 s
  - 25 s
- Lesion to liver contrast
  - 27.2 HU
  - 40.9 HU

---

**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 (\( t_{CMT} + \sim 10-15 \text{s} \))
- Parenchyma, hypoattenuating lesions → large iodine dose (~45g; 600mg/kg BW)
  - Parenchymal phase (\( t_{CMT} + \sim 40 \text{s} \))