CT Venography

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Introduction

- CT venography (CTV) is a technique targeted to assess venous anatomy, determine venous patency & delineate collateral circulation
- Non-invasive, simple protocols, wide anatomic coverage, short acquisition time, and ability to be combined with arterial-phase CTA
Lecture Outline

• Basic Clinical Options for Venous Imaging
  – Venous Imaging Modalities

• CT Scan Protocols
  – Indirect CTV
  – Direct CTV

• Selected Regional Applications
  – UE
  – Chest
Venous Imaging Modalities – The competition

- Doppler Ultrasound (US)
- MR Venography
- Catheter venography
- Nuclear venography
Doppler US

- Well established clinical utility
- No ionizing radiation
- Portable
- Inexpensive
- Flow direction information
- Operator / Patient dependent
- Some areas inaccessible (pelvis, SVC)
- Collateral pathways not well delineated
Doppler US

- Sens/ Spec ~ 95% for fem-pop DVT in ideal situations
# Performance of Doppler vs. CTV in ICU patients – LE DVT

<table>
<thead>
<tr>
<th></th>
<th>Sens</th>
<th>Spec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indirect CTV</td>
<td>70</td>
<td>96</td>
</tr>
<tr>
<td>Doppler US</td>
<td>70</td>
<td>100</td>
</tr>
</tbody>
</table>

Taffoni, AJR, 2004
MR Venography - Positives

- Excellent for pelvic venous system, CNS
- May not require contrast
- SI ratio thrombus:blood higher for MRV vs. CTV
  - 3.7-8:1 vs 1.8-3.2 *
- For PE: Sens 80-95%, Spec 95%, depends on technique (Perf imaging best)+
- For DVT: Sens ~92%, Spec ~95%
- 0.25 mmol/kg Gd better than 0.125 mmol/kg

* Kluge, AJR, 2006  + Sampson, Eur Radiol 2007; 17:175-181
Combo MR-PA / Indirect MRV

- **MRA:** TRuFISP, perfusion, MRA (0.25mmol/Kg)
- **MRV:** 3D FLASH w/ PV coil, voxel size of 1.2x0.8x1.1 mm
  - High agreement w/ CTA/CTV but requires a change in coil and pt. position to obtain MRV after chest MRA
- Good agreement w/ Doppler in legs, moderate in pelvis

Kluge, AJR, 2006
MR Venography - Negatives

- Expensive, availability sometimes limited
- Exam may be lengthy
- Pt. cooperation?
- Spatial resolution (vs other choices)
- Limited anatomic coverage
Radionuclide Venography

• 99mTc-labeled MAA
• 99mTc-labeled RBC
• 99mTc-human serum albumin
• 99mTc-labeled platelets
  – Direct evidence of acute / active DVT
  – BUT: Arduous prep, false positives – pts on heparin
• 99mTc-apcitide (GIIb/IIia receptor binding)
  – Can tell acute (+) vs. chronic (-) clot
  – Interpreter dependent?

Anatomic agents, indirect evidence
Catheter Venography

- Considered the “gold standard”
- Invasive (but can treat lesions)
- You only see what you can fill
- Risks:
  - Minor Complications: 18%
  - Thrombosis: 2%
  - Bronchospasm, Contrast reactions, etc
CTV: Challenges

• Goal: visualize all venous structures, with good opacification, but without artifacts

Direct CTV

Indirect CTV
CTV: Challenges

• Goal: visualize all venous structures, with good opacification, but without artifacts

Direct CTV
• good opacification (too good; needs dilution)
• but difficult to visualize all venous structures or full extent of collateral circulation

Indirect CTV
• visualizes all veins (recirculation of CM)
• but difficult to achieve strong enhancement; timing difficulties
60M smoker, r/o lung cancer

Routine chest with contrast: 100cc contrast @ 2cc/sec, 40 sec diagnostic delay
CTV: Challenges

• Goal: visualize all venous structures, with good opacification, but without artifacts

**Direct CTV**
• good opacification (too good; needs dilution)
• but difficult to visualize all venous structures or full extent of collateral circulation

**Indirect CTV**
• visualizes all veins (recirculation of CM)
• but difficult to achieve strong enhancement; timing difficulties
Indirect CTV

L BRACHIAL, CEPHALIC VV. CLOT

LIJV STENOSIS
CTV: Imaging Techniques

• **Direct Venography (first pass):**
  – Dilute contrast (1:5 - 1:10)
  – Fill veins of interest (50cc or more)
  – Slow infusion, 1-2cc/sec
  – Start acquisition towards end of infusion

• **Indirect Venography (recirculation)**
  – 100-150cc contrast needed for adequate venous opacification
  – Empiric imaging delay
    • 60 seconds: upper extremity and pelvic veins
    • 3 to 3.5 min: lower extremity veins
  – Smart prep off vein of interest

40M prior left arm DVT. Acute pain and swelling of the left upper arm, rule out DVT.

1:5 dilution (20cc contrast + 80cc NS) @ 3cc/sec. Tourniquet around biceps region, released 15 sec before initiation of scan.
CTV: Imaging Techniques

• Direct Venography (first pass):
  – Dilute contrast (1:5 or 1:6)
  – Fill veins of interest (50cc or more)
  – Slow infusion, 1-2cc/sec
  – Start acquisition towards end of infusion

• Indirect Venography (recirculation)
  – 100-150cc contrast needed for adequate venous opacification
  – Empiric imaging delay
    • 60 seconds: upper extremity and pelvic veins
    • 3 to 3.5 min: lower extremity veins
  – Smart prep off vein of interest

65M with metastatic lung ca and recent PEs. An IVC filter was placed but did not fully deploy. A second IVC filter was placed above the first one.

120cc contrast, diagnostic delay = 70sec
CTV: Imaging Techniques

- **Direct Venography (first pass):**
  - Dilute contrast medium (1:5 or 1:6)
  - Fill veins of interest (50cc or more)
  - Slow infusion, 1-2cc/sec
  - Start acquisition towards end of infusion

CTV: Imaging Techniques

- **Indirect Venography (recirculation)**
  - ~ 150cc contrast needed for adequate venous opacification (2 mL/kg)
  - Empiric imaging delay
    - 60 sec: thoracic
    - 70-80 sec: upper extremity
    - 11-15 sec: pelvis
    - 150 – 180 sec: lower extremity veins
  - ? Smart prep off vein of interest
  - Want veins >80HU to be diagnostic
**INDIRECT CT VENOGRAPHY**

- Large bolus of contrast followed by a delay to image the recirculation phase
  - 150 mL (2 mL/kg BW)

- Empiric Delay (depends on venous territory)
  - 60 seconds: thoracic
  - 70–80 seconds: upper extremity
  - 110 seconds: abdomen & pelvis
  - 180 seconds: lower extremity

- NO Bolus Trigger
  - Not an exact science, no target HU
Combo Direct / Indirect CTV

- R/O LUE venous malformation; L hand and arm swelling
- 120 mL @ 5 mL/s followed by 100 mL 1:10 dilution at 2.5 mL/s via L hand IV
- Caudocranial acquisition
Combo Direct / Indirect CTV

Protocol and dataset courtesy of Scott Alexander, MD
Combo Direct / Indirect CTV
Combo Direct / Indirect CTV
CTA for TOS: Combo Direct / Indirect CTA

- Ipsilateral IV, arm over head w/ palm taped up
  120 mL **full-strength** @ 4ml/s
- **Chase**: 100 mL **dilute** (10%) contrast @2.5 ml/s
  - Can inject contralateral arm at same time (dilute)
- 65 sec empiric delay, scan caudo-cranial
- Arm down, immediate re-scan cranio-caudal
- **Volumetric Review**
MRA for TOS: Blood Pool MRA

- Anatomic imaging: Oblique sag and cor T₁/T₂
- Relaxed and Challenged imaging:
  - Gadofosveset (blood pool agent)
  - Breath-hold FSPGR, ECG-gated, high resolution (1.8 mm ST, 448 x 448 matrix) CORONAL acquisition
    - Challenged: Arm Abducted
    - Relaxed: Arm Down
Venography: Common Clinical Indications

**Upper Extremity / Chest**
- SVC syndrome (malignancy, post-XRT)
- Catheter-related complications (clot, stenosis)
- DVT
- Thoracic Outlet syndrome
- Dialysis access

**Lower Extremity**
- DVT (+/- PE study)
- May-Thurner syndrome
- Pre-transplant evaluation

**General**
- Venous stent evaluation
- Vascular Malformations – treatment planning
SVC Obstruction

NOT A COMPREHENSIVE SYSTEM!

- Stanford, *et al.*: Venography series with 4 main collateral pathways
  - I. Partial SVC occlusion w/ patent Azygous v.
  - II. Near complete obstruction SVC w/ antegrade flow azygous → RA
  - III. Near complete obstruction SVC w/ retrograde flow azygous
  - IV. Complete obstruction SVC + one or more major tributaries (e.g. azygous v.)

SVC Occlusion

- Mass / Adenopathy
- Catheter / Device (pacer / ICD leads)
- Fibrosing Mediastinitis
- Catheter + Mass
- Catheter + pleural effusion
- Thrombus
- Catheter + lymph nodes
SVC Syndrome from Tumor
## Classification of all collateral pathways one series


<table>
<thead>
<tr>
<th>Occlusion level&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Collateral pathways&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Stanford scheme</th>
<th>Other features</th>
</tr>
</thead>
<tbody>
<tr>
<td>OSC</td>
<td>2</td>
<td>Unclassified</td>
<td>Systemic portal shunt</td>
</tr>
<tr>
<td>OSC</td>
<td>1</td>
<td>Type I</td>
<td>Systemic portal shunt</td>
</tr>
<tr>
<td>OSC</td>
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<td>Unclassified</td>
<td>Azygos distal opacification</td>
</tr>
<tr>
<td>SVA</td>
<td>2</td>
<td>Type IV</td>
<td>Systemic portal shunt</td>
</tr>
<tr>
<td>SVA</td>
<td>1</td>
<td>Type IV</td>
<td>Systemic pulmonary shunt</td>
</tr>
<tr>
<td>BBI</td>
<td>1</td>
<td>Unclassified</td>
<td>Systemic portal shunt</td>
</tr>
<tr>
<td>BBI</td>
<td>1</td>
<td>Type II</td>
<td>Systemic portal shunt</td>
</tr>
<tr>
<td>SBL</td>
<td>1</td>
<td>Type IV</td>
<td>Systemic portal shunt</td>
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<tr>
<td>SBB</td>
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<td>Unclassified</td>
<td>Systemic portal shunt</td>
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<tr>
<td>SBB</td>
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<td>Unclassified</td>
<td>Systemic portal shunt</td>
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The patterns are grouped by the superior vena cava (SVC) occlusion level and presence of four major pathways. Other features represent variations from the classic pathways.

<sup>a</sup> OSC, only SVC; SVA, SVC + azygos vein occlusion; BBI, bilateral brachiocephalic + incomplete SVC; SBB, SVC + bilateral brachiocephalic vein; SBL, SVC + left brachiocephalic vein; SBR, SVC + right brachiocephalic vein.

<sup>b</sup> Collateral pathways: 1, azygos-hemiazygos; 2, internal mammary vein; 3, lateral thoracic vein; 4, vertebral plexus.
Most common venous collaterals listed in order of frequency (n = 21).

<table>
<thead>
<tr>
<th>Collateral</th>
<th>Incidence in this cohort [n (%)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Azygos vein</td>
<td>19 (90.5)</td>
</tr>
<tr>
<td>Thoracoepigastric vein</td>
<td>18 (85.7)</td>
</tr>
<tr>
<td>Mediastinal vein</td>
<td>17 (80.9)</td>
</tr>
<tr>
<td>Internal mammary vein</td>
<td>16 (76.2)</td>
</tr>
<tr>
<td>Hemiazygos vein</td>
<td>15 (71.4)</td>
</tr>
<tr>
<td>Lateral thoracic vein</td>
<td>15 (71.4)</td>
</tr>
<tr>
<td>Pericardiophrenic vein</td>
<td>15 (71.4)</td>
</tr>
<tr>
<td>Paravertebral vein</td>
<td>14 (66.6)</td>
</tr>
<tr>
<td>Intercostal vein</td>
<td>12 (57.1)</td>
</tr>
<tr>
<td>Thoracoacromion trunk</td>
<td>12 (57.1)</td>
</tr>
<tr>
<td>Capsular/surface liver vein<em>a</em></td>
<td>11 (52.3)</td>
</tr>
<tr>
<td>Bilateral (superior/inferior) phrenic vein<em>a</em></td>
<td>11 (52.3)</td>
</tr>
<tr>
<td>Thoracodorsal scapular vein</td>
<td>10 (47.6)</td>
</tr>
<tr>
<td>Superficial epigastric vein<em>a</em></td>
<td>10 (47.6)</td>
</tr>
<tr>
<td>Superior epigastric vein<em>a</em></td>
<td>9 (42.8)</td>
</tr>
<tr>
<td>Inferior epigastric vein<em>a</em></td>
<td>9 (42.8)</td>
</tr>
<tr>
<td>Accessory hemiazygos vein</td>
<td>8 (38.1)</td>
</tr>
</tbody>
</table>

*a* Abdominal collateral.
A.  
1 = superior vena cava  
2 = inferior vena cava  
3 = azygos vein  
4 = hemiazygos vein  
5 = accessory hemiazygos vein  
6 = ascending lumbar vein  
7 = lateral thoracic vein  
8 = superficial epigastric vein  
9 = internal mammary vein  
10 = inferior epigastric vein  
11 = pericardiophrenic vein  
12 = right superior (highest) intercostal vein  
13 = left superior (highest) intercostal vein  
14 = intercostal vein  
15 = inferior phrenic vein  
16 = suprarenal vein

B.  
1 = superior vena cava  
2 = brachiocephalic (innominate) vein  
3 = subclavian vein  
4 = internal jugular vein  
5 = external jugular vein  
6 = jugular venous arch  
7 = superior thyroidal vein  
8 = middle thyroidal vein  
9 = inferior thyroidal vein  
10 = facial vein  
11 = anterior jugular vein  
12 = vertebral venous plexus  
13 = vertebral vein, and  
14 = deep cervical vein

From: Kim: J Comput Assist Tomogr, Volume 28(1). January/February 2004. 24-33
Left Superior Intercostal Vein

Pericardiophrenic Vein
Inferior Phrenic v. (to IVC)
Paravertebral vv.

Capsular / Liver surface vv.

Systemic – portal collaterals

Paravertebral vv.
Venous collaterals organized by plexus systems – Easier, more complete to report

<table>
<thead>
<tr>
<th>Suggested nomenclature</th>
<th>Includes these venous collaterals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertebral venous plexus</td>
<td>Paravertebral veins, vertebral veins</td>
</tr>
<tr>
<td>Mediastinal venous plexus</td>
<td>Mediastinal vein, pericardial veins, parietal veins, pericardiophrenic vein</td>
</tr>
<tr>
<td>Esophageal venous plexus</td>
<td>Paraesophageal vein, submucous venous plexus, esophageal vein, periesophageal vein</td>
</tr>
<tr>
<td>Diaphragmatic venous plexus</td>
<td>Superior phrenic vein, inferior phrenic vein, phrenic vein, diaphragmatic vein</td>
</tr>
<tr>
<td>Thoracoepigastric venous plexus</td>
<td>Thoracoepigastric vein, subcutaneous vein, areolar venous plexus, veins surrounding breast, anterior chest wall veins</td>
</tr>
</tbody>
</table>

The poster child for revised venous plexus nomenclature......
Chest / Upper extremity cases
Thoracic Outlet Syndrome (TOS)

- Symptomatic compression/entrapment of neurovascular structures by bone and/or soft tissue as they pass through the cervicoaxillary canal

- 90% Neurogenic (PT, postural Tx, NSAIDs)
  - 10% Vascular
  - Venous > Arterial
Components of Cervico-Axillary Canal

- Interscalene Triangle: #1 site of compression
- Costoclavicular Space: #1 site for vascular TOS
- Retro-pectoralis minor space: #1 site for masses
CTA for TOS: Combo Direct / Indirect CTA

- Ipsilateral IV, arm over head w/ palm taped up
  120 mL **full-strength** @ 4ml/s
- **Chase:** 100 mL **dilute** (10%) contrast @2.5 ml/s
  - Can inject contralateral arm at same time (dilute)
- 65 sec empiric delay, scan caudo-cranial
- Arm down, immediate re-scan cranio-caudal
- **Volumetric Review**
Bilateral Direct / Indirect CTA
Venous TOS: “Effort Thrombosis”

- Paget-Schroetter syndrome (PSS)
- AKA axillo-subclavian venous thrombosis
- “Overhead” athletes
- PE in up to 1/3!! *
- Post-thrombotic syndrome (later)

Effort Thrombosis:
36 YO weightlifter
Post-Op 1\textsuperscript{st} rib resection
Arterial TOS

- “Overhead athletes”
- SX: Coolness, weakness, diffuse arm pain (ischemic neuritis)
- Cause: Repetitive compression injury
  - Anatomic predisposition (tight CCS)
  - Post-traumatic, bony callus
  - Scalene hypertrophy
Arterial and Venous TOS: 16 YO Volleyball Athlete
SVC and central veins
LUNG CA with SVC syndrome
35M hx thigh sarcoma. Facial swelling & chest wall varicosities when he bent over to tie his shoes.

Documented central venous obstruction.

Treatment planning: Assess vascular access, particularly axillary & subclavian veins B/L.

Simultaneous bilateral arm injection:
1: 6 dilution (30cc contrast + 170 cc NS, each arm) @ 2cc/sec.
90cc contrast, 60 sec diagnostic delay.
Imaging range: angle of mandible to lesser trochanters.
SVC Occlusion from Aneurysm
RSCV Occlusion – Previous Catheters
LT IJ injection 1:2 dilution (12cc contrast + 12cc NS @ 2cc/sec) acquired on flat-panel detector Dyna-CT.
IV cannula in left arm. 100cc contrast + 20cc NS flush, diagnostic delay = 60sec.

60F ESRD, 3 overlapping stents placed for venous stenosis from previous catheters.

Courtesy of Anne Chin, MD
LIV encasement – Adenopathy
In-stent LIV / SVC thrombus
LIV Occlusion – Dialysis Patient with LUE AVF
EJ arch, lat thoracic, and pharyngeal collaterals
62F central venous catheter for chemotherapy.

100cc contrast, diagnostic delay = 60sec
100cc contrast, diagnostic delay = 60sec

62F central venous catheter for chemotherapy.
MISC UE Cases
RUE Hemangiomatosis
Pelvis / LE Cases
MAY-THURNER:
SUPERFICIAL VENOUS VARICOSITIES
Lack of Augmentation – “suspect upstream obstruction”
S/P Mechnical Lysis, TPA, and PTA
Indirect Dx by arterial CTA
F/U stenting for May Thurner

28F May-Thurner syndrome, CIV/EIV stent placement 3 years ago

- 120 cc contrast
- Monitoring delay = 40sec
- Smart prep at infrarenal IVC

Courtesy of Anne Chin, MD
Vascular Mapping
Extremity Hemangiomatosis Venous Mapping

Protocol:
CTA Runoff; + 40 sec interscan delay;
Caudocranial scan 16x0.75mm

Major drainage routes:
LEFT 12\textsuperscript{th} IC VEIN
Left Gonadal V.
Greater Saphenous V.
IVC Aneurysm
IVC Aneurysm

- Rare
- Saccular > fusiform
- Cause unknown, may be related to anomalous connections in embryologic venous systems
  - Acquired (trauma, AV fistulae)
  - May be associated with other congenital CV anomalies
- Sx: Thrombosis (7/16), pain, rupture, leg swelling
  - Massive penile bleeding (1/16)
  - PE if thrombus
Conclusions

• CTV is a robust, non-invasive technique to visualize venous anatomy, and can be combined with arterial phase CTA

• Direct CTV: better opacification, less CM needed, but only the injected and downstream veins will be visualized

• Indirect CTV: all venous anatomy is delineated, empiric delay or smart-prep at ROI, opacification occasionally unpredictable

• “Combo CTV”: Perhaps the best choice for excellent and consistent venous opacification

• Provides accurate 3D visualization of venous anatomy for treatment planning
Thanks to:

Dominik Fleischmann, MD
Frandics Chan, MD PhD


Sampson, FC, et al. *Eur Radiol* 2007; 17:175-181. (Pooled sensitivity=91.5%; Pooled specificity=94.8% compared with conventional venography)

Kluge, A. et al. *AJR* 2006; 186:1686 – 1696 (Combo MRA/MRV for PE/DVT)


Key References

Kluge, A. et al. AJR 2006; 186:1686 – 1696 (Combo MRA/MRV for PE/DVT)


Lawler LP, et al. Radiographics 2002; 22:S45-S60 (normal and accessory chest venous pathways)

Demos TC, et al. AJR 2004; 182:1139-1150 (Venous anomalies of chest)