CT Contrast Protocols for Different Organ Imaging

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PET-CT: CT Contrast Protocols

Why use Intravenous Contrast (IV) with PET-CT?

- To get the best of both worlds
- PET-CT is PET + CT
PET → PET/ct → PET-CT

Emerging understanding 2002-2009

Diagnostic AC PET → AC PET with CT anatomic localization → PET + diagnostic CT for merged diagnosis exam

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PET-CT Scanners

What was PET-CT originally intended to be?

• “It is to be emphasized that the documented objectives of this development was to offer *clinical CT* and *clinical PET* scans from a single device; the intended purpose of the CT was to provide clinical patient information and not just attenuation correction and localization alone.”

David Townsend, Co-Inventor of PET/CT

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Intravenous Contrast (IV)

- IV contrast do not make a CT “diagnostic” including in the setting of body oncology imaging. IV contrast is an enhancement making interpretation of the morphologic findings of the CT scan easier and more accurate.
- Use of oral and IV contrast in the setting of PET/CT never really was a problem and was used in the late 1990s at the University of Pittsburgh on the first PET-CT prototype and used by many in 2001 as the first commercial scanners became available.

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Fully optimized whole torso breath hold CT with oral and IV contrast performed as part of PET/CT exam using one of the first commercial PET/CT scanners in 2001

Antoch, et. al. AJR 2002; 179:1555-1560
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**Intravenous Contrast**

- Positively depicts vascular space
- Enhances soft tissue delineation
- Depicts internal anatomy of viscera
- Tumor neo-vascularity can be seen
Mediastinal lymph nodes, enlarged and non-enlarged, in patient with right hilar mass positive for NSCLC.
Vascular structures and landmarks and soft tissue features depicted by use of intravenous contrast.
Margins of squamous cell carcinoma depicted on CT by contrast enhancement of tumor neovascularity.
FDG PET delineates primary lung cancer from post obstructive atelectasis grossly, CT contrast enhancement to within mm.
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Intravenous Contrast

• Determining extent of tumor (T staging) is largely dependent on CT findings.
Primary lung carcinoma directly invading diaphragm into liver
Quiet breathing 240 mA with oral and IV contrast and IV fluids and Lasix for urinary tracer washout.
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Intravenous Contrast

• Not all cancer is FDG avid, CT requires IV contrast to depict many of these cancer manifestations

• Non-FDG avid cancers (cystic and mucinous neoplasms, renal cell carcinoma, hepatocellular carcinoma, carcinoid, low grade and small cell type lymphoma, prostate cancer)

• Highly necrotic tumors
Recurrent hepatocellular carcinoma seen in liver on portal venous phase contrast enhanced CT.
Negative non-contrast CT, negative FDG PET
Non-FDG avid renal cell carcinoma with no contour abnormality clearly seen on contrast enhanced CT.
Brain metastasis of breast cancer

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Intravenous Contrast

- Certain clinically important non-cancer incidental findings seen in cancer patients on CT only require IV contrast
- DVT, thrombus associated with central venous lines, pulmonary embolism
Deep venous thrombus
Pulmonary embolism
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Intravenous Contrast

• Negative oral contrast depends on bowel wall enhancement by intravenous contrast for optimal depiction on mucosal and serosal abnormalities
Negative Oral Contrast with IV Contrast
Serosal implant metastases of ovarian cancer depicted on negative oral contrast exam with intravenous contrast. Courtesy of Joseph Busch, MD.
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PET-CT and IV Contrast

- Undiluted contrast laden venous blood in the subclavian vein and superior vena cava will cause beam hardening artifacts on CT with resultant hot spot artifacts on the attenuation corrected PET images at common infusion rates (2-3.5 ml/sec)
- 13% of subjects in study of 30 patients

Subclavian vein contrast artifact can occur when CT scanning protocol is not properly optimized for whole body scanning.

Contrast CT

Attenuation corrected OSEM using contrast CT attenuation

Non-attenuation corrected FBP

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Intravenous Contrast and SUVs

- No statistically or clinically significant spuriously elevated SUV that might interfere with diagnosis due to use of IV contrast enhanced CT for attenuation correction of the PET images (< 10% for tissues)
- No artifacts on images when CT properly performed

Application of Intravenous Contrast in PET/CT. Does It Really Introduce Significant Attenuation Correction Error?

PET/CT With Intravenous Contrast can be used for PET Attenuation Correction in Cancer Patients Berthelsen AK, et. al. Euro J Nucl Med 2005 32: 1167-1175

Quantifying the Effect of IV Contrast Media on Integrated PET/CT: Clinical Evaluation.
Mawlawi O, et. al. AJR 2006 186: 308-319
PET/CT Mythology:

You have to perform two complete CT acquisitions if you want a “diagnostic CT” as part of the PET/CT, a “localization CT scan” and a separate “diagnostic CT scan” to avoid contrast artifacts

• No, if the fully optimized contrast enhanced CT scan is performed properly there are no clinically significant artifacts on images or with SUV values

• Contrast related artifacts are more a problem on the CT than the attenuation corrected PET images
PET-CT Scans

PET-CT protocols

30-50 mAs CT    PET Emission    100-150 mAs CT with contrast

Whole torso PET-CT with diagnostic CT and CT “attenuation scan”
PET-CT Scans

PET-CT protocols

100-150 mAs CT  PET Emission with contrast

Whole torso PET-CT with diagnostic CT
PET-CT: CT Contrast Protocols

Intravenous Contrast

- Chemical composition is iodinated aromatics with solublizing functionality
- Opacification capacity given by mg iodine per mL (ie 270, 300, 320, 350, 370 mg/mL)
- Three general classes:
  - Ionic (hypertonic - no longer widely used)
  - Non-ionic (low osmolarity - commonly used)
  - Isotonic non-ionic (iso osmolar - newest class)

Frequently asked questions: Iodinated Contrast Agents
Bettmann MA  Radiographics 2004; 24:S3-S10

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Intravenous Contrast - Relative Contraindications

- Renal failure
- Renal insufficiency
- History of contrast reaction, allergy
- Diabetes on oral therapy (metformin)
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Intravenous Contrast - Contrast Reactions

- Reviewed 29,508 patients that underwent CT with IV contrast (iopromide)
  - 0.64% mild adverse reaction
  - 0.064% moderate adverse reaction
  - 0.013% severe adverse reaction
  - 0.003% death

Kortele et al AJR 2005; 184: 31-34

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Intravenous Contrast - Contrast Reactions

- Of 29,508 patients that underwent CT with IV contrast (iopromide), 211 had reactions
- Of those that had reaction, 14% had history of prior contrast reaction and 44% had history of allergy
  - 76% urticaria
  - 6.2% facial/laryngeal edema
  - 4.7% nausea and vomiting
  - 3.8% bronchospasm
  - 9% other

Kortele et al. AJR 2005; 184: 31-34
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Intravenous Contrast – Putting it in

- Power injector has become standard
- Twin power injectors have advantage of gradients and saline chase
- A 20 gauge angiocatheter in a peripheral vein is preferred, a 22 gauge is acceptable for slower (2 ml/sec injection rates)
- PICC lines suitable for power injector IV contrast administration are now coming into common use (purple PICC line)
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Intravenous Contrast – Timing

- For most body CT protocols used in cancer imaging, intravenous contrast is injected as a continuous bolus at 2-3 ml/sec initiated at a specified time after scan acquisition commences.
- As with comedy, sex and real estate investment, timing is everything.
- CT scan acquisition must occur when the contrast material is in the desired vessels and had passed into the soft tissues at the time of maximum enhancement.

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Portal venous phase contrast enhancement of the liver
Hepatocellular carcinoma

Irregular FDG uptake corresponds to areas of abnormal contrast enhancement on arterial contrast phase of CT (arrows).
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Intravenous Contrast – Timing

- For most body CT protocols, CT scanning commences 60-65 seconds after initiation of contrast bolus
- For dedicated neck protocols, 35-45 seconds
- For an arterial phase, 25-35 seconds
- Bolus timing will depend on distant contrast has to travel and patient’s vascular flow dynamics (blood-and contrast gets there faster in younger patients... heart failure, aneurysms, ect. slow things down requiring longer bolus delay)

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IV contrast - General Principals

• For general body oncology CT scans, goal is relative equal arterial and venous opacification throughout the scan matching table feed to progress of contrast bolus.
• Contrast bolus can be extended by increasing total contrast infused or slowing infusion rate.
• Contrast opacification (both vessels and tissue) can be increased by high rate of contrast infusion and/or greater density (mg I/ml).
• Artifacts from undiluted contrast in subclavian and SVC can be eliminated by saline chase or biphasic infusion rate and caudad-cranial scan (Beyer et. al. JNM 2005; 46:429-435).
Intravenous contrast opacity for 3 ml/min for 100ml

- arterial (upper chest)
- venous (lower pelvis)
- arterial (lower pelvis)
- venous (lower pelvis)

Scan cranial-caudal

Time post start of intravenous contrast injection

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Intravenous contrast (3 ml/sec) with saline chase: note equal opacification of iliac arteries and veins.
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IV contrast - Technique with MDCT

- Moderate infusion rates (2-3 ml/sec)
- Saline chase using dual injector
- Body 3.0 ml/sec for 100-125 ml with 50 ml saline chase, 60-65 second delay, scan cranial-caudal over roughly 8-30 seconds
- Neck 2.5-3.0 ml/sec for 65 ml with 50 ml chase, 35-40 second delay
- Key is to bring injection route venous blood to similar contrast concentration as distal outflow vessels and not out run bolus at pelvis, and image liver in portal-venous phase
Intravenous contrast (3 ml/sec) with saline chase: note equal opacification of subclavian arteries and veins and absent intravenous contrast related beam hardening artifact.
Metastatic colon cancer to liver depicted on portal venous phase contrast enhanced CT

Pre-therapy

Post chemotherapy

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Intravenous Contrast – Thorax

• Generally desire uniform enhancement of arteries, pulmonary arteries and veins, and central veins in chest
• 60-70 second bolus delay works well with craniocaudal scanning starting at skull base
• Pulmonary arterial phase scanning can be added to better depict relationship of a mass with vessels for surgical planning

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65 second bolus delay
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Multi-phase contrast enhanced CT of thorax

Whole torso PET-CT with limited arterial phase acquisition followed by whole torso enhanced scan.
Dual phase protocol for lung cancer provides intense vascular enhancement with reduced contrast load.

Arterial phase 25 second bolus delay

“Equilibrium phase” 65 second bolus delay
Imaging Sequences for Head and Neck PET-CT

a. PET emission bed position 2-4 min

b. PET emission bed position 4-10 minutes

Reposition patient with arms up

Contrast CT whole torso technique, including neck, with arms down at side

Contrast CT whole torso technique with arms raised

Reposition patient with arms up

Contrast CT skull base to upper mediastinum, neck technique, arms down

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Intravenous Contrast – Head & Neck

• Primary Head & Neck cancers should be evaluated using dedicated CT and PET acquisitions from above the skull base to the thoracic inlet with arms down
• PET acquisition generally performed with a fine matrix and longer emission acquisition (5-10 minutes)
• CT acquisition using thin section reconstruction (< 2 mm) and contrast in arteriovenous phase
• 45 second bolus delay generally works well
Dedicated CT and PET acquisitions with arteriovenous phase CT
Necrotic metastatic lymph node: contrast helps define margins of node to assess for extracapsular spread.
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Intravenous Contrast – Abdomen & Pelvis

• Generally portal venous phase is optimal IV contrast timing for scanning through the abdomen in cancer patients

• 60-70 second bolus delay when CT scanning initiated from the skull base will result in timing such that the portal venous phase is present when the scan acquisition reaches the abdomen

• Faster CT scanners or faster bolus (> 3 ml/sec) require more careful timing such that there is venous opacification at the pelvis (don’t out-run the bolus)
Intravenous contrast (3 ml/sec) with saline chase:
note equal opacification of iliac arteries and veins

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Multi-phase scanning – Abdomen & Pelvis

• Certain diagnostic requirements may require an arterial phase (vascular depiction, hypervascular tumors) in addition to portal venous phase

• Evaluation of kidneys and certain liver masses may require a 3-5 minute delay phase scan in addition to the portal venous phase scanning
PET-CT Scans

Multi-phase contrast enhanced CT

Whole torso PET-CT with limited arterial phase acquisition of the abdomen followed by whole torso scan.
Adenocarcinoma of the pancreas with encasement of celiac axis.
Liver Metastases of Hypervascular Neoplasm

Late Arterial Phase  Portal Venous Phase  FDG PET

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Pancreatic Tail Adenocarcinoma and Liver Metastases

Late Arterial Phase                        Portal Venous Phase                        FDG PET

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Recurrent metastatic colon cancer in upper abdomen

Arterial phase PET-CT of superior mesenteric artery
Recurrent metastatic colon cancer in upper abdomen

Portal-venous phase PET-CT of superior mesenteric vein

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Recurrent metastatic colon cancer in upper abdomen

Portal-venous phase PET-CT of superior mesenteric vein

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Involvement of superior mesenteric vein by mesenteric colon cancer metastasis
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Conclusions

- Intravenous contrast use with PET-CT is not a new concept and is not difficult
- Fully optimized CT with intravenous contrast is part of the “best of both worlds”