Comprehensive Review

# Computed Tomography Guidance for Spinal Intervention: Basics of Technique, Pearls, and Avoiding Pitfalls

Vincent M. Timpone, MD[1], Joshua A. Hirsch, MD[1,2], Christopher J. Gilligan, MD[3], Ronil V. Chandra, MBBS[4]

From: [1]Department of Radiology, Divisions of Diagnostic and [2]Interventional Neuroradiology, Massachusetts General Hospital, Harvard Medical School, Boston, MA; [3]Center for Pain Medicine, Department of Anesthesia, Critical Care and Pain Medicine, Massachusetts General Hospital, Harvard Medical School, Boston, MA; [4]Interventional Neuroradiology Unit, Department of Diagnostic Imaging, Monash Medical Center, Monash Health, Melbourne, Australia

Address correspondence:
Dr. Vincent Timpone
Department of Radiology, Division of Diagnostic Neuroradiology, Massachusetts General Hospital, Harvard Medical School, Boston, MA
E-mail: vtimpone@partners.org

Disclaimer: There was no external funding in the preparation of this manuscript.
Conflict of interest: None.

Manuscript received: o
Revised manuscript received:
Accepted for publication:

Free full manuscript:
www.painphysicianjournal.com

The utilization of spinal interventional pain techniques has grown rapidly over the last decade. However, practitioners use widely different techniques in these procedures, particularly in the use of image guidance. The importance of image guidance was highlighted by the fact that in recent systematic reviews on therapeutic effectiveness of epidural steroid injections and facet joint interventions, only studies that used image guidance were included. The choice of image guidance remains a matter of physician preference with conventional fluoroscopic or Computed Tomography (CT) guidance most common.

There are many advantages to CT guidance for certain spinal interventional pain procedures, mainly due to increased needle tip positioning accuracy. CT guidance provides greater anatomical detail that facilitates accurate needle trajectory planning, monitoring and final placement. Unlike conventional fluoroscopy that may be hindered by tissue overlap and lack of surrounding anatomical detail CT guidance offers direct visualization of the entire needle trajectory and the surrounding soft tissue and bone structures. Large osteophytes and adjacent vascular structures can be identified and safely avoided.

The goals of this narrative review are to provide a basic overview of CT techniques available for spinal interventional pain procedures, to discuss the potential advantages and disadvantages of CT guidance, to provide a simple step-by-step approach to use of CT guidance, to share technical pearls, and to discuss methods to avoid potential pitfalls. This review will provide interventional pain physicians with knowledge of relevant CT image acquisition techniques and appropriate radiation dose reduction strategies. This will contribute to increased technical success rates while reducing radiation dose to the patient and staff.

**Key words:** Computed tomography, fluoroscopy, analgesia, epidural injection, spinal injection, back pain, safety

**Pain Physician 2013; 16:-369-377**

There has been a marked increase in the use of spinal interventional pain procedures over the last decade (1). Epidural steroid injections, facet and sacroiliac joint interventions, vertebroplasty and sacroplasty are commonly performed spinal interventional pain procedures. However, there remains marked heterogeneity in technical aspects, in particular of use of image guidance (2,3). The importance of image guidance was highlighted by the fact that in recent systematic reviews on therapeutic effectiveness of epidural steroid injections and facet joint interventions, only studies that used image guidance were included (4,5). The choice of image guidance modality remains a matter of physician preference; fluoroscopic or computed tomograpy (CT) guidance are the most commonly utilized methods.

The goals of this review are: 1) provide a basic overview of CT techniques that are available for spinal interventional pain procedures, 2) discuss the potential advantages and disadvantages of CT guidance, 3) provide a simple step-by-step approach to use of CT guidance, 4) share technical pearls, and 5) discuss methods to avoid potential pitfalls.

## CT Techniques

The use of CT guidance for an interventional procedure was initially reported in 1975 (6). Since then it has grown to become the image guidance modality of choice for many percutaneous interventions. The CT gantry emits fan shaped x-ray beams that are received by detectors, also housed within the CT gantry. These detectors measure the attenuation of the x-ray beam by the patient's tissues along each x-ray projection. These tissues are then localized within space using mathematical algorithms, and each CT image slice is created. The detectors rotate around the patient, and multiple CT image slices are continuously acquired as the patient is moved through the CT gantry. All the pixels in a CT image are then displayed as a matrix of x-ray attenuation values using a reference scale (Hounsfield units {HU}) relative to water; water is assigned a value of 0 HU on all CT scanners. Air measures approximately -1000 HU and dense cortical bone approximately +1000 HU. The display parameters (window width and level) can be adjusted to suit the particular tissue being targeted. In general, soft tissue anatomy is best viewed using a narrower window width than bony anatomy.

Spinal interventional pain procedures can be performed on all CT scanners. Current generation CT scanners offer multi-detector technology (MDCT) where multiple CT image slices can be obtained simultaneously, increasing the speed of acquisition. This speed in turn enables sub-millimeter slice thickness, which increases the inherent spatial contrast resolution. Isotropic acquisition, with equal spatial contrast resolution in the x, y and z image planes, is possible with MDCT, and image data can be reformatted and displayed in oblique planes at CT workstations without loss of image integrity.

CT guided spinal intervention can be performed using two main techniques — conventional CT or CT fluoroscopy (CTF). Conventional CT refers to the use of a small stack of CT images that are performed by the CT technician to confirm needle trajectory and tip position. The physician typically leaves the room during image acquisition and reviews the limited images on the CT console. Thus, the physician does not require lead shielding. The physician then re-enters the CT room, advances the needle, and the steps are repeated until needle target position is achieved.

The first description of CTF used to guide an interventional pain procedure was in 1996 for a celiac plexus block (7). The authors used *continuous mode* CTF to provide real-time CT image guidance, analogous to conventional fluoroscopy. Notably, even with modern CT scanners, and radiation dose conscious practice, the dose rate from *continuous mode* CTF remains almost 4 times higher than conventional fluoroscopy (8). The alternative that most physicians utilize today is *quick-check* CTF (9). This technique is analogous to conventional CT guidance, however the physician remains in the CT room during image acquisition and thus must use a lead apron, thyroid shield and leaded glasses to minimize radiation dose to sensitive tissues. With modern MDCT, the physician uses a foot pedal within the CT room to acquire multiple single section CTF spot images. Typically a central image slice is acquired at the target needle trajectory; single cranial and caudal slices are also acquired to identify any cranial or caudal angulation of the needle. Once appropriate needle alignment is confirmed, the needle is advanced further. The CTF spot images can be repeated until desired needle target position is achieved. Using this intermittent *quick-check* CTF technique for trans-laminar lumbar epidural steroid injections, procedural CTF radiation exposure time can be reduced to less than 5 seconds, and radiation dose halved compared to conventional fluoroscopy (8).

## Advantages of CT Guidance

Complications from spinal interventional pain procedures generally arise from needle placement and injection of medications (10). The principle advantage of CT guidance lies in the greater anatomical detail provided that facilitates accurate needle trajectory planning, monitoring and final placement. CT guidance provides high spatial and contrast resolution. Unlike conventional fluoroscopy, that may be hindered by tissue overlap and lack of surrounding anatomical detail, CT guidance offers direct visualization of the entire needle trajectory and the surrounding soft tissue and bone structures. Large osteophytes and adjacent vascular structures can be identified and safely avoided, which is particularly useful for cervical spinal interventional procedures (11). While traditional clinical techniques for tip localization, such as "loss-of-resistance" for trans-laminar epidural injections, are prone to 25–50% false positive rate,(12-14) the exact needle tip position can be confirmed on CT, even without use of contrast media.

## Disadvantages of CT Guidance

CT guided spinal interventional procedures may result in longer on-table procedural time and greater radiation doses to the patient and the physician compared to conventional fluoroscopy (8,15). While the *quick-check* CTF method may result in reduced needle placement procedural time and radiation dose compared to conventional fluoroscopy, the addition of the initial planning CT scan results in higher total radiation dose to the patient (8). Almost 90% of the total radiation dose during CTF guided procedures occurs during planning CT scans (8,16).

Utilization of CT guidance requires access to a CT scanner, which may be less readily accessible compared to conventional fluoroscopy. Moreover, successful and safe use requires a sound understanding of CT acquisition techniques and image interpretation. While some patient motion and consequent adjustment of needle trajectory is easily accommodated when using conventional fluoroscopic guidance, similar motion during CT guidance may necessitate repeat imaging, prolonged procedural times and increased radiation dose.

## A Step-By-Step Approach

### Prior to the Procedure

- Review all prior imaging of the relevant anatomical area. If CT has been performed previously, this can be used to help plan the expected needle trajectory and equipment required.
- Position the patient appropriately on the CT table, and place a skin grid marker over the target entry site. Align the radiopaque grid line markers perpendicular to the gantry to ensure visibility on each CT image acquired.
- The CT technician performs a radiographic scout image. The physician then delineates the field of view required for planning CT scan.
- With skin grid markers in place, the initial planning CT scan is performed. This is used to plan the needle trajectory, taking into account local soft tissue and bony anatomy. Ideally, the entire needle trajectory should lie in a single CT image slice. The distance from the skin to the needle tip target and the desired needle entrance angle can be measured and displayed on a monitor in the CT room.
- The skin needle entry site is marked, and the grid is removed prior to sterile preparation and appropriate draping of the needle entry site.

### During the Procedure

- Administer local anesthesia at the marked skin entry site. It is helpful to leave the local anesthesia needle in situ, in the angle of the expected trajectory and confirm the planned trajectory with CT scans. If entering a bony target, such as for CT guided vertebroplasty, the periosteal layer should be anaesthetized.
- Using the local anesthetic needle as a guide to needle entrance angle and trajectory, the definitive needle is placed. If a larger gauge needle or device is used, a small skin incision using a scalpel is helpful.
- The needle trajectory and tip position can then be monitored during advancement to the target using intermittent conventional CT or *quick-check* CTF. The needle is advanced further once appropriate trajectory and tip position is confirmed.
- Once the target is reached, contrast media may be injected to confirm expected spread of injectate.

### Post procedure

- Post-procedural CT of the target region may be performed to assess the technical outcome and for identification of potential complications.

## Technical Pearls

### Patient comfort

Patient motion is minimized if patient comfort is maximized. The prone and supine positions are the best tolerated. Pillows under the chest, hips and ankles in the prone position are helpful for longer procedures such as CT guided vertebroplasty. The lateral decubitus is most difficult to maintain; small movements of the patient's thorax or arms while in the lateral decubitus position can cause significant changes to the scan plane.

### Patient positioning

The simplest needle trajectory to achieve successfully is perpendicular to the floor. Prone oblique patient positioning can be used to achieve a perpendicular needle trajectory. A pillow under the abdomen can open the lumbar interspinous spaces; raising the contralateral arm above the head and depressing the ipsilateral shoulder (Swimmer's radiographic position) can facilitate straight needle trajectories for lower cervical selective nerve root injection (17).

### *Needle trajectory planning*

Ideally, the entire needle trajectory should lie on a single axial CT image (Fig. 1).

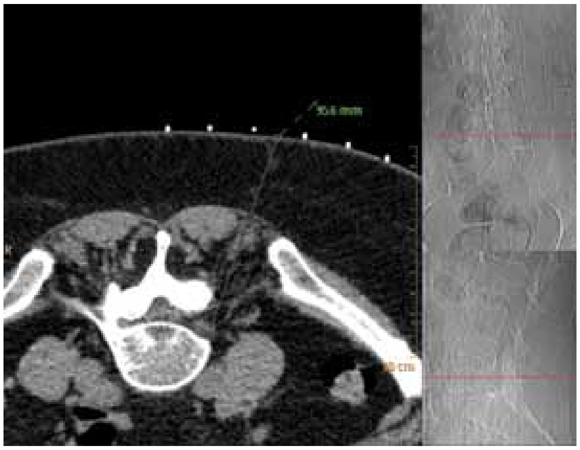

Fig. 1. *Needle trajectory planning. The planned needle trajectory for a L5 nerve root injection is chosen on a single CT slice, away from local bony constraints. Measuring the depth from the skin surface to the target needle position identifies the length of needle required. Note the round dots on the skin surface from the radiopaque grid line markers.*

## Operate within the CT Gantry

Once the initial needle trajectory is established, the needle can be manipulated without moving the patient from the CT gantry. This reduces patient motion during table movement and overall procedural time (Fig. 2).

Fig. 2. *Operating within the CT gantry. Most spinal pain interventional procedures can be performed by operating within the CT gantry. This reduces patient motion during table movement and overall procedural time.*

## Needle Support

It may be helpful to stabilize the needle early in the course with gauze or towels, as there may not be sufficient soft tissue purchase to prevent movement of long needles during imaging.

## Use the Gantry Laser Light Guide during Needle Placement

The laser light is projected in the exact CT image slice plane. Thus if the laser light bisects the needle hub, the tip will be in a single CT image slice (Fig. 3). If the needle hub lies above or below the laser light, the tip is pointing in the opposite direction. The needle can be adjusted without repeating the CT scan.

Fig. 3. *Use the laser light. If the laser light bisects the needle hub, the tip will be in the single central CT image slice.*

## Use CT Fluoroscopy

Procedure times are shorter compared to conventional CT guidance (18).

## Consider Air as Contrast Media

The high contrast resolution of CT allows the use of a small amount of air as contrast media when required, such as patient allergy to iodinated contrast media (19) (Fig. 4). However, the exact needle tip position must be confirmed with imaging before injection of either contrast material or air.

## Avoiding Pitfalls

### Understand the local CT anatomy

Identification of vascular structures on non-contrast CT can be challenging. Nonetheless, major vascular structures, including the vertebral arteries, can usually be identified on unenhanced CT and avoided.

### Use the Smallest Needle Possible

This minimizes the risk of vascular injury and reduces CT artifact during needle placement. The majority of common spinal interventions can be performed using 22 gauge spinal needles; 25 gauge needles are commonly used in the cervical spine.

### Assess the Immediate Cranial and Caudal CT Images

The presence of the needle tip in adjacent CT slices indicates an oblique needle course. If the needle trajectory lies on a single CT slice, use the absence of the needle on adjacent CT slices to confirm correct needle trajectory (Fig. 5).

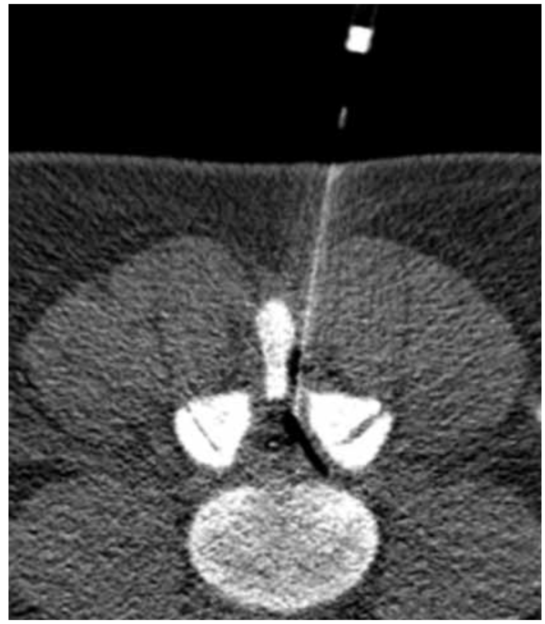

Fig. 4. *Consider air as contrast media. A small amount of injected air outlines the ipsilateral epidural space during a L4/5 translaminar epidural injection. This is particularly useful technique when there is patient allergy to iodinated contrast media. Note that the exact needle tip position must be confirmed with imaging before injection of either contrast material or air.*

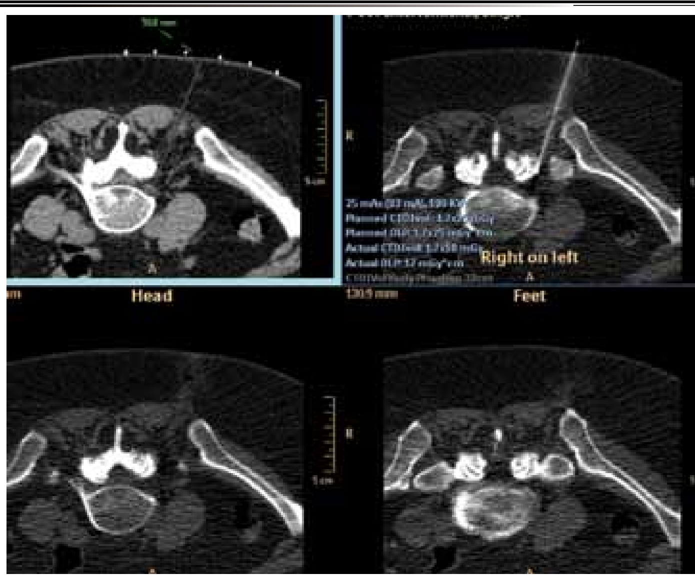


Fig. 5. *Assess the immediate cranial and caudal CT images. L5 nerve root injection performed using quick-check CTF. The monitor in the CT room displays the initial planned needle trajectory and depth (top left), the current needle position (top right), a cranial CT image slice (bottom left) and a caudal CT image slice (bottom right). The lack of needle tip visualization in the adjacent cranial and caudal slices ensures a straight course in the central target CT image slice. Note the "beam hardening" artifact — the dark band emanating from the needle tip. This is a useful CT artifact that identifies the needle tip position, but may be obscured if air has been injected.*

### Identify the Needle Tip Position

The needle tip is most accurately identified by visualization of the bevel. In the absence of bevel identification, use the expected beam hardening artifact arising from the needle tip (Fig. 5).

### Consider Angling the Gantry

If an oblique course is necessary, angle the gantry cranial or caudal along the angle of expected needle trajectory. This ensures that the entire needle trajectory remains on a single CT slice.

### Reduce Radiation Dose During Planning CT

The majority of total radiation dose occurs during the planning CT scans. Planning CT scans do not require the same spatial or contrast resolution as diagnostic CT scans, and tube current can be reduced. However the images must remain of sufficient dose to identify the relevant target anatomy (Fig. 6A-C). Ini-

Exam Information

| | |
|---|---|
| Study ID | 1107 |
| Time | 16/01/2013 1:01 PM |
| Total DLP | 470.5 mGy*cm |

Dose

| # | Scan Label | Scan Mode | mAs | kV | CTDIvol [mGy] | DLP [mGy*cm] | Phantom Type [cm] |
|---|---|---|---|---|---|---|---|
| 1 | SURVIEW | Surview | | 120 | 0.1 | 3.6 | BODY 32 CM |
| 1 | | Surview | | 120 | 0.2 | 7.1 | BODY 32 CM |
| 2 | ACQUISITION | Helical | 455 | 120 | 30.4 | 453.8 | BODY 32 CM |
| 3 | ACQUISITION | Station... | 25 | 120 | 2x3 | 6 | BODY 32 CM |

Fig. 6. *Reduce radiation dose during planning CT. A. Planning axial CT image slice for a L3 nerve root injection. Note the clear delineation of the lateral boundary of the L3 nerve roots. B. CTF spot image with target needle position achieved. Reduced radiation dose results in increased CT image noise and reduction in image quality. Nonetheless, once the relevant target anatomy has been delineated from the planning CT, sufficient anatomical detail is achieved for the procedure. C. Radiation dose summary. Only 1.2 seconds of CTF was used; the radiation dose for the lateral CT scout image (Line #1; DLP=7.1 mGy-cm) was greater than the total CTF dose (Line #3; DLP=6 mGy-cm). Note that 96% of the total radiation dose was delivered during the planning CT scan (Line #2; DLP=453.8 mGy-cm).*

tial CT radiographic scout images can be used to limit the craniocaudal extent of the planning CT scan. For example, lumbar CT scout radiographs in the AP and lateral planes will identify the lumbar levels and can facilitate a limited CT scan from L4 to L5 for planning a L4/5 translaminar epidural injection (Fig. 7).

## Reduce tube current

For procedural CT fluoroscopic spot images during spinal injections, tube current can usually be reduced to between 20–40 mA. While this radiation reduction increases the noise in the CT image, image quality remains adequate for spinal injections, particularly in thin patients (19,20) (Fig. 8).

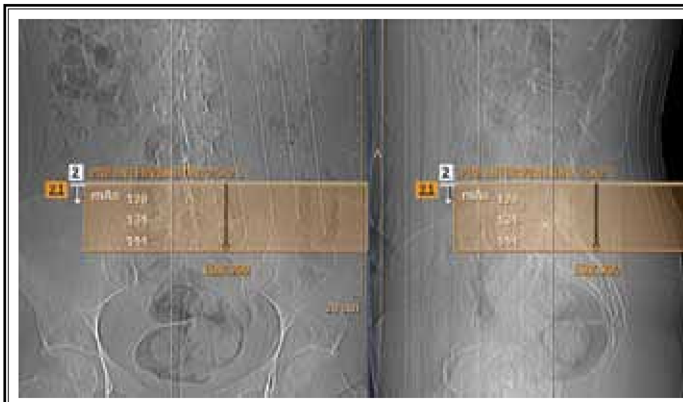

Fig. 7. *Reduce radiation dose during planning CT. Using the CT scout images, only limited craniocaudal planning CT scans are performed for a left L5 nerve root injection. In general, for most epidural steroid and facet joint injections, the planning CT can be limited to one vertebral body cranial and caudal to the targeted level.*

## Stand on the Side of the Gantry during CT Fluoroscopic Acquisition

Radiation exposure to physicians, nurses and technologists arises from the primary x-ray beam and scatter radiation from the patient. The detectors within the gantry, and the gantry itself provide shielding from both the primary x-ray beam and the patient. Standing on the side of the gantry provides the lowest possible radiation dose to personnel remaining in the CT room during image acquisition (16) (Fig. 9). Alternatively, stand as far away as possible from the primary beam and patient, as radiation dose decreases exponentially with distance from the primary beam. Exit the room if not using CTF.

## Use Lead Drapes

Lead drapes placed on the patient adjacent to the interventional site reduce scatter radiation exposure to the physician by over 70% (21,22).

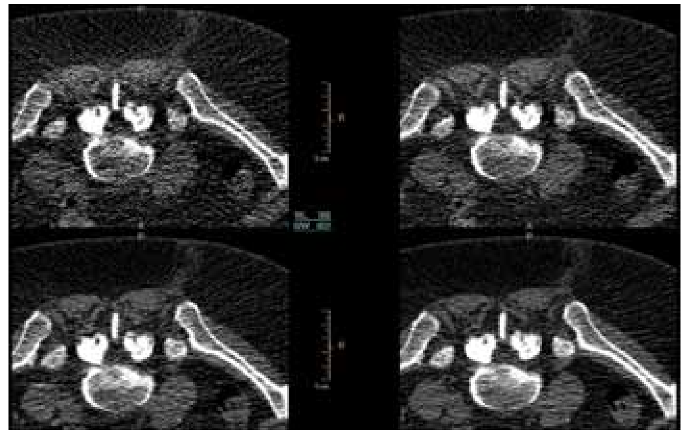

Fig. 8. *Reduce tube current. The effects of alteration of tube current for procedural CTF spot images during L5 nerve root injection. Progressive increase in tube current and radiation dose to the volume of tissue imaged from top left (24 mA; CTDIvol = 0.5 mGy) to top right (40 mA; CTDIvol = 0.8 mGy) to bottom left (60 mA; CTDIvol = 1.2 mGy) to bottom right (83 mA; CTDIvol = 1.7 mGy). There is approximately 50% increased radiation dose delivered with each progressive tube current increase displayed; almost 3.5 times higher radiation dose is delivered by the highest tube current compared to the lowest tube current. Note that anatomical landmarks are still visible and safe spinal intervention can still be performed using the lowered radiation dose settings.*

Fig. 9. *Stand on the side of the gantry during CT fluoroscopic acquisition. The detectors within the gantry, and the gantry itself provide shielding from both the primary x-ray beam and secondary scatter radiation from the patient. Standing on the side of the gantry provides the lowest possible radiation dose to personnel remaining in the CT room during image acquisition(16).*

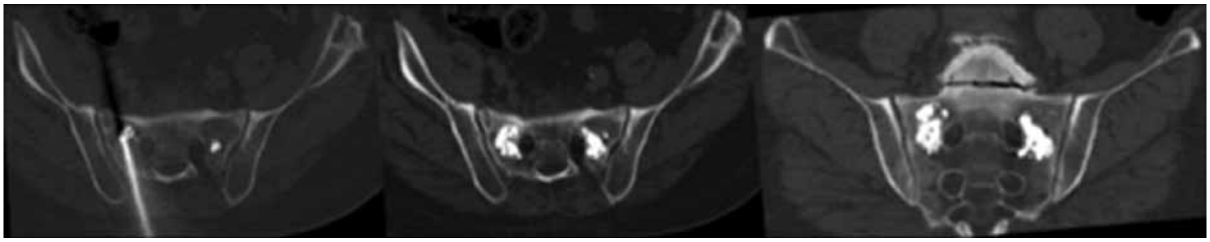

Fig. 10. *Use limited post-procedural CT to exclude serious complications. Patient with sacral insufficiency fractures treated with sacroplasty. Note the beam hardening artifact identifying the needle tip (right image) with subsequent injection of polymethylmethacrylate (PMMA). Note that there is no extension of PMMA into the sacral foramina evident on the limited post procedural CT reformatted in the axial (middle image) and coronal planes (left image).*

### Avoid Continuous Mode CTF

Reduction in CTF time reduces radiation dose. The use of *quick-check* CTF significantly reduces overall CTF time compared to *continuous mode* CTF (18) with consequent dose reduction.

### Use Limited Post-Procedural CT to Exclude Serious Complications

A limited stack of conventional CT images can be performed post procedure and reconstructed in multiple planes to exclude complications, such as cement leak during CT guided vertebroplasty or sacroplasty (23,24) (Fig. 10).

## Conclusion

There remains marked heterogeneity in the technical aspects of performing spinal interventional pain procedures. Image guidance is not universal, and there is no randomized controlled data to confirm the superiority of a particular image guided spinal intervention strategy. Thus, the use of CT guidance for spinal interventional pain procedures is largely guided by physician preference and ease of access to specific imaging modalities. There are many advantages to CT guidance for spinal interventions, mainly related to more accurate needle tip positioning. However physicians using CT guidance should have a sound knowledge of relevant CT image acquisition techniques and image interpretation to ensure high rates of technical success. Comprehensive knowledge of appropriate radiation dose reduction strategies is crucial to reduce dose to the patient, physician and all staff involved.

## References


1. Manchikanti L, Pampati V, Falco FJ, Hirsch JA. Growth of spinal interventional pain management techniques: Analysis of utilization trends and Medicare expenditures 2000 to 2008. *Spine* 2013; 38:157-168.
2. Diwan S, Manchikanti L, Benyamin RM, Bryce DA, Geffert S, Hameed H, Sharma ML, Abdi S, Falco FJ. Effectiveness of cervical epidural injections in the management of chronic neck and upper extremity pain. *Pain Physician* 2012; 15:E405-434.
3. Cluff R, Mehio AK, Cohen SP, Chang Y, Sang CN, Stojanovic MP. The technical aspects of epidural steroid injections: a national survey. *Anesthesia and Analgesia* 2002; 95:403-408, table of contents.
4. Manchikanti L, Buenaventura RM, Manchikanti KN, Ruan X, Gupta S, Smith HS, Christo PJ, Ward SP. Effectiveness of therapeutic lumbar transforaminal epidural steroid injections in managing lumbar spinal pain. *Pain Physician* 2012;15:E199-245.
5. Falco FJ, Manchikanti L, Datta S, Sehgal N, Geffert S, Onyewu O, Zhu J, Coubarous S, Hameed M, Ward SP, Sharma M, Hameed H, Singh V, Boswell MV. An update of the effectiveness of therapeutic lumbar facet joint interventions. *Pain Physician* 2012; 15:E909-953.
6. Alfidi RJ, Haaga J, Meaney TF, MacIntyre WJ, Gonzalez L, Tarar R, Zelch MG, Boller M, Cook SA, Jelden G. Computed tomography of the thorax and abdomen: A preliminary report. *Radiology* 1975; 117:257-264.
7. Katada K, Kato R, Anno H, Ogura Y, Koga S, Ida Y, Sato M, Nonomura K. Guidance with real-time CT fluoroscopy: Early clinical experience. *Radiology* 1996; 200:851-856.
8. Hoang JK, Yoshizumi TT, Toncheva G, Gray L, Gafton AR, Huh BK, Eastwood JD, Lascola CD, Hurwitz LM. Radiation dose exposure for lumbar spine epidural steroid injections: A comparison of conventional fluoroscopy data and CT fluo-

roscopy techniques. *AJR Am J Roentgenol* 2011; 197:778-782.

9. Paulson EK, Sheafor DH, Enterline DS, McAdams HP, Yoshizumi TT. CT fluoroscopy--guided interventional procedures: Techniques and radiation dose to radiologists. *Radiology* 2001; 220:161-167.
10. Goodman BS, Posecion LW, Mallempati S, Bayazitoglu M. Complications and pitfalls of lumbar interlaminar and transforaminal epidural injections. *Current Reviews in Musculoskeletal Medicine* 2008; 1:212-222.
11. Hoang JK, Apostol MA, Kranz PG, Kilani RK, Taylor JN, Gray L, Lascola CD. CT fluoroscopy-assisted cervical transforaminal steroid injection: Tips, traps, and use of contrast material. *AJR Am J Roentgenol* 2010; 195:888-894.
12. Bartynski WS, Grahovac SZ, Rothfus WE. Incorrect needle position during lumbar epidural steroid administration: Inaccuracy of loss of air pressure resistance and requirement of fluoroscopy and epidurography during needle insertion. *AJNR Am J Neuroradiol* 2005; 26:502-505.
13. White AH, Derby R, Wynne G. Epidural injections for the diagnosis and treatment of low-back pain. *Spine* 1980; 5:78-86.
14. Stojanovic MP, Vu TN, Caneris O, Slezak J, Cohen SP, Sang CN. The role of fluoroscopy in cervical epidural steroid injections: An analysis of contrast dispersal patterns. *Spine* 2002; 27:509-514.
15. Ng PP, Wilder MJ, Jenkins PA. CT fluoroscopy-guided cervical interlaminar steroid injections: is it overkill? *AJNR Am J Neuroradiol* 2012; 33:E138; author reply E139.
16. Sarti M, Brehmer WP, Gay SB. Low-dose techniques in CT-guided interventions. *Radiographics* 2012; 32:1109-1119; discussion 1119-1120.
17. Bartynski WS, Whitt DS, Sheetz MA, Jennings RB, Rothfus WE. Lower cervical nerve root block using CT fluoroscopy in patients with large body habitus: Another benefit of the swimmer's position. *AJNR Am J Neuroradiol* 2007; 28:706-708.
18. Silverman SG, Tuncali K, Adams DF, Nawfel RD, Zou KH, Judy PF. CT fluoroscopy-guided abdominal interventions: Techniques, results, and radiation exposure. *Radiology* 1999; 212:673-681.
19. Wagner AL. CT fluoroscopy-guided epidural injections: Technique and results. *AJNR Am J Neuroradiol* 2004; 25:1821-1823.
20. Schauberger JS, Kranz PG, Choudhury KR, Eastwood JD, Gray L, Hoang JK. CT-guided lumbar nerve root injections: Are we using the correct radiation dose settings? *AJNR Am J Neuroradiol* 2012; 33:1855-1859.
21. Nawfel RD, Judy PF, Silverman SG, Hooton S, Tuncali K, Adams DF. Patient and personnel exposure during CT fluoroscopy-guided interventional procedures. *Radiology* 2000; 216:180-184.
22. Neeman Z, Dromi SA, Sarin S, Wood BJ. CT fluoroscopy shielding: Decreases in scattered radiation for the patient and operator. *J Vasc Interv Radiol* 2006; 17:1999-2004.
23. Trumm CG, Pahl A, Helmberger TK, Jakobs TF, Zech CJ, Stahl R, Paprottka PM, Sandner TA, Reiser MF, Hoffmann RT. CT fluoroscopy-guided percutaneous vertebroplasty in spinal malignancy: Technical results, PMMA leakages, and complications in 202 patients. *Skeletal Radiology* 2012; 41:1391-1400.
24. Gupta AC, Yoo AJ, Stone J, Barr JC, Brook A, Tutton S, Ortiz O, Hirsch AE, Larvie M, Fray ME, Jayaraman MV, Hirsch JA. Percutaneous sacroplasty. *J Neurointerv Surg* 2012; 4:385-389.