Case Reports

# C-arm Fluoroscopic Cone Beam CT for Guidance of Minimally Invasive Spine Interventions

Michael F. Powell, MD, Diane DiNobile, and Arra S. Reddy, MD

From: Harvard Medical School, Beth Israel Deaconess Medical Center, Boston, MA.

Dr. Powell is a Fellow in the Department of Radiology at Beth Israel Deaconess Medical Center, Boston, MA.
Ms. DiNobile is a Nurse Practitioner in the Department of Interventional Neuroradiology of Beth Israel Deaconess Medical Center, Boston, MA.
Dr. Reddy is the Chief of Interventional Neuroradiology at Beth Israel Deaconess Medical Center Boston, MA.

Address correspondence:
Michael F. Powell, MD
Harvard Medical School
Beth Israel Deaconess
Medical Center
Department of Radiology
330 Brookline Avenue
Boston, MA 02215
E-mail:
mpowell1@bidmc.harvard.edu

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**Background:** Isocentric C-arm fluoroscopic cone beam CT (CBCT) is a new technique for near real time 3-D volume imaging guidance of percutaneous interventional procedures. In combination with digital flat panel detectors, CBCT has high spatial resolution with isotropic voxel size, allowing for high resolution image reconstruction in any plane, including 3D rotational reconstructions. CBCT combines the advantages of conventional CT imaging guidance with the improved spatial resolution, patient positioning, and access of fluoroscopy.

**Objective:** The aim of this study is to demonstrate the advantages of CBCT over conventional CT and biplane fluoroscopy for imaging guidance of minimally invasive spinal and paraspinal interventional procedures.

**Methods:** Five patients referred to the department of interventional neuroradiology for percutaneous spinal or paraspinal interventional procedures were intraoperatively evaluated with CBCT to assist in guidance of instrumentation placement. Procedures included transoral cervical vertebral biopsy, percutaneous thoracic vertebral biopsy, vertebroplasty, pelvic paraspinal/epidural abscess drainage, and paraspinal fiducial marker placement for treatment of osteoid osteoma.

**Results:** All procedures were successfully performed with satisfactory diagnostic yield or therapeutic effect without procedure-related complications.

**Conclusion:** Isocentric C-arm fluoroscopic cone beam CT (CBCT) is a new technique for 3D volume imaging guidance of interventional procedures of the spine with the capability to produce near real time high resolution image reconstructions in any plane. Compared to conventional CT and biplane fluoroscopy, CBCT offers improved anatomic visualization allowing high accuracy instrumentation placement, improving procedure results and minimizing risk of complications.

**Key words:** Vertebroplasty, kyphoplasty, biopsy, computed tomography, CT, fluoroscopy, C-arm, percutaneous, interventional radiology, imaging guidance

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Minimally invasive percutaneous interventional procedures of the spine have traditionally been performed with real time imaging guidance by 2D biplane C-arm fluoroscopy or, less frequently, conventional computed tomography (CT). In some cases preoperative CT images have been registered with anatomic landmarks and used to guide surgeons and interventionalists intraoperatively by tracking the preoperative CT with real time 2D fluoroscopy. Each of these techniques has inherent advantages but also important limitations (1,2). Registration of preoperative CT with intraoperative 2D fluoroscopy poses challenges with misregistration due to changes in patient positioning. Conventional CT guidance is limited by a small field of view in the Z-axis and greater ergonomic problems with patient positioning and access. Biplane fluoroscopy is limited to 2D imaging and may result in significant operator exposure (3).

Cone beam CT (CBCT) technology using isocentric C-arm fluoroscopic equipment is a new technology which offers many advantages for intraoperative guidance of surgical and minimally invasive procedures (4-12). Also known as angiographic computed tomography (ACT), CBCT makes use of a single orbital C-arm rotation over a 190–220 degree arc to obtain a set of 2D fluoroscopic images with an image intensifier or flat panel detector. The result is a 3D volume data set with isotropic voxel size and image spatial resolution. These full volume 3D data sets can be reconstructed in any plane yielding axial, coronal, sagittal, and even surface-rendered reconstructions. In addition to rapid acquisition of accurate multiplanar reconstructions, advantages of CBCT include large volume of acquisition, improved Z-axis resolution compared to spiral CT, improved patient positioning and access, reduced patient and operator dose, and shorter operating times (3-15).

In 2002 Linsemaier et al (15) reported initial results with a Siemens Siremobil ISO-C-3D C-arm image intensifier system modified with an orbital motor and cone beam CT back projection processing algorithm (16). Using cadaver specimens they showed equivalent axial resolution and improved Z-axis resolution compared to conventional diagnostic spiral CT. High contrast resolution between the 2 modalities was equivalent. Shortly thereafter Euler et al (17) reported the successful use of ISO-C3D for intraoperative assessment of orthopedic hardware placement in traumatic injuries of the cervical spine and upper and lower extremities.

These early portable orbital C-arms equipped with image intensifiers were shown to be useful for both orthopedic surgery of the spine and extremities as well as endoscopic sinus surgery (5,6,10,17-21). The technology found favor among neurointerventionalists performing both cerebral and spinal angiogaphy in the evaluation of aneurysms, arterial stenoses, and vascular malformations (9,22-25). In many reported cases CBCT obviated the need for post procedure diagnostic CT, further reducing patient dose (7-8).

With the recent advent of flat panel detector (FPD) technology CBCT is poised to become even more influential, boasting improved spatial and contrast resolution, faster image acquisition and data processing, and further reduced patient doses. Direct digital transfer of flat panel data and advances in processing speed and technique allow near real-time intraoperative imaging guidance with accurate 3D reconstructions (4,5,17,26-27).

CBCT has begun to show promise as a technique for guidance of minimally invasive percutaneous procedures of the spine such as injection therapy, vertebroplasty, and kyphoplasty (6,11-12,28).

We report 5 cases which demonstrate the utility of fluoroscopic CBCT guidance for spinal and paraspinal interventional procedures. These include cervical and thoracic vertebral bone biopsy, vertebroplasty, paraspinal abscess drainage, and paraspinal fiducial marker placement.

## Methods

Five patients referred to the department of interventional neuroradiology for percutaneous spinal or paraspinal interventional procedures were intraoperatively evaluated with CBCT to assist in guidance of instrumentation placement. The AXIOM Artis biplane C-arm fluoroscopy system was used (Siemens Medical Solutions) for all image acquisition. In most cases the patient was positioned prone on the angiographic table. Images were acquired in a 200-degree rotation of the C-arm equipped with a flat panel detector with 154 micron detector element resolution. The operating personnel moved behind lead shields during the 3D acquisitions to minimize exposure. Images were then transferred directly into a Leonardo workstation. Reconstructions were performed with Inspace 3D software utilizing a modified Feldkamp et al (29) CBCT reconstruction technique and filter algorithms to correct for beam hardening, scattered radiation, truncated projections, and ring artifacts. Postprocessing resulted in volume data sets with 512 x 512 pixel matrix per slice.

## Results

### Case 1

Transoral biopsy of pathologic odontoid fracture. A 64-year old male presented with neck pain after a fall and was found to have a lytic lesion and pathologic fracture of the odontoid process of C2 and spiculated right middle lobe pulmonary nodule. Figure 1 demonstrates the use of fluoroscopic CT guidance to place an 18-gauge spinal needle into the C2 lesion via a transoral approach for successful core biopsy and fine needle aspiration. Pathology showed poorly differentiated carcinoma, presumably from lung primary.

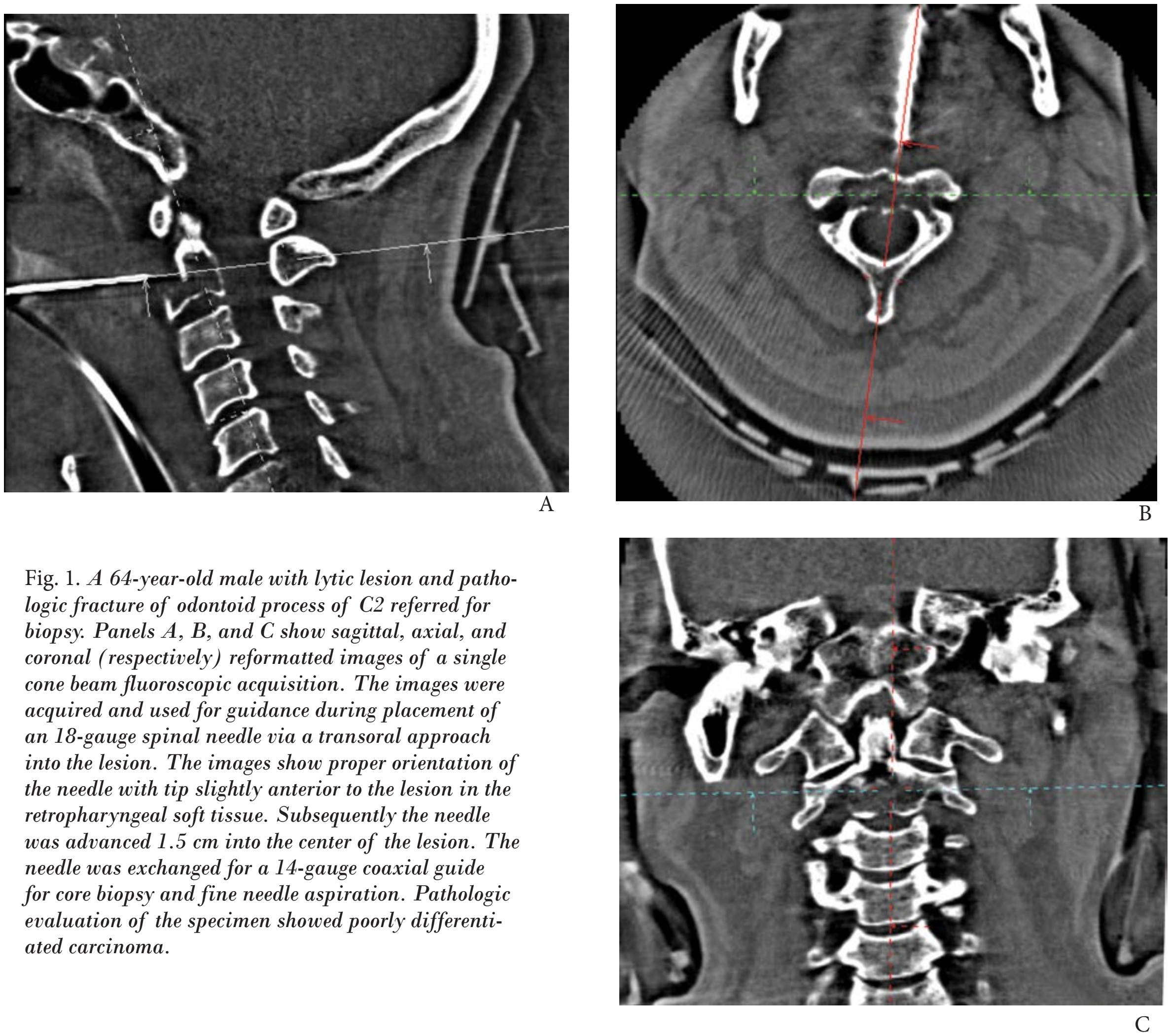


Fig. 1. *A 64-year-old male with lytic lesion and pathologic fracture of odontoid process of C2 referred for biopsy. Panels A, B, and C show sagittal, axial, and coronal (respectively) reformatted images of a single cone beam fluoroscopic acquisition. The images were acquired and used for guidance during placement of an 18-gauge spinal needle via a transoral approach into the lesion. The images show proper orientation of the needle with tip slightly anterior to the lesion in the retropharyngeal soft tissue. Subsequently the needle was advanced 1.5 cm into the center of the lesion. The needle was exchanged for a 14-gauge coaxial guide for core biopsy and fine needle aspiration. Pathologic evaluation of the specimen showed poorly differentiated carcinoma.*

## Case 2

Percutaneous biopsy of pathologic T2 vertebral compression fracture. A 79-year-old male with history of adenocarcinoma of the ampulla and smoldering multiple myeloma presented with 2 weeks of thoracic back pain. He was found to have a pathologic compression fracture of the T2 vertebral body with an underlying lytic lesion. Figure 2 shows use of fluoroscopic CT to guide placement of a 22-gauge needle into the T2 vertebral lesion via a transpedicular approach. In panel A/B multiplanar CT images in plane with the needle demonstrate incorrect needle approach with cephalad angulation. The needle was subsequently repositioned and panel C/D/E shows accurate placement of the tip of the needle in the center of the lesion. The needle was exchanged for a 14-gauge coaxial guide and core biopsy and fine needle aspiration were performed. Pathology showed malignant cells consistent with metastatic adenocarcinoma.

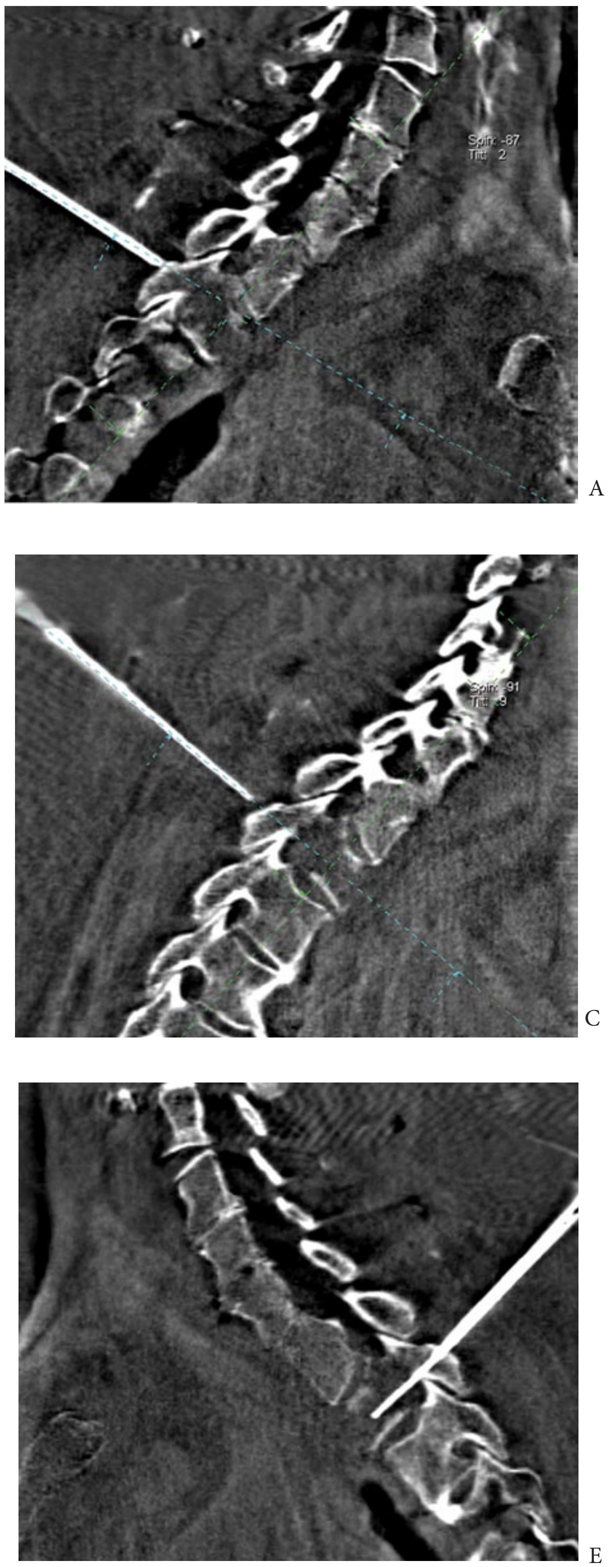



Fig. 2. *A 79-year-old male with lytic lesion and pathologic compression fracture of T2 referred for biopsy. Oblique sagittal and coronal reformatted fluoroscopic CT images (panels A and B) were generated to guide placement of a needle into the lytic T2 lesion via a transpedicular approach. Panels A and B show the position of the needle tip in the paraspinal soft tissues adjacent the T2 pedicle. The needle is incorrectly angled with projected course cephalad to the lesion (intersection of dashed lines). The needle was then repositioned and a second fluoroscopic acquisition obtained with sagittal and coronal reformatted images (panels C and D) now showing correct angulation of the needle with projected course into the center of the lesion. Panel E is a sagittal reformatted image of a third image acquisition showing tip of the needle properly positioned in the center of the lesion. The needle was exchanged for a 14-gauge coaxial guide and core biopsy and fine needle aspiration performed. Pathologic evaluation of the specimen showed metastatic adenocarcinoma.*

## Case 3

Percutaneous vertebroplasty of osteoporotic T10 compression fracture related to steroid use. A 61-year-old year female on steroid therapy for autoimmune hepatitis presented with mid back pain after a fall and was found to have a compression fracture of the T10 vertebral body. The patient was referred for T10 vertebroplasty. A combination of conventional biplanar fluoroscopy and fluoroscopic CT were used for imaging guidance during the procedure.

Figure 3 demonstrates initial placement of 2 11-gauge pedicle needles with biplanar fluoroscopy. Fluoroscopic CT was then used to guide precise positioning of the needles into the vertebral body for transpedicular injection of methylmethacrylate. The procedure was without complication resulting in stabilization of vertebral height and alleviation of patient pain.

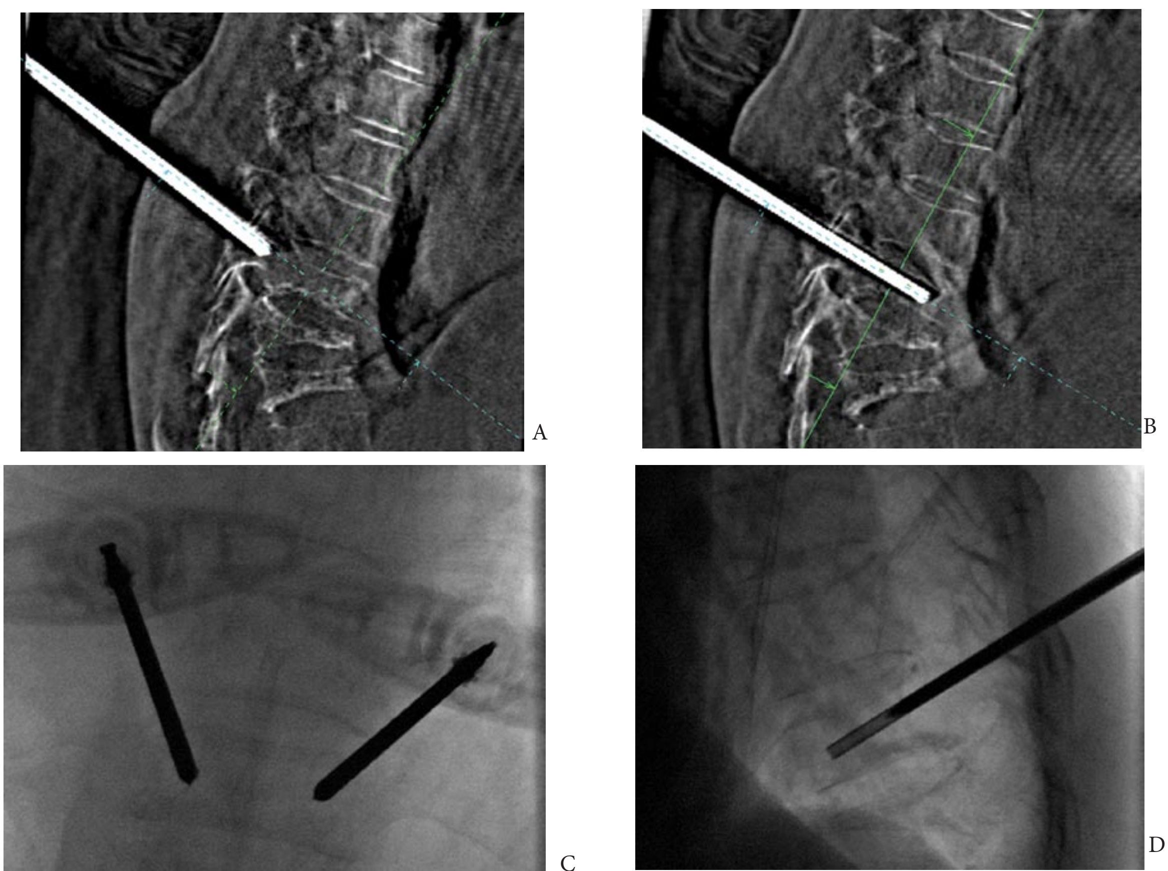



*Fig. 3. A 61-year old female with painful T10 vertebral compression fracture while on steroid therapy for autoimmune hepatitis presented for percutaneous vertebroplasty. A combination of fluoroscopic cone beam CT (panels A, B, E) and conventional biplanar fluoroscopic imaging (panels C and D) was used to successfully guide vertebroplasty. Panel A is a sagittal reformatted image of a fluoroscopic CT acquisition showing proper orientation of an 11-gauge pedicle needle with tip in the T10 pedicle. The needle was then advanced 2 cm and a second fluoroscopic CT acquired. Panel B shows proper positioning of the needle tip in the center of the T10 vertebral body. Panels C and D show corresponding biplanar fluoroscopic views of the final needle positioning. Panel E is a reformatted sagittal image of the final fluoroscopic CT acquisition after injection of methyl methyacrylate cement showing satisfactory distribution within the T10 vertebral body. Chronic compression deformities of T11 and T12 are also demonstrated in these images.*

## Case 4

Percutaneous drainage of sacral epidural abscess. A 51-year-old female presented with 5 days of lower back pain and was found by MRI to have a large anterior lumbosacral epidural abscess with involvement of the paraspinal musculature. After surgical laminectomy and abscess debridement the patient had persistent fevers and was found on follow-up diagnostic CT to have a residual abscess extending through the left S2 neural foramen to involve the piriformis and gluteus medius. Fluoroscopic CT guidance was used to safely place a 13-gauge needle for percutaneous drainage of the multiloculated fluid collection.


Fig. 4. *A 51-year-old female with fever and sacral epidural abscess referred for percutaneous drainage. A preoperative CT was performed for initial diagnosis. Sagittal and axial images (panels A and B) from the diagnostic study demonstrate a rim-enhancing fluid collection extending from the left S2 neural foramen to involve the left piriformis and gluteus medius musculature. Fluoroscopic CT was then used to guide percutaneous placement of a needle for drainage of the abscess. Sagittal, axial, and coronal reformatted images of a fluoroscopic CT acquired during the procedure show proper positioning of the needle with projected course directly into the abscess.*

### Case 5

Percutaneous paraspinal fiducial placement for image guided spine surgery. A 25-year-old female with mid-thoracic back pain was found to have lytic lesion of the left lamina of T9 with ground glass central component thought most likely to represent osteoid osteoma. Fluoroscopic CT was used as guidance for preoperative placement of 5 paraspinal gold fiducial markers to assist with image-guided surgical resection by an orthopedist. Two fiducial markers were placed at the level of the T9 transverse processes, 2 at the level of the lamina, and one at the level of the spinous process. The patient went on to successful resection of the lesion by T9 laminectomy without complication. Pathologic evaluation of the surgical specimen showed findings diagnostic of osteoid osteoma.

## Discussion

We have found the intraoperative use of fluoroscopic CBCT to be beneficial during the performance of a variety of minimally invasive interventional procedures of the spine, including cervical and thoracic vertebral bone biopsy, vertebroplasty, epidural abscess drainage, and placement of paraspinal fiducial markers. High quality image resolution, and rapid data acquisition and reconstruction assisted us with near real time guidance of spinal needle and trocar placement with precision and lack of complication.

Spatial and contrast resolution are the key determinants of precise placement of spinal instrumentation which is the most important factor in achieving good patient outcomes. Many of the complications of spinal

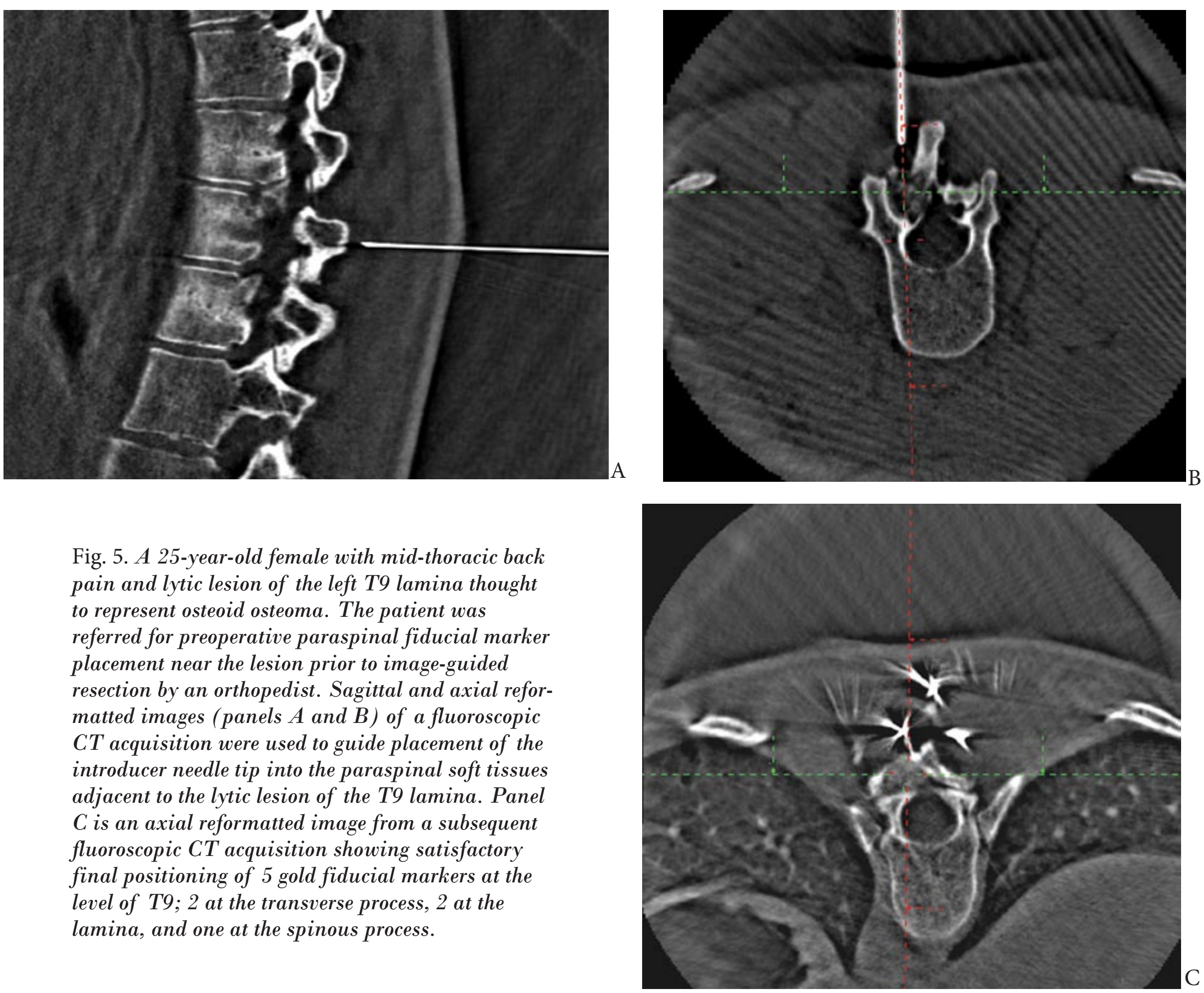


Fig. 5. *A 25-year-old female with mid-thoracic back pain and lytic lesion of the left T9 lamina thought to represent osteoid osteoma. The patient was referred for preoperative paraspinal fiducial marker placement near the lesion prior to image-guided resection by an orthopedist. Sagittal and axial reformatted images (panels A and B) of a fluoroscopic CT acquisition were used to guide placement of the introducer needle tip into the paraspinal soft tissues adjacent to the lytic lesion of the T9 lamina. Panel C is an axial reformatted image from a subsequent fluoroscopic CT acquisition showing satisfactory final positioning of 5 gold fiducial markers at the level of T9; 2 at the transverse process, 2 at the lamina, and one at the spinous process.*

procedures such as pedicle fracture, cement leakage, dural tear, vertebral body and spinal cord injury, and epidural hematoma can be minimized with 3D guidance because these are usually related to suboptimal needle and trocar placement (11,30).

True isotropic spatial resolution is a major advantage of CBCT compared to multichannel CT systems. The 154 micron flat panel detector used on the Siemens system results in a Z-axis spatial resolution down to 200 microns. Sub-mm precision of CBCT has been confirmed in animal models of thoracolumbar pedicle needle placement. Contrast resolution is good but less than multichannel CT, measured at < 10 Hounsefield units. The large rectangular field of view is another advantage of CBCT, allowing an acquired volume data set of up to 20 x 25 cm (6,13-14,21).

In addition to high spatial and contrast resolution, CBCT has been shown to reduce dose to patients during neurointerventional procedures compared to subtraction angiography and conventional CT, in part due to shorter operating times. With the advent of the newer flat panel detector designs dose per acquisition is expected to decline. Dose to operators is minimized because they can position themselves behind lead shields during the acquisition. This allows for multiple intraoperative acquisitions with low overall dose to patient and staff (3-5,12,17,20).

One reported disadvantage of CBCT relative to multichannel CT is more exaggerated dense metal artifact caused by orthopedic screws and plates (14). However in the case of minimally invasive percutaneous spine interventions such as aspiration, biopsy, and vertebroplasty, metal artifact is less of an issue given the small gauge of the needles and trocars used. Further improvements with software filter algorithms are expected to reduce dense metal artifact.

## Conclusion

Cone beam angiographic computed tomography using orbital C-arm fluoroscopy equipped with the latest generation flat panel detectors is a promising new technique for intraoperative 3D imaging guidance of minimally invasive interventional procedures of the spine such as vertebral biopsy, vertebroplasty, paraspinal abscess drainage, and fiducial marker placement. Among the many advantages of CBCT include excellent spatial and contrast resolution, and rapid data acquisition and reconstruction allowing near real time 3D guidance, improved patient positioning and access, and reduced exposures to patient and staff.

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