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New Technology

Fluoroscopic Computed Tomography: A Demonstration of Spinal Imaging Hypothesized Applications for Interventional Pain Management

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Spinal imaging has become an essential tool, assisting the interventional pain physician in providing safe, accurate and efficient needle placement for diagnostic evaluation or therapeutic interventions for chronic pain. Live fluoroscopy provides a two dimensional image of spinal anatomy. A recent technological advance allows adaptation of the C-arm to provide computed tomography (CT) and 3D surface model renderings of spinal anatomy. Compared to conventional CT, penetration power is less, thereby providing less resolution through more massive portions of anatomy. Fluoro CT may provide a cost-effective and real-time application of CT imaging that may prove useful to the interventional pain physician. The authors provide some demonstration of the imaging capability of this technology and some cadaver demonstrations of its potential utility for spinal needle placement.

Keywords: Fluoroscopy, computed tomography, spinal anatomy, spinal injections

Spinal injections for diagnosis and treatment of painful conditions should be precise. Precise placement should improve reliability of diagnosis, efficacy of treatment, and patient safety. Radiological technologies have long assisted physicians and diagnostic evaluation. The use of imaging during interventional procedures has become an essential part of the current standard of care. Common examples include the use of the C-arm fluoroscope with epidural steroid injections, facet injections, discography, and injection of the sacroiliac joint. The ability to accurately place a needle for transforaminal epidural corticosteroid injection has resulted in the lower surgical rates for a study population (1). More sophisticated imaging techniques during procedures may be employed (e.g. CT assisted needle placement for celiac plexus block (2-8), facet and sacroiliac joints (9-11), epidural injections (12), epidural blood patching (13, 14), and peripheral nerve block (15). As more sophisticated technologies and procedures evolve, the spinal injectionist must assess the value of such techniques before incorporating them into a standard of care.

GE OEC provided the authors an enhancement of the C-arm fluoroscope with computed tomography (FCT) capability. Arrangements were made to obtain a cadaver to aid assessment of the potential utility of FCT. It is hypothesized that there are three phases to the spinal injection for which this technology may prove useful: preinjection assessment of anatomy and needle approach; documentation of needlepoint placement within the target; post injection assessment of contrast spread. GE-OEC theorized that this imaging might be useful to the spinal injectionist primarily for cervical injections and diagnostic imaging. The technology had already been used for vertebroplasty.

Visualization of the Atlanto Occipital and Atlantoaxial Joints

In our specimen visualization of the atlantoaxial joints with plain fluoroscopy was excellent, while the atlanto occipital joint appeared significantly narrowed. C-arm FCT provided excellent quality images of the joints, particularly in the coronal views. 3D surface modeling demonstrated very well the occiput, the arch of C1, the C2 lamina and spinous process, the articular processes and joint spaces, the odontoid process and its relationship to C1. Manipulation of this 3D model demonstrated potential obstructions to the needle path; this has obvious educational potential, may be useful for planning needle approachs for AO or AA joints, or for neurostimulator implantation under the arch of C1 (Figs 1A-D). Other cervical facets were visualized (Fig. 1E).

Sacroiliac Joint

CT reconstructions did prove legible in our petite specimen. Coronal and sagittal images did document needle tip within the joint. Some injected contrast was observed, but poor. When a surface model was rendered based on the contrast density, the resulting 3D arthrogram was less rewarding. It was unclear if this model truly represented only the contrast or to some extent the cancellous margins of the sacrum and ilium (Figs. 2A & 2B).

A notable limitation was observed, as the C-arm must be positioned from the head of the bed to rotate through a tilting arc. There was a limit on extension of the C-arm from head to pelvis that would likely be exceeded in taller patients. Additional artifact enters due to spring of the extended C-arm and increased tissue mass at the pelvis (Figs. 2A & 2B).

Costo-Vertebral Joint

Approach to the costo-vertebral joint for needle placement and injection has been described as a modification of the thoracic discography approach above the lamina-superior articular process junc-

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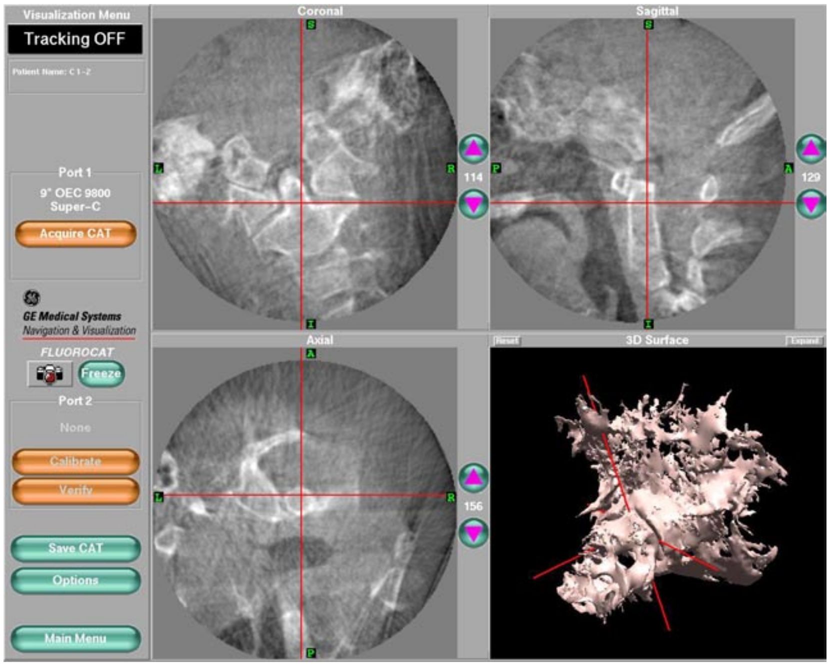


Fig 1A. *A screen shot from the OEC Fluoro/CAT of C1-2*

tion. The most notable hazards include the potential for pneumothorax and segmental nerve or dural sleeve puncture. One needle was placed using the fluoroscope using this technique, then checked with the CT enhancement. The CT did prove very useful in correcting accuracy of this approach, since the first pass was clearly extra-articular (Figs 3A & B). 2D images were clinically useful in confirming accurate needle placement.

A novel approach was then tried with a shallow angle approach of ~45 degrees from caudal to cranial, skipping over the transverse process below, contacting the transverse process at the target level, then turning the curved needle to skip below the process and into the joint capsule. The needle did appear to enter the joint. This approach may lessen the risk of pneumothorax but may increase the risk of neural trauma. No images of this technique were retained (Figs. 3A and B).

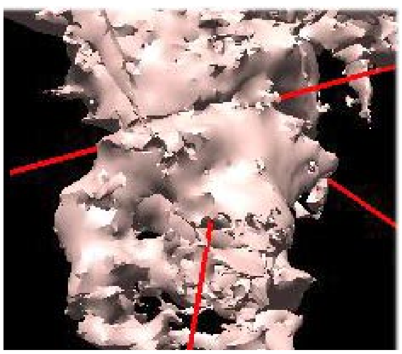


Fig. 1B. *Rendered image of the ventral surface of C1-2 joint*

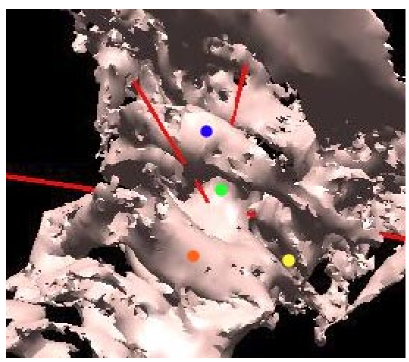


Fig 1C. *Posterior surface of C1-2 joint from below and right. Yellow dot is on the right C1-2 joint line; Blue, arch of C1; Red, lamina of C2; Green, dens of C2.*

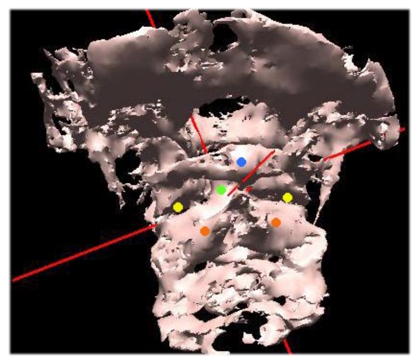


Fig 1D. *Caudo-cranial view posterior, same color key.*

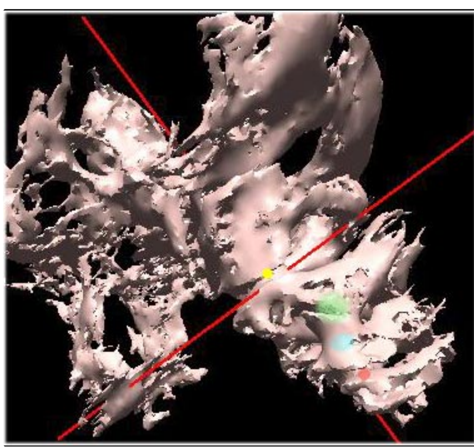


Fig 1E. *The C2-3 and 3-4 facets from left posterior oblique with Green, the region targeted for C2 dorsal medial branch RF neurotomy (DMBN); Blue the 'waist region' target for C3 DMBN; Yellow the C1-2 joint line; Red the C3-4 joint line.*

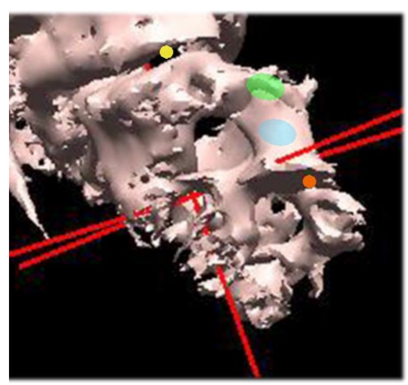


Fig 1F. *C2-3 as seen from somewhat foraminal viewing angle. Same color key. The foramina for C3 and for C4 are well visualized*

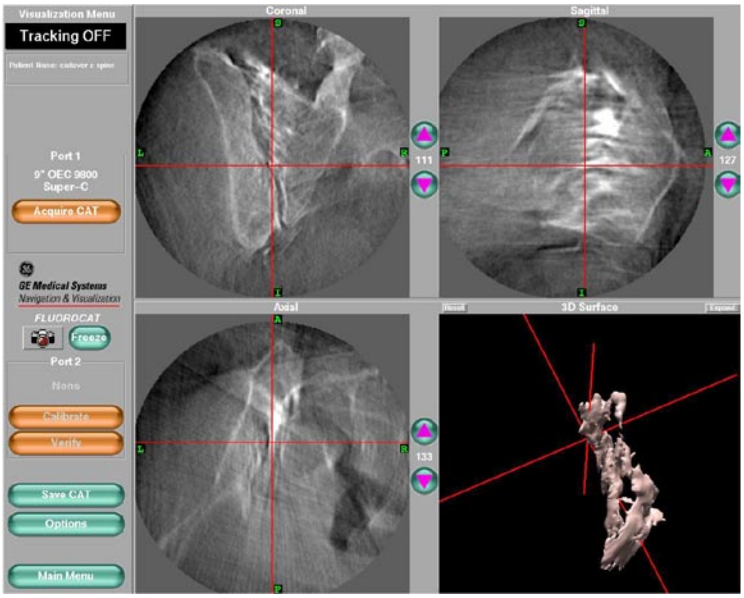


Fig 2A. *Sacroiliac joint screen shot.*

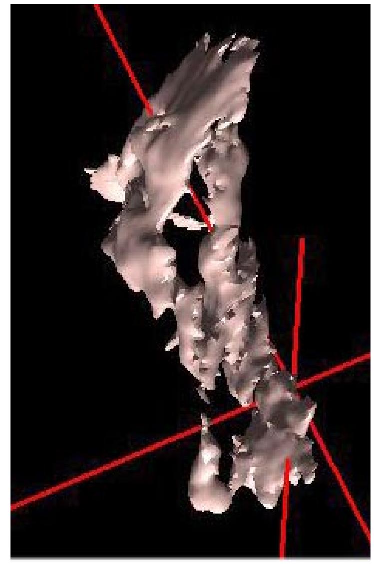


Fig 2B. *Close up of joint line reoriented craniad is top.*

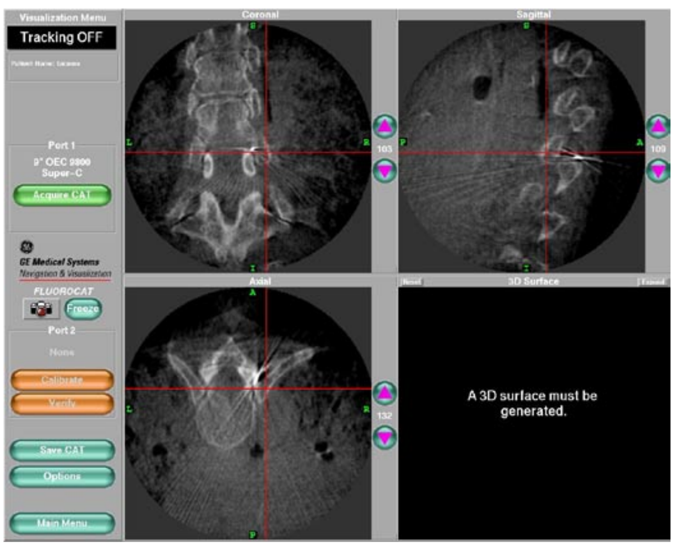
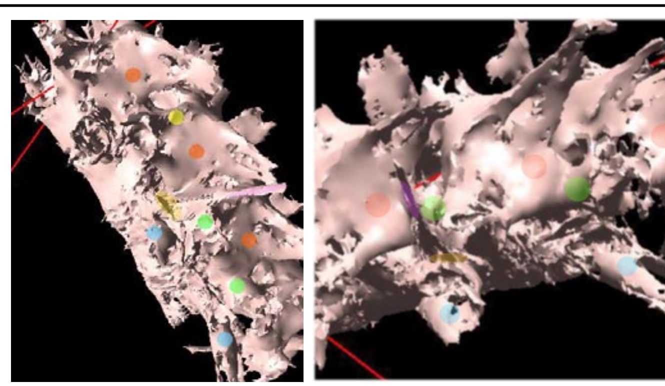


Fig 3A. *Costovertebral joint. Screen shot. The bright white spot is the needle tip within the joint.*

Lumbar Discogram

The mid-lumbar discs were visualized. 1.0 cc of contrast was injected into the 4-5 disc using standard extrapedicular oblique approach. The contrast visualization on 2D axial imaging was not useful. More intriguing was a 3D surface model rendering selecting the contrast density while dropping the vertebral body bone density. This model did yield an apparent 3D nucleogram as seen in Figure 4a, 4b. Confident distinction between nucleogram and hyperostotic vertebral body surface and ossified endplate is lacking. Limitations similar to those noted below under the sacroiliac joint will exist in the lumbar region. The L5-S1 disc was not oriented well for 2D axial images because of the lordotic angulation change. Thus, axial slices were only through a portion of disc, similar to the cervical disc as not-

Fig 3B. *This 3D rendering is posterior left oblique, slightly cranio-caudad. Red marks the thoracic lamina with spinous processes emerging to the right; Yellow, the zygapophyseal joints; Green, the transverse process; Blue, the head of the rib; Purple, the needle passing just craniad to the transverse process medial to the costo-transverse joint and passing just caudad to the interspace to enter the costovertebral joint, Orange. The needle density attenuates to a dashed appearance. Yellow arrows point to intervertebral discs. 3c; same from cranio caudad left oblique.*



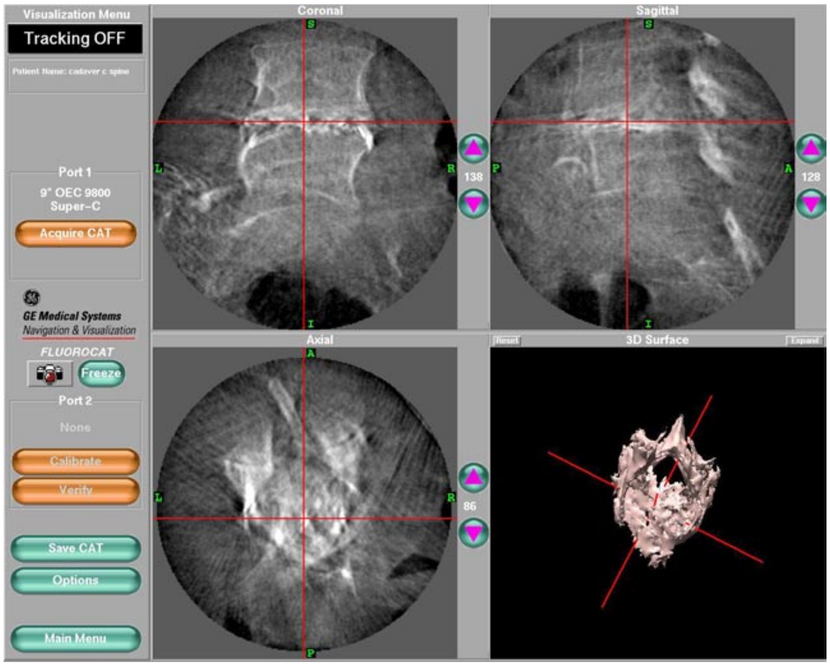


Fig 4A. *Lumbar discogram screen shot*

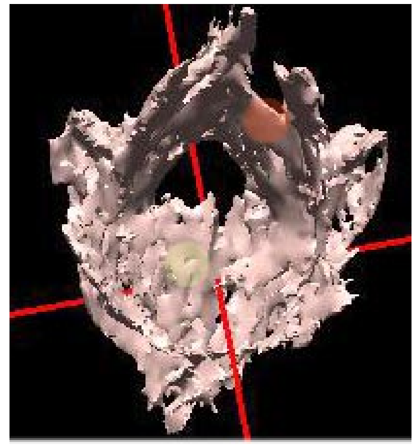


Fig 4B. *Discogram 3D rendering. While contrast density (yellow) was selected, some dense bone was still rendered (red). Therefore, of the intravertebral rendering how much represents contrast and how much bone is unknown. Confidence of this rendering demonstrating mostly intradiscal contrast is increased by the disappearance of the adjacent vertebral body that would otherwise have obstructed the lines intersecting the interspace.*

ed below. Changing the C-arm rotation for each disc and repeating the study may overcome this, but then the attachment may hit the table, preventing a full arc of imaging. 3D surface modeling may prove useful in pre-injection planning and needle placement for an L5-S1 or high thoracic approach in difficult cases (Figs. 4A and B).

Visualization of the Cervical Discs

Computed tomographic images of the cervical discs were judged as poor. The plane of C-arm rotation used to acquire the images was limited to 90 degrees to the axis of the x-ray table. Otherwise rotated, the attachment to the image intensifier was obstructed by the x-ray tabletop preventing a full 180 degrees of rotation. The plane of endplate alignment of our specimen was approximately 25 degrees off of the C-arm plane. The plane of 2D axial image reconstruction could not be altered through the current software. The resultant slices were dominantly through vertebral body with only a portion through disc at a time. Another factor was the specimen's advanced disc degeneration with disc height loss and Modic changes of the adjacent vertebral bodies. However, visualization of the z-joints and lamina were excellent (Figs. 5A and B).

Equipment and Technology

GE-OEC provided the necessary software enhancement to our fluoroscope, an OEC 9800 Super C. It also provided an attachment to the imaging intensifier Fig 6a. At several inches thick and was a limiting factor as it would tend to strike the bed in the lateral positions of the arc of travel necessary to obtain the tomogram.

The C-arm workstation was then linked to a separate workstation Fig 6b for data collection and analysis and display. A number of cables connected between the various components led to a challenging number of wires across the floor. The 14 x 16 foot operating room was reaching capacity.

A reference point must be established with a supplied probe Fig 6c. The system is designed to use one that attaches to bone or otherwise internally located. We were able to simply tape the reference device to the skin. In a patient one should select a point not likely to move in reference to the study site, just outside the operative field and fluoroscopic view.

Once all the equipment was booted to readiness, a soft button on the screen of the second workstation initiated the sequence. The C-arm was manually moved through an arc about a target point in the study region. Optimally, this was 190 degrees over 20 seconds. During that time, the fluoroscope generated about 150 separate images. The second workstation was able to relate in 3D all the pixels from the majority of the images and drop some corrupted images to allow for CT and surface modeling. From initiation of the sequence to the time of 2D CT image display was approximately 7 minutes. In some of our sequences the first run was satisfactory. In two sequences, we repeated the run at least once to obtain a better image. This may be operator fault enhanced by some awkwardness of the equipment. Each sequence resulted in radiation exposure of approximately 500-1000 radcm2.

The 2D CT images may be adjusted for contrast and brightness and scrolled smoothly in x,y and z axes. One is presented with axial, coronal and sagittal views.

One may then select the sensitivity of a 3D surface modeling. The generation of that model required about 5 minutes. If one is not satisfied with the result, another sensitivity setting and rendering may be produced in a similar amount of time.

The entire data set may be saved to a hard drive or Jaz drive. Images may be saved as jpeg files to floppy disc, printer, or Jaz drive.

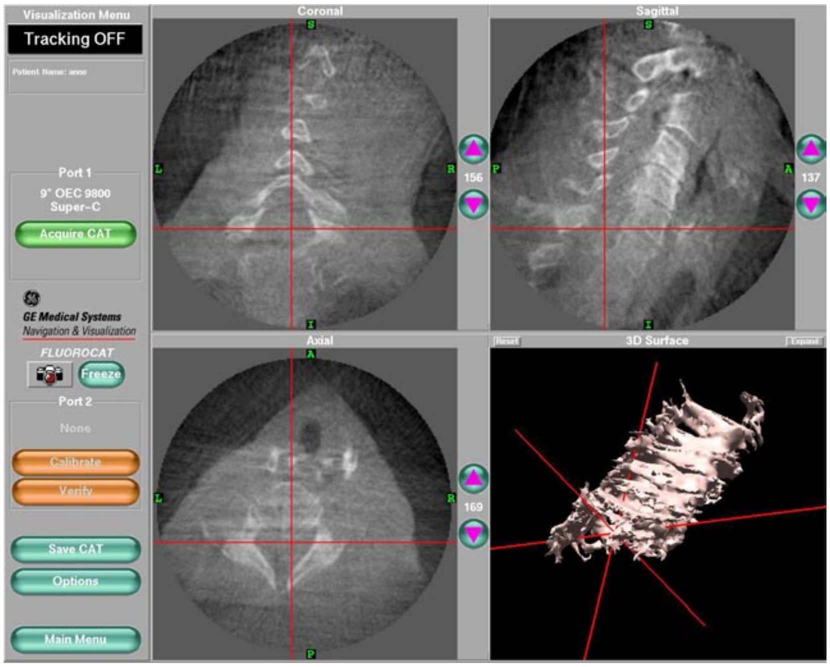


Fig 5A. *Cervical spine screen shot*

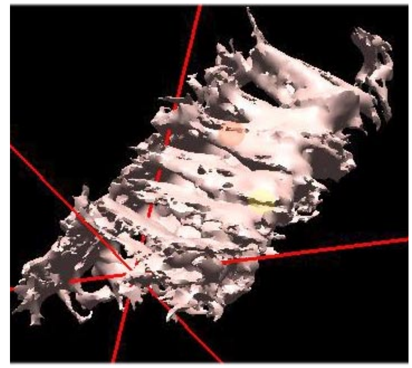


Fig 5B. *Cervical spine 3D rendering with excellent visualization of the lamina (Red) and z-joints (yellow) from right oblique caudo-cranial. A waist region target for the dorsal medial branch nerve is seen just caudad to the yellow dot.*

Discussion

The current study did not allow for follow-up comparison with regular CT, which would help the authors better assess resolution. One must often trade sophistication level of technique with practical considerations. Most interventional pain physicians do not have CT available during procedures. It is possible that this evolving FCT technology will provide a practical and cost effective middle ground between fluoroscopy and CT. The practicality and utility of employing FCT on a regular basis will require further study on a per technique basis, e.g. for cervical discography *versus* SIJ block or any other technique.

In time the technology should improve the clearance between the C-arm and the x-ray table, the time to process a sequence, the time to render a 3D surface model, the connectivity, smooth and automatic image acquisition, the footprint of FCT, and thus overall efficiency and practicality. Perhaps images could be obtained using the Super C-arm rotation rather than tilt; this would be a more natural adaptation to interventional pain work and allow for examination of areas below the waist. The reference EM probe would have to be adapted to spinal injection work, perhaps a flat taped on device. It would be helpful to be able to specify density ranges by point and click, then assign colors and transparency parameters. One might then assign a density range for the needle, another for contrast and one for bone, with the bone semi transparent. In this way, one might appreciate needle placement, contours of a joint and its capsule, or a discogram.

Various epidural and facet joint injections comprise the majority of procedures in common interventional pain practices. We did not concentrate on epidural injection during this trial of FCT. Standard and digital subtraction fluoroscopy techniques are our current accepted standard for epidural injections. It is theoretically possible that a "cast" of the epidural space might be visualized with 3D

Fig 6A. *Attachment to the image intensifier.*

Fig 6B. *Workstation.*

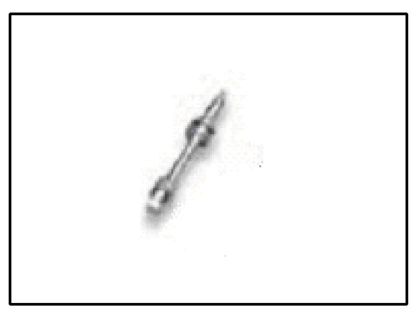


Fig 6C. *Electromagnetic reference probe.*

surface modeling. This will have to await further investigation. Such models, similar to myelography, may prove useful.

With the use of radiological imaging for spinal injections there may be additional education and experience required of the spinal injectionist, associated increased procedure time, expense, and radiation exposure. Radiation exposure must be practical. An automatic movement of the C-arm will allow personnel to step out of the room during sequence acquisition. Dose comparison to standard CT should be made, as well as comparison to performance of the injection with standard fluoroscopy. Most of our sequences required 500radcm2.

While indisputably more accurate than fluoroscopy, CT guided celiac plexus block has not eliminated serious complications (16, 17), just as fluoroscopic guidance has not eliminated risk from epidural steroid injection. It remains to be determined that improved visualization with FCT results in decreased risks of complications. At this time FCT remains an investigational tool that may find utility in teaching, research and some interventional procedures.

The interventional pain physician is always interested in multiple factors of patient care that will include patient safety, accuracy, efficacy, efficiency of technique and time, reimbursement practicality, and ease of use. Presently, we do not have enough evidence or cost analysis to justify any recommendation for or against FCT in medical practice.

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