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# Computer-Assisted Virtual Fluoroscopy

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## Introduction

Intraoperative fluoroscopy is an invaluable tool for the orthopaedic surgeon. It allows the surgeon to visualize patient anatomy in real time and assist in implant insertion. Though most commonly used for orthopaedic trauma, fluoroscopy is utilized in nearly all orthopaedic subspecialties.

Spinal surgeons routinely use instrumentation with pedicle screws. Violation of the pedicle wall or vertebral body while placing these screws carries the risk of injury to neural, vascular, and visceral structures [4,5,15,23]. The C-arm facilitates safe placement of pedicle screws. To ensure correct placement, it can also be used to check the position of other implants, such as hooks and interbody devises.

Although an indispensable tool, fluoroscopy has certain disadvantages. During procedures there is radiation exposure to the patient, the operating room personnel, and the surgeon. Spine surgeons in particular are susceptible to radiation exposure to the hands during pedicle screw placement [19]. Though capable providing real time imagery with continuous operation, fluoroscopy does so only in one plane. To obtain orthogonal or oblique views, it is necessary to reposition the C-arm image intensifier, adding to operative time and surgeon frustration. Moving the C-arm in and out of the surgical field also increases the potential for infection.

Despite the surgeon's skill, misplaced pedicle screw rates of 10–40% have been reported using traditional insertion techniques [2,6,7,10,18,22,24,25]. In the recent past, a number of computer-assisted surgical navigation systems have increased the accuracy rate of pedicle screw placement to 92–100% [1,9,11–14,16,17,20,21]. These systems have certain drawbacks. They require a preoperative CT scan, exposing the patient to additional radiation. For the surgeon, the preoperative planning is both time consuming and frustrating.

Computer-assisted virtual fluoroscopy has the advantage of simplicity and increased accuracy without needing a preoperative CT scan. It combines intraoperative fluoroscopic imagery with computer-assisted surgical navigation software to provide real-time, multiplanar imagery without the need for extensive fluoroscopic exposure to the patient, surgeon, or operating room personnel. The surgeon has the advantage of seeing orthogonal or oblique views without moving the C-arm.

In a simplified virtual fluoroscopy model, the computer forms a mathematical model of the relative positions of the patient, the C-arm, and the surgical instruments.

The software program superimposes the position of surgical instruments and projected implant paths onto multiplanar virtual fluoroscopic images in real time. The surgeon can make adjustments in the pedicle entry point and implant trajectory without additional fluoroscopy.

## Requirements of a Virtual Fluoroscopy System

Computer-assisted virtual fluoroscopy requires the following elements (Fig. 1A,B). First, a standard fluoroscopy unit is used. Attached to it is a calibration grid with light-emitting diodes (LEDs). The surgical instruments also contain LEDs, as does the dynamic reference array (DRA). The DRA is rigidly attached to the patient's anatomy via a spinous process or other fixed landmark. The light emitted by the LEDs is detected by a light-sensing camera, also known as the position-measuring sensor, located at the head of the bed. The cornerstone of the system is the computer software.

In order for the system to function properly, the following steps are necessary. First, an empty C-arm image of the calibration grid is acquired and transferred to the computer for later calibration (Fig. 2A,B). C-arm images of the patient are then transferred into the computer via a standard video or digital link. At the time of image acquisition, the relative position of the patient and the C-arm is measured. During this step, the position-measuring sensor at the head of the bed detects the signal from the LEDs attached to the fluoro unit and the patient (via the DRA). Next, the images are calibrated. The calibration allows the computer to build a mathematical description of the images that geometrically relates how a given position relative to the patient projects onto the fluoroscopic image. At the same time, the mathematical description also relates how a given picture element of the C-arm image projects back through the patient to the radiation source via the calibration grid. Finally, the computer measures the position of the surgical instruments via LED emissions on the instruments to the position-measuring sensor. The position of the instrument is then superimposed onto the fluoroscopic images in multiple planes and in real time [8].

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**Pedicle Screw Insertion via Computer-Assisted Virtual Fluoroscopy**

In our practice, placing pedicle screws with virtual fluoroscopy begins with a standard midline exposure of the spine, out to the tips of the transverse processes of the levels to be fused. A thorough knowledge of spinal anatomy is critical, and one should be familiar with the pedicle entry point before proceeding with virtual fluoroscopy. Computer-assisted virtual fluoroscopy is only an adjunct to surgical experience.

After completing the exposure and obtaining hemostasis, the DRA is attached to the spine (Fig. 3). Generally, the spinous process immediately cephalad to the fusion levels is chosen as a secure attachment point. Placement of the reference array in this manner usually allows the surgeon to proceed with screw placement two or three levels caudal, without needing to reposition the array or reacquire and calibrate images as described above.

Next, an empty C-arm image with the calibration grid is acquired and activated into the computer. Anteroposterior and lateral images of the spine are acquired (Fig. 4A) and

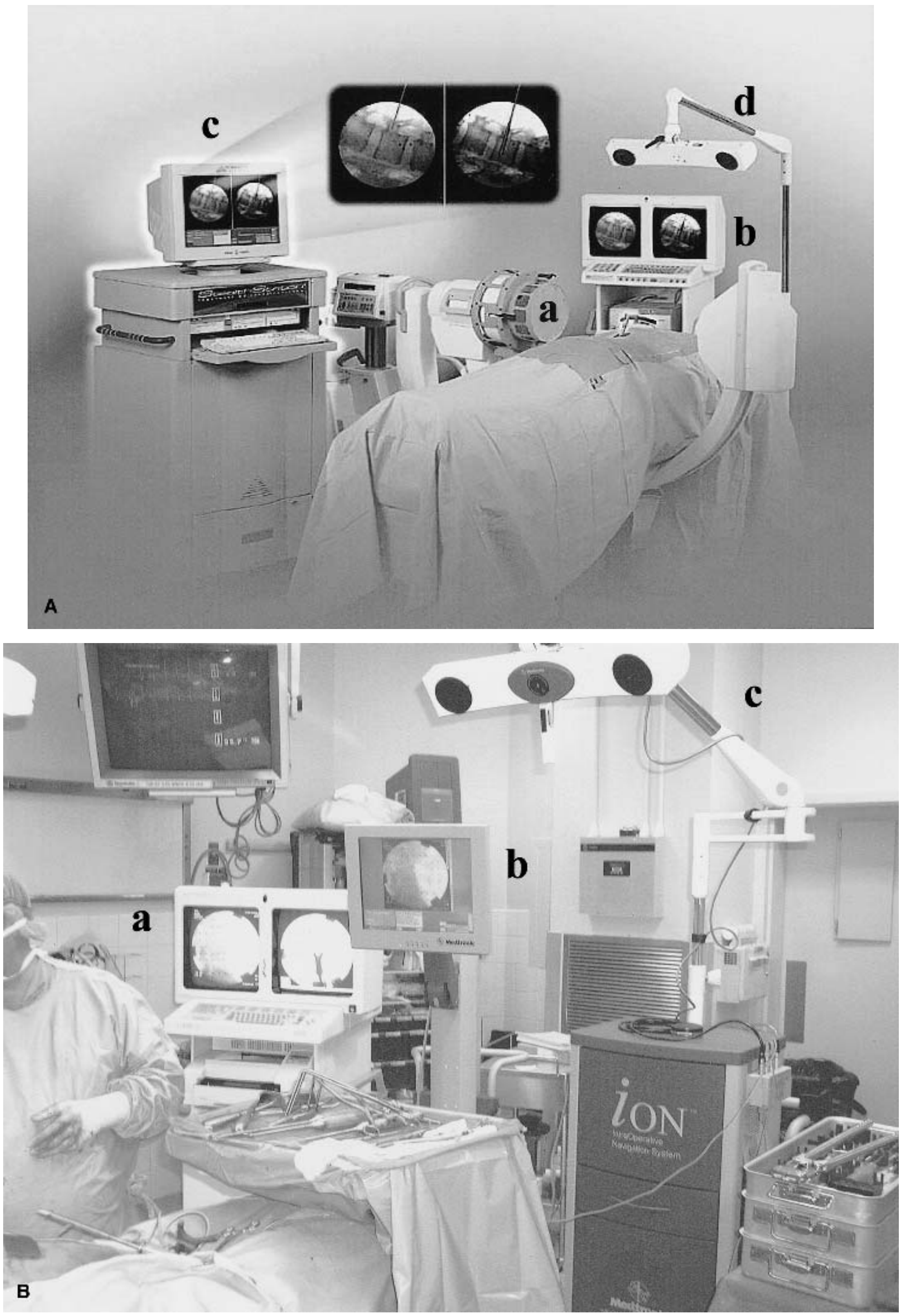


**Fig. 1.** (**A**) Virtual fluoroscopy system. **a**–Fluoroscope with calibration grid, **b**–Fluoroscope monitor, **c**–Computer monitor with virtual images, **d**–Light sensing camera. (**B**) Intraoperative virtual fluoroscopy. **a**–Fluroscope monitor, **b**–Computer monitor with virtual images, **c**–Light sensing camera.

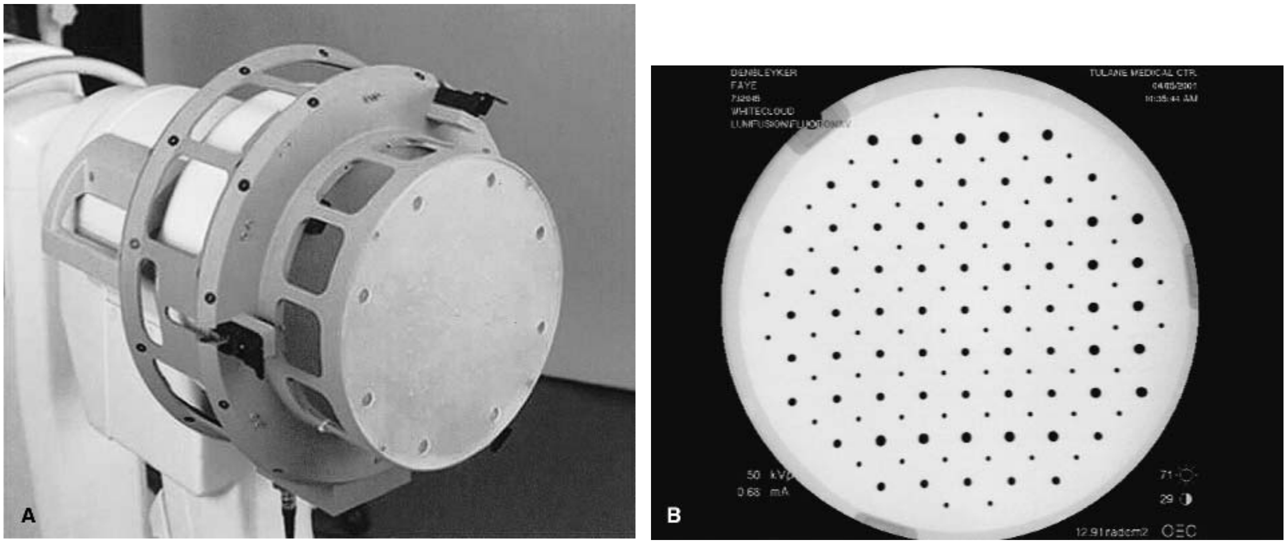


**Fig. 2.** (**A**) Calibration grid attached to C-arm. (**B**) Empty C-arm image with calibration grid.

then activated into the computer (Fig. 4B). If desired, an enface or "owl eye" view of the pedicle may be taken. The quality of these images is of utmost importance, and great care must be taken to get true AP and lateral images that adequately delineate pedicle morphology and geometry.

Finally, the instruments are verified and activated into the computer by touching them to the DRA (Fig. 5). The instruments include an awl, probe, and tap (Fig. 6). These are secured sequentially to a common handle containing LEDs. There is an attachment for a screwdriver as well. The position of the instruments is now superimposed onto the fluoro images that have been activated into the computer. These images are displayed on monitors separate from the C-arm monitor.

After identifying the pedicle entry point via anatomic landmarks, the awl is used to initiate a starting hole. With real time multiplanar capabilities, adjustments to the entry point and trajectory can be made without additional fluoroscopy (Figs. 7). The software also allows the surgeon to check the anticipated screw length. The awl is followed by the probe and tap. The pedicle walls are repeatedly probed between each step to ensure that no violation of the pedicle

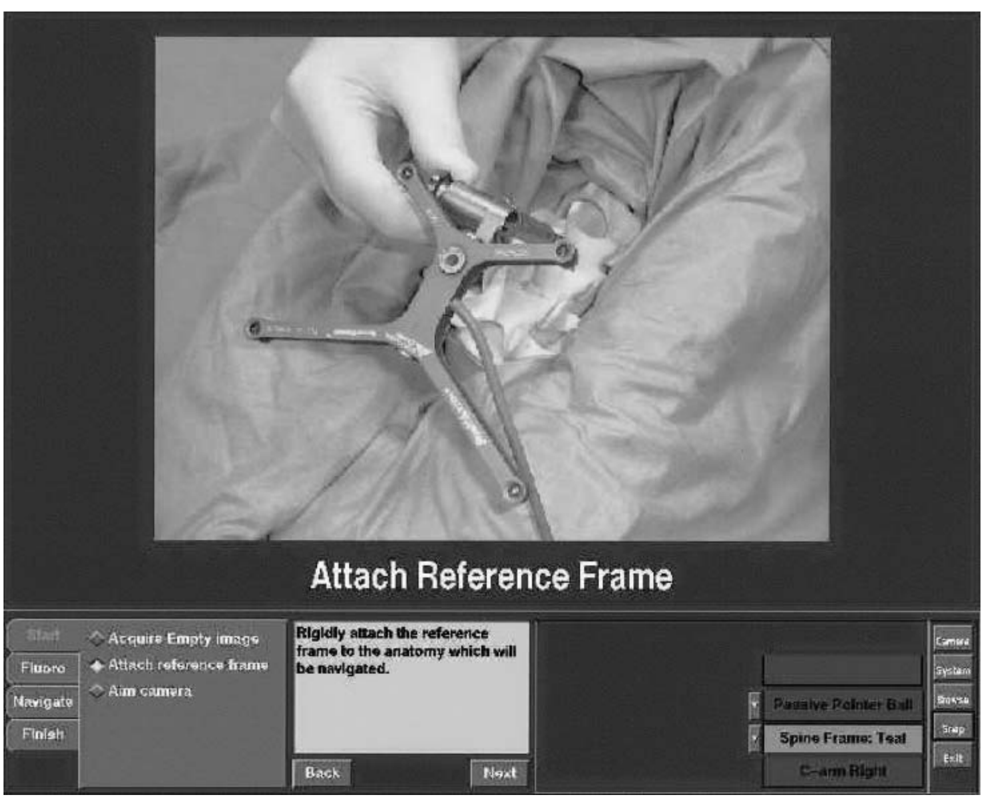


**Fig. 3.** Dynamic reference array atached to spinous process.

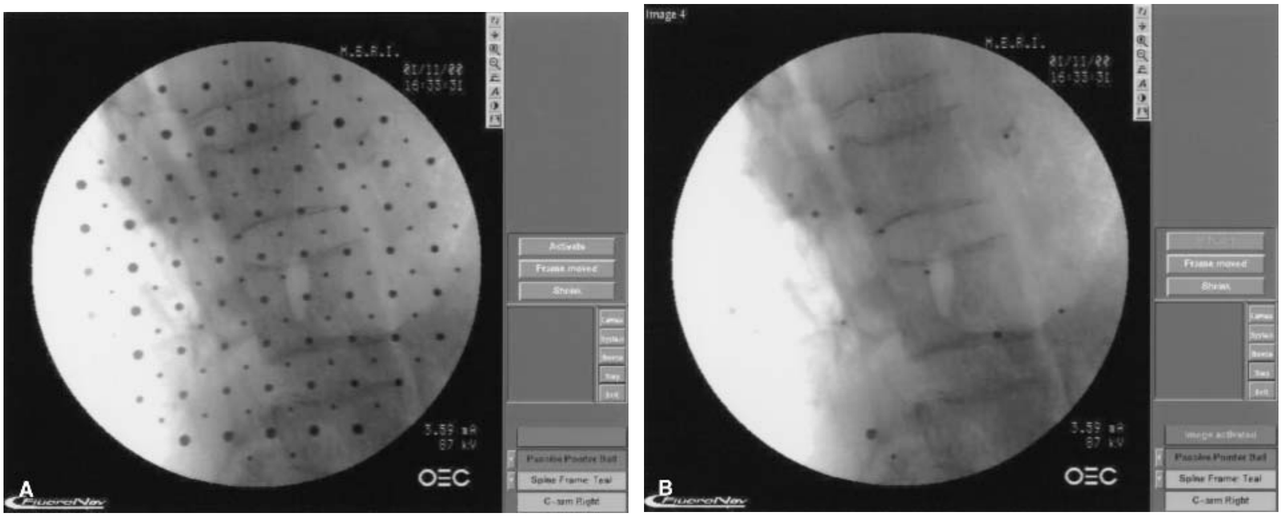


**Fig. 4.** (**A**) Acquired lateral C-arm image. (**B**) Activated lateral C-arm image as seen on monitor.

has occurred. Lastly, the screw is placed. If a violation is detected, attempts are made to redirect. If the screw cannot be placed safely, that site is abandoned. The remainder of the operation then proceeds in a standard manner.

In addition to palpation of pedicle integrity, additional steps are taken intra-operatively to ensure the successful and accurate placement of screws. After placement, each screw at lumbar levels undergoes intra-operative stimulus-evoked electromyography. A reading greater than 10 mA confirms safe screw placement [3]. Our institution has no experience with EMG monitoring at the thoracic level. All cases involving instrumentation at the thoracic level have somatosensory-evoked potential (SSEP) monitoring. Each screw is also examined fluoroscopically. If EMG readings, SSEPs, or fluoroscopy suggest that a screw is out, the pedicle is explored. The screw is then either redirected or removed.

### Accuracy of Pedicle Screw Placement via Computer-Assisted Virtual Fluoroscopy

Between January 2000 and December 2001, computer-assisted virtual fluoroscopy has been used to place 1,039 pedicle screws in 151 patients, 76 women and 80 men (Table 1). One hundred seventy-four screws were placed in previously fused levels where anatomic landmarks were obscured, and 307 screws were placed in deformity cases of scoliosis, kyphosis, and flatback (Tables 2 and 3). Intra-operative stimulus-evoked electromyography, somatosenso-

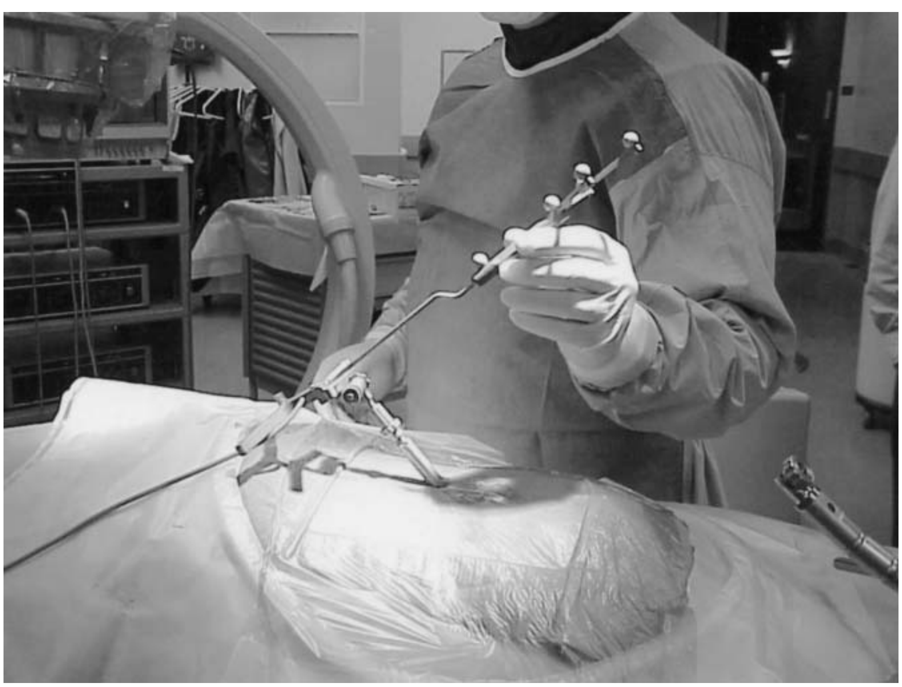

**Fig. 5.** Instrument verification.

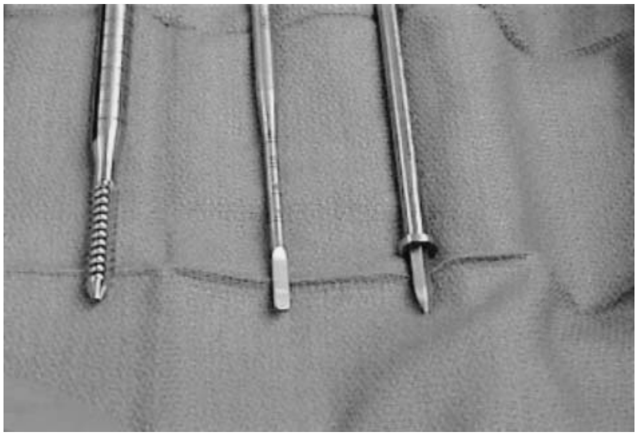

**Fig. 6.** Virtual fluoroscopy instruments. Awl, probe, and tap (right to left).

ry-evoked potentials, pedicle wall palpation, fluoroscopy, post-operative radiographs, and physical exam to detect radiculopathy or myelopathy confirmed correct screw position. Stimulated screws with EMG measurements of greater than 10 mA were considered to be safely within the pedicle [3].

Overall, 1,032 of 1,039 (99.3%) screws were placed accurately within the pedicle. Four screws were determined out by EMG, 2 by pedicle probing, and 1 by intraoperative fluoroscopy. Two missed screws occurred in levels that had not been fused previously and did not have deformity. These occurred at L2 and L5, and were detected by EMG.

In cases of deformity, 303 of 307 (98.6%) screws were placed accurately. Two of these misses, detected by pedicle probing, occurred at L2 bilaterally in the same patient with degenerative scoliosis who had not had previous surgery. A third miss, detected by EMG, occurred at L3 in a patient with acquired lumbar kyphosis. The final miss in this group occurred at T10, and it was noticed on fluoroscopy. This patient had had a previous thoracolumbar fusion for scoliosis and presented with sagittal imbalance from a flatback deformity.

In cases where previous fusion obscured anatomic landmarks, 172 of 174 (98.8%) screws were placed within the pedicle. One misplaced screw occurred at T10 in the patient mentioned previously. The other occurred at L4 and was detected by EMG.

In all patients, there was a low complication rate. No patient demonstrated radicular or myelopathic symptoms related to misplaced pedicle screws. One patient developed an L5 radiculopathy secondary to a pedicle fracture 6 weeks post-operatively that resolved with screw removal. Another developed cauda equina syndrome unrelated to pedicle screws. At surgical exploration it was noted that gelfoam placed over the laminectomy defect had become encased in a hard, dense, fibrotic mass that was compressing the cauda

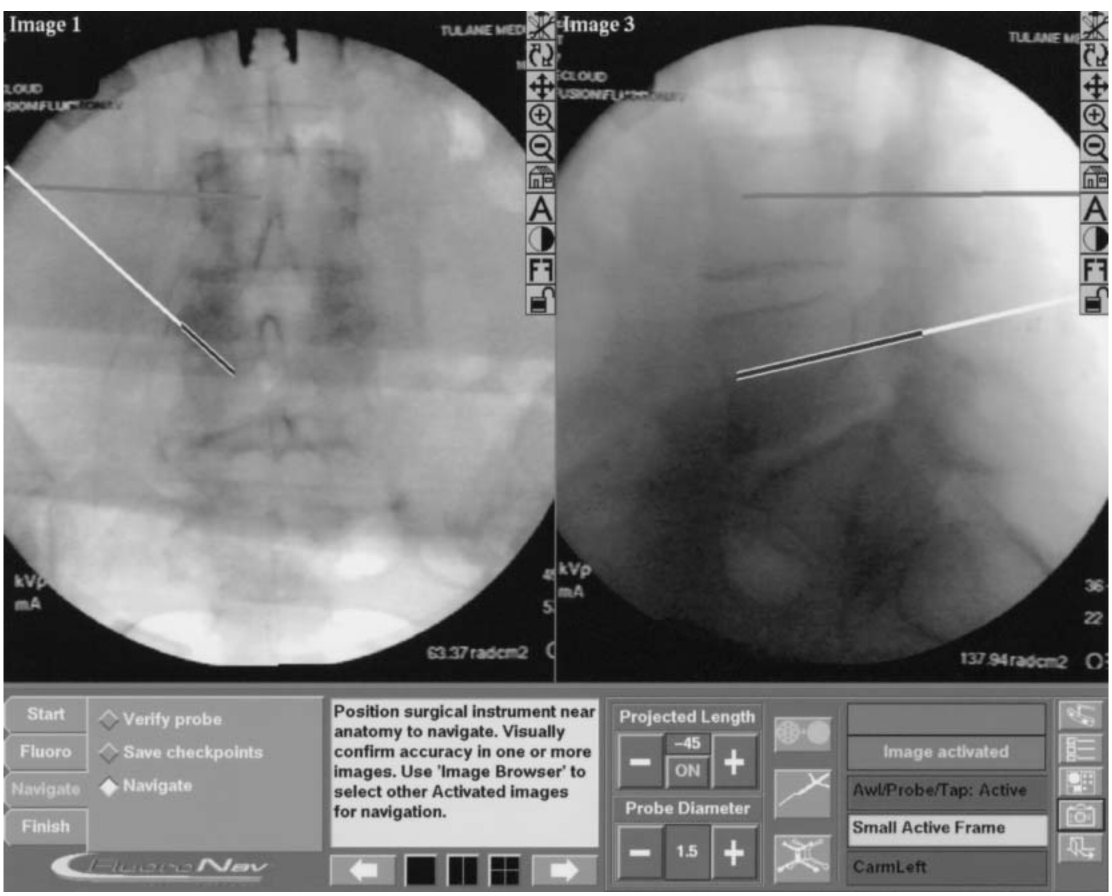


**Fig. 7.** Instrument position and trajectory in virtual fluoroscopy.

**Table 1.** All cases

| Level | Number of screws |
|---|---|
| T2 | 2 |
| T3 | 2 |
| T4 | 2 |
| T5 | 4 |
| T6 | 4 |
| T7 | 14 |
| T8 | 17 |
| T9 | 13 |
| T10 | 24 |
| T11 | 45 |
| T12 | 42 |
| L1 | 46 |
| L2 | 72 |
| L3 | 122 |
| L4 | 233 |
| L5 | 246 |
| S1 | 151 |
| Total | 1039 |

equina. With decompression she went on to make a nearly full recovery, but was lost to follow-up.

## Discussion

Compared to conventional fluoroscopy, computer-assisted virtual fluoroscopy has several advantages. First, virtual fluoroscopy allows real-time imaging in multiple plains. The steps of moving the C-arm in and out of the field and obtaining multiple views are eliminated, saving time and frustration. The system takes less than ten minutes to set up. Radiation exposure to the surgeon, OR staff, and the patient is limited. For example, in a two-level instrumented fusion just three images are needed: an empty image with the calibration grid, and an AP and lateral of the instrumented levels. Historical data reports fluoroscopy times of 20–65 sec per screw [12,25]. In our experience, the fluoro time has averaged 2–9 sec per screw. This time includes all fluoroscopy performed during the case, not just during screw placement. As fluoroscopy times for steps related only to screw placement are recorded, we expect the times to decrease.

**Table 2.** Previously fused levels with no anatomic landmarks

| Level | Number of screws |
|---|---|
| T5 | 2 |
| T6 | 2 |
| T7 | 2 |
| T8 | 2 |
| T9 | 0 |
| T10 | 3 |
| T11 | 4 |
| T12 | 6 |
| L1 | 9 |
| L2 | 10 |
| L3 | 18 |
| L4 | 49 |
| L5 | 43 |
| S1 | 24 |
| Total | 174 |

**Table 3.** Deformity (kyphosis, scoliosis, and flatback)

| Level | Number of screws |
|---|---|
| T5 | 4 |
| T6 | 4 |
| T7 | 10 |
| T8 | 9 |
| T9 | 8 |
| T10 | 17 |
| T11 | 29 |
| T12 | 30 |
| L1 | 27 |
| L2 | 32 |
| L3 | 32 |
| L4 | 47 |
| L5 | 40 |
| S1 | 18 |
| Total | 307 |

Another benefit of virtual fluoroscopy is its accuracy. In our experience, more than 1,000 pedicle screws have been placed with an overall accuracy rate greater than 99%. In cases of deformity (kyphosis, scoliosis, and flatback) and previous fusion where anatomic landmarks are obscured, the accuracy rate approaches 99%. No patient has had a complication related to the placement of pedicle screws. Foley et al. compared the accuracy of placing instruments into cadaver pedicles with virtual fluoroscopy compared to live fluoroscopy. The error observed with the virtual fluoroscopy probe tip position compared to the live images was less than 1 mm. The trajectory differed by only 2.7° [8].

There are no contraindications to this technique, but there are precautions. Most importantly, computer-assisted virtual fluoroscopy is only an adjunct to surgical experience and a thorough knowledge of spinal anatomy. The imagery information generated by the computer can only be as good as the data it receives. One must be absolutely compulsive about the images acquired. If not, the accuracy of the system diminishes. The surgeon has to ensure that the attachments of the DRA to the spine and the instruments to the handle are secure. Again, if they are not, the system becomes inaccurate. Finally, the surgeon must always rely on what he or she sees in the wound, not on the computer monitor. One should not place pedicle screws with virtual fluoroscopy unless one is comfortable placing screws using traditional techniques based on spinal anatomy.

In conclusion, computer-assisted virtual fluoroscopy is extremely accurate for the placement of thoracic and lumbar pedicle screws in primary fusions, deformity cases, and cases of prior fusion where anatomic landmarks are missing. It provides real-time, multiplanar imaging without repositioning the C-arm. The device is easy to set up and use, and it decreases both operative time and radiation exposure.

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