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Contemporary Fluoroscopic Techniques in Spine Surgery

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Intraoperative fluoroscopy has become increasingly popular because of its potential to enhance the safety and efficacy of various surgical procedures while minimizing the risk of complications. The use of this imaging modality has already been documented for a number of spinal applications including decompression of the neural elements and the placement of instrumentation. Fluoroscopic visualization may be particularly well-suited for minimally invasive approaches such as the insertion of percutaneous pedicle screws and vertebral body augmentation. The objective of this report is to present the state-of-the-art fluoroscopic techniques that have been described for the surgical management of spinal pathology.
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For the majority of spinal operations, the critical anatomical landmarks must be fully exposed so that they are accessible to the surgeon for such diverse applications as decompression of the neural elements or the placement of instrumentation. Whether using traditional open approaches in conjunction with standard retractors or minimally invasive strategies through specialized tubes, the direct visualization of the spine involves at least a certain degree of tissue dissection and disruption of other supporting structures which may contribute to greater blood loss, increased infection rates, and longer patient recovery times. Intraoperative fluoroscopy is recognized as a viable method for increasing the accuracy of spinal interventions while reducing the incidence of any associated complications. A variety of fluoroscopically guided spinal procedures have already been elucidated in the literature, including the insertion of thoracolumbar pedicle screws[1,2] or other devices as well as the augmentation of vertebral body compression fractures[3] (ie, kyphoplasty and vertebroplasty). The purpose of this review is to discuss contemporary fluoroscopic techniques for the surgical treatment of spinal disorders.

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Operating Room Setup

Despite recent advances in fluoroscopic technology, the success of this modality is still largely influenced by a number of preoperative considerations. For example, in most cases it may be beneficial to use a completely radiolucent frame (eg, Jackson table) so that the C-arm is freely mobile and able to generate multiple views of the spine. A conventional operating room table may also be acceptable for these surgeries if the portion supporting the anatomic region of interest is radiolucent and the base does not limit the excursion of the image intensifier; in many instances, it may be necessary to add an extension piece or reverse the head-to-foot orientation of the platform. Similarly, positioning the patient so the spine is directly perpendicular to the floor may facilitate the acquisition of true anteroposterior (AP) and lateral projections. This allows the C-arm to be quickly moved between the vertical (90°) and horizontal (0°) planes, respectively, so that the angle of the fluoroscope does not need to be continually modified to reproduce these specific images.

Dual fluoroscopes placed orthogonal to each other may be more efficient for operations that demand biplanar imaging such as percutaneous transpedicular fixation or vertebral body augmentation (Fig. 1). By minimizing the number of times each unit must be readjusted during the course of a procedure, this arrangement may not only improve the flow of the surgery but also decrease the risk of contamination. With a single image intensifier, the operative team must ensure that sterility is maintained as it is repeatedly reposi-

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Figure 1 Picture demonstrating the dual C-arm arrangement for simultaneous biplanar imaging. One unit is set up to acquire lateral images, while the other is placed orthogonally in the AP plane. (Color version of figure is available online.)

tioned to provide different views of the spine. In general, the superior end of the fluoroscope that is situated above the level of the operating room table is enclosed in a sterile plastic cover (ie, "shower cap"); when the C-arm is rotated to obtain lateral images, the inferior part of the unit that is now in close proximity to the surgical field is either covered with another plastic cover or another sterile drape.

Since any access to the patient may be restricted once the patient has been prepped and draped, it is recommended that the surgeon check a series of preliminary images before the operative field has been established to confirm that the x-ray beam will not be obstructed by the upper extremities, table attachments, or any other loose equipment (eg, Foley catheter or electrocardiogram leads). This practice also verifies that the C-arm is functioning properly and that the fluoroscopic settings are suitable for delivering high-resolution images of the spine.

Factors related to the anesthesia may also play an important role in determining the feasibility of intraoperative fluoroscopy. Although procedures such as a single-level vertebroplasty or insertion of an interspinous device may be completed under local sedation, this strategy may not be possible with other fluoroscopically guided spinal interventions during which any movement may give rise to serious adverse events. As a result, general anesthesia may be ideal for most cases requiring a C-arm for visualization of spinal structures; however, while the method of anesthesia is often a matter of surgeon preference, it is essential that the patient be informed of all of the risks and benefits of each of these options before the operation.

Finally, given the hazards associated with excessive radiation exposure, appropriate occupational safety guidelines must be adhered to at all times in an attempt to minimize the effective doses that the surgeon, operating room staff, and the patient are subjected to during the course of the procedure. Without exception, any individuals working in the sterile field who are not able to step away from the C-arm must either stand behind lead barriers or wear appropriate protective equipment consisting of aprons, thyroid shields, gloves, and eye goggles so that they are not as susceptible to the deleterious effects of scattered radiation.

Fluoroscopic Techniques

The fluoroscopically assisted spinal interventions discussed in the remainder of this review are classified according to the type of approach that is utilized, ie, posterior versus anterior. Even though the myriad advantages offered by the C-arm are also applicable to open procedures, these techniques will be described primarily in the context of percutaneous procedures and other minimally invasive strategies where fluoroscopic visualization takes on even greater importance.

Insertion of Spinal Instrumentation

A C-arm has been shown to be an extremely effective tool for placing metal implants throughout the posterior spine from the occiput to the sacrum. Fluoroscopy has also been employed as an imaging modality for the percutaneous fixation of the cervical lateral masses and lumbar facets; nevertheless, at this time the most common minimally invasive procedure that is performed with the assistance of an image intensifier remains the insertion of thoracolumbar pedicle screws. Under fluoroscopic guidance, the pedicles may be localized even if the posterior landmarks of the spine are not exposed.

If only a single C-arm is available, the relative heights, angles, and rotations of the fluoroscope corresponding with true AP and lateral projections of the spine should be noted so that the unit may be easily switched between these two planes. On a true lateral image, the superior and inferior endplates are parallel and the silhouettes of the pedicles appear to be superimposed (Fig. 2A). Similarly, the superior and inferior endplates should also be parallel on the AP view with the pedicles present in the upper third of the vertebral body and the spinous processes situated in the midline (Fig. 2B). When inserting instrumentation in the lumbosacral region, the X-ray beam may need to be tilted in a cranial direction (ie, Ferguson's angle) to adequately visualize the S1 pedicles (Fig. 2C). When making the subtle adjustments necessary to achieve optimal images of the spine, it may be expedient to secure the C-arm so that the X-ray beam is orthogonal to the floor and shift the patient instead.

When two fluoroscopes are present, the unit assigned to the lateral plane should be introduced into the operative field first; once an image of sufficient quality has been obtained with this device, its boom should be deployed as far superiorly as possible so the other C-arm may be brought in to obtain AP images. With this dual arrangement, a perfect AP view is not imperative because this projection is only used to ascertain whether a surgical instrument is medial or lateral to the pedicle.

Once the C-arm has been set up so that it is able to produce satisfactory images for percutaneous operations, the next step is to mark the 2D coordinates on the skin from which the surgeon may pass instruments into the pedicle. The starting points in the sagittal and coronal planes are derived from true lateral and AP projections of the spine, respectively (Fig. 3A and B); an oblique image may also be used to acquire an en face view of the pedicles (Fig. 3C). In the thoracic and upper lumbar regions, the medial/lateral extent of the entry site is located approximately 1 to 1.5 fingerbreadths lateral to the center of the pedicle as observed an AP image. Depending on the size of the patient, this distance typically increases to two to three fingerbreadths in the lower lumbar spine where the medial angulation of the pedicles is more acute. Once a cortical defect has been created, a guide wire is slowly advanced through the pedicle; to avoid entering the spinal canal with an instrument, it is important to remember that the tip should not appear to be medial to the pedicle on the AP view before it has been shown to be within the vertebral body on the lateral image (Fig. 3D and E).

Vertebral Body Augmentation

Fluoroscopic vertebral augmentation techniques such as vertebroplasty and kyphoplasty may also be performed through a percutaneous transpedicular approach similar to that described above. Compared with pedicle screws, the trochar may need to be docked at a slightly different area on the posterior elements so that the cannula may be angled superiorly and inferiorly within the body, allowing the cement to reinforce the fractured endplates and restore the normal appearance of the compressed vertebra. In addition, with these systems the bony pedicle may be penetrated immediately adjacent to the facets; in contrast, screws must be placed more inferolaterally so that their prominent heads do not impinge on the joint, especially at the levels above the intended fusion construct where any alterations in segmental motion or intra-articular pressure may give rise to progressive degeneration. After the cannula has safely traversed the pedicle and has been shown to be safely within the confines of the vertebral body on multiplanar C-arm images, the radiopaque cement is injected into the fracture in a controlled fashion.

Vertebral augmentation may also be accomplished using a

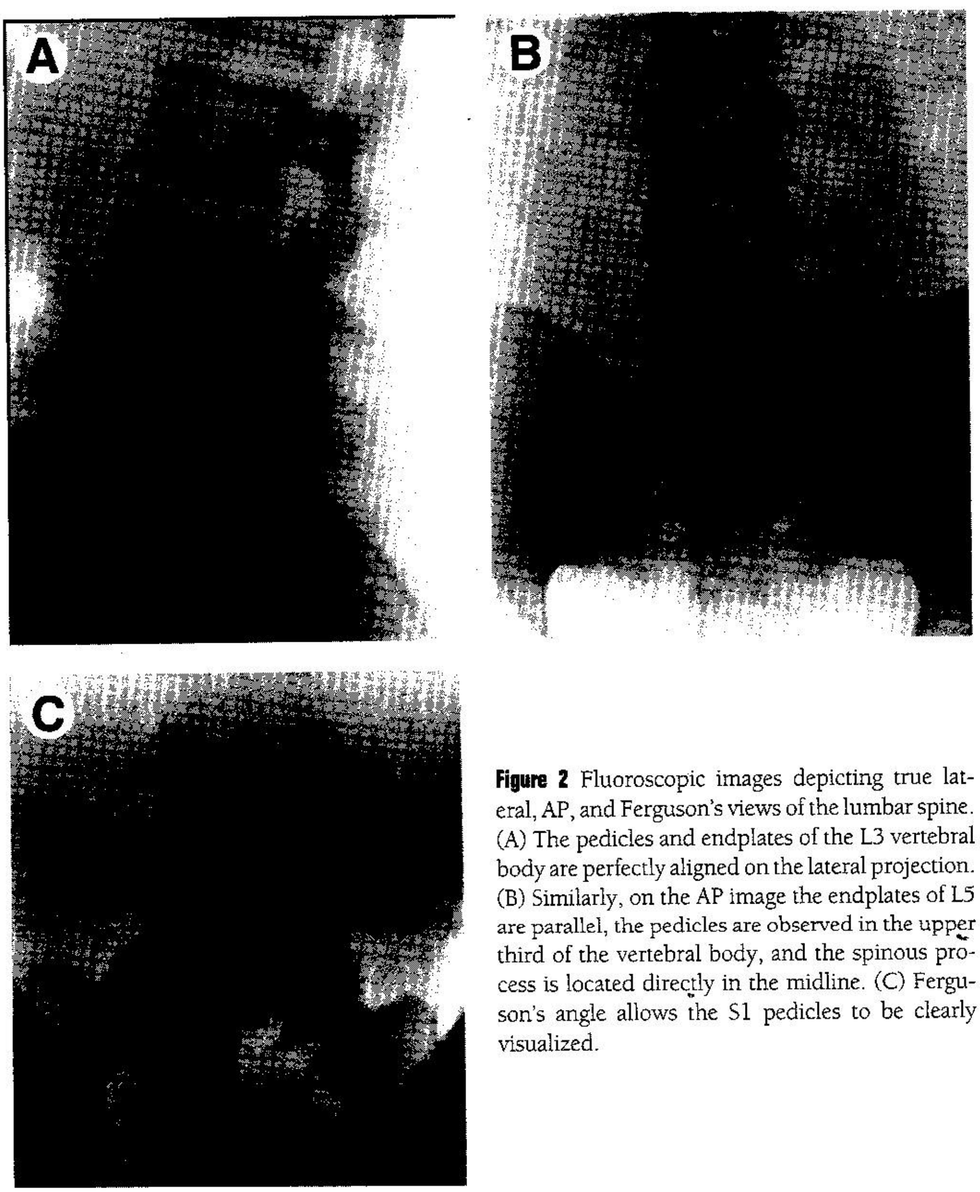
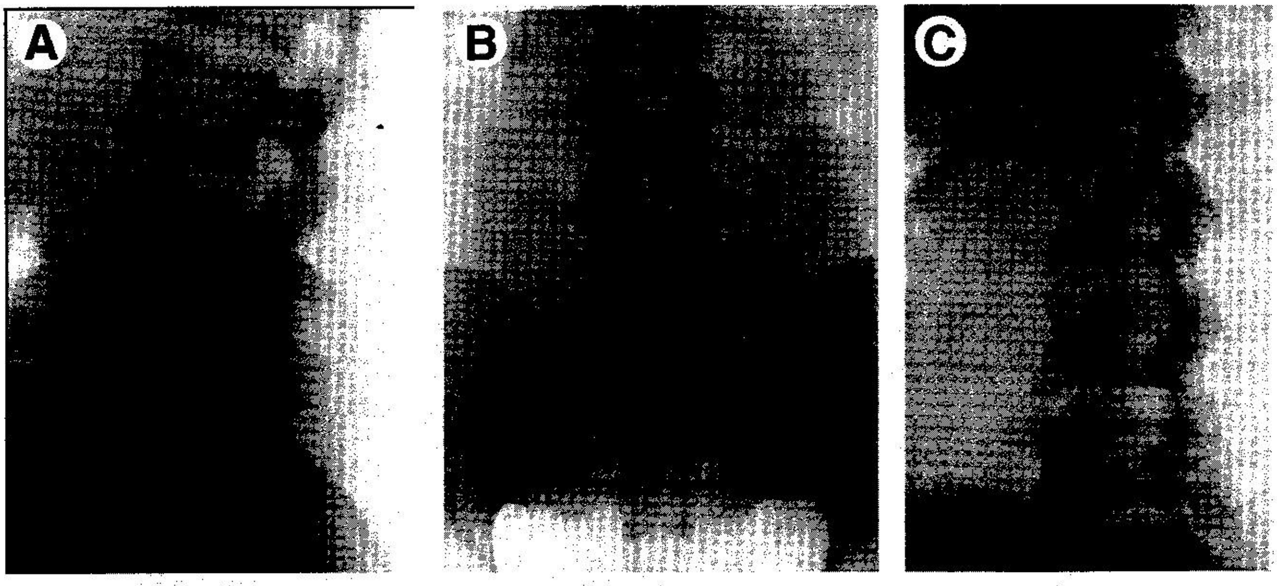


Figure 2 Fluoroscopic images depicting true lateral, AP, and Ferguson's views of the lumbar spine. (A) The pedicles and endplates of the L3 vertebral body are perfectly aligned on the lateral projection. (B) Similarly, on the AP image the endplates of L5 are parallel, the pedicles are observed in the upper third of the vertebral body, and the spinous process is located directly in the midline. (C) Ferguson's angle allows the S1 pedicles to be clearly visualized.



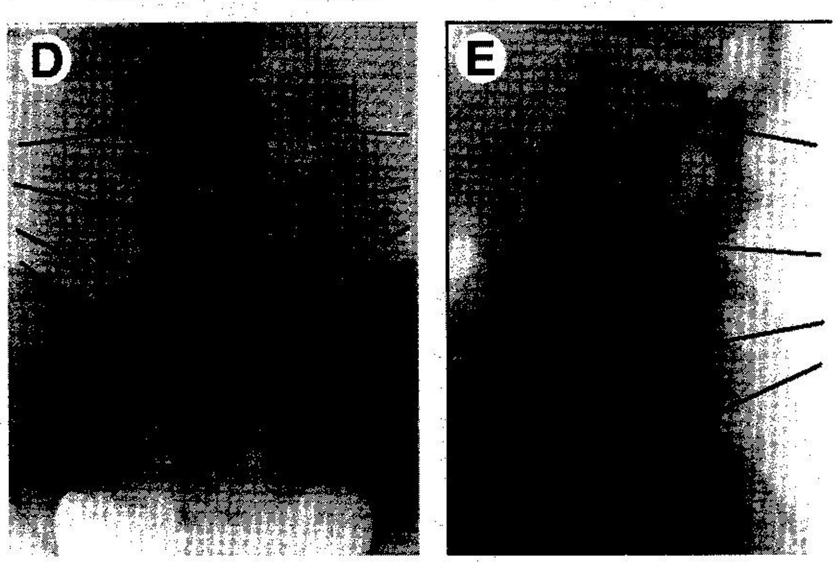


Figure 3 Typical starting points for percutaneous cannulation of the pedicles in the sagittal and coronal planes. (A) The instrument should be centered over the pedicle on the lateral image. (B) On the AP view, the tip is positioned at the junction of the facet and transverse process, immediately lateral to the pedicle. (C) An oblique angle may also be used to obtain an en face view of the pedicles. (D, E) Once the pedicle has been traversed, a guide wire may be advanced into the vertebral bodies.

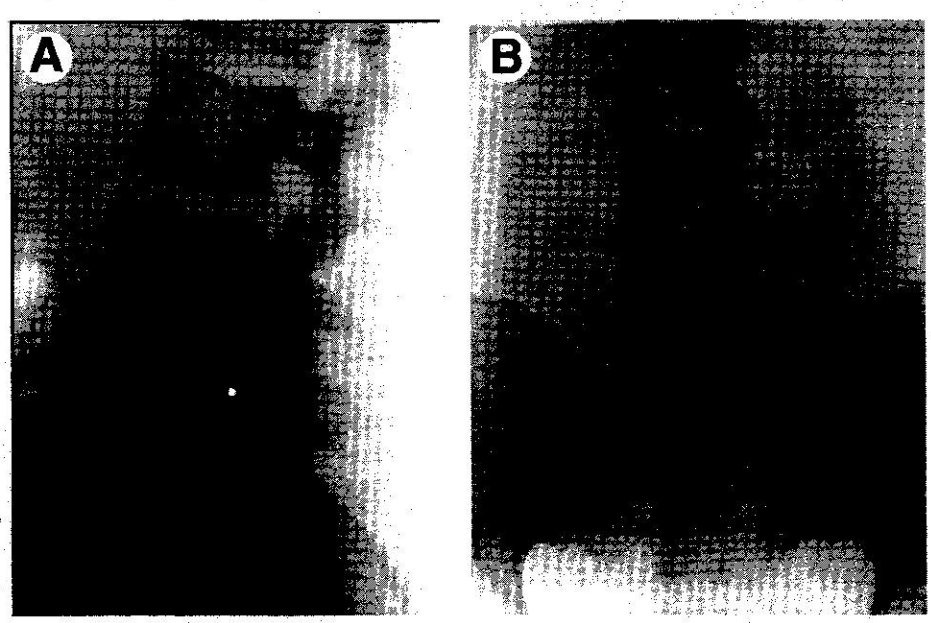


Figure 4 Typical starting points for a paravertebral approach to the vertebral body in the (A) sagittal and (B) coronal planes. Note the more anterolateral entry site, which avoids the pedicles altogether.

parapedicular strategy in which cement is infused into the anterior and middle columns without traversing the pedicle. This method may be well-suited for compression fractures in the upper and middle thoracic spine where the pedicles may otherwise be too small to accommodate standard instruments. Under fluoroscopic guidance, the needle is inserted through the lateral aspect of the base of the pedicle into the body (Fig. 4). Since the initial bony window is based more anterolaterally, the neural elements are less likely to be injured secondary to a breach of the spinal canal; furthermore, the trochar may be more easily directed toward the center of the vertebra so that it is often possible to introduce a sufficient quantity of cement through a unilateral approach. However, the neurovascular structures that are found lateral to the pedicle (eg, exiting nerve root) may be at greater risk with a parapedicular route and there may also be an increased incidence of hematoma formation because it may be more difficult to tamponade any bleeding after the cannula has been removed.

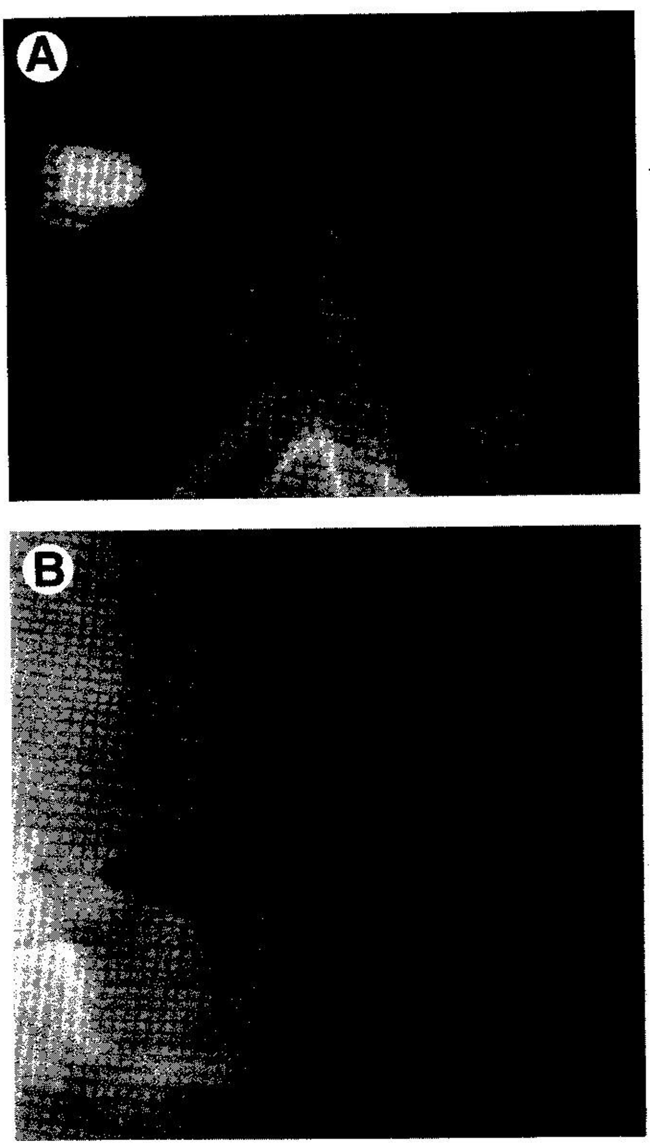


Figure 5 Intraoperative fluoroscopic images demonstrating the optimal position of an X-STOP interspinous process spacer in the (A) lateral and AP (B) planes.

Placement of Interspinous Process Spacer

Interspinous process spacers have recently been touted as an innovative treatment for lumbar stenosis. By distracting the spine and stabilizing unstable motion segments, these implants are thought to relieve the symptoms of neurogenic claudication. Although a number of interspinous spacers are currently in development, the X-STOP device (Kyphon, Sunnyvale, CA) is the only system that has been FDA-approved for this indication[4,5] (Fig. 5). To place these spacers percutaneously as part of a minimally invasive strategy, fluoroscopic visualization is required to identify the surgical levels, determine the correct implant size, and verify its final position between the spinous processes.

Extreme Lateral Interbody Fusion

There is also ample evidence to suggest that fluoroscopy may serve as an indispensable intraoperative imaging modality for anterior spinal procedures such as lumbar diskectomy and interbody fusion. Extreme lateral interbody fusion (NuVasive, San Diego, CA) is a novel technique for attaining an arthrodesis of the spinal column through a lateral approach that precludes much of the morbidity associated with a traditional anterior exposure of the lumbar spine (eg, visceral or vascular injury, retrograde ejaculation in men).[6] For this operation, the patient is placed in the lateral decubitus position on a radiolucent frame; because the surgeon must stand above an incision centered over the flank, there is usually enough space for only one C-arm in the sterile field. A lateral view of the spine is used to target the desired disk space with a guide wire over which a series of dilators and specialized retractors are passed in preparation for a subsequent diskectomy (Fig. 6). Additional fluoroscopic images are also necessary for assessing the adequacy of the decompression, estimating the dimensions of the disk space with multiple trial implants, and safely inserting the final interbody device between the vertebral bodies.

Axial Lumbar Interbody Fusion

The axial lumbar interbody fusion (AxiaLIF, TranS1, Wilmington, NC) system represents another minimally invasive strategy that involves the placement of internal fixation across the L5-S1 disk space for the purpose of achieving a lumbosacral arthrodesis.[7] This surgical protocol comprises a sequence of steps that are all contingent on fluoroscopic guidance including the introduction of a blunt trochar along the anterior and inferior portion of the sacrum, creation of cavity with a protected drill through which disk fragments may be excised, injection of bone graft material, and insertion of a unique threaded rod spanning the L5 and S1 vertebral bodies (Fig. 7). Given the truly percutaneous nature of this technique, this procedure may be completed in conjunction with a single C-arm, which must be intermittently rotated to obtain different projections of the spine or a dual arrangement which allows for simultaneous AP and lateral views. In

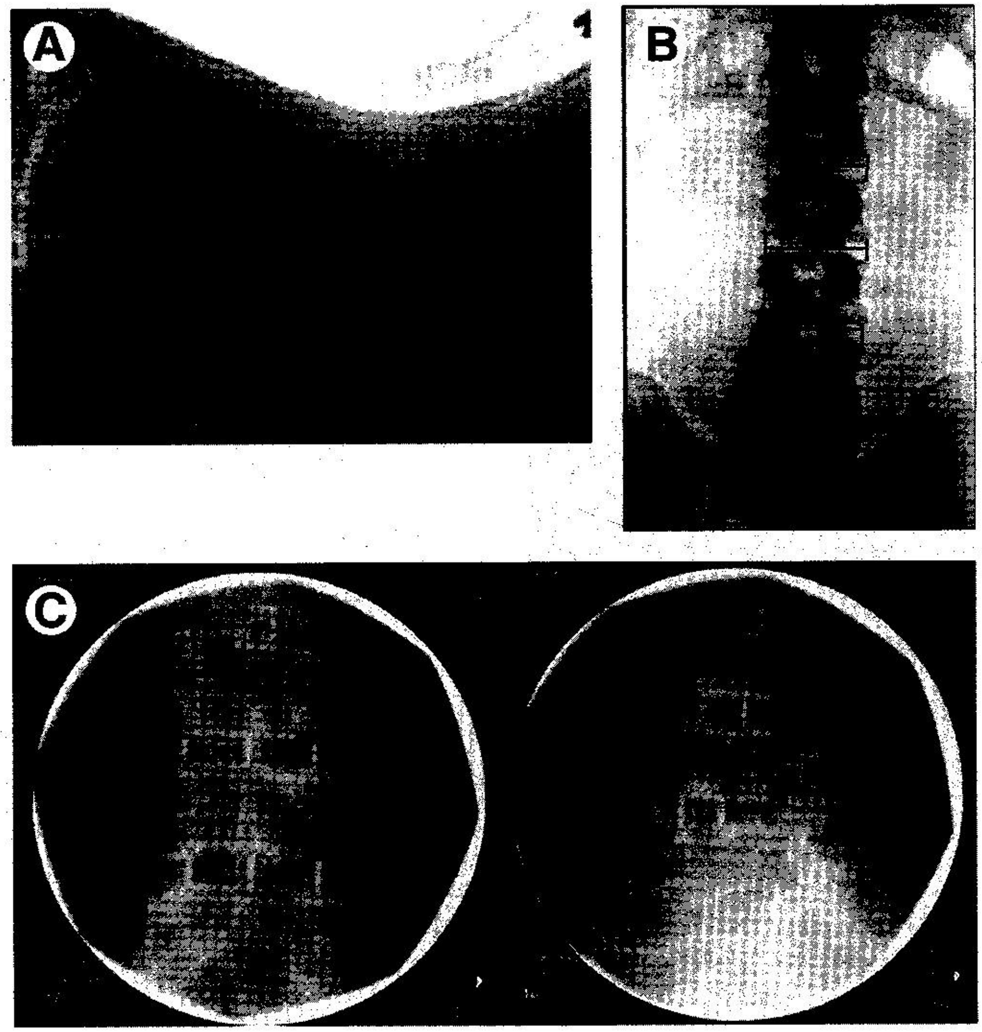


Figure 6 Extreme lateral interbody fusion (XLIF) procedure. The appropriate disk spaces are targeted on (A) lateral and (B) AP images of the lumbar spine. (C) Intraoperative fluoroscopic images confirming the proper placement of the interbody implants.

many patients, this construct is supported with supplementary posterior instrumentation consisting of either transpedicular or facet screws, which may also be implanted through a minimally invasive approach with the assistance of an image intensifier.

Other Techniques

The use of fluoroscopy for spinal operations has also increased concurrently with the advent of motion-sparing technologies, whose clinical outcomes and long-term function are known to be dependent on the proper sizing and positioning of these devices. For example, intraoperative images are mandatory to ensure that cervical and lumbar disk replacements of the appropriate dimensions are implanted symmetrically within the spinal column so that they may reproduce the physiologic center of rotation of the segment. C-arm visualization may also prove to be a valuable adjunctive method for confirming that posterior dynamic stabilization devices are located precisely within the pedicles, thereby maximizing the fixation of these systems, which are designed to facilitate load-sharing and confer stability to the spinal column for extended periods of time.

Pitfalls of Intraoperative Fluoroscopy

While it is clear from the data presented in this review that intraoperative fluoroscopy may have the potential to enhance the safety and efficacy of spinal procedures, the successful implementation of these techniques is not without its complications. In addition to concerns about excessive radiation exposure, longer operative times, and increased infection rates secondary to contamination of the sterile field from the C-arm unit (all of which are discussed in greater detail elsewhere in this periodical), one of the major challenges that must be addressed by the surgeon is the issue of parallax. Because a fluoroscope depicts the spine in only two dimensions, it is possible for certain structures to appear distorted if the gantry is angled such that a true AP or lateral projection is

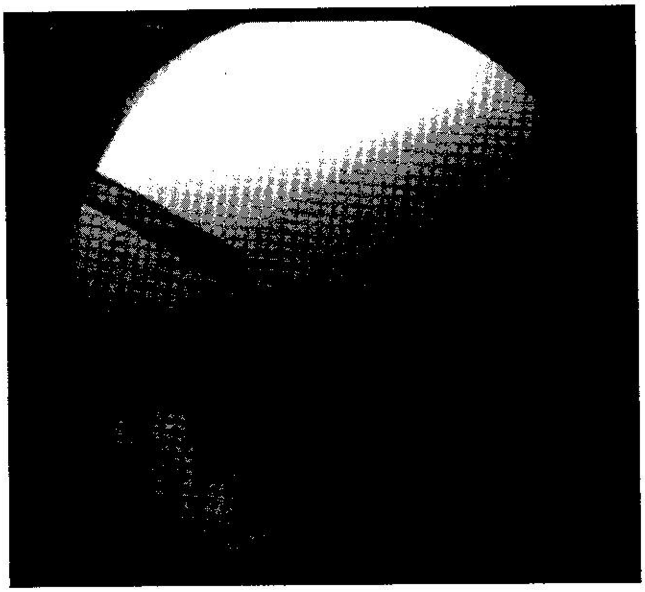


Figure 7 Axial lumbar interbody fusion (AxiaLIF) procedure. With the assistance of intraoperative C-arm images, a threaded intervertebral implant has been inserted across the L5-S1 disk space. In addition, a percutaneous facet screw has also been placed posteriorly under fluoroscopic guidance.

not generated, especially in deformity, trauma, or tumor cases where there are significant alterations in the local anatomy. For example, it may be difficult to differentiate between the two pedicles of a vertebra if they are not perfectly aligned on a lateral view, a problem which may increase the risk of sustaining a cortical breach when placing instrumentation. For this same reason, a screw that appears to be contained within the body may actually be too long if the rotation or inclination of the image intensifier is not closely monitored. Thus, it is critical that the patient, operating room table, or fluoroscope be adjusted so that images of adequate quality may be obtained before any type of intervention. Strict adherence to these guidelines would not only be expected to decrease the incidence of adverse events associated with these techniques but also hopefully to improve the clinical outcomes of patients undergoing spinal surgery.

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