Intraoperative 3D Computed Tomography
Spine Surgery

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KEYWORDS

• 3D navigation • Pedicle screws • Stealth • 3D printing • Spinal fusion

KEY POINTS

- Intraoperative 3D spinal navigation can increase accuray of spinal instrumentation.
- Use of intraoperative spinal navigation can decrease the radiation exposure to the patient and operating room personnel, however, the total radiation dose is variable depending on the imaging technology and modality.
- 3D printing is a potentially novel approach for increasing accuracy of spinal instrumentation while further decreasing intraoperative radiation exposure.

HISTORY OF IMAGE-GUIDED INSTRUMENTATION OF THE SPINE

Early instrumented spinal fusion consisted of rod constructs with sublaminar wiring or hooks, which were placed with nearly direct visualization. Modern three-column fixation with pedicle screws increases fusion rates and provides greater stability, but involves placing instrumentation into unexposed anatomy without direct visualization of the trajectory. Improper placement can lead to complications, such as nerve root impingement, spinal cord compromise, great vessel injury, or an unstable construct that may necessitate further surgery. Two-dimensional (2D) fluoroscopy with a C-arm is the traditional adjuvant to a thorough understanding of the anatomic relationships in the spine, but this is limited by several factors: (1) the surgeon can examine only two planes, anteroposterior (AP) and lateral, and only one at a time; (2) the need for multiple repeated fluoroscopic images in different planes and at each level increases the radiation exposure to the surgeon, operating room (OR) staff, and patient; (3) the size and awkward shape of the C-arm can constrict the surgeon's and assistant's movement; and (4) the image quality is poor in the lower cervical and upper thoracic spine.

The limitation of 2D fluoroscopy was the driving factor for the invention of computed tomography (CT), and the Nobel Prize in medicine and physiology was awarded to Hounsfield and Cormack in 1979 for their independent but nearly simultaneous inventions of this technology. Preoperative CT scans gave the spine surgeon superior insight into the patient's individual spinal anatomy, allowing more thorough planning that involved predetermining appropriate implant size and length, and consideration of any pathologic conditions that might have distorted the normal anatomy. To minimize radiation from repeated 2D fluoroscopic images, early incorporation of CT-guided spine surgery used preoperative CT with passive navigation during surgery. In one study, this was found to decrease erroneous pedicle screw placement from 44% by a freehand technique to 9% with the use of preoperative

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imaging.[1] In the early 1990s, a mobile CT scanner became available, and with it the opportunity to bring three-dimensional (3D) imaging into the OR. However, early mobile scanners were cumbersome and had little intraoperative utility until a decade later when the O-arm (Medtronic, Memphis, TN) and Iso-Centric (Siemens, Malvern, PA) systems were introduced. The open gantry concept afforded greater maneuverability and access to the OR table for instant intraoperative image acquisition. Although 3D navigation may initially extend operative time because of the registration and image processing time, and the associated learning curve, one surgeon's series of one-level fusion in 133 patients, 63 with freehand pedicle screw placement and 70 with 3D navigation–assisted placement, showed that the operative time for navigated surgeries was an average of 23 minutes shorter.[2]

Intraoperative 3D neuronavigation is now widely available, and proponents claim this can increase instrumentation accuracy, decrease radiation exposure, shorten OR time, and improve patient outcomes. However, as with any technical innovation, there is a large capital expenditure necessary to implement these systems. Before making this investment, the surgeon should have a thorough understanding of the advantages and limitations of 3D image–guided instrumentation; and acknowledge that 3D navigation is an adjuvant to, rather than a replacement of, anatomic knowledge. With these proposed advantages in mind, this article critically appraises the available literature to assess the influence of 3D navigation on radiation exposure, accuracy of instrumentation, operative time, and patient outcomes. We also explore the latest technological advance in 3D neuronavigation: the manufacturing of, via 3D printers, patient-specific templates that direct implant placement.

THREE-DIMENSIONAL NAVIGATION IN ADULT SPINE SURGERY: TECHNIQUES

The components of navigation include the patient image, obtained either preoperatively or intraoperatively; the computer workstation with appropriate software to process the image and create 3D reconstructions; an optical camera; instrument trackers; and the reference point, which is placed on a rigid anatomic structure, such as an adjacent spinous process or the posterior superior iliac spine in percutaneous cases (**Fig. 1**). After surgical exposure of the appropriate anatomy, we cover the operative field with two sterile drapes secured together with towel clamps, and then cover the reference frame with a clear sterile drape. The open gantry CT scanner is brought into the field and closed with the patient in the isocenter under direct visualization by the surgical team to avoid contact with the field. The technician operating the intraoperative CT secures these additional sterile drapes underneath the operating table; the drapes tightly fit the patient and cannot get caught or displaced as the scanner moves. AP and lateral radiographs confirm the levels of interest are included in the spin. Members of the surgical team step into a substerile zone, the anesthesiologist provides apnea, and the technician initiates the spin, which concludes in 40 seconds for high-definition at our institution. Following the spin, one member of the surgical team removes the outer drapes and changes their outer gloves before registering the navigated instruments. If desired, the intraoperative CT is fused to a preoperative scan that projects preplanned screw sizes and trajectories. Otherwise, navigation is performed using the intraoperative scan alone, as is the case in our institution. The camera, positioned either at the head or foot of the bed, emits infrared light and detects the light from reflecting spheres on the reference frame and on each navigated instrument. The software determines the multiplanar projections of each instrument and projects this onto a workstation for the surgeon to view during instrumentation placement. To confirm accuracy, the surgeon navigates on known anatomic landmarks before placing instrumentation.

THREE-DIMENSIONAL NAVIGATION IN ADULT SPINE SURGERY: OUTCOMES

Now that 3D navigation has been common practice for many surgeons, patient series are being published about the accuracy of implant placement. Verma and colleagues[3] did a retrospective analysis of 537 patients from a high-volume trauma center that had suffered lumbar spine fractures requiring instrumented stabilization. Spine trauma poses an additional challenge for the surgeon, because the normal anatomy is often distorted. In 278 patients, screw placement was performed using 3D navigation, and in 309 patients, pedicle screws were placed using 2D C-arm navigation. The authors found a statistically significant difference, with approximately 1% of screws being misplaced in the 3D navigation group compared with approximately 9% in the 2D navigation group. Their data suggest that 3D image guidance is especially useful in the setting of trauma, when instability may cause anatomic relationships to change from when the patient is positioned supine in the CT scanner compared with prone on the operating table.