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ABSTRACT

BACKGROUND AND PURPOSE: Wrong-level spinal surgery, especially in the thoracic spine, remains a challenge for a variety of reasons related to visualization, such as osteopenia, large body habitus, severe kyphosis, radiographic misinterpretation, or anatomic variation. Preoperative fiducial marker placement performed in a dedicated imaging suite has been proposed to facilitate identification of thoracic spine vertebral levels. In this current study, we report our experience using image-guided percutaneous gold fiducial marker placement to enhance the accuracy and safety of thoracic spinal surgical procedures.

MATERIALS AND METHODS: A retrospective review was performed of all fluoroscopy- or CT-guided gold fiducial markers placed at our institution between January 3, 2019, and March 16, 2022. A chart review of 179 patients was performed detailing the procedural approach and clinical information. In addition, the method of gold fiducial marker placement (fluoroscopy/CT), procedure duration, spinal level of the gold fiducial marker, radiation dose, fluoroscopy time, surgery date, and complications (including whether wrong-level surgery occurred) were recorded.

RESULTS: A total of 179 patients (104 female) underwent gold fiducial marker placement. The mean age was 57 years (range, 12–96 years). Fiducial marker placement was performed by 13 different neuroradiologists. All placements were technically successful without complications. All 179 (100%) operations were performed at the correct level. Most fiducial markers (143) were placed with fluoroscopy with the most common location at T6–T8. The most common location for placement in CT was at T3 and T4.

CONCLUSIONS: All operations guided with gold fiducial markers were performed at the correct level. There were no complications of fiducial marker placement.

ABBREVIATION: FL = fluoroscopy

Wrong-level spinal surgery occurs for various reasons, including misinterpreting radiographs, miscounting vertebrae, scapular shadowing, large body habitus, and osteoporosis.[1,2] Additionally, anatomic variations such as thoracolumbar transitional vertebrae, rib variants, hemivertebrae, and block vertebrae can contribute to wrong-level surgery.[3] Human error, such as poor communication and fatigue in the operating room, is also a major risk factor for wrong-level spinal surgery.[4] Furthermore, standard operating room fluoroscopy (FL) equipment is often less robust than interventional imaging techniques, generally lacking the biplane capability that allows accurate interrogation of the anatomy.[5] Spinal surgery is the most common neurosurgical malpractice claim, and surveys of neurosurgeons indicate that 50% may perform surgery at the wrong vertebral level at least once during their careers.[6,7] Approximately 8% of wrong-level spinal surgeries occur in the thoracic region.[7]

Wrong-level surgical errors can be prevented with preoperative localization techniques.[8-10] A variety of techniques have been put forward to improve localization of thoracic spine surgeries. Several key features of a technique are needed to prevent wrong-level surgery. The technique needs to be safe, reasonably inexpensive, and not overly invasive. Most important, it needs to be accurate, with the marker remaining in place regardless of patient positioning, movement, anatomy, or body habitus. Use of skin markers, soft-tissue markers, and spinous process injection with methylene blue and percutaneous polymethylmethacrylate have all been reported.[2,10-12] In addition, there are a few small retrospective studies that have shown gold fiducial markers to be useful

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in localizing the correct spinal level.[13,14] Gold fiducial markers are relatively inexpensive, costing approximately US $50 at our institution, which is comparable and typically less expensive compared with a microcoil. Nonetheless, there is a lack of literature describing routine placement of preoperative gold fiducial markers in a large cohort with multiple interventionalists.

The purpose of this retrospective study was to review and describe our institution's experience with routine FL- and CT-guided preoperative percutaneous spinal gold fiducial marker placement by multiple neuroradiologists in a large cohort of patients with varied pathologies. We will discuss the technique, safety profile, and complications.

MATERIALS AND METHODS

Imaging Review

This was a Health Insurance Portability and Accountability Act–compliant retrospective study, approved by the institutional review board of Mayo Clinic. A retrospective search of our radiology data base from January 1, 2019, through March 16, 2022, was performed to identify patients who had FL- or CT-guided spinal gold fiducial marker placement. Inclusion criteria were gold fiducial marker placement in the spine via FL or CT guidance and subsequent spine surgery. The search yielded 183 patients, with 4 patients excluded due to inability to obtain information on ≥1 variable such as radiation dose or procedure duration. Ultimately, 179 patients were included in the final study cohort.

The electronic medical record was reviewed for patient demographics (sex, age, race, body mass index, osteoporosis diagnosis [yes/no], a trainee being present during the gold fiducial marker placement, method of gold fiducial marker placement [FL/CT], procedure duration, spinal level of gold fiducial marker, radiation dose, FL time, surgery date, and complications [including whether wrong-level surgery occurred]). The safety of gold seed placement was also assessed (eg, bleeding, wrong level, fiducial marker migration).

Gold Fiducial Marker Placement Technique

The desired location of the gold fiducial marker was specified in the procedural request and neurosurgery notes. Gold fiducial marker placement typically occurs on an outpatient basis the day before surgery, though on occasion, it is done the morning of the operation. Moderate sedation is typically used with IV midazolam and fentanyl, with continuous hemodynamic monitoring by a nurse under supervision of a spine interventional neuroradiologist. Local anesthetic, typically with 1% lidocaine, at the skin surface and 0.25% bupivacaine along the deeper soft tissues and posterior cortex of the targeted vertebra, was used in each procedure.

Most gold fiducial markers were placed with biplane FL guidance (Figs 1 and 2). Alternatively, CT-guided placement performed on a standard CT scanner was used on the basis of the availability of equipment as well as the preference of the proceduralist. Potentially more challenging FL cases would include patients with osteoporosis or severe thoracic kyphosis, particularly when the intended surgical level is within the upper thoracic spine. An advantage of using a standard CT scanner is being able to review the initial focused CT localizer images, including the axial as well as the coronal and sagittal reformats, allowing the proceduralist to confidently confirm the intended surgical level.

Patients are positioned prone on the table. After the usual sterile technique and before starting the procedure, the spine interventional neuroradiologist carefully determines the location. Identifying the intended surgical pathology via FL or CT guidance alone was unreliable in most cases. Therefore, before the procedure, the interventionalist must perform a complete review of the spine imaging to evaluate any anomalous anatomy (eg, absent ribs, transitional lumbosacral anatomy) and count the vertebral bodies with reference to the cervicothoracic, thoracolumbar, or lumbosacral junctions. In cases with an anomalous vertebral count, especially in those with varying or incorrect counting methods, clear communication of the vertebral counting method is required and should be communicated with the operating surgeon directly and documented in the radiology report.

An 11- or 13-ga bone access needle is used to gain access into the pedicle and is typically positioned near the junction of the pedicle and the vertebral body. In younger patients with extremely dense bone, placement at this location may be impractical and the needle may be placed only into the superficial aspect of the pedicle. Ultimately, the bone access needle must breach the periosteum and be well-seated in the posterior elements to ensure that the gold fiducial marker is not deposited in the overlying soft-tissues where it could be at risk of migration. A gold fiducial marker is placed coaxially through the needle, and the stylet is used to push it into the bone. The needle is removed, and the presence and location of the gold fiducial marker are confirmed with either biplane spot films for FL-guided procedures or a series of postprocedural CT images for CT-guided procedures. Sterile dressing is applied to the site after hemostasis is achieved. The images are labeled, and the interventionalist dictates the side and level of the fiducial marker. Patients are discharged when they met the criteria for recovery from sedation.

RESULTS

There were 179 patients who had gold fiducial marker placement from January 3, 2019, through March 16, 2022. The mean patient age at the time of gold fiducial marker placement was 57 years (range, 12–96 years), and 104 were female (58%). Fluoroscopy was used to place the gold fiducial marker in 143 patients (80%), with CT used in 36 (20%). All procedures were performed by a group of 13 board-certified and fellowship-trained neuroradiologists. See Table 1 for cohort and procedural demographics.

Gold fiducial marker placement occurred at every level of the thoracic spine with single cases of marker placement at C7, L3, and L4. The most common vertebral levels for placement in our cohort were T6–T8, with T7 being the most common. Four patients each received 2 distinct fiducial marker placements during the same procedure (T4/T10, T2/T10, T8/T11, and T6/T10).

The mean radiation dose was 183.43 mGy (range, 13–805 mGy), and the mean FL time was 3.92 minutes (range, 0.4–15.2 minutes). The average radiation dose for CT-guided placement (258.92 mGy) was higher than the average radiation dose for FL-guided placement (164.43 mGy), though the average procedural time was similar (51.19 minutes for CT and 52.09 minutes

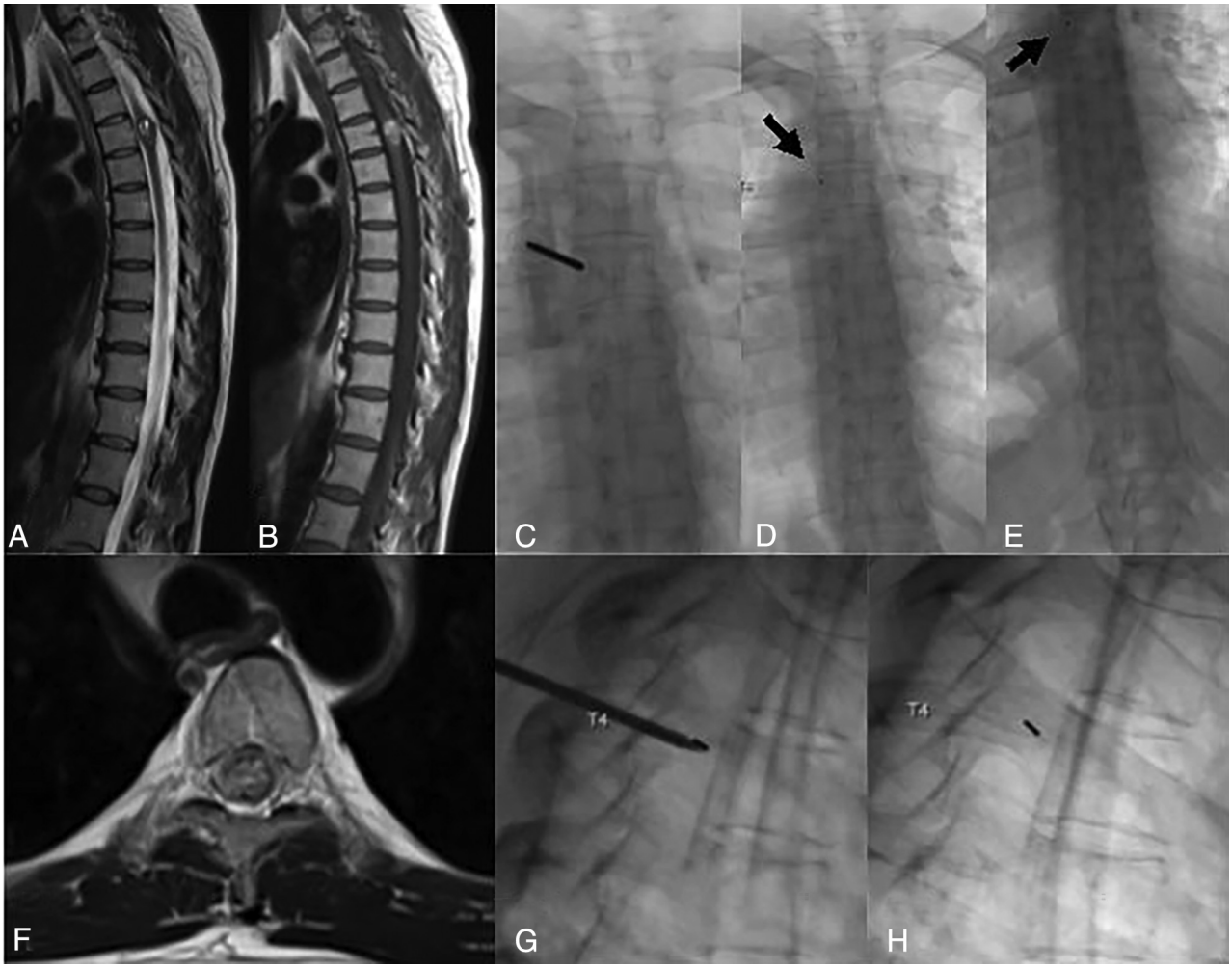

FIG 1. Biplane FL was used to place a gold fiducial marker at T4. Sagittal T2WI (*A*), sagittal TIWI pregadolinium (*B*), and axial T2WI (*F*) demonstrate a multilobulated TI-hyperintense, intramedullary mass with fluid-fluid levels and peripheral T2 hypointensity, which was resected and pathologically proved to be a cavernous malformation. *C*, Anterior-posterior FL image demonstrates the bone access needle traversing the left pedicle of T4. *D* and *E*, Postprocedural images for counting purposes show the first and last ribs, respectively, with the fiducial marker in place (*arrow*). *G*, Intraprocedural image demonstrates the coaxial bone access needle with the stylet in place and the gold fiducial at the tip of the needle. *H*, Subsequently, the needle has been removed, and the gold fiducial remains in place at the junction of the pedicle and vertebral body.

for FL). See Table 2 for the comparison between CT- and FL-guided gold fiducial marker placement. The most common vertebral levels for CT-guided placement were T3 and T4; for FL-guided placement, the most common levels were T6–T8.

The subsequent operations that relied on gold fiducial marker placement for localization all occurred at the correct spinal level. These were performed by 14 different spine surgeons. No complications related to gold fiducial marker placement were reported.

DISCUSSION

The purpose of this study was to review and describe our institution's experience with routine FL- and CT-guided preoperative percutaneous gold fiducial marker placement in the spine in a large cohort of patients with multiple interventionalists. Our results demonstrate that the procedure is safe, and no wrong-level surgeries occurred following gold fiducial marker placement in 179 consecutive cases. Moreover, 13 different radiologists performed this same technique, suggesting that this can be a routine procedure that can be readily learned and performed by procedurally trained radiologists. This outcome provides evidence of the safety and efficacy of this relatively rarely reported technique.

The primary benefit of gold fiducial marker placement is to allow the surgeon to quickly and safely localize the correct vertebral level to mitigate the risk of wrong-level surgery. Additionally, although not directly assessed in our review, fiducial marker placement has been shown to greatly reduce intraoperative FL time and ultimately operative time.[2] In spinal surgery cases performed without a localizing technique, typically the operating surgeon uses a similar method of meticulous counting but often on inferior imaging equipment compared with the radiology suite.

When gold fiducial markers are placed in the spine, the interventionalist must verify the correct level for placement. This verification occurs through carefully reviewing the relevant imaging, noting any anatomic variations, and subsequently verifying the level of gold fiducial marker placement. Assessment for a few common anatomic variations should be performed. Occasionally, C7 will have an elongated transverse process, so-called "cervical

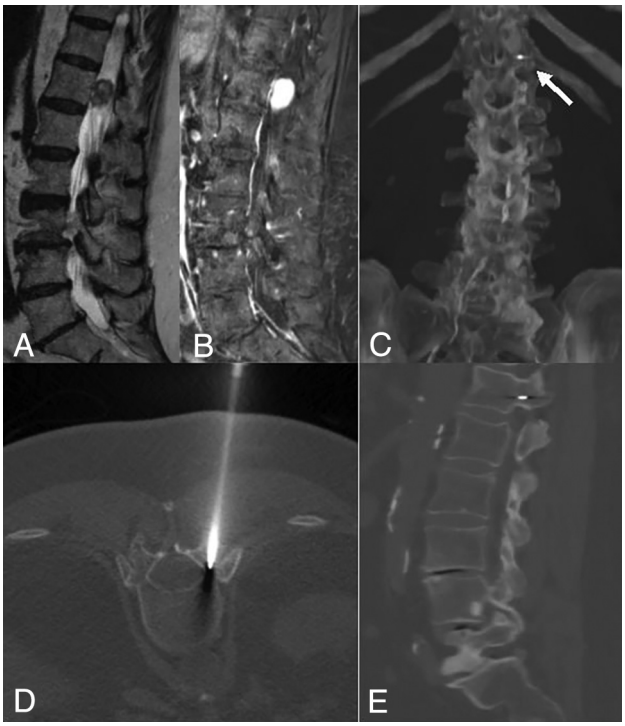

FIG 2. CT-guided gold fiducial marker placement. *A* and *B*, Sagittal T2WI and fat-saturated postcontrast T1WI demonstrate an intradural extramedullary, lobulated, homogeneously intensely enhancing mass that was resected and found to be a schwannoma on pathology. *D*, Intraprocedural axial CT bone windows at T12 demonstrate a coaxial bone access needle located within the left pedicle of T12. *C* and *E*, Postprocedural CT MIP and sagittal reconstructions confirm the gold fiducial marker placement in the left T12 pedicle. *Arrow* points toward gold fiducial marker.

Table 1: Cohort and procedural demographics

Demographics	
Mean age (range)	57 (12–96)
Sex	Male = 75
	Female = 104
Level of gold fiducial marker placement	C7 = 1
	T1 = 5
	T2 = 5
	T3 = 14
	T4 = 14
	T5 = 18
	T6 = 21
	T7 = 26
	T8 = 21
	T9 = 15
	T10 = 19
	T11 = 15
	T12 = 7
	L3 = 1
	L4 = 1
Method	CT = 36
	FL = 143
Mean radiation dose (range) (mGy)	183.43 (13–805)
Mean FL time (range) (min)	3.92 (0.4–15.2)
No. of wrong-level surgeries	0
No. of different radiologists who performed a gold fiducial marker placement	13
Mean BMI (range)	28.9 (16.1–55.8)
Osteoporosis diagnosis	No = 159
	Yes = 20
Trainee present?	No = 107
	Yes = 72
Mean procedure duration (range) (min)[a]	51.9 (20–114)
Mean No. of days when operation was performed after placement (range)	3.6 days (0–92)

Note:—BMI indicates body mass index.
[a] Entry of the room by physician to room exit time.

ribs." At imaging they tend to be much more gracile than the usual first ribs. Close correlation with prior chest x-rays or CTs in conjunction with counting from C2 can ensure correct identification. The absence of ribs at T12 as well as the presence of riblets at L1 are another common anatomic variation that occurs at the thoracolumbar junction. Careful review of the number of ribs on prior imaging and counting not only from C2 inferiorly but also from the sacrum superiorly will assist in verification of the numbering. Finally, it is common to have transitional vertebrae at L5 or S1 with partial sacralization or lumbarization, respectively, of those levels. As with other anatomic variations, correlation with all imaging to determine the total number of presacral segments will allow successful enumeration of the spine. In addition, review of imaging relating to the lesion of surgical interest will help confirm the desired fiducial marker placement for surgery.

This procedure is safe when the appropriate technique is followed because no adverse events occurred in our cohort. Review of the literature would support this outcome, with rare case reports discussing complications. One case report detailed a complication related to fiducial marker placement at C7 from which the patient endured lower extremity pain and vibrations postoperatively, which subsided with a course of steroids.[15] The suspected cause was excessive forceful hyperextension of the neck from anteriorly directed thrusting during needle insertion. This issue highlights the importance of patient positioning for stability during the procedure. In addition, in younger patients without osteoporosis, the bone can be extremely dense, making needle placement very challenging. We recommend consideration of other tools such as a drill, which can be helpful in these situations.

Past research has described fiducial marker placement as a preventative technique to mitigate the risk of wrong-level surgery.[8-10] Additionally, other research has described gold fiducial marker placement to be an advantageous choice because it is relatively inexpensive and can be visualized on several forms of imaging.[13] Moreover, gold fiducial markers have already been used in other specialties such as urology and colorectal surgery.[16,17] Ishak et al[14] also performed a similar review in a smaller sample size ($n = 57$) demonstrating gold fiducial marker placement to be safe and accurate in marking vertebral levels. Past research has described fiducial marker placement as an accurate, relatively inexpensive, and preventative technique to mitigate the risk of wrong-level surgery, and the literature reports its use in multiple specialties such as urology and colorectal surgery.[8-10,13,14,16,17] Increasing awareness and availability of this safe and routine procedure at other institutions could be beneficial in eliminating serious, preventable, and costly medical errors associated with wrong-level spinal surgery.

Limitations of this study include the retrospective nature of the review without a control group. Another limitation is that our study only reviewed procedures that occurred at a single

Table 2: Comparison between CT- and FL-guided gold fiducial marker placements

	CT	FL
Total cases	36	143
Level of gold fiducial marker placement	C7 = 1	C7 = 0
	T1 = 4	T1 = 1
	T2 = 3	T2 = 2
	T3 = 6	T3 = 8
	T4 = 6	T4 = 8
	T5 = 2	T5 = 16
	T6 = 2	T6 = 19
	T7 = 2	T7 = 24
	T8 = 2	T8 = 19
	T9 = 1	T9 = 14
	T10 = 4	T10 = 15
	T11 = 1	T11 = 14
	T12 = 2	T12 = 5
	L3 = 0	L3 = 1
	L4 = 0	L4 = 1
Average radiation dose (range) (mGy)	258.92 (80.69–563.56)	164.43 (13–805)
Average procedural time (range) (min)	51.19 (31–114)	52.09 (20–89)

institution and results could differ when analyzed across multiple institutions.

CONCLUSIONS

Our largest-to-date single-center retrospective study of 179 spinal gold fiducial marker placements supports these procedures being performed safely by neuroradiologists. No wrong-level surgery occurred in these 179 consecutive cases, of which 176 were at the thoracic levels.

Disclosure forms provided by the authors are available with the full text and PDF of this article at www.ajnr.org.

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