

# CT-guided fiducial marker placement for stereotactic radiosurgery

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**I**mage-guided radiation therapy (IGRT) utilizes real-time imaging to deliver more precise radiation therapy with respect to tumors. The development of highly conformal radiation therapy techniques places more stringent requirements on the accuracy of beam targeting.

In practice, large uncertainties exist in tumor volume delineation and in target localization due to physiologic organ motion. IGRT uses orthogonal x-rays to visualize radiopaque fiducial markers implanted within and adjacent to the tumor for real-time tracking during the entire treatment cycle.<sup>1</sup> Stereotactic

radiosurgery (SRS), which is delivered in a single fraction, and stereotactic radiotherapy (SRT), which is delivered in up to 5 fractions, using the Cyberknife robotic system were developed at Stanford University and approved by the U.S. Food & Drug Administration in 2001. A robot (Figure 1) delivers highly focused 6MV photon radiation from a single, highly collimated beam from hundreds of angles. Figures 1 and 2 demonstrate the many components of the radiotherapy system within the vault room, where the patient is treated.

The system continuously synchronizes beam delivery to the motion of the tumor, allowing significant dose reduction in treatment margins while eliminating the need for breath holding. The patient wears a special vest that has light-emitting diodes that track the tumor according to the patient's respiration or other movements. This movement is detected by the ceiling-mounted camera array. This information is displayed on a computer monitor, where a breathing model is made, which can make adjustments in radiation delivery in real time, including predicting tumor location.

The system has interchangeable collimators with sizes from 5 to 60 mm and utilizes its noncoplanar beam arrangement to deliver submillimeter accuracy. Real-time kV imaging is obtained using either bony landmark

reference points (eg, 6-dimensional skull base tracking or spine tracking) or implanted radiographic fiducial markers (eg, gold seeds or coils). Figure 3 demonstrates how digitally reconstructed radiographs are obtained, and compares how the fiducial markers appear on the planning computed tomography (CT) system (synthetic images) with how the markers appear during live imaging (camera images). The combined images, called overlays, help to verify patient positioning and track patient motion.

Fiducial placement may appear adequate to the radiologist in that they are near the lesion, providing the system with the spatial information it needs to accurately deliver radiation. However, what may appear as adequate on CT images to a radiologist may not be acceptable because fiducial tracking is obtained using orthogonal radiographs, from which digitally reconstructed radiographs are made.<sup>2</sup> This may result in overlapping markers which will not be usable. This phenomenon is demonstrated in Figures 4 and 5, showing a diagrammatic representation of a liver tumor and fiducial markers.

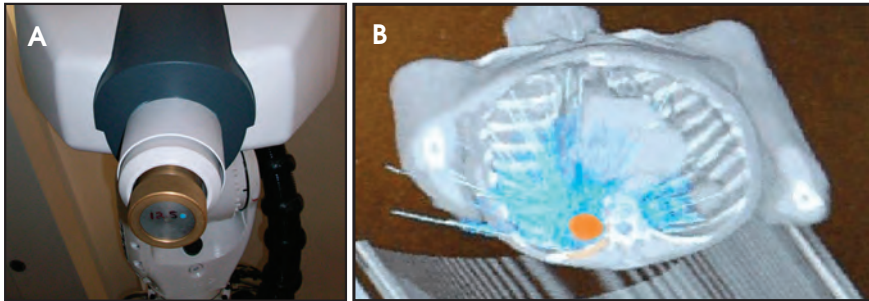
## Fiducial placement guidelines

Ideally, one fiducial should be centered in the treatment volume (within the center of the lesion).

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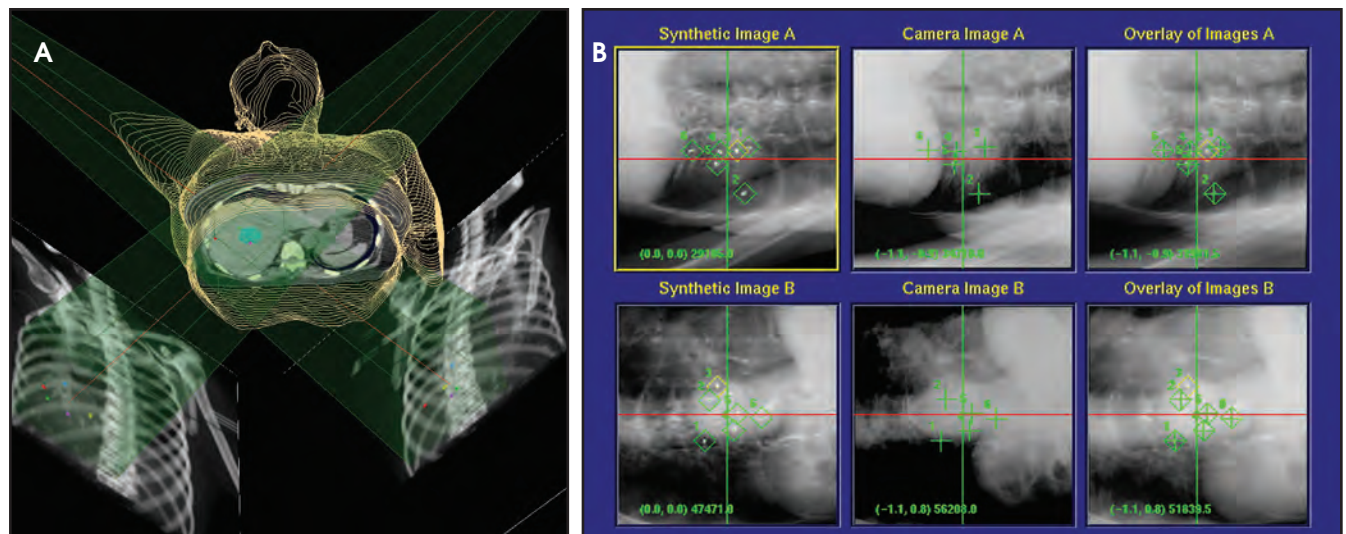
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**FIGURE 1.** (A) A robot delivers focused radiation from a single, highly collimated beam (shown here with a 12.5-mm collimator). (B) A 3-dimensional cutaway image of a completed therapy plan shows hundreds of individual beams (blue) focused on the target tumor (orange).



**FIGURE 2.** A 6-MV linear accelerator (black arrowheads) is mounted on a robotic arm (long black arrow). Diagnostic (kV) x-ray tubes (short, black arrows) are mounted on the ceiling directed toward 2 flat-panel digital imagers (short, white arrow). The patient wears a special vest (long, white arrow) that allows detection of patient motion by the nearby camera array (white arrowheads).



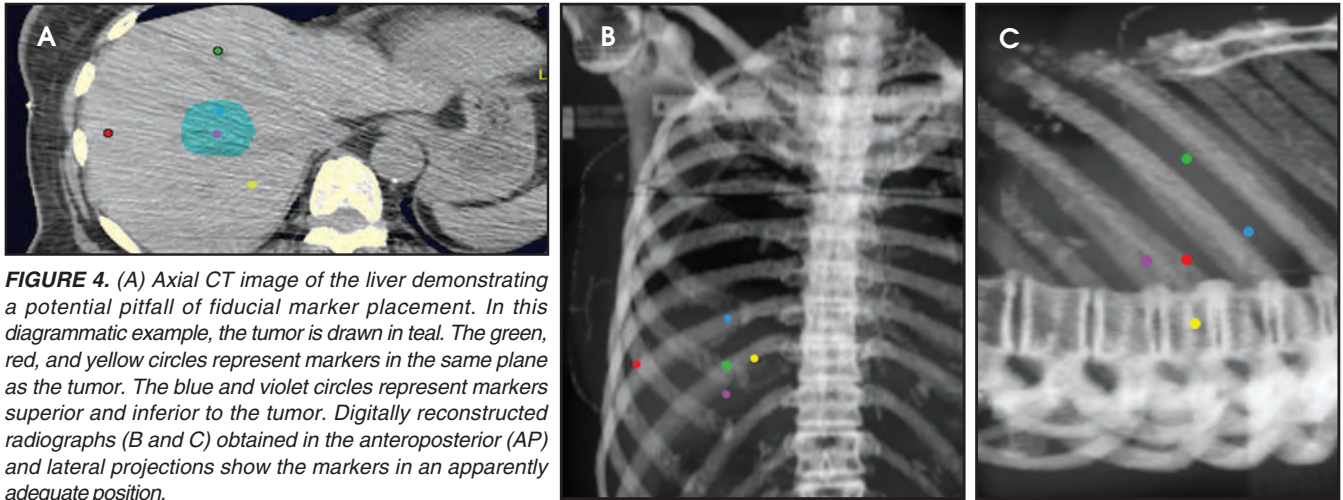
**FIGURE 3.** (A) Digitally reconstructed radiographs are obtained. As shown in B, the images obtained from the planning CT (synthetic images) are compared with the images obtained during live imaging (camera images) resulting in overlay images.

Additional fiducials should be centered around the tumor volume (bracketing the lesion superiorly, inferiorly, medially, and laterally). Optimally, the markers should be placed in different planes in the x-, y-, and z-axes (Figure 6).<sup>3-5</sup>

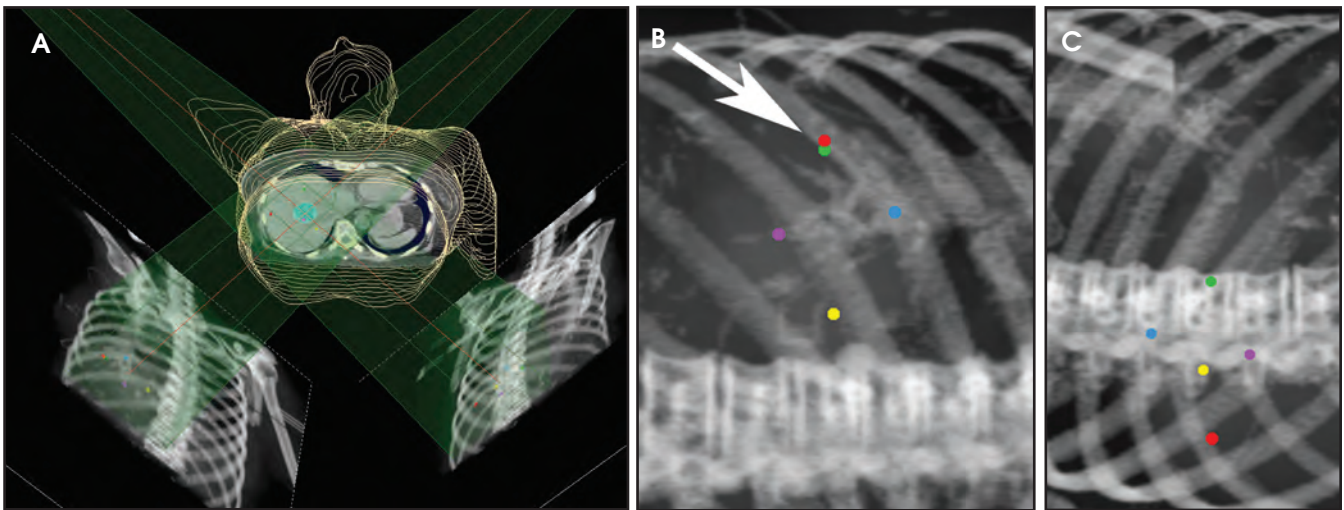
Fiducials should not be placed in the same plane (eg, the same axial-CT image plane), in such a way that they form about a 45-degree angle with the horizon (Figure 7). No fiducial should be >5 cm or >6 cm away from the lesion. There should be a minimum of 1.5 cm between fiducial markers. At least 15-degree angulation should be present between any 3 fiducials (Figure 8).<sup>3-5</sup> A minimum of 3 fiducials are needed to define a plane, which is necessary for the system to be able to localize treatment in space. More fiducial markers are preferred — 5 or 6 are usually placed at the authors' institution because some markers may be unusable due to overlap or marker migration.

## Methods

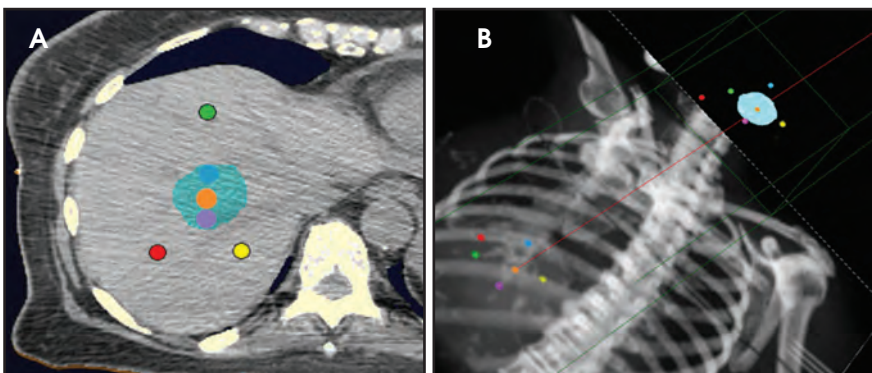
At the authors' institution, a 16-gauge Hawkins needle available in 5-, 10-, or 15-cm lengths is used (Figure 9). This needle has an inner pencil-point stylet, which has a white knob and a blue blunt-tip stylet that is used



**FIGURE 4.** (A) Axial CT image of the liver demonstrating a potential pitfall of fiducial marker placement. In this diagrammatic example, the tumor is drawn in teal. The green, red, and yellow circles represent markers in the same plane as the tumor. The blue and violet circles represent markers superior and inferior to the tumor. Digitally reconstructed radiographs (B and C) obtained in the anteroposterior (AP) and lateral projections show the markers in an apparently adequate position.



**FIGURE 5.** (A) Live orthogonal imaging only utilizes oblique images (rather than AP and lateral). When oblique images of same patient are viewed (B), there is overlap of the red and green markers on the LAO view. This results in neither marker being usable, reducing the effective number of usable fiducials from 5 to 3 (C). The minimum number of fiducial markers required to define a treatment volume is 3.

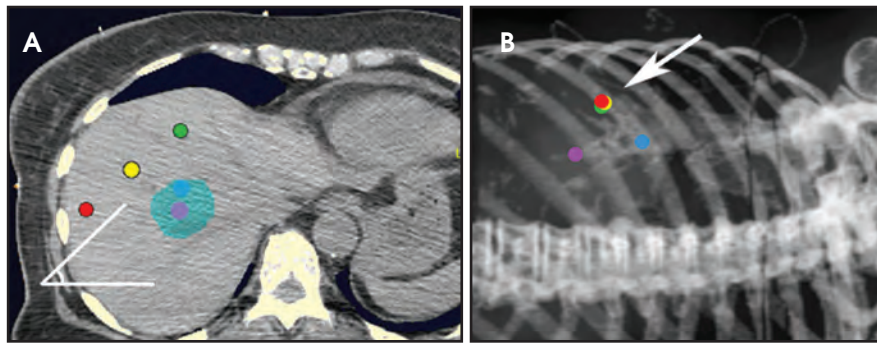


**FIGURE 6.** Axial CT and corresponding digitally reconstructed radiograph show optimal fiducial marker placement. The tumor is drawn in teal. All markers are in different planes along the z-axis (the patient's head-to-toe axis). (A) The orange circle represents a marker in the center of the tumor. (B) The blue, yellow, red, green, and violet circles represent markers bracketing the lesion superiorly, medially, laterally, and inferiorly.

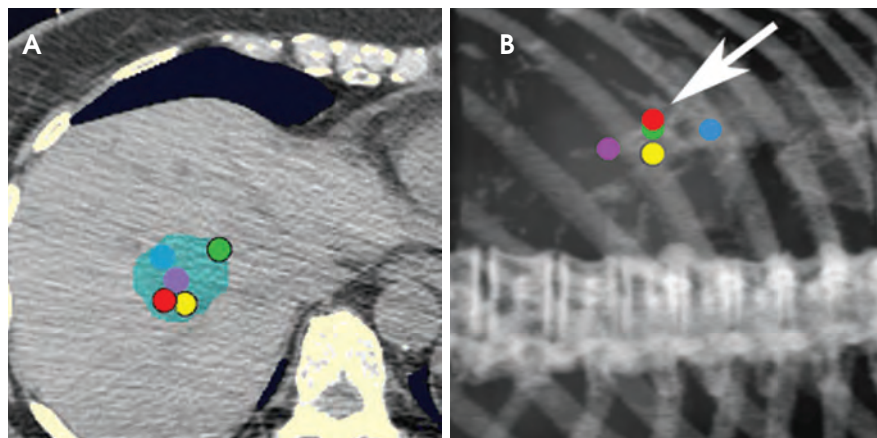
to advance the fiducial marker into the tissues. This needle allows more than 1 marker to be placed after puncturing the skin just 1 time by repositioning the angle of the needle between fiducial placements.

Fiducials are small gold markers that are implanted into the soft tissues or within the lesion. They provide spatial information for the system to accurately guide radiation delivery. Gold is denser than surgical clips and appears unique on imaging with characteristic streak artifacts. Fiducials are typically required for tumors in the chest, abdomen, pelvis, or other soft tissues.

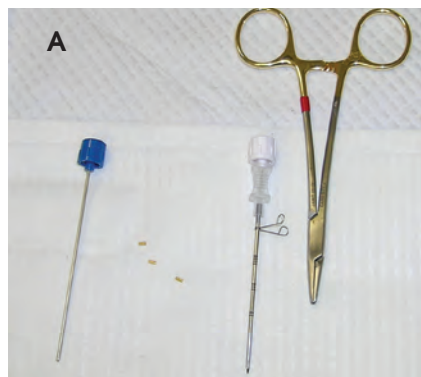
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**FIGURE 7.** Axial CT and corresponding digitally reconstructed radiograph demonstrate suboptimal placement of markers. (A) The blue and violet markers bracket the tumor (teal) adequately (superiorly and inferiorly). However, the green, yellow, and red markers are all in the same axial plane, and are aligned approximately 45 degrees to the horizon (B). This results in overlap on oblique imaging.



**FIGURE 8.** Axial CT (A) and corresponding digitally reconstructed radiograph (B) show suboptimal placement of fiducial markers resulting in overlap. The green, red, and yellow markers are in the same axial plane and the angle formed by the 3 is <math><15^\circ</math>. Also, the red and yellow markers are <math><1.5\text{ cm}</math> apart.

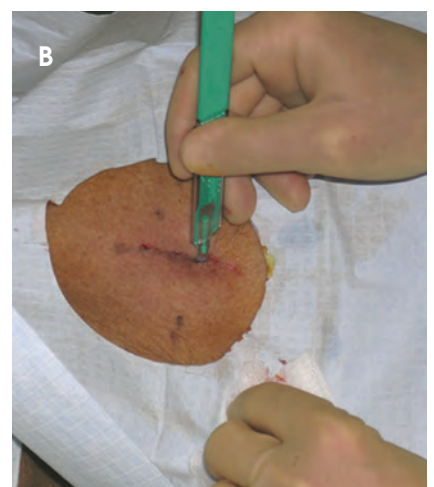
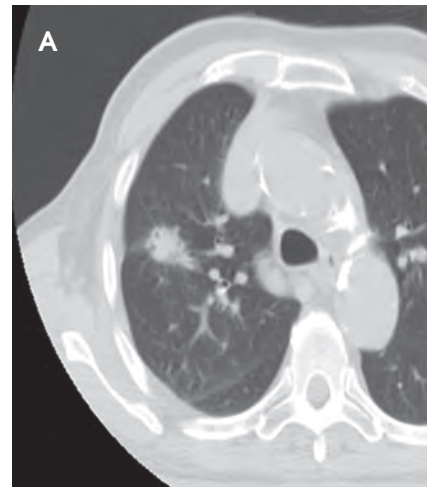


**FIGURE 9.** In addition to a basic biopsy tray (A), a 16-Hawkins needle, gold-seed fiducial markers (close up view in B), and a sterile Kelly clamp are utilized.

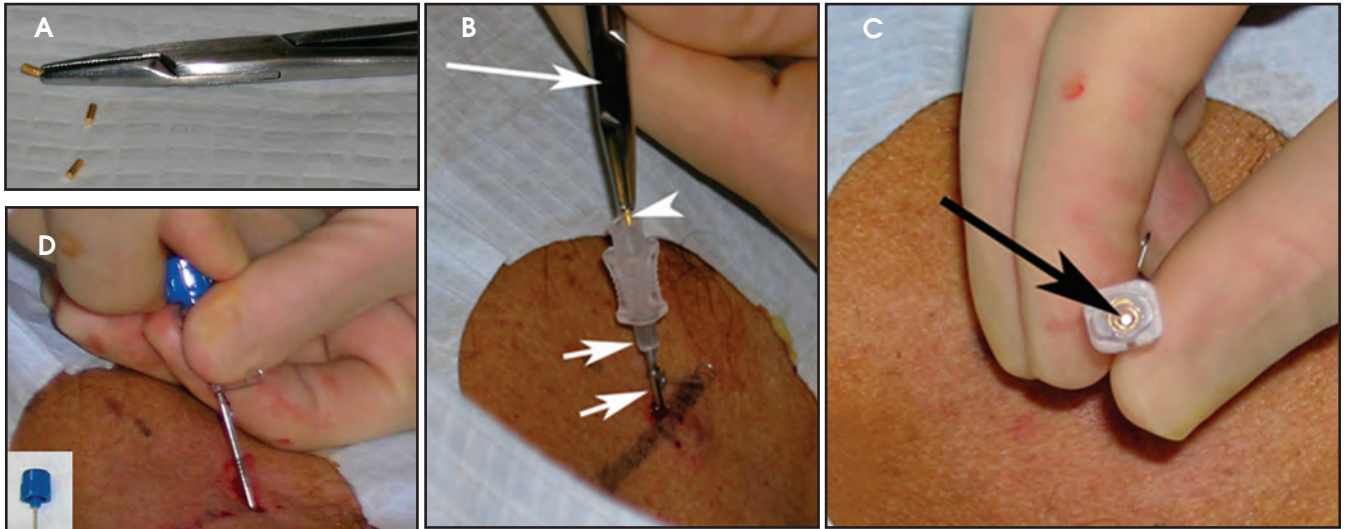
They may not be required for lesions near the spine, as the spine provides spatial localization. Fiducials are not required for intracranial lesions.

For the procedure, a basic biopsy tray is used with a 16-gauge Hawkins

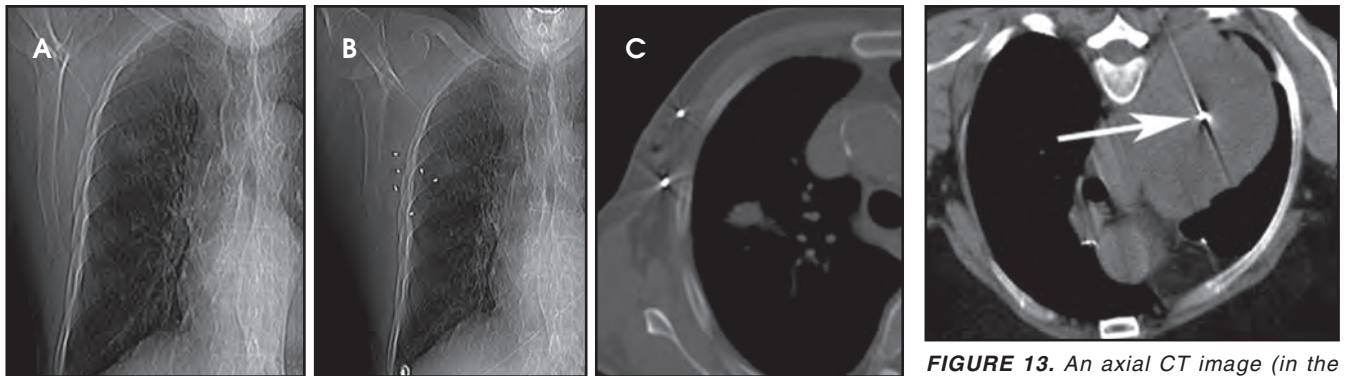
needle, 0.8 x 5-mm gold seed fiducial markers, and a Kelly clamp (Figure 9). Before the procedure, the patient's previous CT is reviewed. The patient is positioned (ie, supine or prone) and initial images



**FIGURE 10.** An initial CT image shows a lung lesion (A). The site is marked on the patient's skin, and 1% lidocaine is administered for local anesthesia. A nick is made in the patient's skin (B). The Hawkins needle is placed (with the inner pencil-point stylet) and CT images are obtained (C).

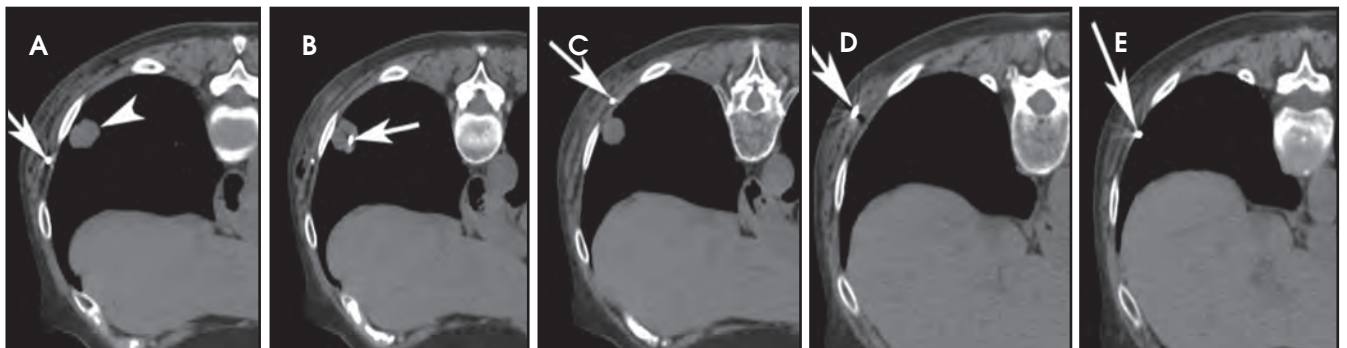


**FIGURE 11.** Figures A and B demonstrate using a Kelly clamp (white arrow) to hold the marker (white arrowhead). The inner pencil-point stylet is removed and the marker is placed into the Hawkins needle (white short arrows). Figure C shows the marker (black arrow) in the proximal part of the Hawkins needle before it is advanced into the soft tissues. Figure D shows the blue blunt-tip stylet being used to advance the marker through the Hawkins needle into the desired location. It is important that the blue portion is turned and hubbed with the clear portion of the Hawkins needle to ensure deployment of the marker.



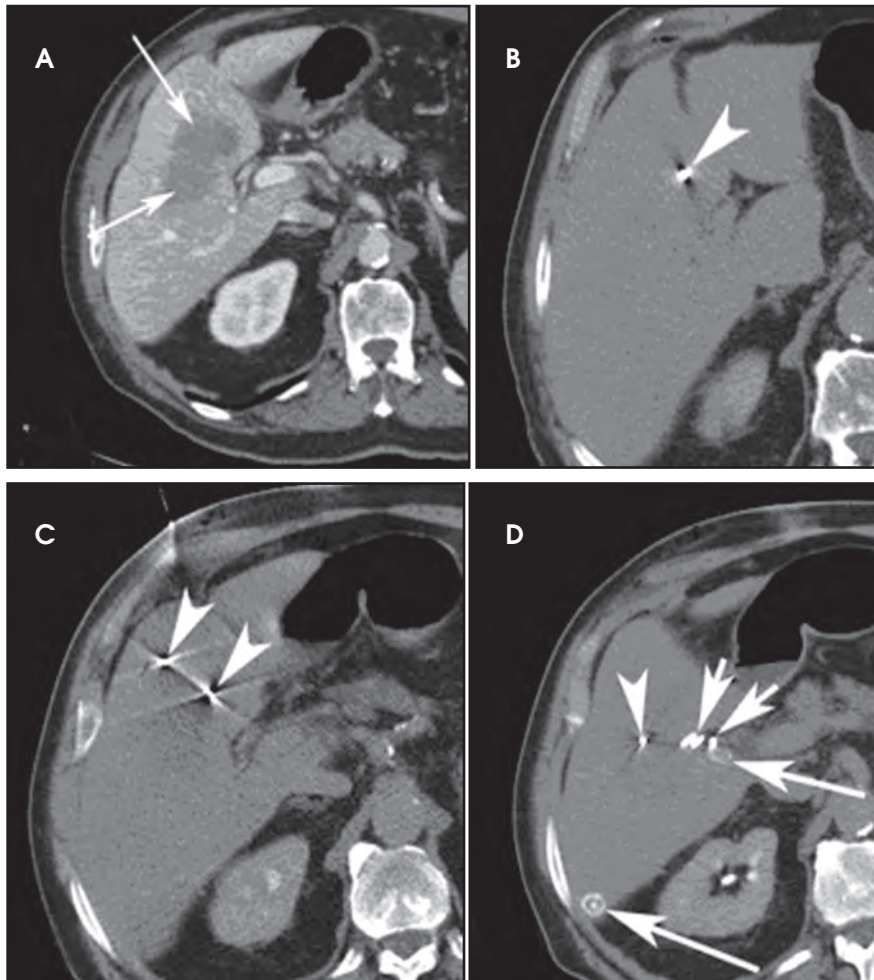
**FIGURE 12.** CT-scout images show a patient before (A) and after (B) marker placement. An axial CT image (C) shows markers in the chest wall.

**FIGURE 13.** An axial CT image (in the prone position) shows a marker (arrow) placed within the center of a lung mass.



**FIGURE 14.** This is an example of proper marker placement. Figures A through E are axial CT images, which are in order superiorly to inferiorly. Five fiducial markers (arrows) have been placed for a lung lesion (arrowhead). One fiducial marker is within the lung lesion, and the others are within the chest wall (extrapleural). Note how the markers are all in different locations with respect to the z-axis (the patient's head-to-toe axis).

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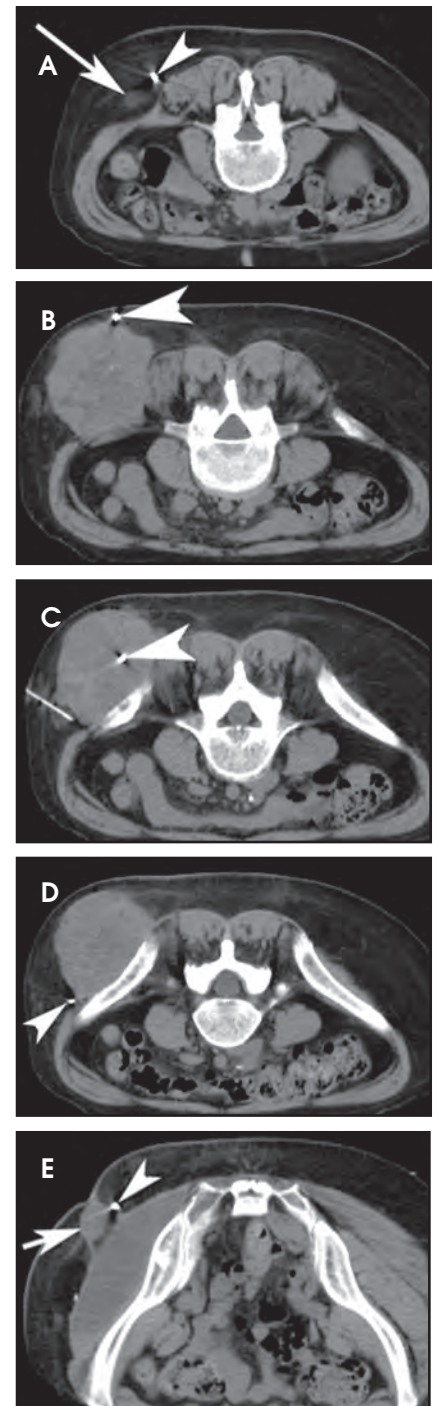


**FIGURE 15.** (A) An axial CT image with contrast in the portal venous phase demonstrates a hypodense mass (long, white arrows) in the area of the gallbladder fossa in this patient with known gallbladder carcinoma. Figures B, C, and D demonstrate 4 markers (white arrowheads) within the lesion, as well as bracketing the superior and inferior aspects of the lesion. The patient could not tolerate lying on his back long enough for additional markers to be placed. The white arrows indicate clips in the gallbladder fossa. The long white arrows in D represent calcified gallstones which are loose in the peritoneal cavity.

are obtained. The patient is prepped and draped in the usual sterile fashion. For local anesthesia, 1% lidocaine is utilized. A small nick is made in the patient's skin (Figure 10). The Hawkins needle with the pencil-point stylet in place is advanced to the desired location and confirmed by CT. Kelly clamps are used to grip the fiducial marker. It is easier to drop the marker into the Hawkins needle if the orientation of the marker is angled slightly with respect to the Kelly clamp (Figure 11). Figures 10 through 12 show a patient

with poor pulmonary function tests in whom fiducial markers were placed in the chest wall to avoid a possible pneumothorax.

The pencil-point stylet is removed from the Hawkins needle. Using the Kelly clamp the fiducial marker is positioned and released into the Hawkins needle. Figure 11 shows the above steps with the fiducial marker within the proximal part of the Hawkins needle. The blue blunt-tip stylet is then placed into the Hawkins needle. This pushes the marker to the tip of the



**FIGURE 16.** (A to E) Axial CT images from superior to inferior, demonstrate 5 fiducial markers (arrowheads) within the center of the lesion (as seen in image C) as well as bracketing the lesion. The long and short arrows show the superior and inferior aspects of the lesion respectively. There is a seroma adjacent to the iliac bone in Figure E.

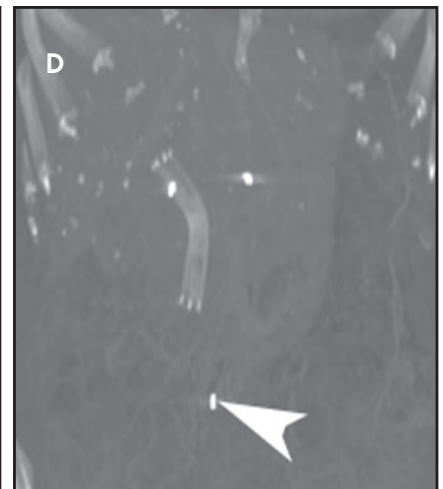
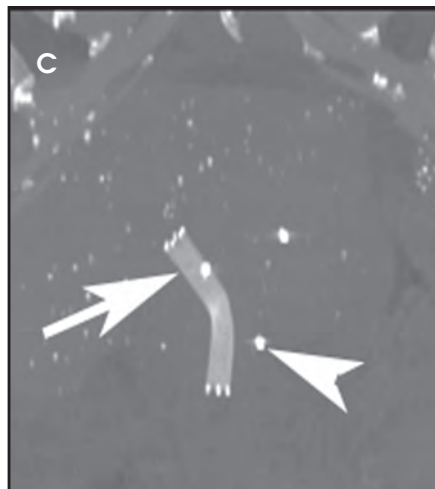
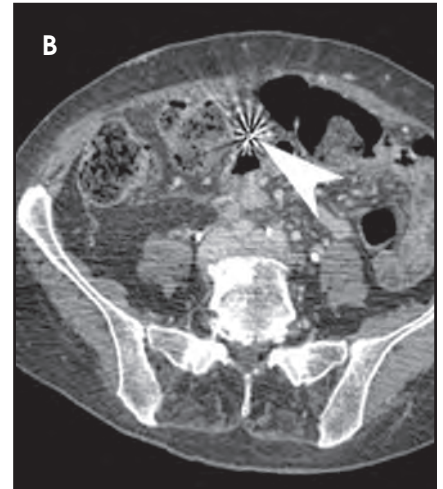
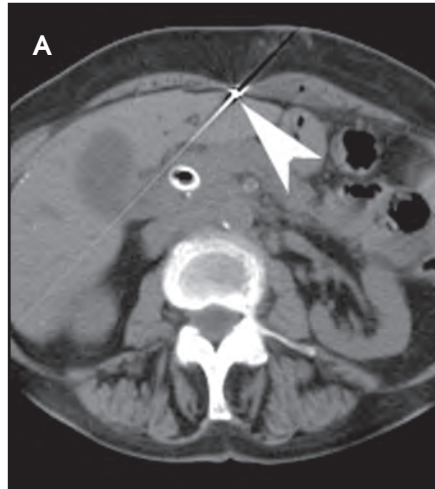


**FIGURE 17.** During placement of fiducial markers into and adjacent to the right upper lobe lesion (arrowhead), a small focal pneumothorax (arrow) developed. This was followed with a chest radiograph showing pneumothorax resolution.



**FIGURE 18.** There is a hematoma of the abdominal wall musculature adjacent to the tip of the Hawkins needle.

To ensure that the marker exits the needle, the blue blunt-tip stylet should be advanced completely by twisting the luer lock components of the stylet and Hawkins needle until the knob is flush with the needle hub. The needle can be removed at this point, or the pencil-point stylet can be replaced and the needle can be repositioned for additional marker placement. When fiducial marker placement is complete, CT images are obtained showing the location of the markers (Figure 12).



**FIGURE 19.** This shows fiducial-marker migration. An axial CT image (A) and corresponding coronal maximum intensity projection (MIP) image (B) show marker location at the time of placement. An axial CT image (C) and corresponding coronal MIP image (D) 8 days later, at the time of the planning CT, show a change in position of the inferior-most marker (arrowheads). The patient has a common bile duct stent (arrow).

Ideally, 5 or 6 markers should be placed. It is important that they are in different planes along the x-, y- and z-axes. If possible, it is optimal to place a marker in the center of the lesion (Figure 13), and then place the other markers around (bracketing) the lesion, so that the isocenter of the markers is the center of the lesion. Sometimes it is not possible, as in the patient presented in Figures 10 through 12, to place a marker in the lesion center, but placing them within 5 cm will still facilitate treatment. Markers placed more than 7 cm from the lesion will likely not be usable. The

system uses a small field of view (20 cm). Examples of fiducial placement in the chest, abdomen, and pelvis are shown in Figures 14 through 16.

### Monitoring and safety

Patients who have fiducials placed in organs (eg, the liver) are typically observed for 2 hours after the procedure. Patients who have fiducials placed only in the soft tissues (eg, the chest wall) are observed for 1 hour. After this time patients are typically discharged. Patients typically wait 7 to 10 days to allow for “scarring in” of

## CME

the fiducial markers before returning for the planning CT. Once the planning CT is performed, the radiation oncologists develop their treatment plan. If fiducial markers migrate between planning and treatment, they will not be usable unless the patient is scanned again and the treatment plan revised.

### Complications

In addition to the usual small risks of bleeding and infection with interventional procedures, potential complications include development of a pneumothorax, lidocaine-related patient confusion, and fiducial-marker migration after placement. If a small pneumothorax occurs (Figure 17), the patient can be followed with radiographs to verify resolution. If a clinically significant pneumothorax occurs, a pigtail catheter can be placed. Another possible complication is development of an intramuscular hematoma. Figure 18 shows a hematoma of the abdominal wall musculature (compared to the normal contralateral side). These

hematomas typically resolve without intervention. The hematoma can be followed clinically or by CT if necessary.

Fiducial-marker migration describes a change in position of markers either between placement and the therapy-planning CT scan or between the planning CT and actual treatment delivery. An example of marker migration is illustrated in Figure 19. This may also occur when markers are placed in the pleural space,<sup>3</sup> or in an intravascular location, such as an artery, although this is uncommon.<sup>4</sup> Placement of markers in an extrapleural location in the chest wall can help avoid migration. Lidocaine-related patient confusion is another potential complication. It has been our experience that some patients who have received >30 cc of lidocaine can become confused. In most patients, <30 cc is adequate to control patient discomfort.

### Conclusion

Stereotactic radiosurgery is an increasingly utilized treatment method. It is important for radiologists

performing CT-guided placement of fiducial markers to be able to do so safely and accurately. This article provides the essentials of how the system utilizes fiducial markers, a step-by-step guide on how to perform the procedure, a review of potential complications and what to do when they occur.

### References

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