

Use of a 3D-Printed Abdominal Compression Device to Facilitate CT Fluoroscopy–Guided Percutaneous Interventions

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OBJECTIVE. The purpose of this article is to describe a handheld external compression device used to facilitate CT fluoroscopy–guided percutaneous interventions in the abdomen.

CONCLUSION. The device was designed with computer-aided design software to modify an existing gastrointestinal fluoroscopy compression device and was constructed by 3D printing. This abdominal compression device facilitates access to interventional targets, and its use minimizes radiation exposure of radiologists. Twenty-one procedures, including biopsies, drainage procedures, and an ablation, were performed with the device. Radiation dosimetry data were collected during two procedures.

CT is commonly used to guide placement of percutaneous needles, catheters, and ablation devices into the abdomen and pelvis [1]. CT fluoroscopy adds a nearly real-time element to the excellent anatomic depictions of CT [1]. The percutaneous approach to abdominal targets, however, may be impeded by intervening critical structures, target mobility, small lesion size, and large skin-to-target distances [2].

Historically, the need for external compression to facilitate CT-guided abdominal interventions was recognized before the era of CT fluoroscopy. De Kerviler et al. [3] and Dachman [4] described compression devices with perforations that allowed needle access while displacing intervening critical structures and reducing skin-to-target distances. Both devices were strapped to the CT table and applied continuous fixed pressure to the abdomen.

The design and development of a handheld compression device that enables the radiologist to simultaneously apply graded compression and steer the needle under CT fluoroscopic control while keeping the hand away from the x-ray beam has been described [5]. Computer-aided design (CAD) software and 3D printing were used. This article reports the initial experience with the device in 21 procedures along with the dosimetry data from two of the procedures.

Materials and Methods

The commercially available F-Spoon device (F-Spoon) is used to assist diagnostic gastrointestinal fluoroscopic examinations such as upper gastrointestinal series, small-bowel series, and barium enema studies [6]. The device was initially modified with a drill and saw so that a keyhole shape was cut into the spoon portion of the device (Figs. 1A and 1B). The modified device was CT scanned, and the DICOM images were uploaded to open source image analysis software for segmentation. Postprocessing and refinement of the 3D device were performed with CAD software. The shape and contour of the device were modified on the basis of physician feedback to allow ambidextrous use and to fit the device within a sterile ultrasound probe cover. Details of the design and 3D printing process are provided in Appendix 1. (Appendix S1, which contains additional details on 3D printing considerations, can be viewed in the *AJR* electronic supplement to this article, available at www.ajronline.org.)

The handgrip and curved armrest allow the operator to control the device while applying continuous pressure to the abdomen (Fig. 1C). The keyhole cutout in the device was designed to help secure two rubber bands that maintain a gap in the sterile cover, facilitating placement of the spoon around a needle while maintaining sterility (Fig. 1D).

In this institutional review board–approved HIPAA-compliant study, we retrospectively assessed how the 3D-printed device facilitated 21 CT fluoroscopy–guided procedures in 21 adult pa-

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Supplemental Data

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TABLE 1: Utility of 3D-Printed Compression Device in 21 CT Fluoroscopy-Guided Procedures

Case No.	How Device Was Used to Facilitate Procedure	Procedure Not Feasible Without Device	Procedure Questionably Feasible but Difficult to Perform Without Device	Procedure Feasible Without Device but Facilitated by Use of Device
1	D, S		X	
2	D, S		X	
3	S		X	
4	D, S		X	
5	D, S			X
6	D, S		X	
7	D, S		X	
8	DA	X		
9	D, S	X		
10	D, S		X	
11	S		X	
12	D, S, I		X	
13	D, S			X
14	D, S	X		
15	D, S		X	
16	D, S		X	
17	D, S		X	
18	D, S		X	
19	D, S		X	
20	D, S, I		X	
21	D, S	X		

Note—D = displace bowel, S = steer needle, DA = displace bowel from liver ablation zone, I = immobilize mesenteric mass.

tients. CT fluoroscopy (Somatom Sensation scanner, Siemens Healthcare) was performed at a slice thickness of 5 mm, 120 kVp, and 30 mAs. The mean procedure duration was 65 minutes (range, 38–151 minutes), and the mean dose-length product was 1059 mGy × cm (range, 541–2938 mGy × cm). A partial-rotation CT fluoroscopic feature turns off the CT beam over a 100° arc closest to the operator-minimized scatter dose to the operator. In two cases, radiation dosimetry measurements were obtained by use of 1-cm aluminum oxide optically stimulated luminescence dosimeters (nanoDots, microStar reader, Landauer) placed at two locations: one adjacent to the keyhole cutout of the device (in-beam, patient skin needle insertion site) and one on the operator’s fingers (20 cm from the keyhole). Dosimetry was performed to ensure that the operator’s hand remained away from the CT x-ray beam while the device was in use.

Results

The 3D-printed paddle was used to perform 18 biopsies, two abscess drainages, and one liver microwave ablation (Table 1). The device was used when bowel loops were

found to preclude safe needle access to the target, when mobility of the target made targeting difficult, and when bowel was too close to the planned ablation zone (Figs. 2–5). In 20 of 21 (95%) cases the device was used to steer the needle toward a target while keeping the radiologist’s hand out of the CT fluoroscopic beam. In 19 of 21 (90%) cases the device was used to displace intervening loops of bowel. In 2 of 21 (10%) cases the compression paddle was used to immobilize a mobile mesenteric mass. In one liver microwave ablation case, compression was used to displace bowel away from the ablation zone to prevent bowel injury. All biopsy procedures yielded diagnostic pathology results. Both drainage procedures resulted in complete resolution of fluid collections, and the liver tumor ablation procedure resulted in complete ablation coverage of the tumor without injury to adjacent bowel. The mean needle path distance was 9.0 cm (range, 4.3–19.2 cm). No adverse events occurred. The dosimetry data from the two clinical cases yielded a mean skin incision (keyhole) dose of 14.95 mGy (16.5 and

13.4 mGy) and a mean operator finger dose of 0.31 mGy (0.27 and 0.35 mGy), a 97.9% difference (98.4% and 97.4%).

Discussion

CAD software and 3D printing enabled rapid design and prototype development of a handheld device to solve problems encountered in some CT fluoroscopy-guided abdominal interventional procedures. The 3D-printed compression device is intended for use during CT fluoroscopic acquisitions and not during routine helical CT acquisitions. Image-guided biopsies or drainage procedures are sometimes not feasible or are difficult to perform owing to intervening bowel, large skin-to-target distance, or mobility of the target mass [2–4]. The iterative design process described in this report allowed physicians to provide immediate feedback and suggestions on CAD renderings displayed on a computer screen. Once the digital concept was finalized, 3D printing enabled immediate prototype production at low cost.

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CT Fluoroscopy-Guided Percutaneous Interventions

Three-dimensional printers have been used in the field of radiology to construct anatomic models from diagnostic imaging datasets for surgical planning and education [7]. In our project, the technology was used to develop a prototype interventional radiology device. In addition to the speed of design of use of CAD software, the use of 3D printing can facilitate immediate production of single prototypes consisting of various materials, including plastics, nylon, and other polymers [8].

Our initial experience using the modified abdominal compression device in 21 procedures revealed several potential advantages. Displacement of intervening mobile organs, such as small and large bowel, enabled creation of a safe needle path to the target lesion. The ability to steer the needle using the compression device allowed the operator to obtain CT fluoroscopic images during compression and steering. This nearly real-time confirmation gave the operator confidence that the needle was being advanced without interval change in position relative to surrounding anatomic structures. The compression device was also used to pin or trap mobile mesenteric masses that were otherwise difficult to target.

Applying compression with the device can decrease the skin-to-target distance and may facilitate access to deep targets in large patients that may be located beyond the range

of conventional devices. When releasing compression that has been applied with the device, there is the potential for needle retraction from the target. To avoid dislodgment of the needle, gradual release of pressure, either while holding the needle hub stationary or while intermittently monitoring with CT fluoroscopy, can be considered.

The position of the handgrip on the device kept the radiologist's hand approximately 20 cm from the CT fluoroscopy x-ray beam when applying compression or steering. This resulted in an approximately 98% lower dose to the radiologist's hand compared with the needle insertion site (in beam), as measured in two cases. Currently, the device design is intended for general use regardless of patient size. In the future, however, devices could be modified for use in small or large patients and for specific purposes. A future study would be helpful to more fully investigate the indications, techniques, and outcomes associated with the use of this prototype device.

Conclusion

A handheld abdominal compression device for CT fluoroscopy was developed by modification of a preexisting device by use of CAD software and 3D printing. The new handheld device facilitates percutaneous needle access to challenging targets by enabling displacement of intervening critical structures, steering interventional needles, and

trapping mobile masses, all while keeping the radiologist's hand out of the CT x-ray beam.

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APPENDIX I: Design and Printing Details

With permission from F. J. Scholz, who designed and owns the F-Spoon device (F-Spoon Co., U.S. patent no. 4836186), we proceeded with the device modification process. A. Hosny, a design engineer, was given detailed instructions for the desired F-Spoon modifications. The requirements included size specifications to facilitate use of a standard sterile ultrasound probe cover, a key-hole cutout measuring 1.5 × 4.5 cm, structural strength for expected manual applications of force, symmetric shape for ambidextrous use, and a handgrip position allowing the operator's hand to remain out of the CT x-ray beam. A surface finish facilitating routine disinfection of the device was also required.

The F-Spoon device was scanned with a 320-MDCT scanner (Aquilion ONE 320, Toshiba America Medical Systems) at 120 kVp and 80 mAs (slice thickness, 1.0 mm;

interval, 0.8 mm). DICOM images were uploaded to open source image analysis software (3D Slicer 2.6) for segmentation. Post-processing was performed with Meshmixer (Autodesk) CAD software. With the scanned digital file as a reference, a new solid geometry model was constructed in Rhinoceros 3D CAD software (Robert McNeel & Associates). With radiologist feedback, iterative design changes were made before the prototype was made. The file was converted to stereolithography format and 3D printed entirely from nylon powder.

A 3D fused-deposition-modeling printer (Fortus, Stratasys) was used to print the 3D object layer by layer by means of selective laser sintering. Choosing a printer with a long print bed enabled printing of the entire compression device in one build, thus avoiding a two-part device with inherent structur-

al weakness. The device was printed with nylon because of its strength and flexibility. The device was then coated with multiple applications of acrylic spray paint to seal microstriations and surface imperfections and to facilitate routine disinfection with standard hospital disinfectant solutions. The time required to print the device was 8 hours with a material cost of approximately \$150.00. Alternative materials, such as polyphenylsulfone, which is highly heat and chemical resistant, can be considered.

The modified, 3D-printed device has not been approved by the U.S. Food and Drug Administration for clinical use. A digital file that can be used for 3D printing of the device is offered as freeware at [ahmedhosny.github.io/compression-paddle](https://github.com/ahmedhosny). Potential users must accept the licensing terms before downloading the file and printing the device.

(Figures start on next page)

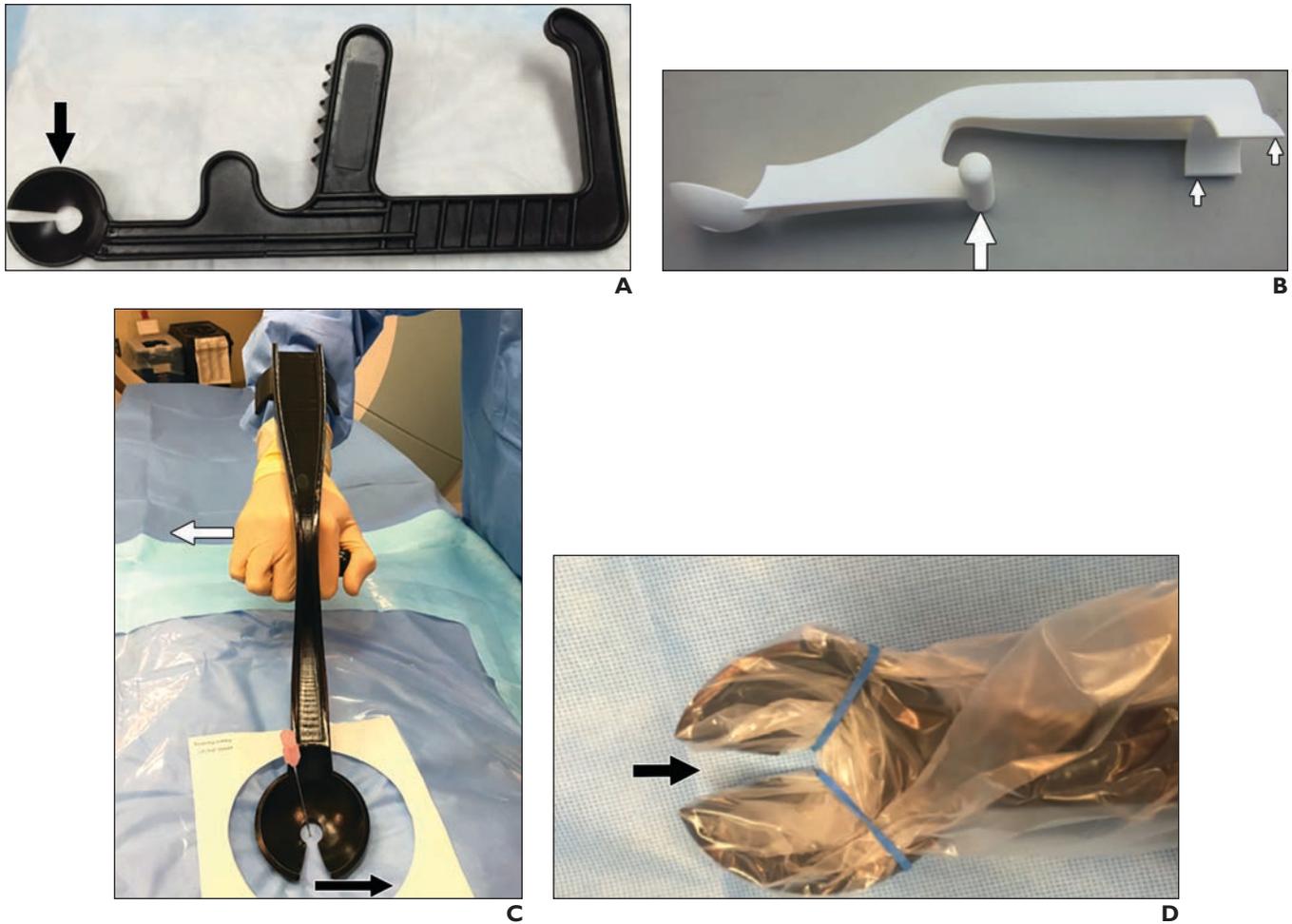


Fig. 1—Compression paddle design and modification.

A, Photograph shows F-Spoon device (F-Spoon) modified with drill and saw to cut out keyhole shape in spoon (*arrow*). Modification facilitates placement of spoon around interventional needle.

B, Photograph shows 3D-printed modified compression device made of nylon. Three-dimensionally printed model incorporates handgrip (*long arrow*) and curved armrest (*short arrows*), which allow ambidextrous use and draping with sterile ultrasound probe cover.

C, Photograph shows radiologist applying graded compression while steering needle in any direction by applying additional lateral force. While radiologist applies compression and moves hand in direction of white arrow, needle tip deflects in direction of black arrow.

D, Photograph shows keyhole cutout (*arrow*) in spoon, which allows secure placement of two rubber bands that maintain gap in sterile cover through which interventional needle is placed and positioned. Round central portion of keyhole cutout measures 1.5 cm in diameter, and entire keyhole measures 4.5 cm in overall length. Black acrylic paint was applied to white nylon device to seal surface pores and facilitate routine disinfectant cleaning.

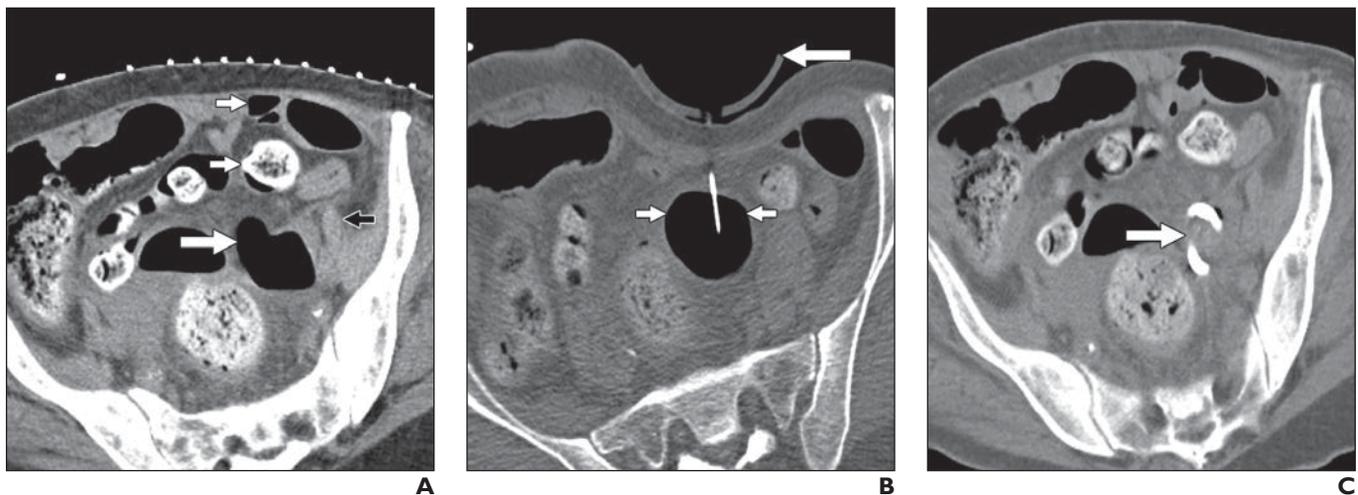


Fig. 2—88-year-old woman with perforated diverticulitis and left pelvic abscess treated with CT-guided percutaneous catheter drainage. **A**, CT image shows pelvic abscess (*long white arrow*) containing air and fluid. Intervening bowel loops (*short white arrows*) are present anteriorly, iliac blood vessels (*black arrow*) laterally, and bone posteriorly. No safe, unobstructed access was available. **B**, Image obtained during intermittent CT fluoroscopy shows displacement of bowel loops by 3D-printed compression device (*long arrow*) to give needle and guidewire access to pelvic abscess (*short arrows*). **C**, CT image obtained after procedure confirms placement of loop catheter (*arrow*) and complete drainage of abscess.

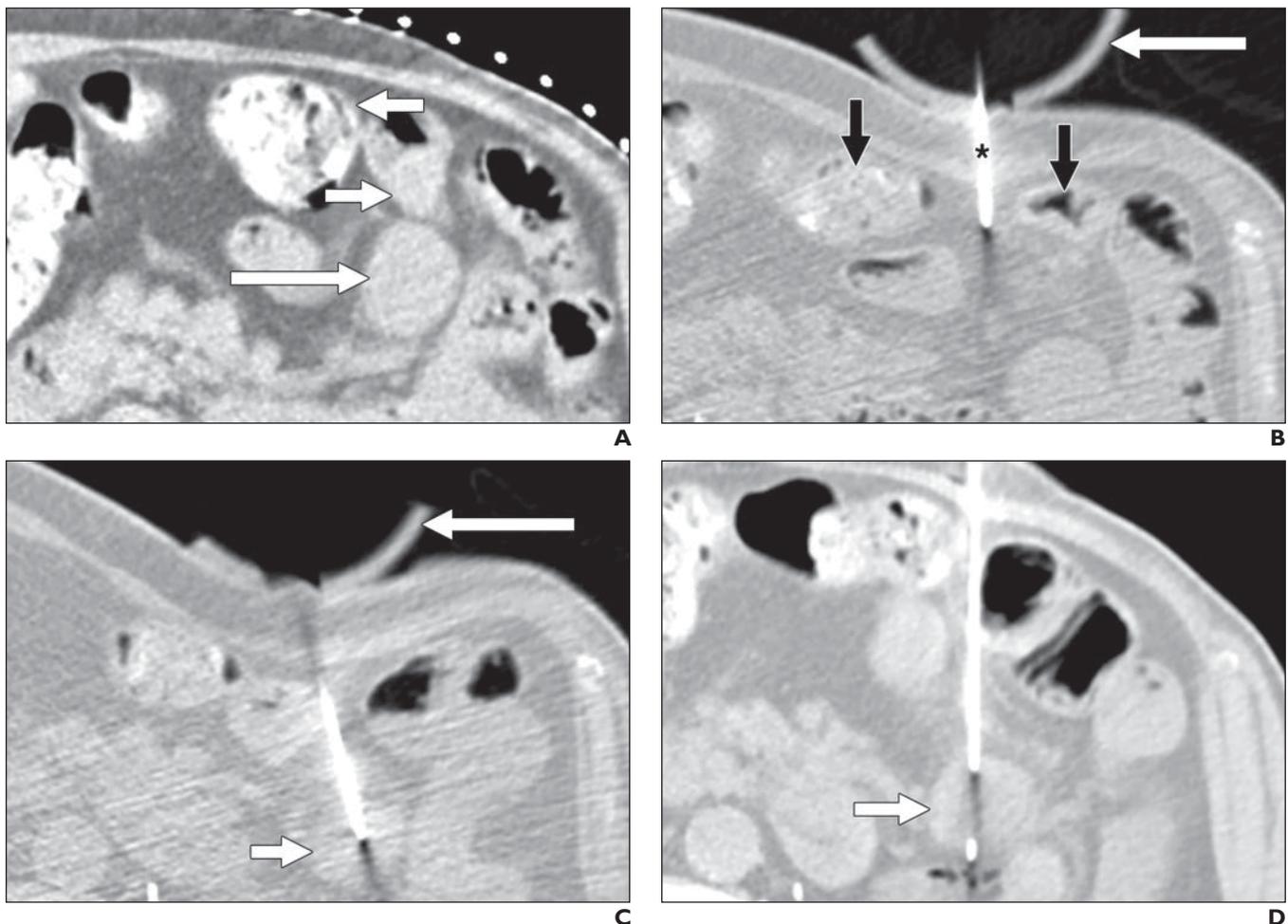
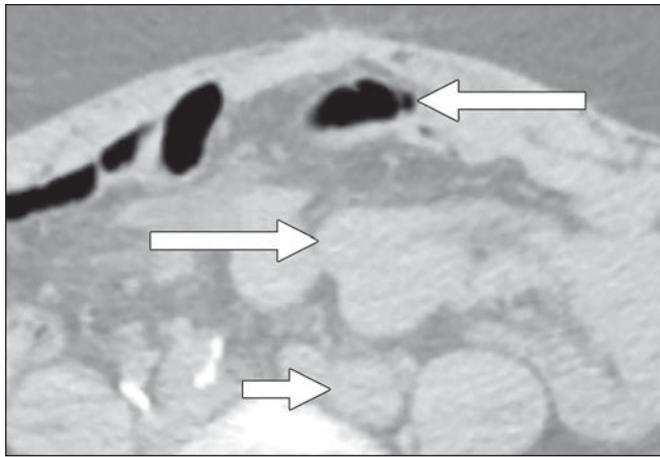
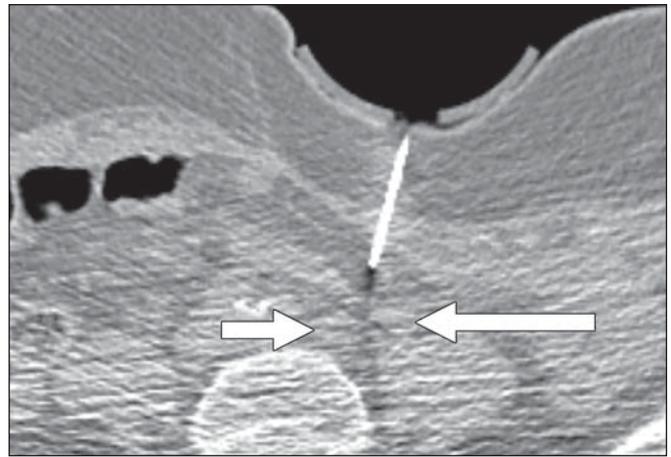


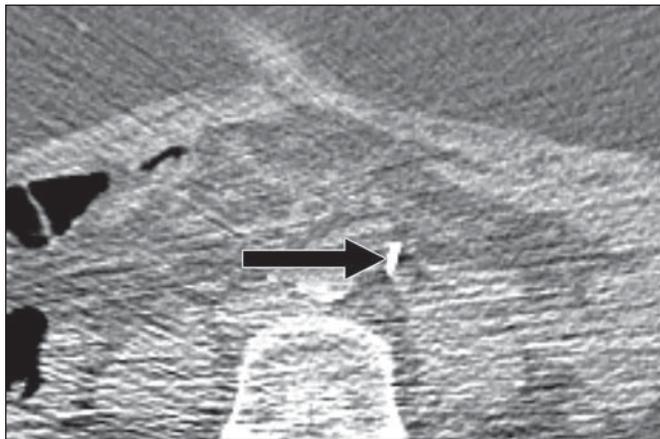
Fig. 3—70-year-old man with history of non-small cell lung cancer and new mesenteric mass. Biopsy revealed metastatic adenocarcinoma. **A**, CT image shows intervening bowel loops (*short arrows*) anterior to mesenteric mass (*long arrow*). No safe, unobstructed access was present. **B**, Image obtained during intermittent CT fluoroscopy shows bowel loops (*black arrows*) displaced with compression device (*white arrow*). Needle (*asterisk*) was advanced beyond intervening bowel before needle was steered into mesenteric mass. **C**, Image obtained during intermittent CT fluoroscopy shows compression device (*long arrow*) used to steer needle out of transaxial plane into mass (*short arrow*). **D**, Image obtained during intermittent CT fluoroscopy shows core biopsy needle positioned in mass (*arrow*). Pressure is slowly released from compression paddle to ensure needle does not retract from target.



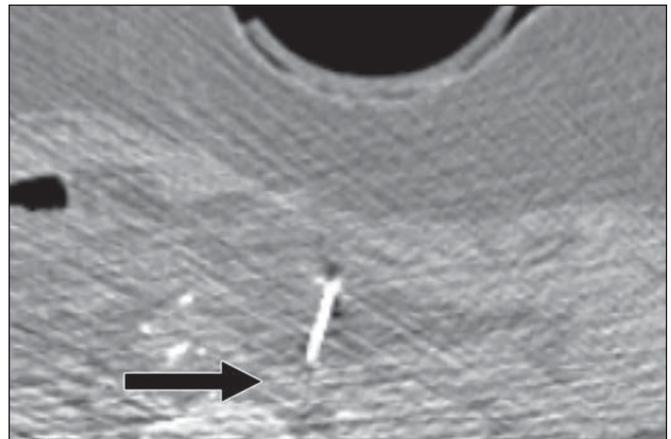
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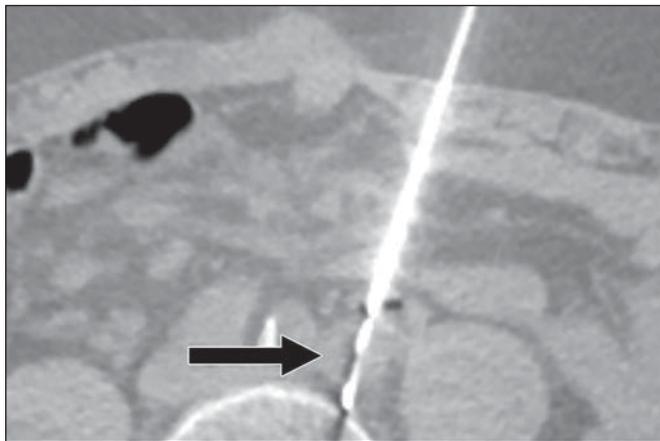
B



C



D



E

Fig. 4—68-year-old woman with serous endometrial carcinoma and enlarging left common iliac lymph node. Biopsy revealed recurrent serous endometrial carcinoma.

A, Image obtained during intermittent CT fluoroscopy shows intervening bowel loops (*long arrows*) anterior to iliac node (*short arrow*). No safe, unobstructed access was available.

B, Image obtained during intermittent CT fluoroscopy shows superficial bowel loops displaced with 3D-printed compression device, enabling needle passage beyond superficial bowel loops but not beyond deep bowel loop (*long arrow*) located immediately anterior to iliac lymph node (*short arrow*).

C, Image obtained during intermittent CT fluoroscopy shows needle tip (*arrow*) steered superior to and beyond nondisplaceable deep bowel loop.

D, Image obtained during intermittent CT fluoroscopy shows needle tip just past deep bowel loop redirected inferiorly with compression device into lymph node (*arrow*).

E, Image obtained during intermittent CT fluoroscopy shows core biopsy needle within target lymph node (*arrow*).

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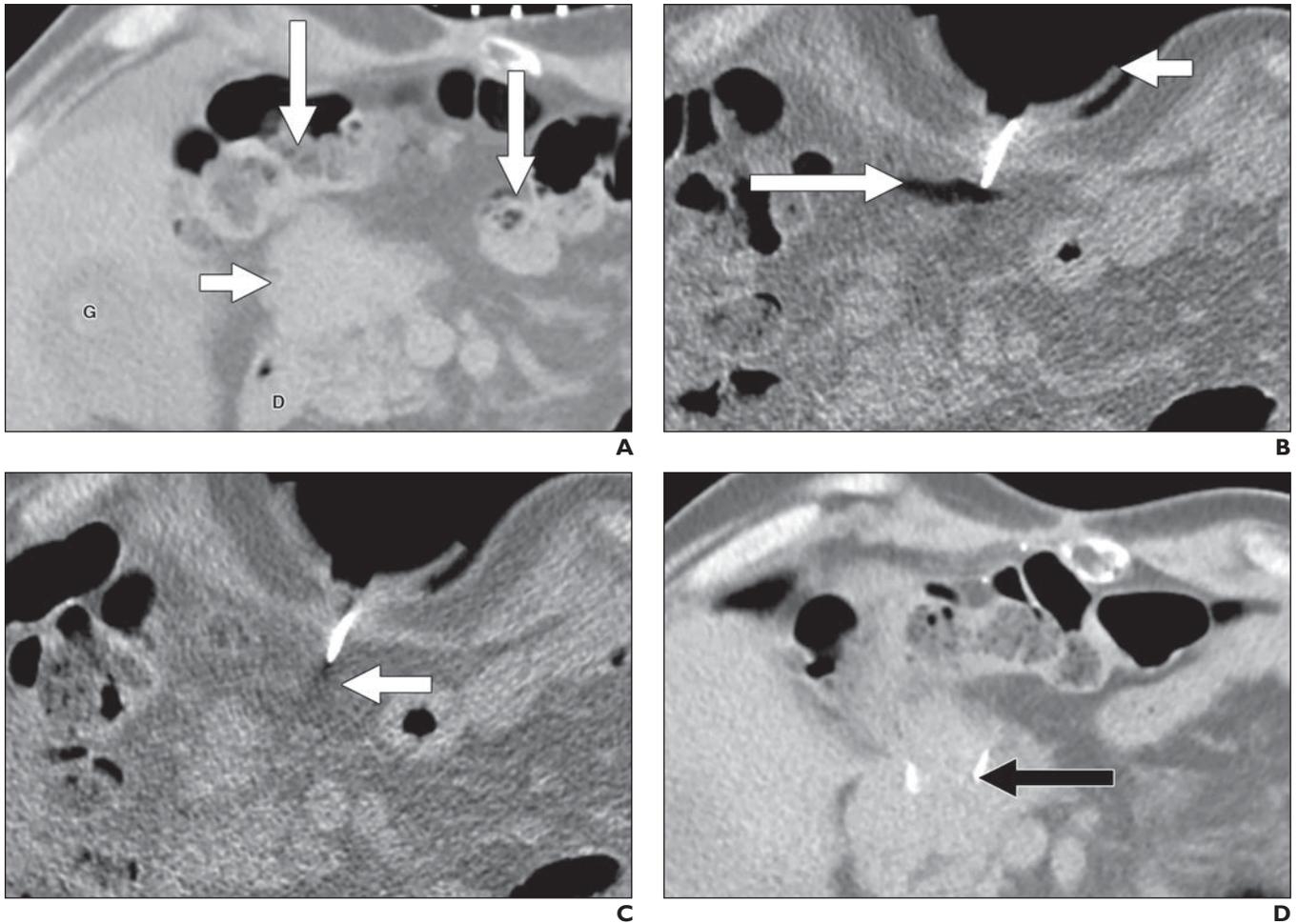


Fig. 5—68-year-old man with gastric cancer and previous gastrectomy and new mass at duodenal stump. Biopsy revealed metastatic gastric cancer. **A**, Image obtained during intermittent CT fluoroscopy shows mass (*short arrow*) surrounded by redundant loops of colon (*long arrows*), duodenum (D), and gallbladder (G). **B**, Image obtained during intermittent CT fluoroscopy shows compression device (*short arrow*) during initial needle insertion partially displacing colon (*long arrow*). Steering of needle with device was essential for out-of-plane guidance of needle superior to colon and toward mass. **C**, Image obtained during intermittent CT fluoroscopy shows that with additional compression and steering of needle tip superiorly, bowel is avoided, and needle is advanced into transverse mesocolic fat (*arrow*). **D**, Image obtained during intermittent CT fluoroscopy shows final needle tip position (*arrow*) within duodenal stump mass confirmed after release of compression by device.

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