Impact of Implementing Contrast-Enhanced Ultrasound for Antegrade Nephrostogram After Percutaneous Nephrolithotomy

David T. Fetzer, MD , Jennifer Flanagan, MSRS, RRA, RT(R), Ali Nabhan, MSRS, RRA, RT(R)(CT), Kim Pongsatianwong, RDMS, RVT, Jodi Antonelli, MD, Margaret Pearle, MD, PhD, Kanupriya Vijay, MD, Lori Watumull, MD

Objectives—To report results from a quality improvement (QI) project evaluating diagnostic performance, hospital resource use, and patient response data for postoperative contrast-enhanced ultrasound (CEUS) antegrade nephrostogram after percutaneous nephrolithotomy.

Methods—For this Health Insurance Portability and Accountability Act–compliant, Institutional Review Board–approved study, QI data were deidentified and analyzed. On the first postoperative day after percutaneous nephrolithotomy, patients underwent both CEUS and fluoroscopic antegrade nephrostogram. For CEUS, 1.0 mL of Lumason (sulfur hexafluoride lipid type A microspheres; Bracco Diagnostics, Inc, Monroe Township, NJ) was injected via an indwelling nephrostomy tube, with ureteral patency confirmed by identifying intravesical ultrasound (US) contrast. Diagnostic performance for ureteral patency and contrast extravasation was calculated (with fluoroscopy as the reference standard). The examination time, room time, physician time, hospital costs, and patient response data were compared. The mean, standard deviation, 95% confidence interval, differences in mean, and 95% confidence interval of differences were calculated.

Results—Eighty-one examinations were performed in 73 patients during the QI period. The sensitivity and specificity of CEUS for ureteral patency were 96% and 57%, respectively. There was no significant difference in time metrics between modalities, and the cost analysis showed lower direct and indirect costs for CEUS. Patient responses revealed lower levels of comfort for CEUS relative to fluoroscopy, without significant differences in reported pain or effort levels.

Conclusions—Contrast-enhanced US showed very high sensitivity for ureteral patency; the relatively low specificity may have resulted from false-negative results in fluoroscopy. The hospital costs and resource use of CEUS compared favorably to fluoroscopy. Contrast-enhanced US also offers inherent advantages, including portability and lack of ionizing radiation.

Key Words—contrast-enhanced ultrasound; fluoroscopy; nephrolithiasis; nephrostogram; pyelography; urolithiasis

Received September 5, 2019, from the Department of Radiology (D.T.F., J.F., A.N., K.V., L.W.) and Urology (J.A., M.P.), University of Texas Southwestern Medical Center, Dallas, Texas, USA; and Imaging Services, University of Texas Southwestern Medical Center, William P. Clements Jr University Hospital, Dallas, Texas, USA (K.P.). Manuscript accepted for publication June 3, 2020.

We thank the Imaging Services Administration at the University of Texas Southwestern Medical Center, William P. Clements Jr University Hospital, for support of the associated quality improvement project from which data were collected, as well as the hospital sonographers for their dedication to high-quality imaging and patient care; in particular, we thank Kelly Albury RDMS, RVT, Sandra Richardson RDMS, RVT, and Skye Smola RDMS, RVT. Finally, we thank Yin Xi, PhD, assistant professor, Department of Radiology, University of Texas Southwestern Medical Center, for statistical advice and services. Dr Fetzer has research agreements with Philips Healthcare and Siemens Healthineers and serves on the speakers bureaus of Philips Healthcare and Siemens Healthineers. All of the other authors of this article have reported no disclosures.

Address correspondence to David T. Fetzer, MD, Department of Radiology, University of Texas Southwestern Medical Center, 5323 Harry Hines Blvd, Dallas, TX 75390-9316, USA.

E-mail: david.fetzer@utsouthwestern.edu

Abbreviations
CEUS, contrast-enhanced ultrasound; CI, confidence interval; CPT, Current Procedural Terminology; *ncCT, noncontrast computed tomography; NPV, negative predictive value; PCN, percutaneous nephrostomy; PCNL, percutaneous nephrolithotomy; PPV, positive predictive value; QI, quality improvement; US, ultrasound*

doi:10.1002/jum.15380

Percutaneous nephrolithotomy (PCNL) is the procedure of choice for treating large or complex renal calculi.[1–3] Although some patients are left without external drainage or with only a ureteral stent after surgery, in many cases, a percutaneous nephrostomy (PCN) catheter, with or without a ureteral stent, is left in place.[4,5] Postsurgical imaging may include noncontrast computed tomography (ncCT) of the abdomen and pelvis to identify postoperative complications and assess for residual stone fragments.[6–11] Fluoroscopic antegrade nephrostogram is often performed to confirm ureteral patency before PCN or ureteral stent removal. These examinations subject a patient to ionizing radiation and may be uncomfortable, particularly considering the design of most fluoroscopic tables. Additionally, fluoroscopy subjects radiology staff to scatter radiation.

As a relatively low-cost, portable technology with a high safety profile, ultrasound (US) is an ideal modality for evaluating a wide variety of conditions and can be found in many care environments such as in operating rooms, emergency departments, intensive care units, and primary care clinics. Contrast-enhanced ultrasound (CEUS), which has been widely available throughout Europe and Asia for many years,[12,13] is quickly gaining acceptance in the United States with the Food and Drug Administration approval of Lumason (sulfur hexafluoride lipid type A microspheres; Bracco Diagnostics, Inc, Monroe Township, NJ) for focal liver lesion characterization in both adults and children and for vesicoureteral reflux in children. With the addition of CEUS-specific category 1 *Current Procedural Terminology* (*CPT*) codes, physicians can get reimbursed for these examinations.

Contrast-enhanced voiding urosonography has become an accepted alternative to fluoroscopy in pediatric patients in whom vesicoureteral reflux is suspected,[14] comparing favorably to standard fluoroscopic cystourethrography, without the associated radiation risks.[15] Ultrasound contrast agents are well tolerated with few contraindications, low allergic reaction rates, and no known toxicity compared to iodinated and gadolinium agents.[16] These agents are composed of microbubbles, measuring approximately 2 to 3 μm in size (similar in size to red blood cells), too large to cross endothelial- or epithelial-lined spaces. Therefore, intravascular microbubbles remain within the vascular space, whereas intracavitary microbubbles remain within the space in which they are injected, making CEUS particularly useful for vesicoureteral reflux.[14,16]

Recently, CEUS has been described as an additional imaging tool for the assessment of ureteral patency in post-PCNL patients.[17–19] Although the feasibility and accuracy have been shown, to the best of our knowledge, no publication has described the impact on hospital resource use or on patient acceptance. The purpose of this article is to report results from a hospital quality improvement (QI) project, designed to evaluate diagnostic accuracy, hospital resource use, and patient survey data, undertaken when CEUS was implemented as an alternative to standard-of-care fluoroscopy at our institution.

Materials and Methods

For this Health Insurance Portability and Accountability Act–compliant study, hospital resource use and patient preference data were initially collected under a hospital QI project. After project completion, data were deidentified, following an Institutional Review Board–approved protocol for retrospective review of clinical data. A wavier of informed consent was granted. No funding was received for this work.

Patient Data and Work Flow

From December 21, 2017, to August 17, 2018, adult patients scheduled for postoperative antegrade fluoroscopic nephrostogram after PCNL were enrolled. Standard practice at our institution is for patients to undergo ncCT on the first postoperative day to identify residual stone fragments and to detect clinically important postoperative complications.[7–9,11] After the ncCT, fluoroscopic antegrade nephrostogram is used to confirm ureteral patency before removal of the balloon-tipped drainage tube (PCN) and ureteral stent left in situ after stone removal.

During the evaluation period, the standard-of-care ncCT was performed. Then, a CEUS examination was performed immediately after the ncCT, before fluoroscopy. Both CEUS nephrostogram, using a microbubble contrast agent, and fluoroscopic antegrade nephrostogram, using an iodinated contrast agent, were performed using the indwelling PCN for injection of microbubble and iodinated contrast agents, respectively; as there is no cross-reactivity between these contrast agents, both can be administered on the same day without concern. Survey responses (described below) were obtained immediately after each examination. Imaging and demographic data were recorded from the electronic medical record.

Imaging Protocol

The CEUS antegrade nephrostogram was performed similar to previous publications.[17,18] Briefly, the reconstituted US contrast syringe (sulfur hexafluoride lipid type A microspheres) and a spiked 250-mL saline bag were connected to the indwelling PCN via a 3-way stopcock connected to the draining Foley catheter side port, while the primary drainage pathway from the PCN was clamped to prevent retrograde flow of contrast (Figure 1). The patient was placed in a semilateral decubitus position, 35° to 45° oblique away from the side to be imaged, to facilitate collecting system drainage and optimize the acoustic window.

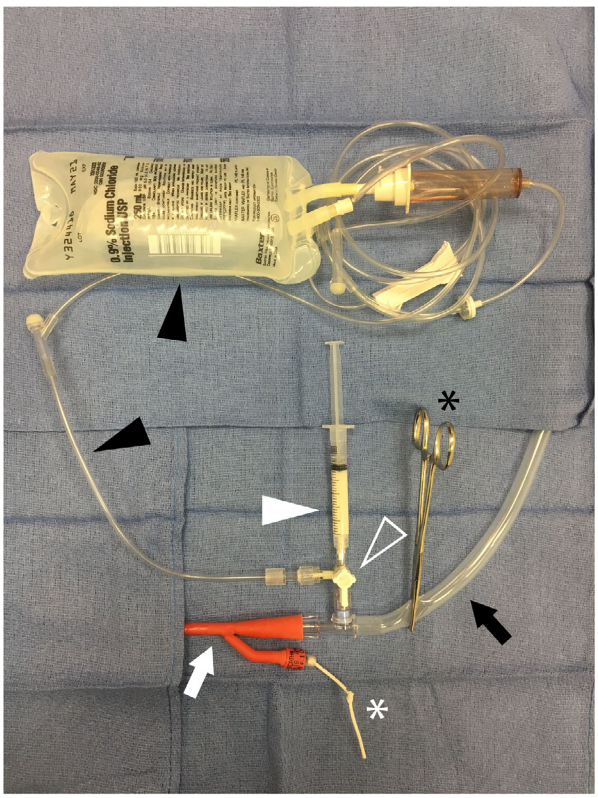


Figure 1. Photograph showing the CEUS antegrade nephrostogram setup. The PCN tube (white arrow) is seen with a tied-off angiographic stent exiting the side port (white asterisk). The Foley catheter (black arrow) is clamped with forceps (black asterisk) to prevent retrograde flow of contrast. The microbubble US contrast agent (white arrowhead) is attached to the Foley side port via a 3-way stopcock (open arrowhead). A saline bag is attached to the stopcock side port via a flushed intravenous tube (black arrowheads).

Ultrasound imaging was performed with either an EPIQ 7G system (Philips Healthcare, Bothell, WA) or an ACUSON Sequoia system (Siemens Healthineers, Issaquah, WA) with a 1–5-MHz curved array transducer operating in either a mid- or low-frequency bandwidth setting depending on the patient's body habitus. The contrast-specific imaging mode was used; this contrast mode allows for low-mechanical-index imaging to minimize bubble destruction. The default mechanical index setting for each scanner was used (no adjustments to the output power). Images with grayscale and "contrast-only" images viewed side-by-side were saved and submitted to the clinical picture archiving and communication system for clinical interpretation.

Baseline grayscale and contrast mode images of the kidney and bladder before contrast agent administration were recorded, focusing on the PCN tract, renal collecting system, and region around the bladder, making note of any artifactual high signal seen on the contrast-only image (Figure 2). Three to 4 mL of normal saline was injected to ensure patency of the PCN and to dislodge debris. Then, 1 mL of the US contrast agent was injected by hand and flushed with saline by gravity; this 1-mL volume was arbitrarily chosen during the first examination at our institution and remained consistent for subsequent examinations.

At the time of contrast agent injection, the on-system contrast timer was activated. Images of the kidney were obtained as microbubbles entered the renal collecting system. After collecting system filling, imaging along the PCN tract was performed to identify leakage of contrast into the perirenal or pararenal space or toward the skin surface (extravasation). Then the bladder was imaged. Ureteral patency was confirmed by identifying US contrast in the bladder lumen. Patency was confirmed by identifying new intraluminal echogenicity not present on baseline images, echogenic foci seen to be mobile within the lumen, and dissipation and replenishment of the signal after using the system "flash" or "burst" function. This bubble destruction function transmits a brief high-power series of US pulses to purposefully destroy microbubbles in the field of view and can be used to confirm that the intraluminal signal is from microbubbles, as opposed to an artifact from the Foley catheter balloon or bowel gas.

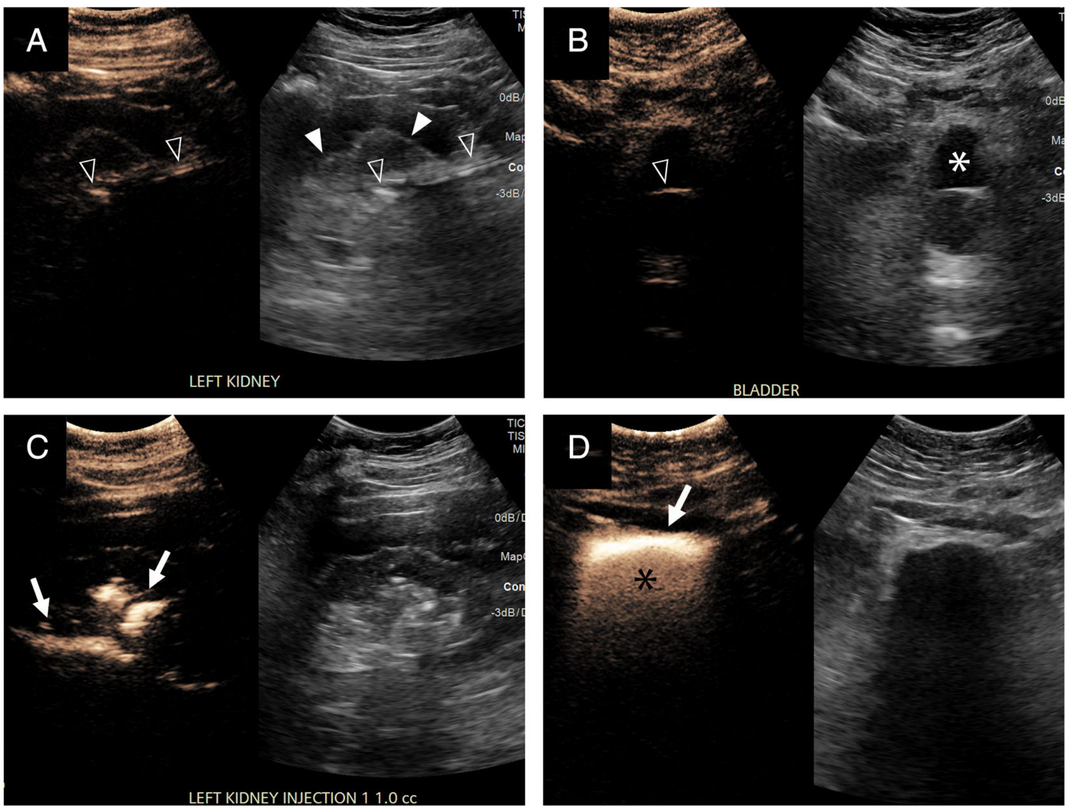
If bilateral nephrostomy tubes were present, before interrogation of the contralateral side, the ipsilateral nephrostomy tube and Foley catheter were unclamped, and the microbubble contrast agent was flushed from the urinary system. If contrast remained within the bladder lumen, remaining microbubbles were destroyed in the flash mode. The patient was repositioned and the above process repeated for the contralateral kidney.

Data Collection

Patient demographics were recorded. Results from the clinical interpretation of each of the exams (CEUS and fluoroscopic nephrostogram) were recorded. The presence of ureteral patency (as defined above) and contrast extravasation were noted. The resource use time, in minutes, was recorded from the electronic medical record and included the modality room time (difference between patient arrival and departure times) and examination time (difference between examination beginning and ending times). The provider time (physician in-room time), in minutes, was recorded by 1 of 2 fluoroscopic operators (J.F. and A.N.).

Direct and indirect hospital costs for the 2 associated *CPT* codes (XR nephrostogram antegrade, *CPT* 50431; and US target dynamic microbubble first lesion, *CPT* 76978) were requested from our institution's cost center. Patient and insurance charges were not requested, as these postoperative examinations

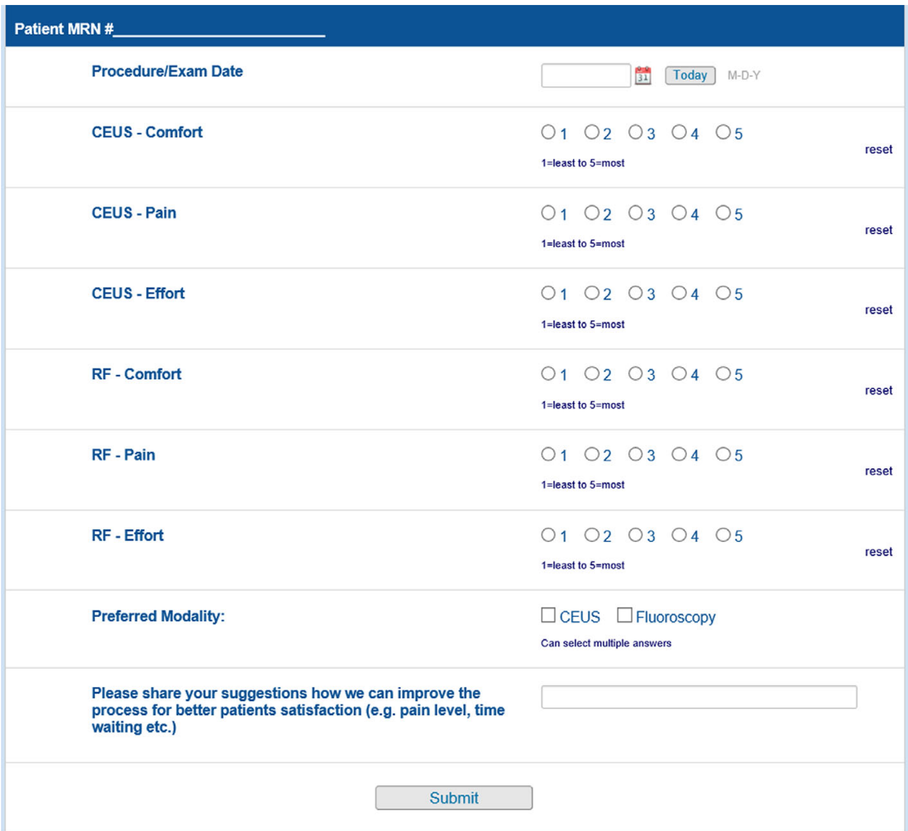
Figure 2. Contrast-enhanced US antegrade pyelogram from a 59-year-old female patient after left PCN tube placement for nephrolithotomy. Dual-screen contrast mode US images, with contrast only (left side of images) and B-mode (right side of images), show the left kidney (**A**, arrowheads) and bladder (**B**, asterisk) before contrast agent administration. Precontrast images (**A** and **B**) should be reviewed for intrinsically echogenic structures and interfaces, such as the nephrostomy tube and Foley balloon (open arrowheads), which may appear in the contrast-only image and should not be confused with microbubbles. After contrast agent administration via the nephrostomy tube, a longitudinal view of the left kidney (**C**) and a transverse view of the bladder (**D**) show microbubbles within the renal collecting system and subsequently in the bladder (white arrows), confirming ureteral patency. Note shadowing and attenuation due to the high concentration of bubbles in the bladder (black asterisk).



are performed within the diagnosis-related group bundled hospital payment.

As part of the QI project, patients were asked to complete a short survey after the completion of each of the fluoroscopic and CEUS antegrade nephrostogram studies (Figure 3). For each examination (CEUS and fluoroscopy), patients were asked to rate their comfort level, pain, and perceived required effort, on a scale from

Figure 3. Screen shot capture of the electronic feedback form offered to patients after their CEUS and fluoroscopic (RF) antegrade nephrostogram studies. The patient response rate was 38.4%.


Patient MRN #____________________

Procedure/Exam Date — Today M-D-Y

CEUS - Comfort — 1 2 3 4 5 — 1=least to 5=most — reset

CEUS - Pain — 1 2 3 4 5 — 1=least to 5=most — reset

CEUS - Effort — 1 2 3 4 5 — 1=least to 5=most — reset

RF - Comfort — 1 2 3 4 5 — 1=least to 5=most — reset

RF - Pain — 1 2 3 4 5 — 1=least to 5=most — reset

RF - Effort — 1 2 3 4 5 — 1=least to 5=most — reset

Preferred Modality: — CEUS — Fluoroscopy — Can select multiple answers

Please share your suggestions how we can improve the process for better patients satisfaction (e.g. pain level, time waiting etc.)

Submit

Table 1. Diagnostic Performance of CEUS Versus the Fluoroscopic Antegrade Nephrostogram for Ureteral Patency

	All Exams			After 10-Patient Wash-in Period		
Parameter	**All Exams**	**Unilateral**	**Bilateral**	**All Exams**	**Unilateral**	**Bilateral**
n	81	65	16	71	57	14
Positive cases	74	59	15	64	51	13
Negative cases	7	6	1	7	6	1
Sensitivity, %	94.6	96.6	86.7	95.3	98.0	84.6
Specificity, %	57.1	50.0	100.0	57.1	50.0	100.0
PPV, %	95.9	95.0	100.0	95.3	94.3	100.0
NPV, %	50.0	60.0	33.3	57.1	75.0	33.3
Accuracy	91.4	92.3	87.5	91.5	93.0	85.7

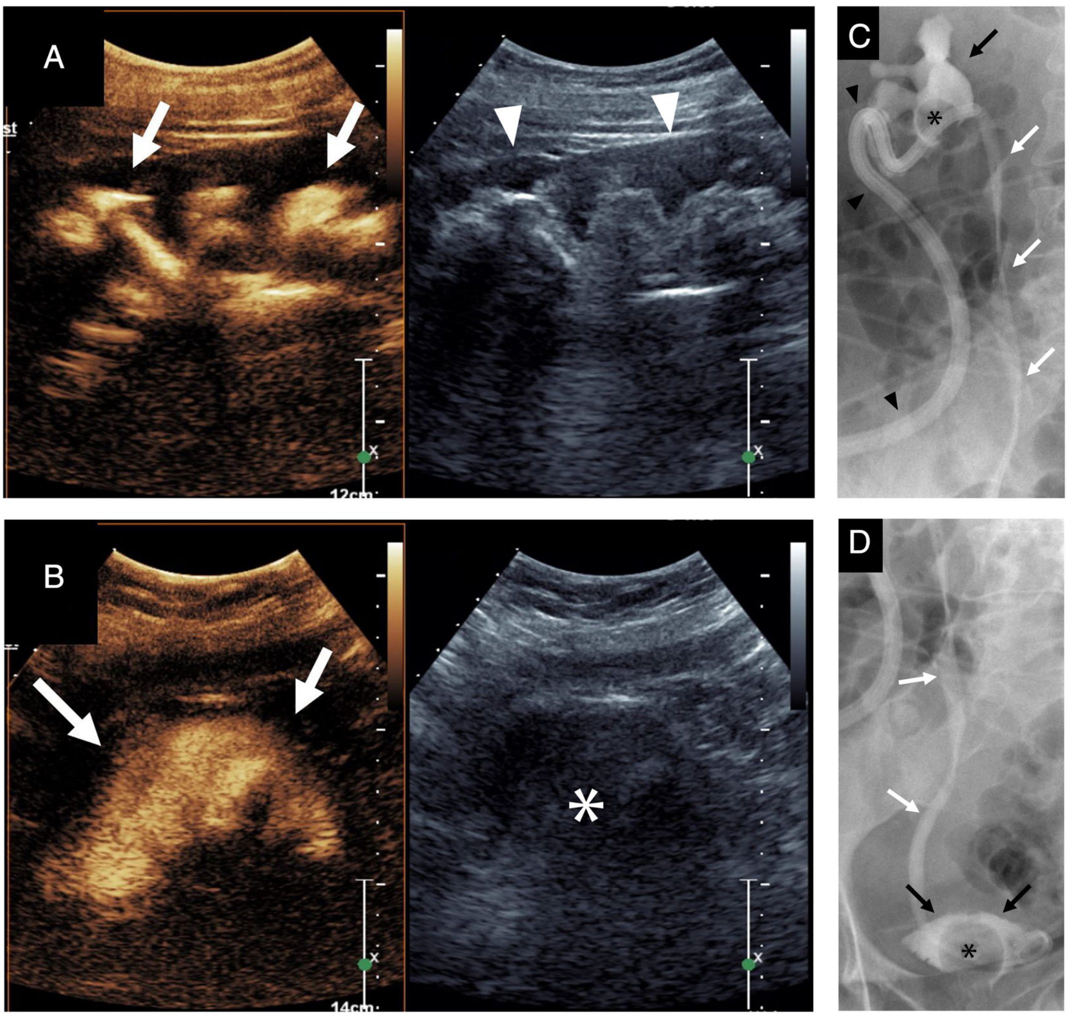
Positive indicates ureteral patency confirmed; and negative, ureteral patency not confirmed.

1 (least) to 5 (most), whether they preferred one modality over the other overall, and to provide any comments regarding their experience.

Statistical Analysis

With the fluoroscopic results as the reference standard for both ureteral patency and identification of contrast extravasation, the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy were calculated. The mean, median, standard deviation, and 95% confidence interval (CI) were calculated for continuous time data and ordinal patient response data. Paired *t* tests were used to compare differences in means, with $P < .05$ indicating statistical significance; 95% CIs of differences in time data and response scores were also calculated. Results excluding the initial 10 studies were calculated separately to determine differences from the “wash-in” adoption phase of

Figure 4. Antegrade pyelogram showing ureteral patency by CEUS and fluoroscopy from a 41-year-old female patient after right-sided PCN tube placement for nephrolithotomy. Dual-screen contrast mode US images, with contrast only (left side of images) and B-mode (right side of images), after microbubble contrast agent administration via a nephrostomy tube, show a longitudinal view of the right kidney (**A**, arrowheads) and a transverse view of the bladder (**B**, asterisk) with microbubbles within the right renal collecting system and subsequently in the bladder (white arrows), confirming ureteral patency. An image from a follow-up fluoroscopic antegrade pyelogram (**C**) after iodinated contrast agent administration via the indwelling nephrostomy tube (black arrowheads) shows the balloon in the renal pelvis (asterisk). Contrast is seen in the renal collecting system (black arrows) and ureter (white arrows). A fluoroscopic image of the pelvis (**D**) shows contrast in the distal ureter (white arrows) and bladder lumen (black arrows), confirming ureteral patency. The Foley catheter balloon is noted (asterisk).



this new technique. Calculations were performed in Excel (Office for Mac, version 15.13.4; Microsoft Corporation, Redmond, WA).

Results

Patient Demographics

During the QI period, 73 patients underwent PCNL followed by both CEUS and fluoroscopic antegrade nephrostogram. Among these patients, a total of 81 CEUS studies were performed: 36 unilateral right, 29 unilateral left, and 8 bilateral examinations (an additional 8 right and 8 left). The cohort included 45 male and 36 female patients with a mean age of 57.2 years (range, 23–87 years). Survey data were successfully collected from 28 (38.4%) of the patients. No patient had an allergic reaction or other substantial complication from either the CEUS or fluoroscopic examination.

Figure 5. Antegrade pyelogram showing ureteral patency by CEUS only from an 83-year-old female patient after left-sided PCN tube placement for nephrolithotomy. A dual-screen contrast mode US image of the bladder (**A**) after microbubble contrast agent administration via a nephrostomy tube shows microbubbles (arrows) in the bladder (asterisk). A subsequent fluoroscopic antegrade pyelogram failed to show iodinated contrast within the bladder despite troubleshooting techniques. An image of the pelvis (**B**) shows a ureteral stent (black arrows) and the tip of the Foley catheter (black arrowhead) without contrast in the bladder.

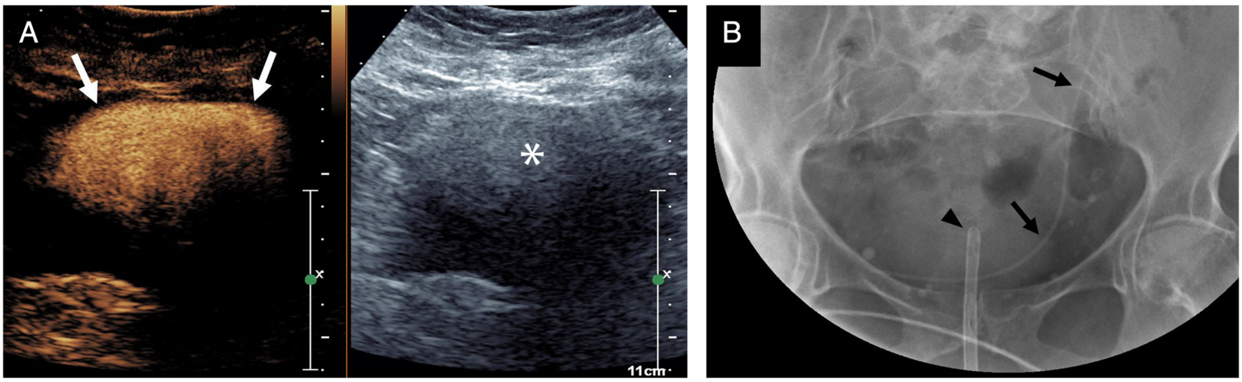
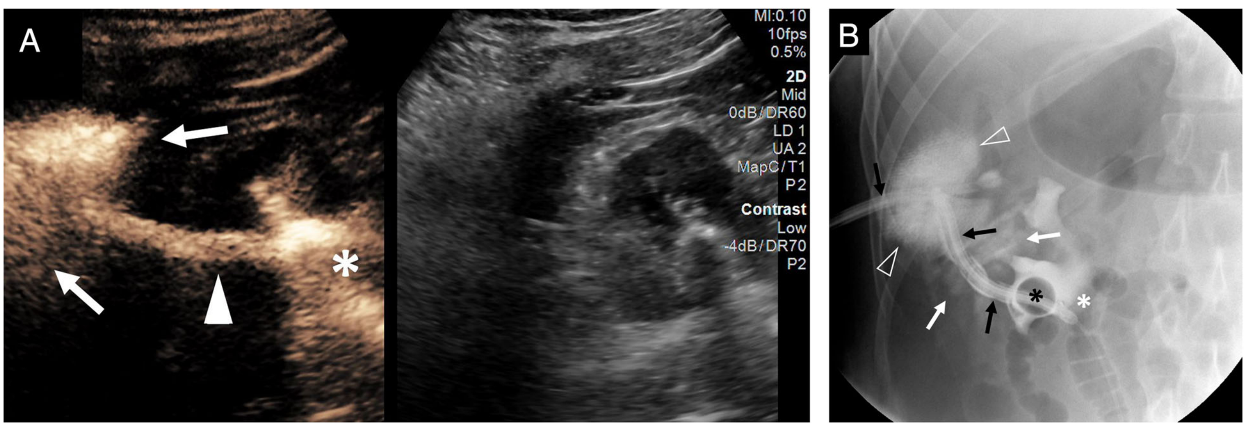


Figure 6. Antegrade pyelogram showing a leak from a 32-year-old male patient after right-sided PCN tube placement for nephrolithotomy. A dual-screen contrast mode US image of the right kidney (**A**) after microbubble contrast agent administration via a nephrostomy tube shows microbubble contrast within the renal collecting system (asterisk) and extravasating along the nephrostomy tube tract (arrowhead) into the paranephric space (white arrows). A subsequent fluoroscopic antegrade pyelogram (**B**) confirmed moderate extravasation along the nephrostomy tube (black arrows) to the paranephric space (white arrows) and toward the skin surface (open arrowheads). The nephrostomy tube balloon (black asterisk) is seen in the renal collecting system (white asterisk).



Diagnostic Performance

Assuming results of the fluoroscopic nephrostogram as the reference standard, diagnostic performance is detailed in Table 1. Briefly, including all examination types (unilateral and bilateral), the sensitivity of CEUS for ureteral patency was 94.6%; specificity, 57.1%; PPV and NPV, 95.9% and 50.0%, respectively; and accuracy, 91.4%. Diagnostic performance did not significantly change when excluding the initial 10 patients (training, wash-in period). Figure 4 provides an example of positive findings of ureteral patency. Figure 5 provides an example of false-positive CEUS results for which ureteral patency was not confirmed by the subsequent fluoroscopy.

Results for contrast extravasation for all examinations, with fluoroscopy as the reference standard, were as follows: sensitivity, 57.4%; specificity, 88.2%; PPV and NPV, 87.1% and 60.0%, respectively; and accuracy,

Table 2. Comparison of Time Metrics Between CEUS and the Fluoroscopic Antegrade Nephrostogram

	CEUS			Fluoroscopy		
Parameter	RoomTime, min	ExamTime, min	Physician Time, min	RoomTime, min	ExamTime, min	Physician Time, min
All exams						
Mean ± SD	24.87 ± 11.59	5.77 ± 3.92	4.86 ± 3.3	25.06 ± 10.14	7.09 ± 5.04	4.37 ± 3.24
Median	22	5	4	25	5	3
95% CI	22.3, 27.44	5.01, 6.53	4.36, 5.35	22.96, 27.16	6.03, 8.14	3.75, 4.99
Unilateral exams						
Mean ± SD	24.81 ± 11.56	5.34 ± 3.34	4.36 ± 2.09	25.15 ± 10.37	6.77 ± 4.76	4.05 ± 2.67
Median	21.5	5	4	25	5	3
95% CI	21.94, 27.67	4.52, 6.17	3.84, 4.88	22.58, 27.71	5.59, 7.95	3.39, 4.71
Bilateral exams						
Mean ± SD	25.38 ± 12.6	9 ± 6.37	8.63 ± 7.09	24.38 ± 8.7	9.5 ± 6.68	6.88 ± 5.79
Median	22.5	7.5	7	21	7.5	5.5
95% CI	18.66, 32.09	5.61, 12.39	4.85, 12.4	19.74, 29.01	5.94, 13.06	3.79, 9.96

95% CI indicates interval containing the middle 95% of cases.

Table 3. Analysis of Differences in Time Between CEUS and the Fluoroscopic Antegrade Nephrostogram

Parameter	RoomTime	ExamTime	Physician Time
Unilateral exams			
t test *P*	.821	.052	.458
95% CI of difference	−3.16, 2.51	−2.85, −0.04	−0.52, 0.98
Bilateral exams			
t test *P*	.866	.859	.422
95% CI of difference	−5.55, 6.62	−3.15, 2.62	−1.3, 3.17

Table 4. Summary of Patient Survey Responses

	CEUS			Fluoroscopy		
Parameter	Comfort	Pain	Effort	Comfort	Pain	Effort
Mean ± SD	3.39 ± 0.99	2.75 ± 1.04	2.54 ± 1.04	4.04 ± 0.88	2.54 ± 1.20	2.68 ± 1.02
95% CI	2.27, 4.52	1.31, 4.19	1.10, 3.97	3.17, 4.90	0.87, 4.20	1.26, 4.09

95% CI indicates score range containing the middle 95% of responses.

70.4%. Figure 6 provides an example of contrast extravasation along the nephrostomy catheter tract.

Resource Use

Details regarding the resource use time are detailed in Table 2. Briefly, including both unilateral and bilateral examinations, the median modality room times were 22 minutes for CEUS and 25 minutes for fluoroscopy, with examination and physician times of 5 and 4 minutes for CEUS, and 5 and 3 minutes for fluoroscopy, respectively. Table 3 lists results from the 2-sample paired t test for differences in the mean times between the CEUS and fluoroscopy room time, examination time, and physician time; all values were $P > .05$, indicating that a significant difference was not identified. The 95% CIs of differences in times show that for unilateral examinations, the difference in room and exam times fell within 3 minutes and physician time within less than 1 minute, whereas for bilateral examinations, differences in room time were less than 7 minutes, examination time approximately 3 minutes, and physician time up to 3 minutes.

The hospital cost breakdown for the examinations, as provided by our health care system's cost analysis center, were as follows: for fluoroscopy, XR nephrostogram antegrade (*CPT* 50431), the total hospital cost was reported as $386.35, with direct costs of $262.30, and indirect costs of $124.06, whereas for US target dynamic microbubble first lesion (*CPT* 76978), the total cost was reported as $313.69, with direct costs of $229.73 and indirect costs of $83.95. The indirect costs are reported to be associated with building depreciation, nonclinical employee salaries and benefits, and administrative support.

Patient Responses

Patient survey results, including responses for comfort and pain levels and effort required for each of the modalities, are detailed in Table 4. The 95% CIs in responses showed a substantial overlap. P values from the paired t test for differences in patient responses (and 95% CI of differences in scores) for the comfort level, pain, and effort level were .007 (−1.09, −0.19), 0.42 (−0.32, 0.75), and 0.56 (−0.65, 0.36), respectively, revealing a statistically significant difference in the comfort level between the modalities, with fluoroscopy reported as offering more comfort relative to CEUS; no statistical significance was seen in either the pain level or effort required.

Patient comments regarding their experience included a preference for CEUS because of the lack of radiation (n = 3), pain during the CEUS examination due to transducer pressure on the abdomen (n = 5), and that fluoroscopy required less effort relative to CEUS ($N = 3$). Patients listed each modality as their preferred examination type an essentially equal number of times: CEUS, 14; and fluoroscopy, 13.

Discussion

Postoperative imaging in patients after PCNL often includes antegrade fluoroscopic nephrostogram for confirmation of ureteral patency. Contrast-enhanced US has recently been shown to be a viable alternative to fluoroscopy in this setting[17–19]; however, no report to date has assessed the impact on resource use. Results from our internal QI initiative show that at our institution, there was no significant difference in resource use, such as examination room and modality times or physician time, between fluoroscopy and CEUS in the post-PCNL patient population. In addition, a slight financial advantage of CEUS over fluoroscopy is predicted. Contrast-enhanced US appears to be an accurate modality for confirming ureteral patency and has become an excellent, well-accepted alternative to fluoroscopy in our practice, particularly given its portability, ongoing concerns of rising health care costs, and attention to minimizing unnecessary radiation exposure to health care personnel and their patients.

Diagnostic performance for our cohort mirrored that recently described in the literature, with a high sensitivity and PPV for ureteral patency (>95%).[17–19] Also similar to prior reports, the specificity and NPV were noticeably low (50%–60%); however, it has been hypothesized that this finding is a result of false-negative fluoroscopic results.[19] As US is exquisitely sensitive to microbubble contrast agents, CEUS may be more sensitive to intravesical contrast relative to fluoroscopy, possibly indicating that ureteral patency was missed by fluoroscopy (intravesical iodinated contrast not seen; Figure 5).

Unique to our report is the use of CEUS for detecting contrast extravasation along the nephrostomy catheter tract into the perirenal or pararenal space or to the skin surface (Figure 6). Although the sensitivity and NPV were low for CEUS compared to fluoroscopy as the reference standard, the specificity remained high. However, our study was not designed to either grade the severity of or assess the clinical importance of this finding. In addition, CEUS may not be appropriate for evaluation of the ureter if ureteral injury is suspected; however, this complication is rare in our population and was not encountered in our cohort.

There were insufficient data to detect a statistically significant difference in the room time, examination time, or physician time between CEUS and fluoroscopy during our QI period, if one existed. What is likely more revealing is that the 95% CI of differences in time between the modalities was within a few minutes for room and examination times and less than 1 minute for the physician time for unilateral examinations. Whereas examinations performed with modalities such magnetic resonance imaging may be assessed on a per-minute basis, typically a difference of a few minutes between a US and fluoroscopic examination is likely not substantially impactful for most radiology departments.

Total costs, based on our hospital cost center database, are comparable between fluoroscopy and CEUS antegrade nephrostogram studies. In addition, CEUS may be considered a safer alternative for additional procedures that may require intracavitary injection, such as placement of PCN catheters under US guidance.[20]

Although response data were not collected from all patients (likely because of work flow conditions or patient deferment), there was no significant difference in scoring for the effort required or for pain felt during each of the modalities, although patient comments suggested that fluoroscopy may have required less effort; this was a surprising finding, as patients were scanned in their hospital beds for their CEUS examinations, and both modalities required the patient to turn to an oblique or even lateral decubitus position to optimize contrast drainage. A relatively frequent comment was discomfort from the US transducer pressure; this is often required by the sonographer to obtain the highest-quality US images possible and may have influenced examination comfort responses.

Urologists at our institution who specialize in stone disease rely on an ncCT examination on the first hospital day after surgical PCNL to assess the residual stone burden; if stones greater than or equal to 2 millimeters are identified, a second operation during the same admission may be performed, given the risk of obstructing or progressive stone disease if these calculi are left in place.[7,11] For these patients, our urology colleagues prefer that the patients undergo fluoroscopic antegrade nephrostogram to obtain a roadmap of the stone position within the opacified collecting system. However, after our QI study, our surgeons determined that patients without residual calculi or calculi measuring less than 2 millimeters may proceed to CEUS antegrade nephrostogram for determination of ureteral patency before PCN tube removal, foregoing the fluoroscopic study.

Several study limitations did exist. Our analysis was based on a urology practice that relies on both postoperative ncCT and fluoroscopy. For practices that rely solely on fluoroscopy, CEUS may not provide all of the diagnostic information needed for a complete postoperative assessment and may currently be limited to sites with access to and expertise in CEUS. Diagnostic performance was based on the initial clinical interpretation, and our study design was not powered for interobserver and intraobserver variability testing; however, our results mirror those reported previously. Survey response data were not collected from every patient because of patient deferment and clinical work flow limitations. In addition, we were unable to randomize patients first to US versus fluoroscopy, which may have biased survey data. Time data were based on start and end times as entered by the modality technologists into the electronic medical record: a potential source of bias. Finally, modality costs were obtained from our hospital cost center, the details of which were not provided and may not be directly transferrable to other institutions. We acknowledge that work flow, modality costs, local expertise, and ordering-provider preferences may differ considerably between different institutions.

In conclusion, CEUS appears to be an accurate, patient-friendly modality for the evaluation of ureteral patency in patients after PCNL. Our results suggest that resource use, such as examination room and modality times, the physician time, and financial costs, should not be seen as barriers to adopting this emerging technique. By providing CEUS as an alternative to fluoroscopy, patients as well as fluoroscopic practitioners can be saved from radiation exposure, and the hospital can rely on a safer and potentially less expensive modality for at least a subset of patients.

References

1. Assimos D, Krambeck A, Miller NL, et al. Surgical management of stones: American Urological Association/Endourological Society guideline, part I. *J Urol* 2016; 196:1153–1160.
2. Assimos D, Krambeck A, Miller NL, et al. Surgical management of stones: American Urological Association/Endourological Society guideline, part II. *J Urol* 2016; 196:1161–1169.
3. Turk C, Petrik A, Sarica K, et al. EAU guidelines on interventional treatment for urolithiasis. *Eur Urol* 2016; 69:475–482.
4. Zhao PT, Hoenig DM, Smith AD, Okeke Z. A Randomized controlled comparison of nephrostomy drainage vs ureteral stent following percutaneous nephrolithotomy using the Wisconsin stone QOL. *J Endourol* 2016; 30:1275–1284.
5. Srinivasan AK, Herati A, Okeke Z, Smith AD. Renal drainage after percutaneous nephrolithotomy. *J Endourol* 2009; 23:1743–1749.
6. Pearle MS, Watamull LM, Mullican MA. Sensitivity of noncontrast helical computerized tomography and plain film radiography compared to flexible nephroscopy for detecting residual fragments after percutaneous nephrostolithotomy. *J Urol* 1999; 162:23–26.
7. Acar C, Cal C. Impact of residual fragments following endourological treatments in renal stones. *Adv Urol* 2012; 2012:813523.
8. Tonolini M, Villa F, Ippolito S, Pagani A, Bianco R. Cross-sectional imaging of iatrogenic complications after extracorporeal and endourological treatment of urolithiasis. *Insights Imaging* 2014; 5:677–689.
9. Gnessin E, Mandeville JA, Handa SE, Lingeman JE. The utility of noncontrast computed tomography in the prompt diagnosis of postoperative complications after percutaneous nephrolithotomy. *J Endourol* 2012; 26:347–350.
10. Sofer M, Druckman I, Blachar A, et al. Non-contrast computed tomography after percutaneous nephrolithotomy: findings and clinical significance. *Urology* 2012; 79:1004–1010.
11. Skolarikos A, Papatsoris AG. Diagnosis and management of post-percutaneous nephrolithotomy residual stone fragments. *J Endourol* 2009; 23:1751–1755.
12. Jakobsen JA, Correas JM. Ultrasound contrast agents and their use in urogenital radiology: status and prospects. *Eur Radiol* 2001; 11: 2082–2091.
13. Correas JM, Bridal L, Lesavre A, et al. Ultrasound contrast agents: properties, principles of action, tolerance, and artifacts. *Eur Radiol* 2001; 11:1316–1328.
14. Duran C, Beltran VP, Gonzalez A, Gomez C, Riego JD. Contrast-enhanced voiding urosonography for vesicoureteral reflux diagnosis in children. *Radiographics* 2017; 37:1854–1869.
15. Ntoulia A, Back SJ, Shellikeri S, et al. Contrast-enhanced voiding urosonography (ceVUS) with the intravesical administration of the ultrasound contrast agent Optison for vesicoureteral reflux detection in children: a prospective clinical trial. *Pediatr Radiol* 2018; 48: 216–226.
16. Ranganath PG, Robbin ML, Back SJ, Grant EG, Fetzer DT. Practical advantages of contrast-enhanced ultrasound in abdominopelvic radiology. *Abdom Radiol (NY)* 2018; 43:998–1012.
17. Chi T, Usawachintachit M, Mongan J, et al. Feasibility of antegrade contrast-enhanced US nephrostograms to evaluate ureteral patency. *Radiology* 2017; 283:273–279.
18. Chi T, Usawachintachit M, Weinstein S, et al. Contrast enhanced ultrasound as a radiation-free alternative to fluoroscopic nephrostogram for evaluating ureteral patency. *J Urol* 2017; 198: 1367–1373.
19. Daneshi M, Yusuf GT, Fang C, et al. Contrast-enhanced ultrasound (CEUS) nephrostogram: utility and accuracy as an alternative to fluoroscopic imaging of the urinary tract. *Clin Radiol* 2019; 74:167.e9–167.e16.
20. Cui XW, Ignee A, Maros T, et al. Feasibility and usefulness of intra-cavitary contrast-enhanced ultrasound in percutaneous nephrostomy. *Ultrasound Med Biol* 2016; 42:2180–2188.