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REVIEW ARTICLE

CT-Fluoroscopy: Tool or Gimmick?

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Abstract

Recent advances in CT scanner technology and computer hardware have led to the development of CT fluoroscopy (CTF), which allows real-time acquisition and display of cross-sectional images (with a rate of up to 8 frames per second). Since the introduction of the first CT fluoroscopy scanner in 1993, a variety of these scanners have been installed world-wide and many reports on the clinical use of this device have appeared recently. However, use of this new technology for the guidance of interventional radiologic procedures, such as percutaneous biopsy and percutaneous drainage, is not uniformly advocated by interventional radiologists. Concerns have been reported regarding radiation exposure and outcome of the procedures when compared with sequential CT guidance or other alternative guiding modalities. This article is intended to present an overview of CTF technology, to summarize the results of published papers on various interventional applications and to reflect on its specific advantages and disadvantages.

Key words: Computed tomography (CT), guidance—Interventional procedures, technology—Computed tomography, radiation exposure—Fluoroscopy, technology

Various imaging techniques such as ultrasonography, fluoroscopy, computed tomography (CT) or magnetic resonance imaging (MRI) may be used alone or together for guidance of percutaneous interventional procedures. CT-guided interventions in particular have become indispensable clinical tools in recent years because of the associated high spatial resolution, superior reproducibility, wide field of view, and applicability to air-filled, soft tissue and bony structures [1, 2]. Sequential CT allows assessment of puncture localization, needle direction and evaluation of needle positions within the body. However, time-consuming acquisitions of various single or spiral CT images are required [3]. The lack of real-time imaging capability has been the greatest disadvantage associated with CT-guided interventions, especially when compared with sonographic and fluoroscopic image guidance [4]. Particularly in body regions subject to respiratory movement, small target lesions may shift and disappear during the course of a sequential CT-guided procedure, making these interventions cumbersome and associated with a high-radiation dose [5]. This seems to be one of the major reasons why CT-guided interventions may be unsuccessful or need to be repeated [1].

To overcome this limitation, CT fluoroscopy (CTF) systems were developed, providing real-time image reconstruction and display of CT images on a monitor. This has become possible by the synergistic and dynamic advances in CT technology and computer hardware [3]. Since the initial report on CTF development by Katada et al. in 1994 [6], several studies have been performed evaluating the feasibility and applicability of this innovative image guidance modality to a variety of nonvascular and vascular interventions. With the increasing clinical applications of CTF there have been controversial reports regarding the advantages and disadvantages of this new image guidance modality, specifically concerning radiation exposure, procedure times and patient outcomes. At the authors' institution, more than 300 different interventional procedures have been performed with CTF guidance since 1997. This article reviews our clinical experience and that of other investigators with CTF-guided biopsy, drainage and other interventional procedures, to determine whether CTF is a valuable tool for image-guided diagnosis/therapy or just a dispensable radiologic gimmick.

CT Fluoroscopy Technology

The technical development of CTF began in 1993 [1, 6]. This first Toshiba scanner generated 3 images per second, had a limited field of view and a fixed table position during CTF. Subsequently, major technical improvements have distinctly improved CTF technique and image quality. Currently available CTF systems are summarized in Table 1. All these systems use slightly modified continuous rotation, fan-beam geometry CT scanners by adding a high-speed array processor to increase image reconstruction speed and image display rate up to 8 frames per second. This has resulted in

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Table 1. Composition of all CT fluoroscopy manufacturers and individual product specifications

Manufacturer	Product name	Min. rotation time (sec)	Image delay (sec), max. scan time (sec)	Max. frame rate/sec	Tube voltage (kV) and amperage (mA)
GE Medical Systems	SmartView	N/A	N/A	N/A	N/A
Marconi Medical Systems	Continuous CT	N/A	N/A	6	N/A
Philips Medical Systems	CT Fluoro	N/A	N/A	N/A	N/A
Siemens Medical Systems	CARE Vision	0.75	0.5, 80	8	90, 120, 140
Toshiba Medical Systems	Aspire	N/A	N/A	N/A	N/A

N/A indicates that no specifications were available from the manufacturer following multiple requests

reconstruction and display of continuously acquired CT images at delay times between 500 and 800 msec. Due to this delay time, it would be more appropriate to consider CTF as a "close to real-time" imaging modality rather than a real-time technique.

CTF images are acquired during continuous scanning at a rotation speed between 0.5 and 1.0 sec. Various power steps, up to 10.8 kW (between 30 and 90 mA at 90–140 kV) are available. A display rate of up to 8 images per second with an average inter-image spacing of 0.17 sec is obtained while all standard collimator settings (1–10 mm) may be selected. Generally, image reconstruction is performed on a 256 × 256 matrix, with images displayed in full resolution of a 1024 × 1024 matrix. The maximum continuous CTF scan time is approximately 80–100 sec when using the lowest tube currents and voltages.

Generally, CTF images are displayed on a mobile in-room monitor next to the patient table directly facing the interventional radiologist. On the scanner in our Radiology Department (Somatom 4 Power/CARE-Vision, Siemens Medical Systems, Forchheim, Germany), the field of view may variably be selected from 5 to 50 cm and gantry tilt is possible. During CTF the patient couch may simultaneously be moved in and out of the gantry, controlled by joysticks or interface panels. Similar to conventional fluoroscopy, CTF may be started by pressing down a foot pedal and will be continued by holding the foot pedal down. Reconstructed images are converted to standard television signals and a video recorder interface card allows connection to a VCR for documentation of the complete set of images acquired during CTF. Commonly, the last fluoroscopic image remains displayed on the monitor (last image hold) until fluoroscopy becomes reactivated. Usually only the last images are stored on hard disk (last image store). Additionally, the complete set of CTF images may be recorded on video tape.

Radiation Exposure

Unlike other image guidance techniques such as ultrasound or MRI, CT-assisted interventions are associated with exposure to radiation. In sequential CT-guided procedures, radiation exposure generally is confined to the patient, while with CTF additional radiation exposure of the radiologist occurs, as the operator is in the room at the time. To shield the interventional radiologist from radiation exposure, a standard protection is worn (lead apron, thyroid shield and lead glasses or goggles) [3] and exposure is monitored with an under-apron body radiation badge. In our institution, as in others, read-outs from these badges were always well below statutory limits [3]. However, there is persistent concern regarding the radiation close to the operator's hands and fingers when guiding needles or other interventional tools are used within the CT gantry [7, 8]. Another potential risk to the operator arises from scattered radiation since the interventionist has to work close to the radiation beam [9].

The initial CTF-guided interventions were performed without needle holders and the operator's hands were placed directly within the CT beam. Radiation dosimetry readouts from hand rings, however, showed excessive absorbed radiation doses during these interventions [1, 7]. Therefore dedicated needle holders have been developed to increase the distance of the operator's fingers from the CT beam [7, 8, 10]. Our own experience with various of these devices has encouraged us to routinely use 20–25 cm long surgical needle holders or a simple surgical stainless steel sponge forceps. Even though these instruments consist of metal, radial artifacts do not disturb the CTF image (Fig. 1) or interfere with the interventional procedure [11]. Whenever needle advancement does not have to be monitored continuously, intermittent CTF may be used between needle advancement episodes to further reduce the radiation dose while not appreciably lengthening procedure time.

Several investigations have evaluated the radiation exposure of patients and operators that is associated with CTF. In phantom measurements, surface doses estimated by thermoluminescence dosimetry and the pencil chamber technique ranged from 2.3 to 10.4 mGy/sec while scattered exposure rates for 120 kV and 50 mA (10 mm slice thickness) were 27 and 1.2 μGy/sec at 10 cm and 1 m respectively [9]. The authors conclude that high exposures to patients and personnel may occur during CTF-guided interventions and suggest reducing tube currents and scanning times to a minimum. Additionally, it was found that scatter exposure to personnel may be substantially reduced by placing a lead drape adjacent to the scanning plane [9]. The average activation time of CTF has been reported to be less than 3 min [12, 13] for typical biopsy or fluid drainage procedures. Our own initial experience has shown mean CTF times of 29 sec for percutaneous abscess drainage procedures [2], approxi-

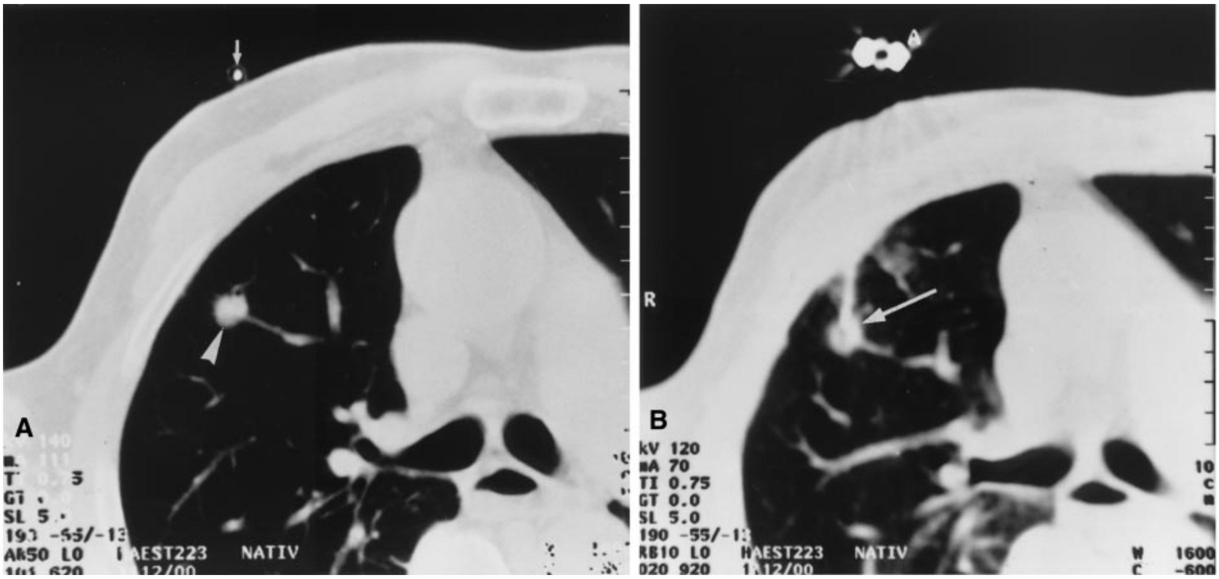

Fig. 1A, B. Percutaneous biopsy of a small pulmonary nodule (**A,** arrowhead) after localization of the puncture site using sequential CT technique (arrow). Consequently CTF allows exact placement of a biopsy needle tip within the target lesion (**B,** arrow) with sufficient image quality and spatial resolution.

mately 90 sec for pulmonary and nonpulmonary biopsy procedures [5, 11] and 20 sec for initial percutaneous puncture of bile ducts for placement of external biliary drainage catheters [14]. With increasing individual experience and intermittent activation of CTF between single needle advancement episodes, however, times may be reduced further.

However, taking into account the reported radiation exposure from phantom and patient studies to the patient and to the personnel, both from direct skin exposure and from scattered radiation, protocols for aggressive dose reduction (low tube potential and current, reduction of slice thickness, lead drape placed caudal to the imaging plane) should be established at every institution. Careful assessment of radiation exposure to the personnel by means of radiation badges is mandatory. As with all interventional radiological procedures, it has to be considered that the best radiation reduction always is a strong indication.

Interventional Techniques

Biopsy Procedures

As indicated in Table 2, several clinical studies have been performed to evaluate CTF. However, prospective randomized trials contain only small numbers of patients. Papers containing larger numbers of patients are either retrospective studies or review articles.

Numerous feasibility studies on the use of CTF to guide transthoracic biopsy of pulmonary lesions demonstrated high technical success rates [1, 5, 11, 15–17] with sensitivity ranging from 89% to 95% and a specificity of 100%. The effectiveness of CTF for directing transbronchial mediastinal lymph node biopsy has been shown recently [16, 18]. To the best of our knowledge, there is only one prospective randomized trial comparing sequential and fluoroscopic CT for guidance of pulmonary biopsy procedures. This study revealed some advantages of the CTF system. Compared with sequential CT guidance, procedure times were significantly shorter and fewer percutaneous or pleural needle passages were required for precise placement of the biopsy devices [5]. De Mey and colleagues [15] found a higher sensitivity of 94% for biopsy of intrapulmonary nodules as compared with results from their previous experience using sequential CT guidance (87%). Especially in patients with reduced cooperation, sequential CT-guided access may be difficult, since targets are easily lost within the scan plane and biopsies can not be performed accurately [3, 5]. As a consequence, an increased number of percutaneous or pleural punctures may aggravate induction of complications [19]. CTF seems to increase procedure safety since fewer pleural needle passages are necessary in our experience. Even if a pneumothorax has initially occurred during a pulmonary biopsy procedure, real-time CTF still reliably depicts the target, allowing reliable subsequent access for salvage of an adequate biopsy specimen [5]. Even pulmonary nodules so small that they would previously not have been eligible for percutaneous biopsy, may safely be accessed with CTF guidance to retrieve a histopathologic specimen (Fig. 1).

Within the abdominopelvic region several reports have demonstrated similar results of CTF-guided biopsy to those in the chest, with a high sensitivity and specificity for diagnosing suspected malignancies [3, 11, 15, 20–22]. Again most of these investigations either contain only small patient numbers or are retrospective studies. Two of these reports have highlighted the ability of CTF to guide biopsies in

Table 2. Overview of clinical studies related to CT fluoroscopy

Authors	Year published	Reference no.	Study design	Type of procedure	No. of patients
Katada et al.	1996	1	Feasibility	Biopsy and drainage	57
Froelich et al.	1998	2	Comparison	Drainage	20
Froelich et al.	2001	5	Comparison	Biopsy	20
Froelich et al.	1999	11	Comparison	Biopsy	20
Daly et al.	1999	12	Review	Various	97
Meyer et al.	1998	13	Review	Drainage	20
Froelich et al.	2000	14	Comparison	Biliary	20
De Mey et al.	2000	15	Review	Various	337
Goldberg et al.	2000	16	Feasibility	Transbronchial biopsy	12
Hirose et al.	2000	17	Feasibility	Biopsy	50
Silverman et al.	1999	20	Comparison	Biopsy and drainage	87
Spies et al.	2000	21	Comparison	Biopsy and drainage	78
Gianfelice et al.	2000	22	Review	Biopsy	190
Kirchner et al.	1999	23	Case report	Biopsy	1
Schweiger et al.	2000	24	Case report	Biopsy	3
Froelich et al.	2001	28	Comparison	Drainage	40
Kanno et al.	1997	29	Feasibility	Intracerebral	12
LeMaitre et al.	2000	30	Feasibility	Nephrostomy	25
Takayasu et al.	1999	31	Feasibility	Ethanol ablation	10
Kirchner et al.	1999	32	Feasibility	Chemoembolization	21
Yoshida et al.	1999	33	Feasibility	Nodule localization	8

Only a few prospective randomized trials with small patient numbers have been published and references containing larger patient numbers are either retrospective studies or reviews

hepatic lesions which demonstrate only transient contrast enhancement or non-enhancement on non-contrast scans [23, 24]. Two other comparative studies have addressed abdominal biopsy with CTF. One prospective randomized trial yielded a decreased number of needle passes, significantly shorter procedure times, similar results for radiation exposure and similar histologic results with CTF compared with sequential CT guidance [11]. In contrast, however, another prospective randomized trial found similar histopathologic results, similar procedure times and significantly increased radiation doses for CTF [21]. Two other studies compared the CTF biopsy results with data of historic patient groups treated at the same institution with sequential CT guidance. Silverman and colleagues [20] reported similar sensitivity and negative predictive values for CTF and sequential guidance, but again significantly decreased needle placement times. Gianfelice et al. [22] found an increased procedural success rate for CTF (94% vs 88%; statistically nonsignificant) and statistically significant reduced procedure times. Both reports seem to support the initial findings by Froelich et al. [11] and are in concordance with an additional phantom study simulating hepatic metastases. In this trial, it was shown that CTF required a significantly shorter procedure time than helical CT for guidance of biopsy procedures [4]. This study also evaluated sonographic guidance and found that CTF- and ultrasound-guided biopsy required similar procedure times. The two modalities were equally effective at obtaining a histologic specimen. However, early observations with similar radiation doses for sequential CT guidance and CTF should be considered critically, because the number of patients was restricted to only 10 per patient group [11]. In accordance with investigations by several other authors [1, 7, 8, 9, 20–22], it seems evident that CTF is associated with higher radiation exposure to patient and personnel than sequential CT guidance.

An important advantage of CTF may be precise placement of biopsy devices within certain areas of a target lesion to improve diagnostic accuracy of biopsy samples for histologic diagnosis from representative target areas, potentially avoiding extraction of diagnostically worthless necrotic material for histopathologic examination. Especially because needle positioning is easily visible with real-time CTF, the operator's skill, which is considered to be essential for the diagnostic precision of CT-guided biopsies, may be less important for future biopsy procedures, potentially offering high success rates to less experienced operators that currently can be achieved only by experienced interventional CT radiologists [1, 11].

With the introduction of CTF, certain modifications of the percutaneous puncture technique could be observed when compared with sequential CT-guided approaches. Especially in lesions located within the base of the lung or in patients with reduced cooperation, respirational shift frequently causes targets to disappear from the puncture plane during sequential CT-guided biopsies [21]. As already reported by Katada et al. [1], CTF puncture of such lesions may be performed during respiration while the target is shifting along [5]. Also, obstruction of needle access during sequential CT-guided procedures due to rib superposition frequently requires repeated punctures and additional confirmation of correct needle placement by means of time-consuming single control scans or short spiral CT intervals. With CTF, however, the biopsy needle may easily be guided across such obstacles, targeted and safely placed within the lesion during a single CTF interval—repeat punctures and pleural passages may therefore be avoided in a majority of cases [5]. Using a coaxial access technique additionally allows the immediate performance of autologous blot clot seal [25] or thoracocentesis to prevent or treat pneumothoraces respectively. In nonpulmonary biopsy procedures, embolization of the puncture tract may instantly be performed and monitored with "close to real-time" CTF imaging to treat biopsy-related bleeding complications.

As already reported [1, 5], needle pull-back due to rebound of subcutaneous tissue can clearly be observed in real-time CTF. Artificial pleural indentation may be depicted during needle penetration and occasionally downward displacement of intrapulmonary target lesions is recognized during needle contact [15]. The needle-tip sign which is observed in both sequential and CTF-guided procedures helps to assure correct positioning of a needle tip within the target, particularly when angulated punctures are performed, away from the axial needle insertion plane [1, 11].

Drainage Procedures

As with biopsy procedures, the clinical experience, comparing sequential CT assistance and CTF-guidance in drainage procedures has shown several advantages for CTF. Targeting and advancement of needles, guidewires and drainage catheters can easily be monitored with CTF. Particularly in angulated access routes, use of joystick-controlled table feed accelerates real-time visualization of interventional tools during various drainage procedures.

Drainage procedures under CTF guidance have been reported by numerous authors [1–3, 13, 15, 20, 21], generally with only small patient numbers. The first comparative trial between CTF-guided drainage and sequential CT-guided drainage was undertaken by Froelich et al. [2]. They found that significantly fewer needle punctures were required for the initial fluid collection puncture and significantly shorter procedure times for the 10 patients in the CTF group compared with the 10 patients in the sequential CT group. Calculated radiation doses were similar for the two groups. Because of the small patient numbers, however, radiation exposure was not assessed reliably in this investigation, where mean fluoroscopy time for CTF was found to be 29 sec [2]. Meyer and colleagues [13] reported on CTF-guided drainage of 10 loculated pleural effusions, two mediastinal fluid collections and 12 focal pneumothoraces in 20 patients. All drainage catheters were placed successfully with an average CTF time of 143 sec. The authors found the technique particularly helpful in patients who could not cooperate with breathing instructions [13]. Silverman and colleagues [20] also reported a 100% success rate for aspiration ($n = 13$) or catheter drainage ($n = 21$) of abdominal fluid collections. The mean CTF time in this population was 79 sec; however, this included 61 biopsy procedures [20]. Daly and colleagues [12] performed CTF-guided fluid collection aspiration or drainage catheter placement in 59 patients. Their success rate was >90% and mean CTF time was 186 sec [12]. Compared with other investigations, however, this CTF time seems extraordinary long and, depending on the applied tube amperage and voltage, patient surface doses may have reached 0.5 Gy. In another prospective randomized trial Spies et al. [21] found no difference regarding procedure time in 14 drainage procedures under CTF guidance compared with 21 procedures performed with sequential CT. However, a statistically significant increase in the CTDI was noted. All drainage procedures were technically successful [21]. DeMey et al. [15] reported the largest population of 61 abdominal and 13 chest needle aspiration ($n = 35$) or drainage catheter insertions ($n = 39$) under CTF guidance. The authors found that needle or drain placement was facilitated with the CTF guiding technique [15].

The most obvious advantage of CTF-guided drainage is that sequential CT-guided access may become difficult in problematic and tight anatomic situations and cannot be performed safely without risk to the patient. Specifically in such situations, CTF still allows safe puncture of the target because the advancement of puncture needles, guidewires and drainage catheters is clearly visible in real-time display [2].

A further step might be the combination of CTF with conventional fluoroscopy. It has been reported that cross-sectional image guidance after initial needle placement may be supported by the additional use of conventional C-arm fluoroscopy by sliding the patient couch out of the CT gantry to have the patient positioned under the C-arm unit without risk of needle displacement during patient transfer to another room [26, 27]. Fixed combinations of a flat-panel detector fluoroscopy unit adjacent to the CT gantry are already available (Marconi, FACTS). Because the combination of CTF and C-arm fluoroscopy greatly improves topographical orientation along the patient's longitudinal axis, abscess drainage catheters can be placed more precisely within loculated abscess cavities, thus resulting in complete initial evaporation of abscess cavities, significantly reducing postinterventional drainage periods as well as drainage catheter revisions during follow-up. Due to superior image guidance, procedure times may further be improved when compared with cross-sectional image-guidance alone [28].

Various Applications

The unique capability of real-time cross-sectional imaging to visualize manipulations of interventional tools in all body regions has led to new applications of CTF in recent years.

Percutaneous Transhepatic Biliary Drainage. At many institutions initial bile duct puncture for transhepatic cholangiography and drainage is performed as a blind procedure because bile ducts are non-radiopaque under conventional fluoroscopy. Therefore, initial puncture may be difficult, requiring multiple hepatic needle passes. Even though bile ducts may successfully be punctured with CTF, conventional fluoroscopy must still be considered essential for further

Fig. 2A–C. Percutaneous biliary drainage with CTF guidance. In a patient with hepatocellular carcinoma, a dilated bile duct is identified within the right hepatic lobe (**A,** arrow) and a 22 G puncture needle is targeted within the subcutis (**A,** arrow) to be advanced into the selected duct (**B,** arrow) during continuous CTF. After insertion of an external drainage catheter, the biliary system has been opacified with diluted contrast material (**C**).

management of guidewire or catheter insertions during the course of a biliary drainage procedure (Fig. 2).

In a recently published prospective randomized study a C-arm supported CTF technique ($n = 10$) was compared with conventional fluoroscopy ($n = 10$) for percutaneous biliary drainage in 18 patients. Bile ducts were punctured with less than two hepatic needle passages in the CTF group, resulting in significantly reduced procedure times (11.0 vs 16.2 min) and fluoroscopy times (3.4 vs 11.4 min) with the use of C-arm supported CTF [14].

An advantage of the new technique might be the precise placement of drainage catheters within preselected subsegmental bile ducts to improve therapeutic accuracy at potentially reduced complication rates. Compared with exclusive fluoroscopy, CT guidance may require application of intravenous contrast material to intensify opacification of bile ducts against portal veins and hepatic tissue, especially in patients with fatty liver degeneration. However, no advantage for C-arm supported CTF is expected when bile ducts are not dilated, because generally nondilated peripheral intrahepatic ducts are beyond the spatial resolution of CT and therefore cannot be targeted selectively. To avoid excessive radiation exposure of the physician's hand within the CT gantry, needle holders (e.g., hemostats) are again mandatory [1, 3, 5, 9].

Intracranial Procedures. The initial clinical report of Katada and colleagues [1] on CTF-guided interventions included nine aspiration or drainage procedures for intracranial hematomas. The same group has meanwhile reported a total of 12 patients (10 intracranial hemorrhages, 2 tumors) who underwent successful needle placement for biopsy or aspiration under CTF guidance [29]. We have performed two drainage catheter insertions in patients with massive intracerebral hematoma. The ability to monitor needle advancement through critical cerebral regions into the desired position is of paramount importance in the brain. Compared with standard stereotactic procedures, CTF-guided interventions can

Fig. 3A–C. Percutaneous nephrostomy using CTF guidance after previous unsuccessful sonographic puncture in a patient with acute pyelitis and urosepsis. Note the preexisting complicating rupture of the renal pelvis with retroperitoneal contrast extravasation (**A,** arrow). After an access route has been defined and the puncture site has been marked on the skin (**A,** arrowhead), a 22 G needle is advanced to the renal capsule (**B,** arrowhead) to be positioned within a mid-posterior calix (**C,** arrow) during continuous CTF. Subsequent insertion of a guidewire and a drainage catheter is preferably performed using conventional C-arm fluoroscopy (images not shown).

be performed rapidly, allowing immediate decompression in the case of time-critical cerebral edema.

Percutaneous Nephrostomy. A group from France has recently published the first report on CTF guidance for percutaneous nephrostomy. In 24 of 30 attempted placements the drainage catheter was successfully inserted under CTF only, while in the remaining cases the renal calix was punctured with CTF guidance and the catheter placed under fluoroscopy. The mean CT fluoroscopy time was 49 sec, the mean procedure time, 25 min. The authors concluded that CTF is especially effective, if access to the urinary system is difficult [30]. However, since these interventions have not been compared with the standard approach (ultrasound-guided puncture), the advantages of CTF for percutaneous nephrostomy procedures remain uncertain.

We have successfully placed four percutaneous nephrostomy catheters in three patients. For these procedures, again a combination of C-arm fluoroscopy and CTF was used, i.e., initial pelvicaliceal puncture under CTF guidance (Fig. 3) and guidewire, dilatator and drainage catheter manipulations under conventional C-arm fluoroscopy without movement of the patient in prone position. All of the treated patients had previously undergone unsuccessful ultrasound-guided percutaneous nephrostomy attempts in nondilated calices with pyelitis and urosepsis. Procedure times were below 14 min and no complications were observed, while renal calices could be reached with a single puncture in all cases.

Percutaneous Ethanol Injection. CTF for monitoring of needle advancement and ethanol injection and distribution into hepatocellular carcinoma (HCC) has been reported by two groups [12, 31]. Daly et al. [12] reported on six patients and Takayasu et al. [31] on 10 consecutive patients with 15 HCC. In the latter group, seven HCC were not visible on ultrasound. Both groups describe that real-time monitoring of ethanol injection facilitated tumor ablation and also allowed refinements of needle placement.

Chemoneurolysis. The guidance of chemoneurolysis, e.g., celiac plexus blockade or lumbar sympathicolysis, with CTF has been reported by Daly et al. in four patients [12]. We perform lumbar sympathicolysis routinely under CTF. Even though the exact needle position can be visualized with sequential CT alone, intermittent CTF during injection of the ethanol/local anesthetic mixture allows instantaneous monitoring of the correct distribution of neurolytic agents in the prevertebral space, avoiding intravascular injection into the lumbar veins. Additionally extension of the neurolytic agent toward the ureteral neighborhood can be recognized rapidly.

Gastrostomy. Spies and colleagues [21] performed five percutaneous gastrostomies under CTF and compared these with three percutaneous gastrostomies under sequential CT guidance as part of their randomized trial comparing the two guiding techniques. They did not find a significant difference with regard to procedure time or radiation dose in this small patient population. All gastrostomies were successfully placed [21]. However, as there is already a much cheaper and highly effective imaging guidance method for radiological gastrostomy placement (conventional fluoroscopy), CT plays a minor role in this procedure in the majority of hospitals.

Miscellaneous. Case reports or small case series have dealt with the application of CTF to guide transarterial chemoembolization of hepatic malignancies [32], to guide injection of cyanoacrylate to mark pulmonary nodules for thoracoscopic resection [33] or to guide intrathoracic fibrin sealant application to treat persistent pulmo- and bronchopleural fistulas [34]. Additionally, we have occasionally performed bilateral transpedicular osteosynthesis of vertebral fractures in patients where a traditional surgical approach was cumbersome (i.e., upper thoracic spine, etc.).

Further Developments. Occasionally, we have used CTF guidance to puncture the intrahepatic portal vein from the hepatic vein in the creation of a portosystemic shunt. In these cases CTF was felt useful to avoid puncture of the liver capsule or extrahepatic portions of the portal vein. Cross-sectional CT imaging allowed superior planning of the puncture route. However, after the portal vein had successfully been punctured with CTF-guidance, the remaining TIPS procedure was best monitored with conventional fluoroscopy by means of a C-arm unit positioned adjacent to the CT gantry.

Conclusion

CTF is a valuable tool for image guidance in a variety of percutaneous interventional procedures. Its major advantage is precise device localization throughout the body in almost real-time, which allows safe advancement and manipulation of various interventional devices. Therefore, the more difficult the access to a lesion is, the more advantageous is the use of CTF for the interventionist. In highly sophisticated procedures, CTF increases safety for the patient and the interventionist. However, in standard procedures, such as biopsy of hepatic metastases (>2 cm) or drainage of large intra-abdominal fluid collections, the advantages are counterbalanced by the major drawback, namely high radiation exposure. Use of the novel technique, especially in the hands of less experienced interventional radiologists, requires strict regulations for radiation protection and close surveillance of the radiation exposure for both the patient and the radiologist [35]. Current developments such as the combination of CTF with conventional C-arm fluoroscopy will lead to new applications in interventional radiology. However, further randomized trials in large patient populations comparing this new guidance technique with its competitive alternatives of ultrasound, sequential CT and MRI are mandatory to define its future role in the spectrum of image-guided therapy.

In conclusion, careful use of CTF is certainly a helpful tool for the interventional radiologist; however, its careless use in every procedure previously performed under sequential CT guidance would be a gimmick, placing both patient and operator at risk of radiation injury, and the interventionist additionally at risk of losing his basic skills and reputation.

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