Special Communication

C-arm Computed Tomography for Hepatic Interventions: A Practical Guide

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With adoption of catheter-based techniques that require technically difficult catheterization, the need for imaging platforms that exploit the advantages of multiple modalities and offer three-dimensional visualization has correspondingly increased. At the authors’ institution, C-arm computed tomography (CT) is routinely used to complement conventional digital subtraction angiography for transcatheter therapy. The goal of the present report is to share experience with the use of C-arm CT in hepatic interventions, with the aim to provide practical tips for optimizing image acquisition and postprocessing. Although the authors’ direct experience is limited to the equipment of a single manufacturer, many of the principles and guidelines can be readily extrapolated to other C-arm CT systems.

Abbreviations: DSA = digital subtraction angiography, FOV = field of view, MIP = maximum-intensity projection, MPR = multiplanar reconstruction, 3D = three-dimensional

C-ARM computed tomography (CT) uses the principles of cone-beam CT producing multiplanar CT-like soft tissue images and three-dimensional (3D) volume-rendered images from a single rotational acquisition (1–3). This ability has resulted in an innovative technique for image guidance of intra-vascular interventions. C-arm CT was first developed for application in neurointerventional procedures (4,5); with improvement in technology, availability of flat-panel detectors and improvement in image quality, C-arm CT has found applications for abdominal interventions (1,6,7). At the time of the present writing, three C-arm CT–capable systems are commercially available in the United States: DynaCT (Siemens, Forchheim, Germany), XperCT (Phillips, Eindhoven, The Netherlands), and Innova CT (GE Medical Systems, Waukesha, Wisconsin).

At our institution, we routinely use C-arm CT (eg, DynaCT) for all transhepatic arterial therapies such as chemoembolization and radioembolization for primary and secondary hepatic malignancies. The advantage of the use of C-arm CT for transhepatic arterial interventions is the ability to obtain CT-like multiplanar views during injection of contrast medium in the hepatic artery and provide 3D maximum-intensity projection (MIP) reconstructions of the hepatic vessels (Fig 1). The present report has the goal of sharing experience with C-arm CT in hepatic interventions in an effort to provide useful tips, from setup to image reconstruction, for a time-efficient use of the C-arm CT system. Some of the techniques and terminology reported here are specific to the equipment of one manufacturer, but other, more generic strategies such as patient positioning can be applied to all C-arm CT systems. In addition, we note that the few vendor-specific techniques are for illustrative purposes only and are not meant to imply superiority of any one system over another. Details on the principles of cone-beam CT imaging and C-arm CT have been described elsewhere (8,9) and are beyond the scope of this report.

C-ARM CT SYSTEM

Presently, our interventional radiology suites are equipped with Axiom Artis dTA ceiling-mounted systems (Siemens) with flat detectors (30 × 40 cm, 48 cm diagonal, 154-μm pixel size). These systems allow for a spatial resolution of 3.25 line pairs per millimeter and adequate contrast resolution for soft tissues. For high-quality C-arm CT images, the C-arm itself should be capable of high-speed movements, preferably up to 60°/seconds, acquiring 60 frames/seconds. This allows for expeditious acquisition in rotational and orbital...
One page of a document that discusses the use of C-arm CT for hepatic interventions, focusing on directions within a single breath-hold. In addition to high-speed acquisitions, the postprocessing software platform itself should be efficient, allowing the operator to view reconstructed images promptly. At our institution, our C-arm CT systems are equipped with software level VB31 that currently allows the syngo DynaCT software platform to efficiently reconstruct high-quality C-arm CT images. However, we would like to note that, with new applications and/or improvement in the technology, C-arm CT systems will continue to see a steady need for imaging platform and software updates that will incur additional costs. At the time of this writing, the next generation of C-arm CT capable angiographic systems and software updates has already become commercially available, capable of faster reconstructions and some added applications.

For hepatic interventions, we use an 8-second rotational scan of 210° and 26° rotation/sec, image acquisition every 0.5° for a total of 419 images, 512 × 512 voxel matrix, source power of 125 kVp, and receiver dose of approximately 0.36 μGy per frame. A brief overview of the organ program setup used at our institution (DynaCT) is presented in the Table. Similar programs, although not identical, are available on the other C-arm CT systems.

Data acquired from the rotational acquisition are automatically postprocessed. These reconstructed images can than be viewed in multiple planes as well as manipulated by the operator. At our institution, all C-arm CT images are postprocessed, reconstructed, and manipulated on a separate 3D workstation (syngo-X), placed in the control room next to the standard “live monitor” used for viewing live fluoroscopy and digital acquisitions. This allows the operator to review the digital subtraction angiography (DSA) and C-arm CT images simultaneously, which not only increases operator ease, but also helps to solve problems in difficult cases in which DSA and C-arm CT complement each other. In the suite itself, the C-arm CT images can be reviewed on an additional monitor using an “electronic control console,” which has a joystick that works as a mouse.

**PATIENT SETUP FOR ABDOMINAL INTERVENTIONS**

Room and patient setup is a fundamental step to maintain efficiency during procedures that would benefit from C-arm CT imaging. The goal is to be able to switch between DSA and C-arm CT without having to reposition the patient or lose precious time between the transitions. The following time-saving steps are universal and are applicable to all C-arm CT systems.

**Patient Position**

Unlike DSA imaging, C-arm CT may require what is known as “offsetting.” This term is used in reference to positioning the patient on the table (Fig 2). For example, if the tumor to be treated is located in the peripheral portions of the
right lobe of the liver, the patient should be positioned such that (s)he is just slightly off center to the left of the table. Similarly when the region of interest is in the left lobe of the liver, the patient is off center slightly to the right. In doing so, the operator ensures that the region of interest is as close to the center of the field of view (FOV) as possible. Often, when patients are not offset, the operator may need to move the table too far to the left or right to move the region of interest to the center of the FOV, which can result in insufficient room for the 200° C-arm sweep and inability to perform a test run or an acquisition as a result of insufficient clearance. Positioning the patient correctly on the table before draping the patient eliminates the need to reposition the patient at the time of C-arm CT, maintaining efficiency and, more importantly, the sterility of the procedure.

**Placement of Monitoring Devices and Intravenous Drip Poles**

Any device that can be a potential obstacle during the C-arm rotation should be positioned outside the rotation trajectory. This includes poles for intravenous drips, pulse oximetry cables, and leads for electrocardiographic monitoring. Objects that can cause streak artifacts (eg, jewelry, electrocardiographic leads) should also be situated outside the FOV. At our institution, we use radiolucent electrocardiographic leads (Red Dot; 3M, St. Paul, Minnesota), with the electrocardiography box located under the table bottom end. Setup of poles for intravenous drips, blood pressure cuffs, and pulse oximeters is such that a complete C-arm CT rotation can be performed without the C-arm snagging on the tubes or cables (Fig 3a, b). Tubing for intravenous fluids and medications required to be hung from a pole, as well as the tubing for nasal oxygen required through the procedure, is positioned at the head of the table, cranial to the C-arm. This prevents the tubing from getting caught or entangled with the x-ray source during the 200° sweep of the C-arm during a CT acquisition. Similarly, the blood pressure cuff and pulse oximeter device are placed on the lower extremities. If the lower extremities are unsuitable for accurate monitoring, the devices can be placed on one of the arms, ensuring that the junction between the cuff and inflation tube and transducer is easily accessible during the procedure, allowing for a quick temporary disconnection during C-arm rotation.

**Positioning the Patient’s Arms**

For angiographic studies, it is not uncommon to position the patient’s arm by their side. However, streak artifact from the forearms can lead to image degradation of the C-arm CT images. Hence, ideally for C-arm CT acquisitions, the arms should be positioned above the head, a position similar to that required for a routine helical CT. Unfortunately, maintaining this position throughout the entire procedure is difficult and can lead to shoulder and arm strain. Positioning and repositioning the arms by the patient’s side can be time-consuming and carries the risk of compromising the sterile field, and is therefore less than ideal. To maintain patient comfort and maintain efficiency, we position the patient’s arms on a butterfly-shaped armrest device (Fig 3a–c), which was custom-made for our institution. Similar armrests are now available commercially from Siemens. On devices such as these, the arms are at an angle 70°–90° to the torso and the forearm is flexed at the elbow and is at a 90° angle to the arms (Fig 3a,b). In our experience, this relieves the strain on the shoulders, and most patients are able to maintain this position throughout the procedure while keeping the upper extremities out of the FOV and the C-arm trajectory.

**Contrast Agent Injectors**

C-arm CT requires the use of diluted iodinated contrast medium (as detailed later), whereas DSA requires full-strength iodinated contrast medium. To maintain efficiency, our interventional suites are equipped with double-barrel contrast agent injectors (Mark V ProVis; Medrad, Warrendale, Pennsylvania). Routinely, for all procedures that use a combination of C-arm CT and DSA, one barrel is loaded with full-strength iodinated contrast medium (Omnipaque 300 or Visipaque 320; Mallinckrodt, St. Louis, Missouri) for dilution.
standard DSA imaging and the other barrel is loaded with the same contrast medium diluted to 150 or 160 mg/mL iodine concentration for C-arm CT acquisitions. In our experience, the use of dilute iodinated contrast agent not only reduces the contrast agent burden on the kidneys while maintaining the same image quality, but, more importantly, reduces the streak artifact on the CT-like soft tissue images obtained by C-arm CT. Sterile injector tubes are attached to both barrels (Fig 3d) and marked appropriately with sterile color-coded stickers. Having this set up before the procedure is started enables the operator to efficiently switch between DSA and C-arm CT by attaching the appropriate tubing.

By following these steps before starting the procedure, we ensure safe, efficient, and seamless C-arm CT acquisitions.

**C-ARM CT SETUP AND SCAN PARAMETERS FOR ABDOMINAL INTERVENTIONS**

The first step before obtaining any C-arm CT scan is to perform a test rotation to ensure that the C-arm can rotate unobstructed. Presently all C-arm CT systems require similar test runs to avoid table collision during the actual rotational acquisition. The test rotation for DynaCT is done in two steps: isocentering on two views 100° apart (usually anteroposterior and left or right anterior oblique depending on the position of the C-arm in respect to the table) followed by the selection of the scanning C-arm position preset. At our institution, the preferred preset is a 48-cm FOV, with a 0° anteroposterior and a 100° left anterior oblique (or right anterior oblique if the C-arm is positioned on the right side of the table) position.

For abdominal C-arm CT acquisitions, we use the 8-second rotational acquisition. For operator convenience, the tab to select this program is placed adjacent to standard mesenteric DSA imaging protocols on the electronic control console for the angiographic table (Fig 4). Other possible options include a shorter (5 seconds for DynaCT) or longer (20 seconds for DynaCT) scan duration. Both these alternatives have advantages and disadvantages: the 5-second rotation is useful in patients who are unable to hold their breath, but is limited in its resolution by the corresponding decrease in the number of images obtained. The 20-second acquisition, conversely, has excellent resolution, but is severely limited by the long breath-hold as well as motion artifact from adjacent moving structures such as peristaltic bowel as a result of the long scan time. Hence, at our institution, we routinely use the 8-sec acquisition as an acceptable solution.

Typically in patients who have never undergone previous chemoembolizations, we obtain two sets of C-arm CT images. The first one is obtained during the injection of contrast medium in the common or proper hepatic artery to identify and characterize tumors to be targeted and to plan the treatment, and the second set is an unenhanced (ie, noncontrast) set obtained after delivery of the chemotherapeutic agents to assess adequacy of tumor treatment. Ethiodol uptake in the tumor is assessed as a surrogate measure of completeness of tumor treatment, triggering additional selective catheterizations if incomplete uptake is observed. In patients with a history of chemoembolizations, a nonenhanced C-arm CT scan is obtained before the contrast-enhanced study to allow the operator to distinguish areas of residual Ethiodol uptake from areas

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**Figure 3.** Appropriate patient setup is essential to maintain efficiency while using C-arm CT. (a) Cranial view of a patient positioned to expedite C-arm CT acquisition. The patient is positioned off center to the left to allow adequate imaging of the right lobe of the liver. His arms are positioned on a butterfly-shaped armrest device. The intravenous pole and associated tubing (arrows) is at the head of the table and hence away from the arc of the C-arm CT rotation. (b) Similar image of a volunteer demonstrating the position of the arms and the intravenous pole. The blood pressure cuff in both patients was placed at the ankle (not shown). (c) Close-up view of the butterfly-shaped armrest device to allow comfortable positioning of the arms through out the procedure. (d) Double-barrel injector preloaded with full-strength and half-strength iodinated contrast agent. An injector tube is attached to each barrel and marked appropriately at the time of setup. This allows for convenient and expeditious switching between full-strength contrast agent for DSA and half-strength contrast agent for C-arm CT. (Available in color online at www.jvir.org.)
of tumor enhancement. Additional C-arm CT images are occasionally obtained during the procedure if needed to solve problems.

CONTRAST AGENT INJECTION PROTOCOL

The contrast-enhanced acquisitions are obtained with the use of dilute iodinated contrast agent (Omnipaque 300 or Visipaque 320; Mallinckrodt) diluted to 150 or 160 mg/mL iodine concentration with equal volume of normal saline solution.

Initial contrast-enhanced images with injection of the common or proper hepatic artery are routinely acquired by injecting at a rate of 2 mL/sec for a fixed duration of 12 seconds (total of 24 mL) and an imaging delay of 4 sec. Injection rates and relative total contrast volumes for more selective catheterizations vary according to size of the artery and type of microcatheter, usually from 0.1 mL/sec to 1.5 mL/sec with a fixed injection duration of 12 sec.

We found that a 4-sec imaging delay with the 8-sec acquisition time with injection of contrast agent through the entire 12 seconds allows the iodinated contrast agent to enhance parenchymal tissue before the start of data acquisition and maintains maximal enhancement of the vessels throughout the acquisition. For vessels that may take a long, tortuous course such as extrahepatic supply from an omental branch, a longer acquisition time or a longer x-ray delay may be needed.

IMAGING RECONSTRUCTION AND POSTPROCESSING

The exact steps for 3D image reconstruction and ease of postprocessing may differ among equipment vendors, but all systems ultimately result in multiplanar images and a volumetric dataset (eg, MIP) that can be manipulated. In our experience with the current software system, postprocessing is generally accomplished in less than 1 minute.

Multiplanar Reconstructions

For 3D multiplanar reconstructions (MPR), the image volume needs to be loaded onto the 3D task card for the DynaCT software. The 3D image display is subdivided in three segments displaying, respectively, each of the three perpendicular reconstruction planes: sagittal, coronal, and axial (Fig 4). The following adjustments can be made to optimize the multiplanar images.

Slice thickness.—Default thin slices (< 1 mm; 0.83 mm with DynaCT) can be extremely useful in visualizing small tumors or branch vessels, but it can also lead to poor signal-to-noise ratio. This can be improved by increasing the slice thickness. On DynaCT, slice thickness can be increased using the MPR thick mode icon on the subtask card. The default slice thickness for the thick MPR is usually set at 5 mm, but it can be manually changed.
by right-clicking the MPR thick icon and entering the desired thickness in the pop-up box. We have found that this is especially helpful in the coronal plane, where MPR images of 7–10-mm thickness can demonstrate the vessel(s) supplying the tumor(s) with soft-tissue landmarks and serves as a roadmap, similar to 3D MIP images. However, unlike MIP images, these images are often difficult to rotate.

Window and contrast levels.—Similar to slice thickness, the window and contrast level values can be set as defaults or individually adjusted for each patient by using the middle button on the mouse.

Ioscentering of the treatment target.—The best way to display the hepatic tumor(s) and their vascular feeders is to isocenter the reconstruction planes to the tumors by moving the cross-reference lines from the center of the screen to the center of the lesion. The three MPR planes are reconstructed on three perpendicular planes 90° apart, but the angulation between planes can be changed by rotating the cross-reference lines as needed on the syngo workstation.

Image registration.—A feature on DynaCT is the ability to fuse two volume sets on the 3D task card. This process allows the operator to fuse two sets of images (contrast-enhanced prechemoembolization C-arm CT and unenhanced postchemoembolization C-arm CT or pretreatment diagnostic CT, positron emission tomography/CT, or magnetic resonance imaging with C-arm CT images). Images from the two sets can be viewed superimposed on each other, with different color scales to distinguish one from the other or side-by-side with simultaneous scrolling. We have found this feature useful in patients with multiple segmental arteries feeding the tumor, to evaluate and ensure complete geographic uptake of the chemoembolic drugs. For systems that do not have this upgrade, a similar comparison can be done manually. Both sets can be viewed on the workstation under the “Viewing” task card and by setting the monitor to display two panels (two panels are obtained by selecting 2:1 under “View” on the top toolbar). The two volumes can be loaded and scrolled side by side using the stack mode (Fig 5). Limitation of using this task card is that it allows for viewing axial images only.

MIP Images

Cases with difficult anatomy may benefit from MIP reconstructions of the contrast-enhanced C-arm CT images. All C-arm CT systems are capable of generating a volumetric reconstruction. DynaCT generates volume-rendered reconstruction from the images loaded on the 3D task card and are ready to be viewed and manipulated on the “In-Space” task card (Fig 6a). In our experience, optimal 3D imaging of the vasculature can be achieved as follows. The acquired contrast-enhanced or unenhanced volume is first loaded in the InSpace task card. Image manipulation is then performed by first adjusting the window and center level to best opacify the vessels. This often requires converting the images from “VRT” to “MIP” images. Next, skeletal structures and nontarget solid organs (e.g., kidneys) can be cropped to isolate the vasculature (Fig 6b). Although various methods can be used to do this, we have found that the quickest way to crop out the undesired anatomic structures is to select the caudocranial view (with the “Orient” subtask card on DynaCT; Fig 6b). The volume of interest is then outlined.

Figure 6. MIP on the InSpace task card. (a) Rotated MIP image that best lays out the origin of a segment VII hypervascular tumor. C-arm angulation is depicted in the top right corner, a useful tool for the operator. (b) Icons required to create a MIP image to isolate the vascular anatomy. The simplest way, we believe, is to orient the image in the caudocranial view (1). The volume of interest is then outlined using the “VOI punching” icon (2), listed under the “Tools” subtask card. The final 3D vascular map can be freely rotated to best lay out overlapping vessels and identify the vessel to be selectively catheterized, allowing for planning that eliminates the need for DSA acquisitions in multiple oblique projections. (Available in color online at www.jvir.org.)
allows the operator to move the C-arm to match the tube orientation chosen on the Inspace image by the mere push of a joystick.

**DISCUSSION**

At the time of writing, we have been using C-arm CT for more than 3 years and have performed approximately 800 hepatic interventions with a combined approach of DSA and C-arm CT. CT-like multiplanar views obtained form C-arm CT during injection of contrast medium in the hepatic artery have helped us identify and characterize tumors that are not clearly characterized on DSA or cross-sectional imaging (10), as well as differentiate pseudolesions (eg, arterioporal shunts or degenerative nodules) from tumors without moving the patient to a dedicated CT scanner (6).

The 3D MIP reconstruction of the hepatic arteries is an important problem-solving tool for patients with difficult anatomy, especially in patients with “corkscrew” vessels caused by underlying cirrhosis. Three-dimensional mapping helps identify the arterial supply to the tumor, allowing superselective catheterization that targets the tumor while decreasing the collateral damage to uninvolved liver parenchyma (10). C-arm CT also provides crucial information in patients with tumors that have extrahepatic supply, in tumors that are located in a segment that may have more than one segmental branch supplying it (eg, segment IV), or in isolating viable regions of previously chemoembolized tumors where dense Ethiodol retention obscures areas of enhancement after administration of contrast medium on uniplanar DSA images (10). Finally, C-arm CT can identify critical, nontarget areas of perfusion such as the stomach, as well as confirm adequate treatment of the tumor itself, hence increasing operator confidence (10,11).

As any new modality, the learning curve can be steep, but with routine use and increasing comfort level for the staff and the physicians, our time to switch from DSA to C-arm CT, the actual C-arm CT rotation, and the transfer of images to the workstation is now less than 3 minutes. This is drastically less time than reported by early users of C-arm CT (12), in part because of advancement in the technology itself, but also because of the staff’s understanding of the modality and hence of positioning and setting up the room correctly and consistently. Finally, as a result of increasing comfort and confidence in the modality, operating physicians can now review, analyze, and manipulate images quickly, again maintaining efficiency and making C-arm CT an integral part of our arsenal.

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**References**