

Imaging Guidance with C-arm CT: Prospective Evaluation of Its Impact on Patient Radiation Exposure during Transhepatic Arterial Chemoembolization

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ABSTRACT

Purpose: To prospectively evaluate the impact of C-arm CT on radiation exposure to hepatocellular carcinoma (HCC) patients treated by chemoembolization.

Materials and Methods: Patients with HCC (N = 87) underwent digital subtraction angiography (DSA; control group) or combined C-arm CT/DSA (test group) for chemoembolization. Dose-area product (DAP) and cumulative dose (CD) were measured for guidance and treatment verification. Contrast agent volume and C-arm CT utility were also measured.

Results: The marginal DAP increase in the test group was offset by a substantial (50%) decrease in CD from DSA. Use of C-arm CT allowed reduction of DAP and CD from DSA imaging ($P = .007$ and $P = .017$). Experienced operators were more efficient in substituting C-arm CT for DSA, resulting in a negligible increase (7.5%) in total DAP for guidance, compared with an increase of 34% for all operators ($P = .03$). For treatment verification, DAP from C-arm CT exceeded that from DSA, approaching that of conventional CT. The test group used less contrast medium ($P = .001$), and C-arm CT provided critical or supplemental information in 20% and 17% of patients, respectively.

Conclusions: Routine use of C-arm CT can increase stochastic risk (DAP) but decrease deterministic risk (CD) from DSA. However, the increase in DAP is operator-dependent, thus, with experience, it can be reduced to under 10%. C-arm CT provides information not provided by DSA in 33% of patients, while decreasing the use of iodinated contrast medium. As with all radiation-emitting modalities, C-arm CT should be used judiciously.

ABBREVIATIONS

CD = cumulative dose, DAP = dose-area product, DSA = digital subtraction angiography, HCC = hepatocellular carcinoma, MIP = maximum-intensity projection, PSD = peak skin dose, 3D = three-dimensional

During the past decade, imaging modalities have seen a marked increase in sophistication, including in those used

for image-guided procedures. For radiation-emitting technologies, the promise of faster, better, and more accurate

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Solutions with regard to C-arm CT. R.F. has received a research grant from Siemens Medical Solutions, is an unpaid consultant for Siemens Medical Solutions, and has received royalty payments Siemens Medical Solutions for intellectual property (under \$10,000). None of the other authors have identified a conflict of interest.

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From the SIR 2010 Annual Meeting.

J Vasc Interv Radiol 2011; 22:1535–1543

N.K. has received a research grant from Siemens Medical Solutions (Forchheim, Germany) and is an unpaid scientific advisor for Siemens Medical

DOI: 10.1016/j.jvir.2011.07.008

imaging is assumed to come at the cost of increased patient exposure to ionizing radiation. Interventional radiologists today need to balance the benefit of the information provided by the systems with the deterministic and stochastic risks inherent to ionizing radiation (1).

One such hybrid technology is C-arm computed tomography (CT), which uses the principles of cone-beam CT to produce multiplanar CT-like soft-tissue images from a single rotational acquisition (2). Used most often for liver-directed therapies, concerns rightfully exist about the radiation exposure from a C-arm CT compared with that received from digital subtraction angiography (DSA). Radiation-induced skin injuries are deterministic in nature, and characterized by a threshold dose. They increase in severity as duration of exposure increases, and are of particular concern in lengthy procedures, such as embolizations (3,4). The often sequential and repetitive nature of liver-directed therapies can also lead to an increased lifetime risk of stochastic effects, such as radiation-induced fatal cancer. However, these are rare, have a long latent period, and are less consequential in this particular patient group that has a preexisting, often fatal cancer. Exact calculation of effective dose and peak skin dose (PSD) is challenging, but surrogates such as dose-area product (DAP) and cumulative dose (CD) provide an adequate estimation for the stochastic and deterministic risks respectively (1,3).

In the present study, we attempt to understand the differences in radiation exposure that a patient undergoing transhepatic arterial chemoembolization would incur when portions of DSA imaging are replaced or complemented by C-arm CT imaging compared with standard DSA imaging alone.

MATERIALS AND METHODS

The present prospective single-institution study was compliant with the Health Insurance Portability and Accountability Act and was granted institutional review board approval. From April 2009 to February 2010, 190 patients with unresectable hepatocellular carcinoma (HCC) underwent 260 transhepatic arterial chemoembolization (hereafter referred to as chemoembolization) procedures with an emulsion of ethiodized oil (Ethiodol; Savage Laboratories, Melville, New York), cisplatin, and doxorubicin. A total of 87 patients met inclusion criteria and were sequentially assigned to undergo standard imaging (DSA only) or combined imaging with C-arm CT and DSA.

Inclusion and Exclusion Criteria

All candidates included in the study had evidence of HCC as defined by the American Association for the Study of Liver Diseases guidelines (5). Only patients with focal disease that met University of California, San Francisco, criteria for transplantation (6) were included, as these pa-

Table 1. Inclusion and Exclusion Criteria

Inclusion criteria	
HCC > 1 cm with arterial hypervascularity and washout on delayed phase (by CT/MR imaging) or biopsy proven (AASLD criteria)	
Size and focality (UCSF criteria)	
Single tumor < 6.5 cm or 3 tumors with largest < 4.5 cm and total tumor diameter < 8 cm	
No evidence of gross vascular invasion	
Exclusion criteria	
Age < 18 y	
Already enrolled in present study once	
GFR < 30 mL/min/1.73 m ²	
Suspected extrahepatic supply on cross-sectional imaging	
Poor-quality diagnostic study: tumors could not be characterized properly	

Note.—AASLD = American Association for the Study of Liver Diseases, GFR = glomerular filtration rate, HCC = hepatocellular carcinoma, MR = magnetic resonance, UCSF = University of California, San Francisco.

tients are typically treated with superselective catheterization (Table 1).

Modality Assignment

Alternating patients for each operator were randomly assigned to undergo DSA alone (control group) or complementary use of DSA and C-arm CT (test group). The operators were blinded to the modality assignment until after it was assigned and were not allowed to influence or change the group at the time of assignment.

C-arm CT imaging was obtained in all patients, including those randomized to the control group. However, in this group, the acquisition was not reconstructed or reviewed by the operator until after superselective DSA imaging was performed. The rationale for obtaining C-arm CT in all patients was based on published data (7,8) that indicate that a C-arm CT examination can provide information that is not detected by DSA that could alter the patient's treatment or transplantation status. For the purposes of the present study, when calculating the radiation exposure for the control group, the dose accumulated from the C-arm CT was subtracted from the total dose for appropriate comparison.

Protocol

The protocol for both arms is described in Figure 1 and briefly summarized in the subsequent sections. Fluoroscopy and/or DSA imaging was used to catheterize the celiac artery and advance an angiographic catheter into the common hepatic artery. Similar techniques were used in patients with variant hepatic artery anatomy.

Standard DSA-only group. In the DSA-only group, catheterization of the common hepatic artery was first per-

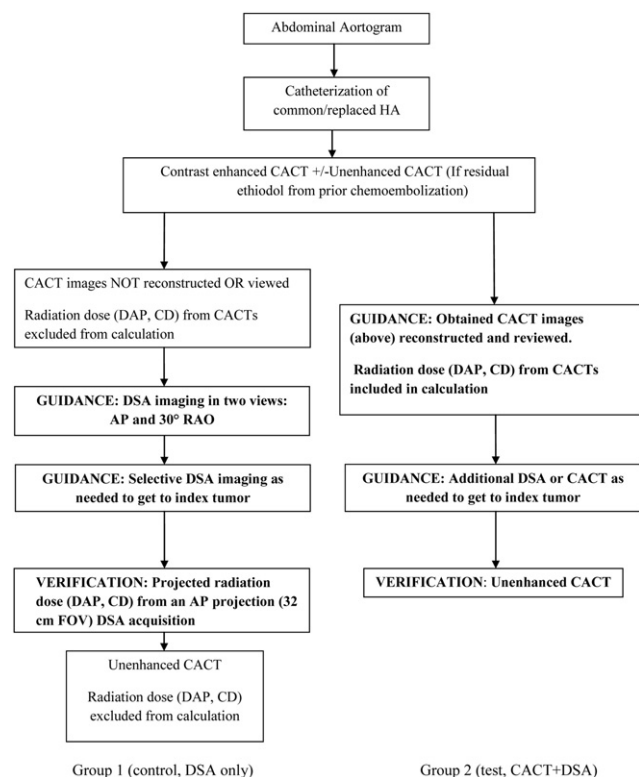


Figure 1. Schema for imaging protocol for both arms of the study. Blocks labeled “guidance” or “verification” in each arm were used to calculate accumulated DAP and CD.

formed, followed by an unenhanced (in patients with residual Ethiodol from previous chemoembolization) and/or contrast-enhanced C-arm CT scan, with the C-arm CT data not reconstructed or reviewed.

Next, conventional DSA imaging with a power injector in two obliquities—anteroposterior and 30° right anterior oblique—was performed, supplemented by additional selective DSA as needed to catheterize the target vessel.

Finally, unenhanced C-arm CT was obtained at the termination of the procedure to evaluate Ethiodol uptake in the tumor and to identify any nontarget embolization (in lieu of a postembolization DSA study). However, the DAP from all C-arm CT acquisitions was subtracted to represent exposure accrued with DSA imaging only.

Combined DSA and C-arm CT group. In the combined C-arm CT and DSA group, catheterization of the common hepatic artery was first performed, followed by an unenhanced and/or contrast-enhanced C-arm CT scan. Three-dimensional (3D) planar and volume rendered maximum-intensity projection (MIP) images were used for planning and navigation.

Next, selective DSA angiograms or additional C-arm CT acquisitions were obtained only as deemed necessary for superselective catheterization. Completion unenhanced C-arm CT was then performed to evaluate Ethiodol uptake in the tumor, as well as any nontarget embolization.

Note was made of tumors that required selective cath-

eterization of two or more segmental vessels and were termed “complex.” For patients with two or more vessels supplying the same tumor, the DAP reflected the dose required to treat the entire tumor; for tumors in two separate Couinaud segments, the DAP reflected the dose accumulated to reach the first dominant tumor.

Crossover between treatment groups was allowed in the interest of patient care. In the control group, the operator was allowed to use C-arm CT if he or she was unable to visualize the tumor with DSA or unable to identify the tumor-supplying artery despite multiple DSA acquisitions. In the test group, the operator was allowed to revert back to DSA alone if the quality of the C-arm CT images were degraded by respiratory artifact. Collective data were recorded for all patients, but comparative statistical analysis was done only between cases in which crossover did not occur, allowing for a comparison of the modalities under optimal conditions.

Chemoembolization Technique

All chemoembolization procedures in the study cohort were performed by one of four board-certified interventional radiologists specializing in interventional oncology but with a range of years of experience. The angiography units with C-arm CT capability used in this study were installed in 2007, and all operators had at least 2 years of experience in obtaining and reconstructing 3D images. However, for the purposes of data analysis, operators 1 and 2, who had 7 and 13 years of experience and had performed approximately 350 and 700 chemoembolization procedures, respectively, were considered to be “experienced,” and operators 3 and 4, who had 2 and 3 years of experience and had performed 90 and 150 chemoembolization procedures, respectively, were considered to be “less experienced.”

Procedures were performed in a single-plane angiography suite capable of C-arm CT (Axiom Artis dTA ceiling-mounted system with DynaCT; Siemens, Forchheim, Germany) with a 30-cm × 40-cm flat-panel detector. All C-arm CT acquisitions were obtained by using technical parameters previously reported (2,7,9).

Chemoembolization procedures were performed in a routine fashion as described previously, with an emulsion of cisplatin, doxorubicin (maximum of 50 mg each), and Ethiodol (10–20 mL) delivered in a superselective fashion under fluoroscopic guidance (7,10). Treatment strategies were identical in both arms of the study.

Data Collection and Outcome Analysis

As C-arm CT is performed after catheterization of a visceral artery, the data reported later reflect that gathered after placement of the catheter in the common hepatic artery. This allowed a more equitable comparison of the differences in radiation exposure for the parts of the procedure that would be affected by the availability of C-arm CT. The procedure was divided into two phases, guidance and verification, as described in the subsequent sections.

DAP, a measurement of the entire amount of energy delivered to the patient by the beam, was used as an indicator for the stochastic risk (1). CD, a measurement of the total radiation to the skin, summed for the entire body, was used to measure the deterministic risk (1). Both measures are well accepted surrogates for the more precise—but logistically difficult—effective dose and PSD (1).

Guidance Imaging Dose

DAP (in Gy·cm²) was defined as the radiation dose per square meter of exposed skin accumulated from catheterization of the common or replaced hepatic artery to superselective catheterization of the dominant tumor vessel(s). In the control group, this included the DAP from DSA imaging in two obliquities and DSA imaging for selective catheterization. In the test group, this included the DAP from the C-arm CT acquisitions and DSA imaging needed to reach the target.

As 3D data from C-arm CT can replace the data from multiple DSA acquisitions, the number of DSA acquisitions and the associated DAP from the DSA itself was compared.

The CD from DSA is concentrated in the right upper quadrant and distributed over 200° in C-arm CT. Replacing or reducing DSA imaging, in theory, should decrease CD to the right upper quadrant. To measure this effect, we compared the CD (in mGy) accrued by DSA imaging in both arms.

Verification Imaging Dose

As a qualitative surrogate to gauge the adequacy of chemoembolization, uptake of Ethiodol in the tumor was evaluated by C-arm CT. In the test group, the DAP from the postembolization C-arm CT was included, and in the control group, the DAP accumulated during DSA with a 32-cm field of view in the anteroposterior plane was used as an approximation of the DAP to which the patient would have been exposed if a postembolization angiogram had been acquired.

As secondary endpoints, data on the total volume of iodinated contrast medium used and the procedural time were collected and analyzed. Failed acquisitions, eg, as a result of contrast medium injector malfunction or operator error, were excluded from the final calculation.

Because most endpoints had skewed distributions, multivariate quantile (median) regressions of each endpoint were used to assess the effects of imaging modality, operator experience, and their potential interaction. Although the tabulated numbers reflect raw data, all regressions used body mass index as a covariate to remove the effect of body mass index as a confounding factor. Count data were analyzed by negative binomial regression. In all regressions, robust variance estimators were used. Model fit was estimated by linear correlation of predicted versus observed values. Percentage variation of the test group from the control group was reported. All statistical analyses were performed by using Stata software (release 9.2; StataCorp, College Station, Texas). A significance level of 0.05 was used.

Table 2. Patient and Tumor Characteristics

Characteristic	DSA Only	C-arm CT/DSA
Age (y)		
Mean	63	66
Range	44–86	50–84
Sex		
Male	29 (70.3)	37 (86)
Female	12 (29.3)	6 (14)
Mean BMI (kg/m ²)		
Mean ± SD	27.4 ± 6.92	28.2 ± 5.59
Range	18.2–46.1	17.4–42.3
Etiology		
Hepatitis C	16	27
Hepatitis B	11	5
Alcohol	3	8
Hepatitis C/alcohol	6	1
Cryptogenic	4	2
Primary biliary cirrhosis	1	—
Pretreatment cross-sectional imaging		
Triphasic CT	34	30
Multiphase MR imaging	7	13
Pts. with chemoembolization before enrollment	16	22
Index tumor size (cm)		
Mean ± SD	2.9 ± 1.4	2.8 ± 1.3
Range	1–6.5	1.6–5.8

Note.—Values in parentheses are percentages. BMI = body mass index, MR = magnetic resonance.

RESULTS

Patient Population

Patient and tumor characteristics were similar between the two groups and are summarized in **Tables 2 and 3**. The cohort included 87 patients: 68 men and 19 women. The time interval between diagnostic cross-sectional imaging and chemoembolization was 32 days (median, 26 d ± 19.5 [SD]; range, 1–81 d). Three patients were excluded because of progression to multifocal disease at the time of therapy, inability to visualize tumor by either modality, and iatrogenic complication (femoral artery injury), leaving 84 patients: 41 patients in the DSA-only control group and 43 in the C-arm CT/DSA test group.

The majority of procedures (n = 62; 73.8%) required catheterization of only a single tumor-supplying artery, and distribution of these cases was similar between the two groups. Although each operator was expected to enroll 40 patients (20 in each arm), a shortage of Ethiodol throughout the United States necessitated early termination of the study. Hence, a disparately large number of patients (n = 60; 71.4%) were treated by the more experienced operators with mature practices that allowed easy accrual.

The assigned modality was sufficient for tumor targeting in 33 patients (80.5%) in the control group and 39

Table 3. Case Distribution between Treatment Groups

Variable	DSA Only	C-arm CT/DSA
Pts. enrolled and completed study	41	43
Pts. enrolled but excluded from study	2	1
Complexity		
Simple	32 (78)	30 (70)
Complex	9 (22)	13 (30)
Operator experience		
Experienced	30	30
Less experienced	11	13
Procedures completed on protocol		
Assigned modality sufficient for targeting	33 (80.5)	39 (90.7)
Crossover to alternate imaging modality	8 (19.5)	4 (9.3)

Note.—Values in parentheses are percentages.

patients (90.7%) in the test group ($P = .22$), for a total of 72 patients (85.7%; **Table 4**). The remaining 12 patients (14.3%) crossed over to the other treatment group and underwent the alternate imaging modality. The proportion of patients in whom the assigned imaging modality was adequate did not vary with complexity ($P = .285$).

Guidance

In the test group ($n = 39$ C-arm CT acquisitions), the experienced operators required a median of one C-arm CT acquisition per patient (mean, 1.5 ± 0.8) for the purpose of guidance, and the less experienced operators required a median of two (mean, 2 ± 1). Each of the three patients had one C-arm CT acquisition removed from the calculation because of technical error (two injector malfunctions and one case of improper patient positioning).

Total DAP. In the control group, the mean total (unadjusted) DAP used for guidance was $137.4 \text{ Gy}\cdot\text{cm}^2$, compared with $184.2 \text{ Gy}\cdot\text{cm}^2$ in the test group—a 34% difference (95% CI, 101.1–173.7 vs 148.2–220.2; $P = .03$; **Fig 2**). Operator experience did not play a role in the control group, but in the test group, the total DAP for the less experienced operators was twice that for the more experienced operators ($276.8 \text{ Gy}\cdot\text{cm}^2$ vs $143 \text{ Gy}\cdot\text{cm}^2$, respectively). In other words, the difference in the DAP between the two arms was negligible for the seasoned operators (+7.5%) and substantial for the less experienced operators (+75%). This interaction of the increased DAP from C-arm CT when used by less experienced operators was statistically significant ($P = .04$).

Use of DSA for guidance. Fewer DSA acquisitions were obtained in the test group because of the availability of C-arm CT (mean, 4.4 vs 5.4; 95% CI, 3.8–5.1, 4.7–6.3; $P = .007$), resulting in a lower DAP from DSA in the test group ($92.4 \text{ Gy}\cdot\text{cm}^2$) than in the control group (137.4

$\text{Gy}\cdot\text{cm}^2$; 95% CI, 67.2–117.6 vs 101.1–173.7; $P = .007$). Experienced operators were more successful in using 3D data provided by C-arm CT to replace the data from DSA imaging. In the test group, experienced operators needed a mean of 3.2 DSA runs per patient, compared with 7.3 among less experienced operators. In the control group, experienced operators used a mean of 5.1 DSA runs, compared with 7.2 among the less experienced operators ($P < .001$). Consequently, the DSA-associated DAP in the test group was substantially lower (by 53.5%) than that in the control group for the experienced operators (mean $62.2 \text{ Gy}\cdot\text{cm}^2$ vs $133.8 \text{ Gy}\cdot\text{cm}^2$), but not for the less experienced operators (+2.8% in the test group; $P < .001$; **Fig 3**). By decreasing the number of DSA acquisitions, experienced operators decreased the CD from DSA, with a mean of 784.7 mGy for the control group versus 626.4 mGy for the test group (95% CI, 537.3–1,032.1 mGy and 439.5–813.3 mGy, respectively; $P = .017$; **Fig 4**).

Verification

The DAP of $56 \text{ Gy}\cdot\text{cm}^2$ (95% CI, 52.4–59.8) accumulated from the use of C-arm CT to verify accurate targeting was double the DAP of $26.7 \text{ Gy}\cdot\text{cm}^2$ (95% CI, 18.5–34.6) accumulated from standard postembolization DSA acquisition ($P < .001$). Deterministic effects, including radiation-induced transient erythema, epilation, moist desquamation, or skin ulceration, were not observed in any of the enrolled patients, including those who crossed over and hence had a lengthier procedure. CD accumulated to the right upper quadrant as a result of DSA imaging was less than 1 Gy for most patients (25 of 33 in the control group and 31 of 39 in the test group). The 3-Gy threshold was crossed in one patient in the control group (3.8 Gy).

The amount of iodinated contrast medium used for guidance was significantly greater ($P < .001$) in the control group (mean, 67 mL; 95% CI, 60.6–73.5) than in the test group (mean, 50.3 mL; 95% CI, 46.2–54.5). As completion C-arm CT is unenhanced, one can further extrapolate that this difference would be greater if one were to include a standard contrast-enhanced postembolization DSA acquisition in the control group. There was no statistically significant difference in contrast agent use between operator subgroups ($P = .24$). Mean volumes of contrast agent used in the control and test groups were 68.1 mL and 49 mL, respectively, for the experienced operators and 60.8 mL and 53.4 mL, respectively, for the less experienced operators.

Reconstruction and review of C-arm CT images did not add significantly to the procedure time. Experienced operators required less time to get to the target ($P < .001$), but there was no difference between the two modalities ($P = .57$). Operators with experience were more efficient in terms of time (88 min vs 99 min in control and test groups, respectively) than those with less experience (109 min vs 141 min in control and test groups, respectively).

Table 4. DAP and CD Results Based on Operator Experience

Group	Overall (N = 72)	Experienced Operators (n = 55)	Less Experienced Operators (n = 17)
Guidance: total DAP (Gy·cm²)			
DSA only	137.4 (101.1–173.7)	133.8 (95.1–172.5)	157.6 (35.3–279.9)
C-arm CT/DSA	184.2 (148.2–220.2)	143 (112.4–173.7)	276.8 (200.5–353.1)
Δ vs DSA	+34% (P = .03)	+7.5%	+75%
Guidance: DSA DAP (Gy·cm²)			
DSA only	137.4 (101.1–173.7)	133.8 (95.1–172.5)	157.6 (35.3–279.9)
C-arm CT/DSA	92.4 (67.2–117.6)	62.2 (43.4–81)	160.4 (103.7–217.1)
Δ vs DSA	–32.7% (P = .007)	–53.5%	+2.8%
Guidance: DSA runs			
DSA only	5.4 (4.7–6.3)	5.1 (4.3–6)	7.2 (5.2–9.9)
C-arm CT/DSA	4.4 (3.8–5.1) (P = .007)	3.2 (2.5–3.9)	7.3 (5.9–8.9)
Guidance: DSA CD (mGy)			
DSA only	784.7 (537.3–1,032.1)	771.3 (489.7–1,052.9)	859.9 (315.1–1,404.7)
C-arm CT/DSA	626.4 (439.5–813.3)	416.4 (277.6–555.2)	1,099 (655.2–1,542.9)
Δ vs DSA	–20.2% (P = .017)	–46%	+27.8%
Verification: DAP (Gy·cm²)			
DSA only	26.7 (18.5–34.6)	—	—
C-arm CT/DSA	56 (52.4–59.8)	—	—
Δ vs DSA	+109.7% (P < .001)	—	—

Note.—Values in parentheses are 95% CIs. CD = cumulative dose, DAP = dose-area product, DSA = digital subtraction angiography.

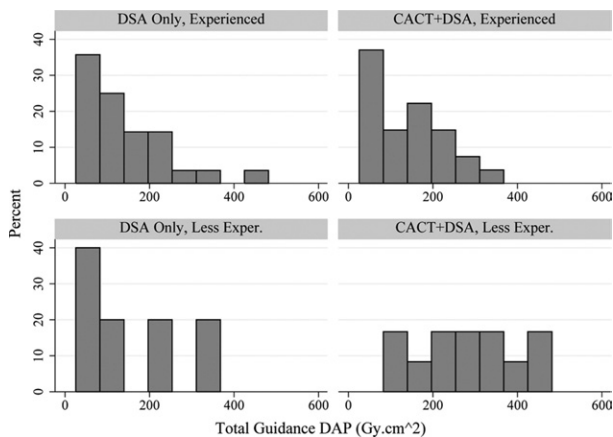


Figure 2. Histogram demonstrates total DAP accumulated during guidance phase of the procedure. The test group accumulated an average of 34% more DAP than the control group (P = .03). However, when stratifying for experience, the experienced operators had a marginal (7.5%) increase in DAP compared with less experienced operators, who had a much higher total DAP (P = .04).

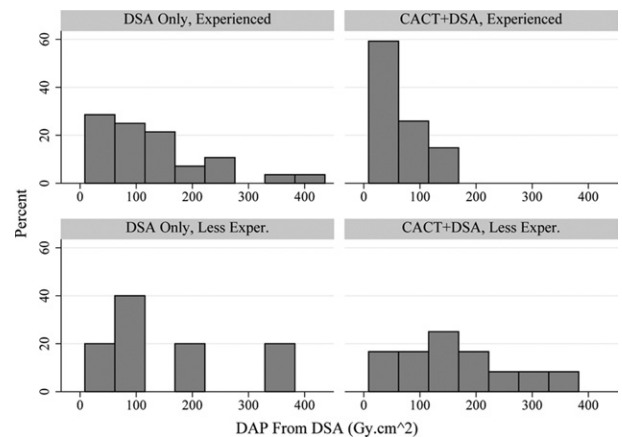


Figure 3. Histogram demonstrates mean DAP from DSA imaging accumulated during guidance phase of the procedure. Experienced operators successfully replaced a large portion of DSA imaging by a single rotational C-arm CT examination, resulting in 50% less DAP from DSA in the test group. Less experienced operators obtained more DSA images, leading to a greater DAP.

Subjective Analysis

Twelve patients (14.3%) crossed over to the other study group, including eight from the control group (19.5%) and four from the test group (9.3%; P = .22; Table 5). Experienced operators kept a greater proportion of patients in their assigned imaging arm than operators with less experience (91.7% vs 70.8%; P = .033). C-arm CT image degradation caused by respiratory artifact led to crossover

in the test group. Inability to identify and/or characterize the tumor on DSA (n = 4; Fig 5), confirm complete targeting of watershed tumors (n = 2), or identify of the “culprit” tumor-supplying vessel (n = 2) led to crossover in the DSA-only group.

Although deviation from the assigned protocol occurred in only a small percentage of patients, a subjective analysis of operator comments revealed that operators relied heavily on C-arm CT in the test group. In nine patients in the C-arm CT

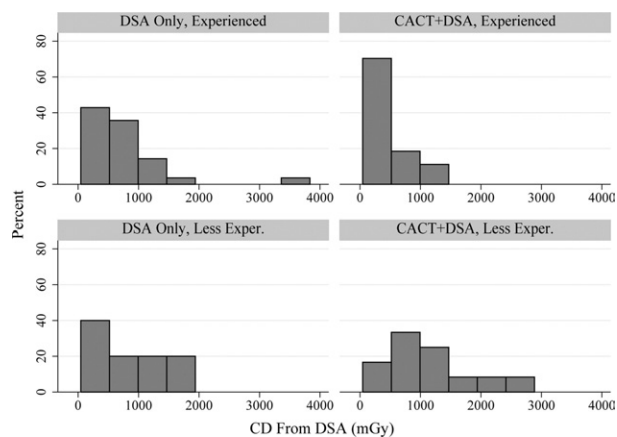


Figure 4. Histogram demonstrates mean CD from DSA imaging accumulated during guidance phase of the procedure. Experienced operators used the 3D imaging obtained from a single C-arm CT study (rotational acquisition over 200°) for navigation to replace multiple DSA acquisitions, thereby decreasing the CD to the liver by 46%. Less experienced operators obtained more DSA images, leading to a higher CD to the liver.

Table 5. Subjective Analysis of Impact of C-arm CT

Subjective Effect	Incidence (N = 84)
Images degraded by respiratory artifact	7 (8.3)
C-arm CT information critical	17 (20.2)
C-arm CT information helpful	14 (16.7)

Note.—Values in parentheses are percentages.

arm (20.9%), C-arm CT provided critical information that included recognition of incomplete treatment of tumors triggering additional selective catheterizations ($n = 4$), visualization of tumors that were not easily recognizable on DSA ($n = 3$), and extreme tortuosity of vessels requiring 3D MIP images to aid catheterization of the culprit vessel ($n = 2$). In an additional seven patients (16.3%), 3D MIP images from a single C-arm CT acquisition determined a complex C-arm tube angulation that best delineated the origin of the tumor-supplying vessel. Hence, C-arm CT helped solve a problem or provided additional information in 37.2% of the patients in this treatment group. In the control group, in which only DSA was available, operators indicated that C-arm CT would have provided valuable information in seven patients (17%) in addition to the eight patients who crossed over to the test group. This included easier tumor detection and characterization ($n = 5$) and navigation ($n = 2$). Overall, operators believed that C-arm CT provided critical or helpful information in 20.2% of patients ($n = 17$) and would have provided critical or helpful information in 16.7% ($n = 14$).

In contrast, C-arm CT images were severely degraded as a result of respiratory artifact in seven patients (8.3%), including the four patients who crossed over from the test group to the DSA-only group. DSA images were also degraded in these patients, but to a lesser extent.

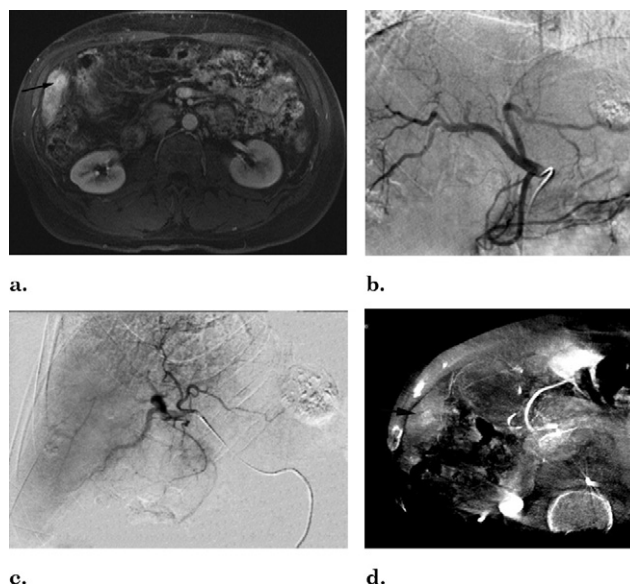


Figure 5. Angiographically occult tumor in a 55-year-old man with HCC secondary to hepatitis C. (a) Preprocedural contrast-enhanced magnetic resonance image obtained in the arterial phase demonstrates a hypervascular tumor (arrow) in segment V. DSA image (right anterior oblique, 30°) obtained during contrast medium injection into the common hepatic artery (b) and selective catheterization (c) does not demonstrate a hypervascular mass in the expected location. (d) C-arm CT scan obtained during injection of the common hepatic artery demonstrates the segment V tumor (arrow) that was not visualized on DSA.

DISCUSSION

The safety of Lipiodol-based hepatic arterial chemoembolization depends on accurate visualization and precise targeting of the tumor. Superselective catheterization, rather than lobar embolization, minimizes nontarget drug delivery and toxicity (11–13) while maximizing the effect on the tumor itself (10–12,14,15). However, superselective catheterization with DSA imaging alone has its limitations, and the complementary role of C-arm CT in these procedures has been well explored in recent years (7,8,16,17). MIP and volume-rendered images provided by C-arm CT serve as important navigational tools in nodular cirrhotic livers (7,18). Small HCCs discovered on early screening that may not be apparent on DSA images are often readily apparent on an arterially enhanced C-arm CT because of the high spatial resolution and soft-tissue contrast of that modality (7,8,17,19). In addition, 3D verification of Ethiodol uptake on C-arm CT can detect untreated portions of the tumor, triggering the search for additional feeding vessels (7,8,16). Finally, soft-tissue information provided by C-arm CT can be used in context with the adjacent structures to identify enhancement of nontargeted tissues such as bowel (7,20), as well as extrahepatic supply to a tumor (21).

The results of the present study again highlight the utility of C-arm CT as a vital problem-solving tool for transarterial treatment of hepatic malignancies, as it provided treatment-altering information in 20.2% of patients and additional help-

ful information in another 16.7% patients. Despite the known merit of C-arm CT, concerns about additional radiation exposure, administration of additional iodinated contrast medium, and the time expended to perform rotational acquisitions rightfully exist (7,8,17,22,23). These concerns, although not rigorously validated, have precluded the routine use of C-arm CT for hepatic interventions.

Guidelines from the United States Food and Drug administration (24), International Commission on Radiological Protection (25), and American College of Radiology (26) highlight the importance of monitoring and recording patient radiation dose. The most widely used metrics of patient radiation dose in interventional radiology are fluoroscopy time, DAP, CD, and PSD. Fluoroscopy time is the most widely available, but is not accurate (1). DAP is a more widely accepted measure and is a good indicator of stochastic risks (1,27). Effective dose, an even more precise indicator of stochastic risks, can be calculated from the DAP by using a conversion coefficient. However, the coefficients vary by institution and equipment, making these calculations tedious and possibly incorrect (28). Hence, for all practical purposes, DAP itself is considered an adequate surrogate for stochastic risks (1). PSD measures the highest accumulate dose to any portion of the patient's skin during the procedure and is a precise indicator of deterministic injuries, but is again tedious to measure (1). Therefore, CD is the more commonly recorded method to determine the patient's risk for x-ray-induced skin injury (1,29). CD is an approximation of the skin dose summed over the entire body. However, common practice is to angulate the x-ray beam during the procedure, making CD an overestimation of the PSD (1,3,29,30).

As one would expect, C-arm CT does increase the overall patient DAP and can therefore influence stochastic risk. Complex Monte Carlo simulations that predict individual patient's risk for radiation-induced cancer were not performed here. Instead, the percentage variation from standard DSA imaging was reported, as the benefit of the therapy outweighed the risk of radiation-induced cancer in this patient population. Based on our observations, we believe this increment can be minimized to less than 10% when DSA and C-arm CT are used prudently. As a matter of fact, the DAP in both our patient groups was well within the range proposed by Miller et al (31) for hepatic chemoembolization with DSA alone. In addition, as perspective, Hidajat et al (32) demonstrated that the risk estimation of radiation-induced fatal cancer in patients undergoing chemoembolization is on the magnitude of 10^{-4} , and even in the case of repetitive procedures, this risk was less than 0.1%. Despite the overall low risk, it is important to acknowledge that operator experience plays a key role in efficiencies that further minimize the stochastic risk to the patient, and the present study was no exception. Detailed knowledge of the hepatic vascular anatomy, ability to discern the tumor-feeding artery in cirrhotic livers, substitution of multiple DSA acquisitions with a 3D roadmap for navigational purposes, limiting or preferably eliminating midprocedure superselective C-arm CT, and limiting the use of magnified DSA

runs are some of the techniques that decrease the DAP and were routinely used by the more experienced operators.

The addition of a completion C-arm CT does increase the DAP significantly, irrespective of operator experience, and brings into discussion the necessity of a completion C-arm CT. Unquestionably, C-arm CT provides a more concrete demonstration of deposition, revealing areas of incomplete treatment (7,8,16). Based on studies correlating the efficacy of chemoembolization to the degree of Ethiodol retention (33), it is not unusual in practices with DSA-only systems to obtain an unenhanced CT image immediately after the procedure for this purpose. Although effective organ dose from a multiple-detector CT varies with patient size, CT parameters, and slice thickness, on average, it ranges between 5 and 16 mSv (34,35), compared with approximately 7 mSv for a standard 8-second C-arm CT rotation. In this scenario, a completion C-arm CT scan can serve the same purpose, is more convenient, and eases the burden on limited health-care resources, all with a similar radiation dose. Needless to say, if a completion C-arm CT scan is not deemed necessary, it should be avoided altogether.

On the other hand, C-arm CT significantly decreases the risk of deterministic injuries in this patient population. The present study demonstrated that that judicious use of C-arm CT can replace some or all of the DSA acquisitions, thereby decreasing the DSA-related skin dose concentrated to the right upper quadrant. This is of particular importance in view of the lengthy nature of these procedures, which frequently require higher pulse fluoroscopy and magnified images, and for which practically the entire dose is concentrated to a small area of the body (1,3,4,32). Compared with other interventional procedures, chemoembolization procedures are considered to be high-dose procedures, during which CD can exceed 1 Gy and reach 5 Gy in some instances (4,29,31,32). The rotational nature of the C-arm CT acquisition confers a dose advantage to the patient. By using the RAD-IR study (29) to convert between DAP and PSD, our preliminary results indicate that the PSD for an abdominal C-arm CT is 0.3 ± 0.15 of the PSD that would result if the same dose was deposited at a single imaging angle, as in DSA acquisitions. Moreover, in the present study, the CD absorbed by most patients was well within the American College of Radiology's 3-Gy threshold for detailed follow-up (26).

Finally, the use of C-arm CT significantly reduces the volume of iodinated contrast medium used for the procedure while increasing the amount of information obtained compared with DSA only. In patients with cirrhosis and associated renal dysfunction, that in itself may be an important consideration.

Limitations of the present study include inherent heterogeneity among the patient groups and operators. The study reports the dose from the portion of the entire procedure that would be affected by the availability of C-arm CT in the interest of effectively comparing C-arm CT and DSA. For similar reasons, calculations were terminated after the index tumor had been reached, as the delivery rate of the

chemotherapeutic drugs can vary highly among patients. For ethical reasons, we were unable to subject the patients in the DSA group to purely DSA alone for a true head-to-head comparison. Hence, the reported data in the DSA-only group reflects the calculated or adjusted dose. Finally, subjective comments (**Table 5**) vary among operators and are often influenced by individual preferences.

In conclusion, C-arm CT continues to prove to be a valuable tool in hepatic chemoembolization, often providing information that is not available by DSA alone. In experienced hands, use of C-arm CT can result in a negligible increase in DAP and therefore stochastic risk. In addition, C-arm CT can replace some of the DSA acquisitions, and by distributing the skin dose of radiation over a range of 200°, it significantly reduces the possibility of deterministic injury. Less iodinated contrast medium is generally needed when C-arm CT is used, which can be an important issue for patients at risk for hepatorenal syndrome. Like any other radiation-emitting modality, C-arm CT should be used judiciously.

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