Original Article

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Assessment of Radiation Dose and Phantom Skin Dose in Transarterial Chemoembolization in a Single Center with 2 Digital Subtraction Angiography Units

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Abstract:

Objectives: This study aimed to assess and compare the radiation dose and phantom skin dose in transarterial chemoembolization (TACE) of two digital subtraction angiography (DSA) units (unit A: Philips Allura Xper FD20, unit B: Artis zee biplane)

Material and Methods: The dose area product (DAP), reference air kerma (RAK), number of images (NI) and fluoroscopy time (FT) of 240 cases (120 cases/DSA unit) were retrospectively reviewed and collected. To assess skin dose, 28 nanoDot optically stimulated luminescence dosimeters (OSLDs) were placed on the phantom's back and the TACE procedure was performed with 2 DSA units.

Results: The median DAP, RAK, NI, and FT of unit A were 200.49 Gy·cm^2, 379.84 mGy, 115 images, and 9.04 minutes, while for unit B were 109.74 Gy·cm^2, 276.55 mGy, 121 images, and 10.19 minutes, respectively. Significant differences were observed in DAP, RAK, and FT. The RAK of all patients was less than 2 Gy. The phantom skin dose obtained from unit B was significantly lower than that of unit A in all positions. The peak skin doses of the phantom studies from both units were 973.15 and 658.66 mGy, respectively.

Conclusion: The median DAP of the unit A DSA was higher than the national diagnostic reference levels (DRLs). The TACE procedure from both units is safe from skin reaction. To benefit patients, the planning of a dose optimization process of unit A DSA and management of TACE cases using the existing DSA machine must be considered.

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Introduction

It has been reported that liver cancer is the sixth most commonly found new cancer, and the third leading cause of cancer death in the world[1]. In Thailand, liver cancer has the highest number of new cases and is the most common cause of death[2]. Hepatocellular carcinoma (HCC) is a primary tumor of the liver and transarterial chemoembolization (TACE) is the first choice of treatment in intermediate state HCC with well-defined nodules, and the second line of treatment for the early state if the first treatment option is not feasible or fails[3–5]. TACE is the process of injecting chemotherapy drugs directly into the cancerous lump via its supply artery with the assistance of a small catheter and a digital subtraction angiography (DSA) machine which produces a high radiation dose. It is interesting that TACE is one of the most common interventional radiological procedures. In our institute, TACE was performed using 2 DSA units based on different technologies and angiographic parameters. Unit A has been established since 2007 while unit B has been used since 2013. It has been reported that numerous factors influence the radiation dose received by both patients and staff including the different DSA technologies[6–10]. The monitoring of radiation doses has become an important issue for radiation safety and an opportunity for optimization in the TACE procedure.

Diagnostic reference levels (DRLs) is an important tool for radiation dose optimization and patient radiation safety[11]. Determination of radiation dose is based on the measurement of various parameters including dose area product (DAP), reference air kerma (RAK), fluoroscopy time and number of angiographic images using a DAP meter.[12] Several lines of evidence have demonstrated national DRLs (NDRLs) or local DRLs (LDRLs) of the TACE procedure, including in Thailand[11–15]. Since the 2 DSA units have been used in performing the TACE procedure at our institute, the assessment of typical values of radiation dose of both DSA units is required for the further optimization process following the International Commission on Radiological Protection (ICRP) recommendation[16]. Therefore, this issue has been focused on.

The reference air kerma or RAK is the measurement of cumulative air kerma at the reference point which is used as a crude estimation of patient skin dose[17]. At present, the peak skin dose or real-time peak skin dose can be monitored by a DSA machine with the new technology[13]. Both RAK and peak skin dose can be used to predict the deterministic effect from a fluoroscopic guidance procedure[18,19]. Therefore, knowing the actual skin radiation dose could be used to monitor the deterministic effects. However, the DSA machines used in our institute do not provide the peak skin dose. In addition, the direct measurement of skin dose by attachment of small dosimeters, such as nanoDot OSLDs, is not convenient and is impractical in clinical practice. The monitoring of skin doses using a nanoDot OSLDs in a phantom study may be beneficial to this issue. Therefore, this study aimed to assess the typical values of radiation dose and phantom skin dose in a TACE procedure from 2 digital subtraction angiography (DSA) units.

Material and Methods

Ethical considerations and study population

This study was a retrospective and phantom study to determine patient radiation dose from a TACE procedure using 2 different DSA units (unit A and unit B). The study method and protocol had been approved by the Institutional Ethics Committee for Human Research (HE641394), while the patient's data collection was authorized by the Director of Hospital.

According to the ICRP 135 report, data for at least 30 patients with a weighing range close to the average weight of the general population were to be collected[16]. Therefore, a retrospective review of 240 patients (120 patients from unit A DSA and 120 patients from unit B DSA) weighing between 40–85 kilograms who underwent TACE during June 2020–June 2021 was conducted.

The TACE procedure

The TACE procedures were performed by 3 interventional radiologists with over 10 years of experience in body interventional radiology. The procedures were performed using 2 DSA units: unit A was a Philips Allura Xper FD20 (Philips, Amsterdam, Netherlands) while unit B was an Artis zee biplane (Siemens Medical Solutions, Munich, Germany). The working focal spot size of the DSA units was 0.7/0.6 (Unit A/Unit B). The flat panel detectors (30x40cm) were amorphous silicon/cesium iodide (aSi/CsI) with a pixel pitch of 154 µm, 14-bit depth resolution, and X-ray detection efficiency of 73%. Both DSA units were supplied by a 100 kW high-frequency generator. The TACE procedures in all patients were performed via femoral access and under fluoroscopic guidance with a pulse fluoroscopy of 15 pulses/second (p/s). Selective angiography of the celiac artery was performed using a 5F catheter with a field of view (FOV) of 48 cm (diagonal). The super selective angiography of the specific artery was performed with a FOV of 42 cm using a microcatheter. The standard acquisition angiography of unit A was set at 3 frames/second (f/s) for 6 seconds (sec), 2 f/s for 5 sec, and 1 f/s, while unit B was 4 f/s for 4 sec, 2 f/s for 4 sec, and 1 f/s. Mitomycin (6–20 mg) was the standard chemotherapeutic agent while fluorouracil or 5FU (150–500 mg) or mitomycin+5FU were additional treatment options based on the interventionist's criteria. Embolization was performed using gelfoam (Gelfoam®, Pfizer Inc., New York). Lipiodol (Lipiodol® Ultra Fluid, Guerbet Group, Villepinte, France) was mixed with a chemotherapeutic agent and embolic agent for visualization under fluoroscopic guidance. Post-embolization angiography and post-TACE radiography were performed. Both DSA units were annually checked by the Department of Medical Sciences, following the standard guidelines. Dose area product (DAP) meters were also checked for uncertainty. All quality control parameters and the uncertainty of the DAP meters were within the normal limits.

Patient data and radiation dose collection

Patient data were collected retrospectively between June 2020–June 2021 utilizing information from the database of the body interventional radiology (BIR) unit, health object system, and picture archiving communication system (PACs). The general data of all cases, including age, gender, weight, and height were collected. Quantities of dose reference levels (DRLs) including dose area product (DAP), fluoroscopy time (FT), reference air kerma (RAK), and total number of angiographic images (NI) were also collected. All data were recorded into a Microsoft Excel spread sheet.

Phantom study

The phantom study was performed by using an anthropomorphic phantom and nanoDot OSLDs (Landauer Inc., Glenwood, Illinois, USA). To evaluate the phantom skin doses, 28 nanoDot OSLDs were placed on the back of the phantom. The levels of the nanoDot OSLDs placed ranged from the intervertebral space of the L1 lumbar spine to the T10 thoracic spine and laterally to cover the left and the right sides of the back as shown in Figures 1A and 1B. The head and body phantoms were placed on an angiographic table in the same condition as the patient (Figure 1C). Table 1 shows the settings of the TACE protocol and the parameters for a phantom study to compare the skin radiation doses of both DSA units. The FOV during the selective angiography (celiac angiography) and super selective angiography are presented in Figures 1B and 1D, respectively.

NanoDot OSLD preparation and analysis

In this study, the nanoDot OSLDs used were calibrated using the whole body or slab phantom. The photon beam qualities were calibrated from X-ray standard beams. Five nanoDot OSLDs were placed on the slab representing a trunk. These dosimeters were irradiated using X-ray beams of qualities N40, N80, and N100. The delivered air kerma value was 2.0 mGy at 0 degrees angle of incidence. The air kerma values were measured using dosimeter which was calibrated by Physikalisch-Technische Bundesanstalt (PTB), Germany. The (Hp(0.07)) doses were delivered using the conversion coefficients from the ISO 4037:2019 part 3.20 The irradiated nanoDot OSLDs were read using a microStar mobile reader (Landauer Inc., Glenwood, Illinois, USA), which had been was previously calibrated with an X-ray generator at 80 kVp by National Institute of Standard and Technology (NIST), USA. The phantom radiation dose was calculated by subtraction of irradiation dose from the baseline data and multiplied with the correction factor. The data were presented in mGy.

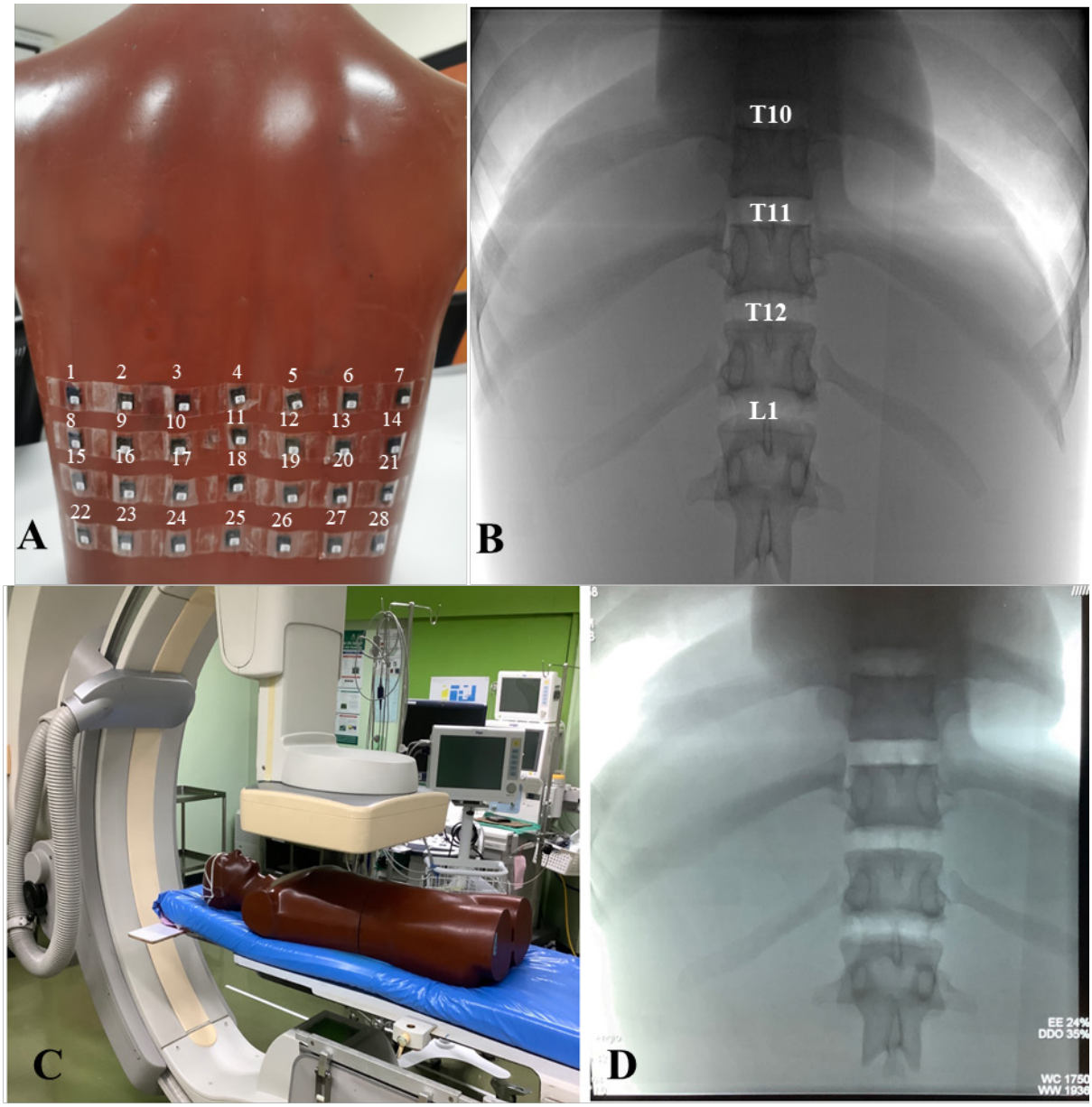
Statistical analysis

Data analysis was performed using IBM® SPSS® Statistics 21. Patient radiation doses and related data from both DSA units were examined using descriptive analysis and reported as means±S.D. and medians. The data of the phantom study are presented as means±S.D. The comparative analysis of radiation dose parameters, age, BMI, and DRL quantities data from the two DSA units were performed using the Mann Whitney U-test, while gender was analyzed using the Fisher's exact test. The phantom study was analyzed using paired t-test. In addition, the correlations of DRL quantities and body mass index (BMI) were also investigated using Spearman's rho correlation test. A significant difference was defined as a p-value of less than 0.05.

Table 1 Angiographic protocol and parameters for TACE procedure from 2 DSA units

Angiographic protocol and parameters	Unit A	Unit B
SID	93 cm	107 cm
SOD	55 cm	55 cm
Fluoroscopy technique	15 p/s	15 p/s
	12 minutes	12 minutes
Exposure parameters	AEC with small focal spot	AEC with small focal spot
Frame rate	3 f/s for 6 sec	4 f/s for 4 sec
	2 f/s for 3 sec	2 f/s for 4 sec
Total image	121 with 5 series of acquisition angiography	
Selective angiography (Celiac angiography)	24 images (FOV 48 cm)	24 images (FOV 48 cm)
Super selective angiography	72 images (FOV 42 cm)	72 images (FOV 42 cm)
Post-embolization angiography	24 images (FOV 48 cm)	24 images (FOV 48 cm)
Post TACE radiography	1 image	1 image

FOV=field of view and 48 and 42 cm were the diagonal size of FOV, TACE=transarterial chemoembolization, DSA=digital subtraction angiography, SID=source to image distance, SOD=source to object distance, AEC=automatic exposure control



OSLDs=optically stimulated luminescence dosimeters, FOV=field of view

Figure 1 The placement of 28 nanoDot OSLDs on the phantom back and the number of each nanoDot OSLD placed on the phantom back (A), The position of each nanoDot OSLD was marked by using intervertebral space as a landmark from L1 to T10 and FOV during a selective angiography (B), the setting of the phantom on the angiographic table (C) and FOV during a super selective angiography (D).

Results

Demographic data of participants

The demographic information for all participants who underwent TACE from both DSA units is shown in Table 2. The majority of the TACE patients were male with the percentages of 79.20 and 81.70 from units A and B, respectively. The median age of the patients from units A and B was 60 years old. There were no significant differences between the two DSA units. However, the median BMI of the unit A patients (23.43) was significantly higher than that of the unit B patients (21.71) (p-value<0.001).

Median values of the DRL quantities

The median values of the DRL quantities are listed in Table 3. The median DAP and RAK obtained from unit A (200 Gy·cm^2, 397.84 mGy) were significantly higher than those from unit B (109.74 Gy·cm^2, 276.55 mGy, respectively) (p-value<0.001). However, the fluoroscopy time of unit A (9.04 minutes) was significantly shorter than that of unit B (10.19 minutes) (p-value=0.034). The results showed that the median DAP of the TACE procedure from unit A was much higher than that of the national DRLs (141 Gy·cm^2)[14]. No patients from any DSA unit had a RAK value greater than 2 Gy.

Phantom skin dose and peak skin dose

Figure 2 depicts the phantom skin doses obtained from the TACE procedure in the phantom study. Except for the 22nd nanoDot OSLD, the skin doses obtained from unit B in all positions were significantly lower than those of unit A (p-value<0.05, all). The highest TACE skin doses of units A and B were 973.15 and 658.66 mGy, respectively.

Correlation of DRL quantities and BMI

Since BMI differed significantly between the two DSA units, the correlation between DRL quantities and BMI was further investigated. It was found that the correlations between BMI and DRL quantities including DAP, RAK, and fluoroscopy time were statistically significant (p-value <0.001, 0.001, and 0.002, respectively). As shown in Table 4, BMI had a strong positive relationship with DAP and RAK but a weak negative relationship with fluoroscopy time (r=0.417, 0.466, -0.196, respectively).

Discussion

This study examined the typical patient radiation dose and phantom skin dose obtained from the TACE procedure in our institute using our 2 different DSA units. The median DAP of unit A, which was higher than the national DRLs[14], allowed us to find strategies to optimize patient radiation dose and manage TACE cases from the existing DSA units. In addition, the peak skin dose and radiation dose distribution data in the phantom study were novel information for our institute. Both RAK and phantom skin dose were less than 2 Gy, which is safe level for skin reaction from the TACE procedure. This finding was in accordance with a previous report[13].

Table 2 Demographic data of patients undergoing TACE from 2 DSA units

Demographic data	Unit A	Unit B	p-value
Gender			
Male	95 (79.17%)	98 (81.67%)	0.745[a]
Female	25 (20.83%)	22 (18.33%)	
BMI	23.43	21.71	<0.001[b]
Age (years)	60.00	60.00	0.619[b]

[a]analyzed using Fisher's exact test, [b]analyzed using Mann–Whitney U test
TACE=transarterial chemoembolization, DSA=digital subtraction angiography

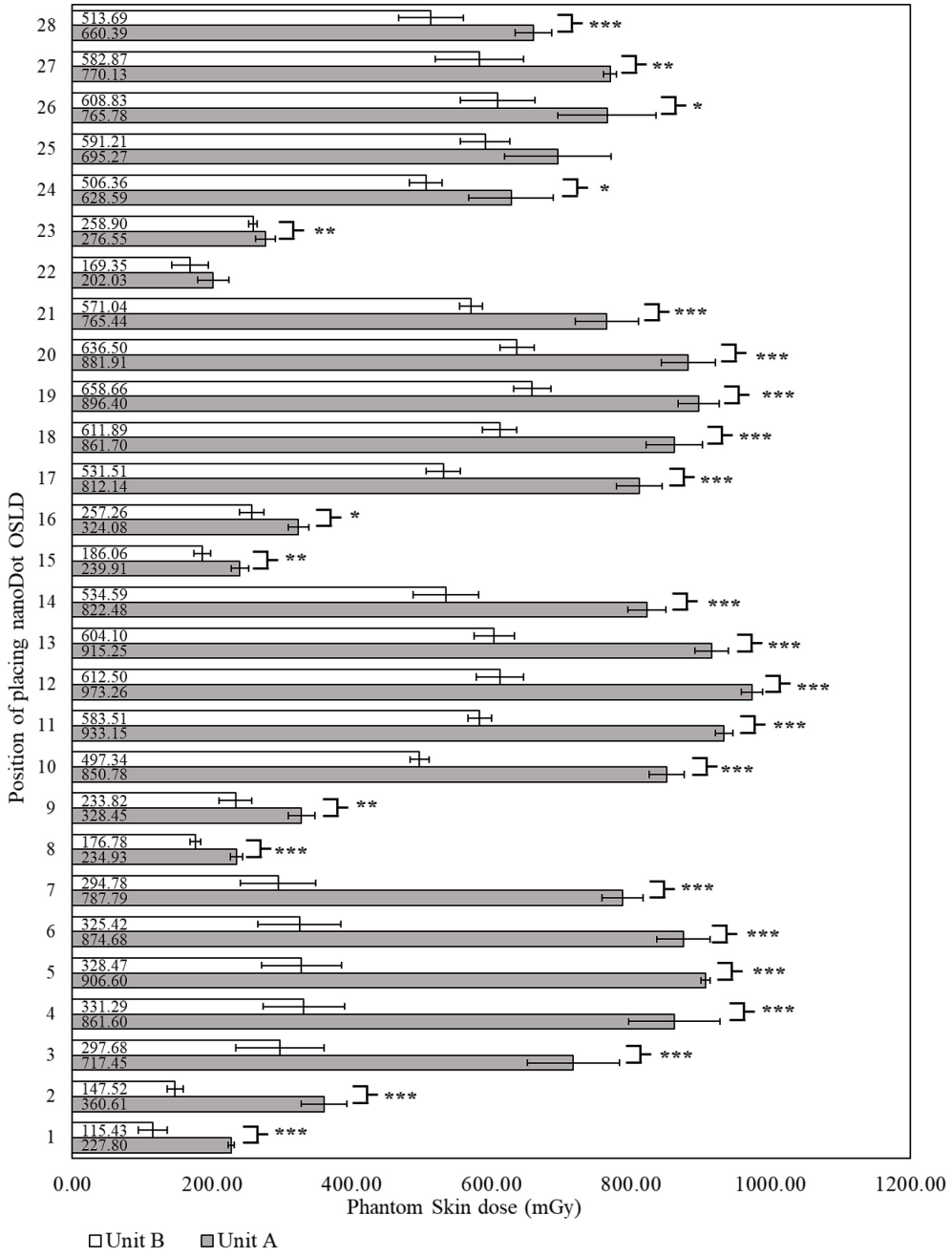
DRLs is a helpful tool to promote radiation safety for patients undergoing medical imaging and radiological procedures[11,16]. The primary DRL quantity for intervention fluoroscopy is the 75th percentile of DAP, while RAK fluoroscopy time and number of angiographic images are additional DRL quantities[16]. Recently, national DRLs for radiological procedures including the TACE procedure have been established in Thailand. The median DAP of the TACE procedures from unit A exceeded the national DRLs. Hence, an optimization process must be performed. Among the DRL data of the TACE procedure, Thailand has presented comparatively lower DRLs with 2-dimensional angiography (141 Gy·cm^2) and 3-dimensional angiography (226 Gy·cm^2) than other countries[14,21]. Although the median DAP of unit A at our institute was higher than the national DRLs, it was also lower than in previous report[21].

It has been reported that the estimation of skin dose during and after interventional radiology can be used to predict the probability and severity of a deterministic effect[19,22] In this study the phantom peak skin dose was lower than 2 Gy. A skin reaction or deterministic effect is not likely. Since the placing of a dosimeter on the patient's skin in clinical practice is impractical, RAK or peak skin dose (PSD) is a tool used in monitoring the deterministic effect from this procedure. RAKs from the TACE procedure of the study patients did not exceed 2 Gy. Nevertheless, the PSD from OSLD was higher than the RAK of these 2 DSA units. Therefore, monitoring a patient's deterministic effect using an RAK quantity must be performed carefully.

It has been reported that BMI had an effect on radiation dose due to an increase in tube voltage and current[23–25]. A significant correlation between BMI and DAP and RAK was also found in a previous study[23–25]. Since the BMI of patients from our unit A DSA was slightly higher than in the unit B DSA patients, this may have contributed to a higher radiation exposure in the unit A DSA patients. Furthermore, a significant difference of fluoroscopy time was also observed. Although the fluoroscopy time of unit B DSA was higher than unit A DSA, the DAP and RAK of unit B DSA was not greater than unit A DSA. Therefore, fluoroscopy time was not a cause of radiation dose in the TACE procedure. Several lines of evidence have demonstrated that a novel DSA imaging system played an important role in radiation dose reduction[26–28]. Furthermore, for the tumor anatomy characteristics, addition of a copper filter and reduction of the detector dose were also reported to be associated with radiation dose during TACE procedures[28–30]. unit B DSA was established later and consisted of a newer imaging system in terms of both hardware and software. Moreover, reduction of the detector dose was performed in unit A DSA for a short time but not in unit B. These factors may have had a key role in reducing the radiation dose in unit B DSA. Therefore, further investigation of these factors should be conducted

Table 3 Median values of the DRL quantities of unit A and unit B

Patient radiation dose	Unit A median (min-max)	Unit B median (min-max)	p-value
DAP (Gy·cm^2)	200.49 (65.85-909.12)	109.74 (16.23-317.83)	<0.001
RAK (mGy)	379.84 (132.18-1,985.30)	276.55 (80.20-647.70)	<0.001
Fluoroscopy time (Minutes)	9.04 (3.27-23.45)	10.19 (2.02-36.29)	0.034
Number of angiographic images	115 (28.00-324.00)	121 (48.00-255.00)	0.616



TACE=transarterial chemoembolization, DSA=digital subtraction angiography

Figure 2 Phantom skin dose from TACE procedure using 2 DSA units

*, **, *** a significant difference between 2 DSA units with p-value<0.05, 0.01, 0.001, respectively

Table 4 Correlations between DRL quantities and BMI

		Fluoroscopy time	Number of angiographic images	DAP	RAK
BMI	Correlation Coefficient	−0.196	0.078	0.417	0.466
	p-value	0.002	0.227	<0.001	<0.001
	Number of patiient	240	240	240	240

BMI=body mass index, DAP=dose area product, DRL=diagnostic reference level, RAK=reference air kerma

to elucidate this issue, and there may be a potential to improve and optimize the radiation dose of unit A DSA by using these factors.

There were several limitations to this study. Firstly, both DSA units were clinically operated with different exposure parameters such as frame rate, fluoroscopy pulse rate, magnifications of FOV during the procedures and quality of the flat panel detectors. These factors might have confounded the radiation dose each patient received. In addition, some factors were not controlled or limited in the phantom study because the authors desired to perform the TACE procedure followed by the protocol of clinical practice in each machine. Lastly, collection of these factors and the separate records of exposure parameters, radiation dose of fluoroscopy, acquisition, and radiography could not be performed in a retrospective study. Therefore, further studies on this issue must consider these factors.

Conclusions

The median DAP of this study was higher than the national DRL. There was a difference of radiation dose between the DSA units. To benefit patients, the planning of dose optimization process and management of TACE cases using the existing DSA machines must be considered.

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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