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Occupational dose and associated factors during transarterial chemoembolization of hepatocellular carcinoma using real-time dosimetry

A simple way to reduce radiation exposure

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Abstract

Transarterial chemoembolization is the standard treatment option for intermediate-stage hepatocellular carcinoma (HCC). However, during the interventional procedure, occupational radiation protection is compromised. The use of real-time radiation dosimetry could provide instantaneous radiation doses. This study aimed to evaluate the occupational dose of the medical staff using a real-time radiation dosimeter during transarterial chemoembolization (TACE) for HCC, and to investigate factors affecting the radiation exposure dose.

This retrospective observational study included 70 patients (mean age: 66 years; age range: 38–88 years; male: female = 59: 11) who underwent TACE using real-time radiation dosimetry systems between August 2018 and February 2019. Radiation exposure doses of operators, assistants, and technicians were evaluated. Patients' clinical, imaging, and procedural information was analyzed.

The mean dose–area product (DAP) and fluoroscopy time during TACE were 66.72 ± 55.14 Gycm^2 and 12.03 ± 5.95 minutes, respectively. The mean radiation exposure doses were 24.8 ± 19.5, 2.0 ± 2.2, and 1.65 ± 2.0 μSv for operators, assistants, and technicians, respectively. The radiation exposure of the operators was significantly higher than that of the assistants or technicians ($P < .001$). The perpendicular position of the adjustable upper-body lead protector (AULP) on the table was one factor reducing in the radiation exposure of the assistants ($P < .001$) and technicians ($P = .040$). The DAP was a risk factor for the radiation exposure of the operators ($P = .003$) and technicians ($P < .001$).

Occupational doses during TACE are affected by DAP and AULP positioning. Placing the AULP in the perpendicular position during fluoroscopy could be a simple and effective way to reduce the radiation exposure of the staff. As the occupational dose influencing factors vary by region or institution, further study is needed.

Abbreviations: AULP = adjustable upper-body lead protector, BMI = body mass index, CAK = cumulative air-kerma, DAP = dose–area product, DSA = digital subtraction angiography, Fr = French, HCC = hepatocellular carcinoma, SMA = Superior mesenteric artery, TACE = transarterial chemoembolization, TLD = thermoluminescent dosimeter.

Keywords: dosimetry, hepatocellular carcinoma, occupation, radiation dose, transarterial chemoembolization

1. Introduction

Hepatocellular carcinoma (HCC) is the sixth most common cancer worldwide and the third leading cause of cancer-related deaths in 2020.[1] The Barcelona Clinic Liver Cancer (BCLC) staging system is widely accepted in clinical practice and provides treatment recommendations for each of the five tumor stages.[2] For example, transarterial chemoembolization (TACE) is recommended for intermediate-stage HCC.[3] Some studies have

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The authors declare that they have no conflict of interest.

The datasets generated during and/or analyzed during the current study are not publicly available, but are available from the corresponding author on reasonable request.

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reported that TACE can improve the survival rate of patients with advanced HCCs, such as advanced liver cirrhosis with vascular invasion, and metastatic HCCs.[4–6] TACE is frequently performed by interventional radiologists and repeated sessions are often required.[7]

As fluoroscopy-guided procedures have lower medical costs, shorter hospital stay, and less pain from surgery,[8] they are generally performed despite the risk of radiation exposure of patients and medical staff, thus emphasizing the need for radiation protection.[9,10] A thermoluminescent dosimeter (TLD) badge is commonly used to indicate occupational radiation exposure doses.[11] However, as TLD badges are typically processed once a month or after several months, the radiation dose immediately after a procedure cannot be measured using these badges.[12] To overcome this disadvantage, a real-time radiation dose-measuring machine has been developed, which allows for the measurement of the radiation exposure dose during or immediately after each procedure. The effectiveness of this device has been verified through several clinical trials.[13–16] However, to evaluate the radiation dose of medical staff during TACE, only a few studies used real-time dosimetry, and only the operators were targeted.[13] We hypothesized that factors affecting radiation exposure may be different for each occupational group and that the use of a real-time radiation dosimeter would facilitate the identification of factors that can affect radiation exposure. Therefore, this study aimed to evaluate radiation exposure doses of operators and medical staff using real-time radiation dosimetry during TACE and the factors affecting the radiation exposure dose.

2. Methods

2.1. Study participant

From August 2018 to February 2019, records of 100 consecutive patients who had been diagnosed with HCC at our institution and treated with TACE in the angiography room were set up with a real-time radiation dosimetry system (RaySafe i2; Unfors RaySafe, Inc., Billdal, Sweden) and retrospectively reviewed. HCC was diagnosed based on characteristic imaging findings of computed tomography or magnetic resonance imaging, according to European Association for the Study of the Liver guidelines.[17] Cases of ambiguous imaging findings were confirmed histologically through percutaneous biopsy. Exclusion criteria were no use of real-time radiation dosimetry during TACE (n=10); deviation of the medical staff from the specified position during the procedure (n=9); and missing record of the radiation exposure dose or location of the protector (n=11). Finally, 70 patients were included in this study. The study was conducted in accordance with the Declaration of Helsinki and Ethical Guidelines for Clinical Studies. The study protocol was reviewed and approved by the institutional review board of our hospital, and the requirement of informed consent was waived because of the retrospective study design.

2.2. Study design and endpoints

This study was a retrospective cross-sectional study. The primary endpoint of this study was to evaluate the radiation exposure doses of each occupational group. The secondary endpoints were to evaluate factors affecting radiation exposure dose for each occupational group.

2.3. TACE protocol

Two experienced radiologists (with >5 years of experience) performed TACE according to the CIRSE standards of practice document for quality-improvement guidelines for hepatic TACE.[18] Arterial access was achieved using a 6-French (Fr) sheath (Radiofocus Introducer; Terumo Corp., Tokyo, Japan) via the common femoral artery. Superior mesenteric artery (SMA), celiac axis, and common hepatic artery angiographies were performed using a 5-Fr catheter (Yashiro; Terumo, Tokyo, Japan). Tumoral feeders were selected using a 0.016″ microguidewire (ASAHI Meister; Asahi Intecc, Seto, Japan) and a microcatheter (2.0-Fr Progreat; Terumo Corp., Tokyo, Japan, and 1.7-Fr Veloute; Asahi Intecc, Seto, Japan). The microcatheter was placed as distal to the tumoral supplying arteries as possible. Doxorubicin (Adriamycin; Ildong, Seoul, South Korea) in an aqueous non-ionic contrast agent and lipiodol (Guerbet; Roissy, France) were mixed to make a water-in-oil emulsion, and via a microcatheter, were slowly injected. Subsequent embolization was performed using 150–300-μm gelatin sponge particles (EGgel S PLUS; ENGAIN, Seongnam, South Korea). TACE was terminated when the portal vein was visible using the drug; tumor vessels were completely saturated; and tumoral hypervascularity had disappeared from the follow-up angiogram.

2.4. Angiographic equipment setting and radiation protection

A fluoroscopic angiographic system (Allura Clarity FD20; Philips Healthcare, Best, the Netherlands) was used to perform TACE. The source–image distance was set to 100 cm, and the source–object distance was 70 cm. Fluoroscopy was performed at a rate of 15 frames/s, and the rate of digital subtraction angiography (DSA) was 2 frames/s. The detector was positioned consistently as guided by markings on the floor for all procedures. During TACE, the operator stood as far from the detector as possible and performed it at a distance of approximately 50 to 70 cm from the detector. An assistant was present approximately 50 cm behind the operator. The technician stood 250 cm away from the detector to handle the controller at the end of the table. During the procedure, each occupational position was marked on the floor to maintain a constant position distance from the detector. Each employee received feedback on the assigned location from another employee outside the IR room. Individuals wearing radiation dosimeter badges during TACE maintained as consistently positioned as possible, for each procedure. When performing angiography of the celiac axis, common hepatic artery, or SMA, staff were not present inside the angiography room. Monitors were positioned on the left side of the patient's body and in front of the radiologist. Fixed lower-body shields under the table and adjustable upper-body lead protectors (AULP) were vertically placed on the table. The AULP was positioned perpendicular or parallel to the table direction, as close to the operator as possible (Fig. 1). All staff wore protective devices, including lead glasses, thyroid protectors, and lead aprons.

2.5. Radiation dosimetry system

The radiation doses for operators, assistants, and technicians were measured using a real-time dose-monitoring system (RaySafe i2; Unfors RaySafe, Inc., Billdal, Sweden). This system comprises of personal dosimeters with real-time display monitors that allow the operator to see the measured radiation dose data

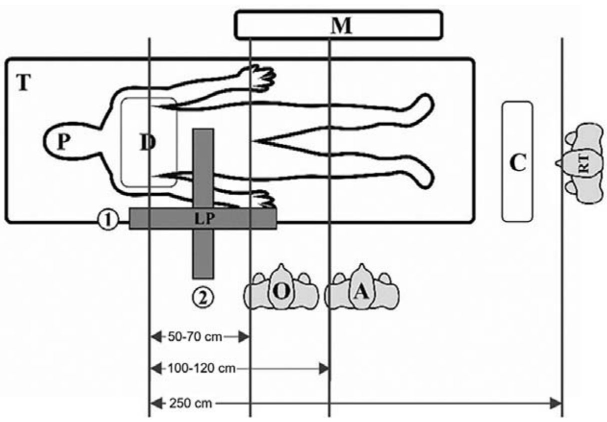

Figure 1. Positions of the staff and the adjustable upper-body lead protector. (1) parallel position to the table; (2) perpendicular position to the table; A = assistant; C = controller; D = detector; LP = Adjustable upper-body lead protector; M = monitor; O = operator; RT = radiology technician; T = table.

and software for connecting the data stored in each dosimeter to a computer. Staff wore dosimeter badges outside their lead aprons. Three months before the study period, all staff were given time to learn how to properly wear the personal dosimetry badges and to be accustomed to them. The badges were placed on the left upper chest (Fig. 2). Radiation doses were recorded immediately after each procedure using a computer software. In this study, the real-time display monitor was not referenced.

2.6. Radiation exposure affecting parameter assessments

Fluoroscopy time (minutes), number of times that DSA was performed, dose–area product (DAP; Gy·cm^2), and cumulative air-kerma (CAK; mGy) were recorded on the structured report of the angiographic system. A valid calibration and quality control certificate was revalidated every 6 months. In addition, procedure time (minutes) from arterial assessment to completion angiography, number of lipodol-doxorubicin emulsion injected selected tumoral feeders, and position of AULP (perpendicular or parallel to table) were evaluated. These data were recorded in our picture archiving and communication system by the medical staff, immediately after the end of each procedure. Patient characteristics, including the age, sex, body mass index (BMI), medical history of diabetes mellitus or hypertension, alpha-fetoprotein level, Child–Pugh score, tumor number, and presence of extrahepatic feeders, were recorded. Obesity was defined as BMI $\geq$ 25 kg/m^2.[19]

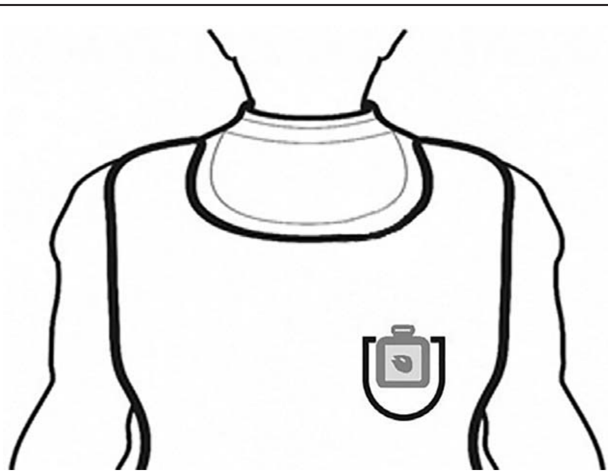

Figure 2. Radiation dosimeter badge-wearing sites for the staff.

2.7. Statistical analyses

Statistical analyses were performed using SPSS version 25.0 (IBM Corp., Armonk, NY). Continuous variables are expressed as means ± standard deviations; categorical variables are expressed as frequencies (%). The one-way analysis of variance with post-hoc Tukey's test was used to compare radiation exposure doses among operators, assistants, and technicians. A simple correlation analysis was performed to confirm the correlation of DAP with patient characteristics and factors affecting radiation exposure. Univariate linear regression analysis was performed to estimate the relationship between the radiation dose and the variables possibly affecting the radiation dose. Multivariate linear regression analysis was performed to estimate the association between the radiation dose and parameters that showed meaningful values in the univariate analysis. Both univariate and multivariate linear regression models were calculated using the operator, assistant, and technician radiation doses. Statistical significance was determined by a P-value < .05.

3. Results

3.1. Patient characteristics and radiation exposure dose-related factors

Table 1 summarizes the demographic data, laboratory characteristics, and factors affecting radiation exposure, for the enrolled

Table 1

Baseline characteristics of patients and factors affecting radiation exposure.

Baseline characteristics	
Age	66.86 ± 11.30
Male sex	59 (84.29%)
BMI, kg/m^2	24.59 ± 3.89
DM	38 (54.29%)
HTN	24 (34.29%)
Creatine	1.33 ± 1.21
AFP	166.24 ± 576.78
Child–Pugh class	
A	56 (80%)
B	14 (20%)
Number of tumors	2.14 ± 1.52
Extrahepatic collaterals	12 (17.14%)
Operator	
1	23 (32.86%)
2	47 (67.14%)
Selected feeder number	2.03 ± 1.22
Position of AULP to table	
Vertical	25 (35.71%)
Horizontal	45 (64.29%)
Procedure time, min	30.81 ± 11.78
Fluoroscopic time, min	12.03 ± 5.95
Number of DSA	9.69 ± 3.07
Total DAP, Gycm^2	66.72 ± 55.14
Cumulative Air-kerma, mGy	205.20 ± 161.61

AFP = alpha fetoprotein, AULP = adjustable upper-body lead protector, BMI = body mass index, DAP = dose–area product, DM = diabetes mellitus, DSA = digital subtraction angiography, HTN = hypertension.

patients. In the simple correlation analysis, DAP and CAK had strong positive correlations ($r=0.928$, $P<.001$). BMI ($r=0.600$, $P<.001$), fluoroscopic time (0.353, $P<.001$), and the number of angiography ($r=0.281$, $P=.020$) showed positive correlations with DAP (Fig. 3).

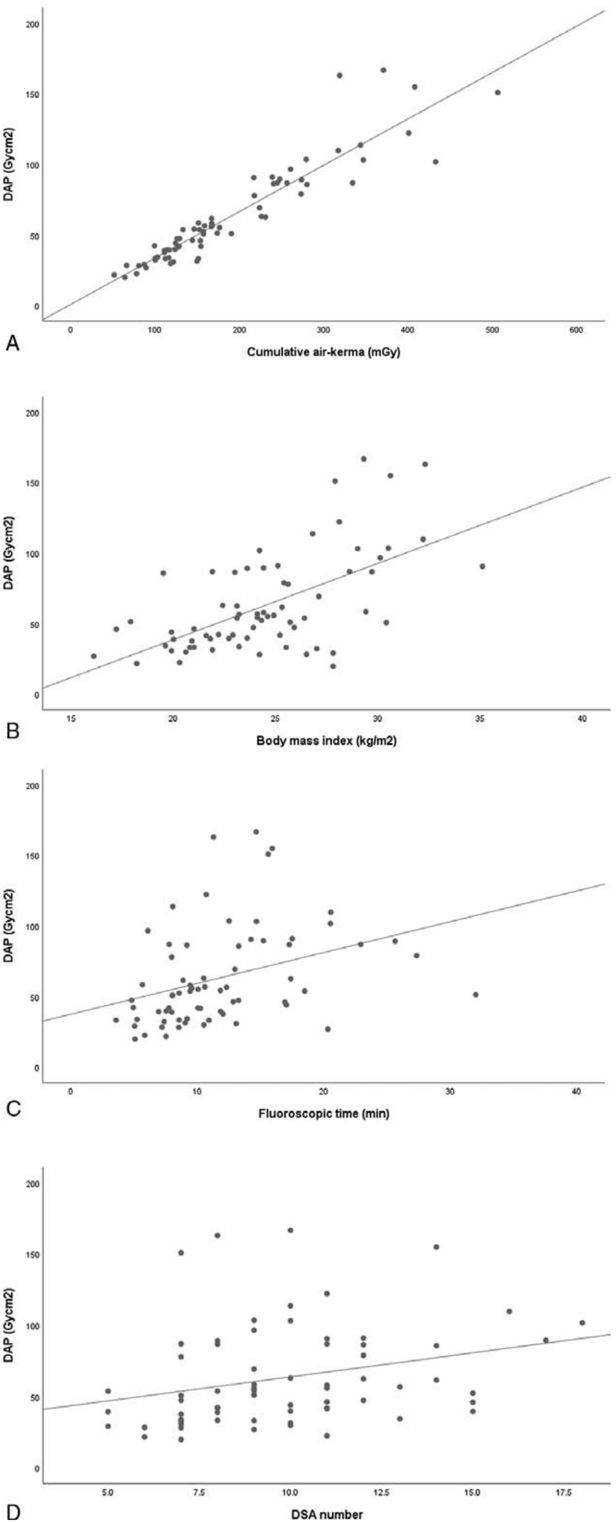

Figure 3. Correlation of the dose–area product with the cumulative air kerma (A), body mass index (B), fluoroscopic time (C), and digital subtraction angiography number (D). DAP=dose–area product.

3.2. Radiation exposure dose of medical staff

The mean radiation exposure doses of the operators, assistants, and technicians were 24.8 ± 19.5, 2.0 ± 2.2, and $1.65 \pm 2.0\,\mu Sv$, respectively. The mean radiation exposure dose of the operators was significantly higher than that of the assistants or technicians ($P<.001$). There was no significant difference in the radiation exposure dose between the assistants and technicians (Fig. 4).

3.3. Factors affecting increased radiation exposure in medical staff

In the univariate linear regression analysis, factors affecting increased radiation exposure dose of the operators were prolonged fluoroscopic time ($P<.001$), number of DSA ($P=.001$), DAP ($P<.001$), and CAK ($P<.001$). Factors affecting increased radiation exposure dose of the assistants included obesity ($P=.001$), prolonged fluoroscopic time ($P=.005$), DAP ($P=.001$), and CAK ($P=.009$). Factors affecting increased radiation exposure dose of the technicians were increased DAP ($P<.001$) and CAK ($P<.001$). The perpendicular position of AULP to the table was a factor reducing the radiation exposures of the operators ($P=.025$), assistants ($P<.001$), and technicians ($P=.032$; Table 2).

CAK was excluded from the multivariate analysis because DAP and CAK had multi-collinearity with a variance of factor over 10. In the multiple linear regression analysis, the perpendicular AULP position was the reduction factor of the radiation exposure for the assistants ($P<.001$) and technicians ($P=.040$, Fig. 5). Increased DAP was a risk factor for the radiation exposure of the operators ($P=.003$) and technicians ($P<.001$; Table 3).

4. Discussion

Our study showed the approximate environment of radiation exposure and factors affecting each occupational group during TACE. During TACE, radiation exposures of assistants and technicians are much less, relative to those of operators. In this study, DAP affected operators and technicians. It positively correlated with CAK, BMI, fluoroscopy time, and the DSA number. The AULP position reduced radiation exposures of assistants and technicians. These results demonstrate that real-time dosimetry can be helpful in measuring occupational dose and finding influencing factors during TACE.

The radiation dose measured by real-time dosimeter is not approved as a legal system for occupational dosimetry and does not represent an effective dose.[20] However, real-time dosimetry could be helpful in measuring the approximate radiation dose of the working environment. The real-time dosimetry can visualize the dose through a real-time display monitor, provide detailed information on an occupational dose, and correlate factors related to radiation dose during procedures.[13–15] These advantages can provide information on unintended or unnecessary radiation exposure, which could guide appropriate protective action and reduce the occupational dose.

Radiation exposure during interventional procedures is a known occupational hazard, and various protective devices are used to minimize it.[21] Among such equipment, AULP is unique in that the operator can manipulate its position by moving the protector before or during the procedure. Therefore, the effectiveness of AULP could be operator-dependent. Studies have reported that in procedures employing the femoral approach, the protector should be as close to the operator as possible; in addition, better shielding from radiation is achieved

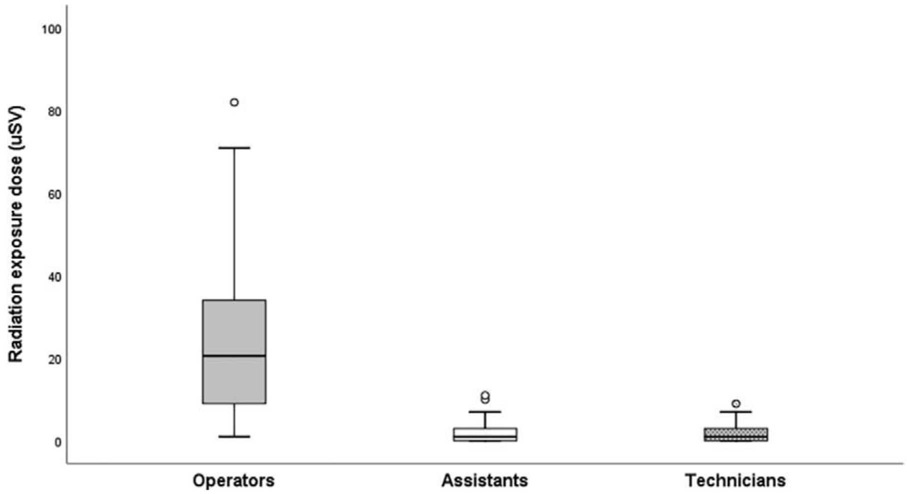

Figure 4. Occupational doses of operators, assistants, and technicians.

when the lower edge of the protector is closer to the patient's body.[22] A previous phantom study showed that operators and assistants were better shielded from scattered radiation exposure when the lead screening shield was positioned closer to the operator.[23] In our multiple regression analysis, the radiation exposure dose of the operator depending on the location of AULP was not statistically significant, although radiation exposure decreased when it was perpendicular to the table. This may be because AULP was sufficiently close to the operator even if it was parallel to the table. However, the exposure doses of the assistants and technicians decreased in the perpendicular position to the table. It was the only significant factor in the radiation exposure of the assistants. These results suggest that operators should make active shielding efforts to reduce their and the staff's radiation exposures.

The radiation exposure dose is primarily affected by the radiation dose, exposure time, and distance from the radiation source.[24] According to the inverse square law, the radiation dose is inversely proportional to the square of the distance from the X-ray source.[25] In a previous study that measured the radiation exposure dose during TACE using an electronic personal dosimeter, the radiation exposure dose of operators was significantly higher than that of technicians.[26] Similarly, in this study, the radiation exposure dose of the operators was higher than that of other staff. However, the radiation exposure dose of the assistants was not significantly different from that of the technicians. It might have significantly reduced the scattered radiation directed to the assistants by the operators and the AULP.

DAP and CAK are strong factors that have a close correlation with the radiation exposure dose of patients.[27,28] In previous studies, DAP was related to the fluoroscopic time, DSA, image frame, obesity, and operator's experience.[10,28–31] In our study, increased DAP was a risk factor for the radiation exposure of the staff, and DAP positively correlated with CAK, BMI, fluoroscopic time, and the number of DSA. Decreasing the radiation

Table 2

Univariate linear regression of radiation exposure doses of each subgroup and variable.

Variables	Operator Coef (95% CI)	*P*	Assistant Coef (95% CI)	*P*	Technician Coef (95% CI)	*P*
Age	0.083 (−0.339–0.505)	.697	−0.046 (−0.093–0.001)	.053	−0.005 (−0.047–0.037)	.804
Male	−17.193 (−35.192–0.821)	.068	−0.324 (−1.801–1.152)	.545	−1.267 (−2.553–0.021)	.058
Obesity	5.023 (−4.535–14.581)	.298	1.666 (0.647–2.684)	.001	0.541 (−0.412–1.493)	.262
DM	2.472 (−7.057–12.002)	.606	0.874 (−0.190–1.938)	.106	0.517 (−0.427–1.461)	.278
HTN	3.644 (−6.289–13.577)	.732	0.261 (−0.886–1.407)	.651	0.725 (−0.256–1.706)	.145
Creatine	−0.536 (−4.450–3.378)	.785	0.091 (−0.356–0.537)	.687	−0.184 (−0.574–0.205)	.349
AFP	−0.002 (−0.010–0.007)	.393	−0.000 (−0.001–0.001)	.924	−0.001 (−0.001–0.000)	.166
Child–Pugh class	−1.483 (−6.988–4.022)	.593	−0.127 (−0.732–0.478)	.677	−0.175 (−0.727–0.376)	.528
Number of tumors	0.236 (−2.905–3.377)	.881	−0.191 (−0.546–0.165)	.288	−0.236 (−0.546–0.073)	.132
EHC	−1.893 (−14.387–10.601)	.763	1.009 (−0.398–2.416)	.157	0.421 (−0.828–1.670)	.503
Operator	−3.254 (−13.288–6.797)	.521	−1.043 (−2.163–0.076)	.067	−0.937 (−2.971–1.112)	.356
Feeder number	1.195 (−2.707–5.098)	.543	−0.112 (−0.566–0.341)	.597	−0.148 (−0.539–0.243)	.452
Position of AULP	−11.049 (−20.646–2.452)	.025	−2.492 (−3.452–−1.531)	< .001	−1.047 (−2.002–−0.093)	.032
Fluoroscopic time	1.799 (0.969–2.630)	< .001	0.125 (0.039–0.212)	.005	0.080 (−0.003–0.163)	.058
Number of DSA	2.535 (1.017–4.053)	.001	−0.017 (−0.194–0.160)	.848	1.112 (−0.050–0.274)	.172
Total DAP	0.298 (0.183–0.414)	< .001	0.015 (0.006–0.025)	.001	0.033 (0.022–0.044)	< .001
CumuAir-kerma	0.111 (0.071–0.151)	< .001	0.004 (0.001–0.007)	.009	0.011 (0.007–0.015)	< .001

AFP = alpha fetoprotein, AULP = adjustable upper-body lead protector, BMI = body mass index, CI = confidence interval, Coef = coefficient, DAP = dose–area product, DM = diabetes mellitus, DSA = digital subtraction angiography, EHC = extrahepatic collateral, HTN = hypertension.

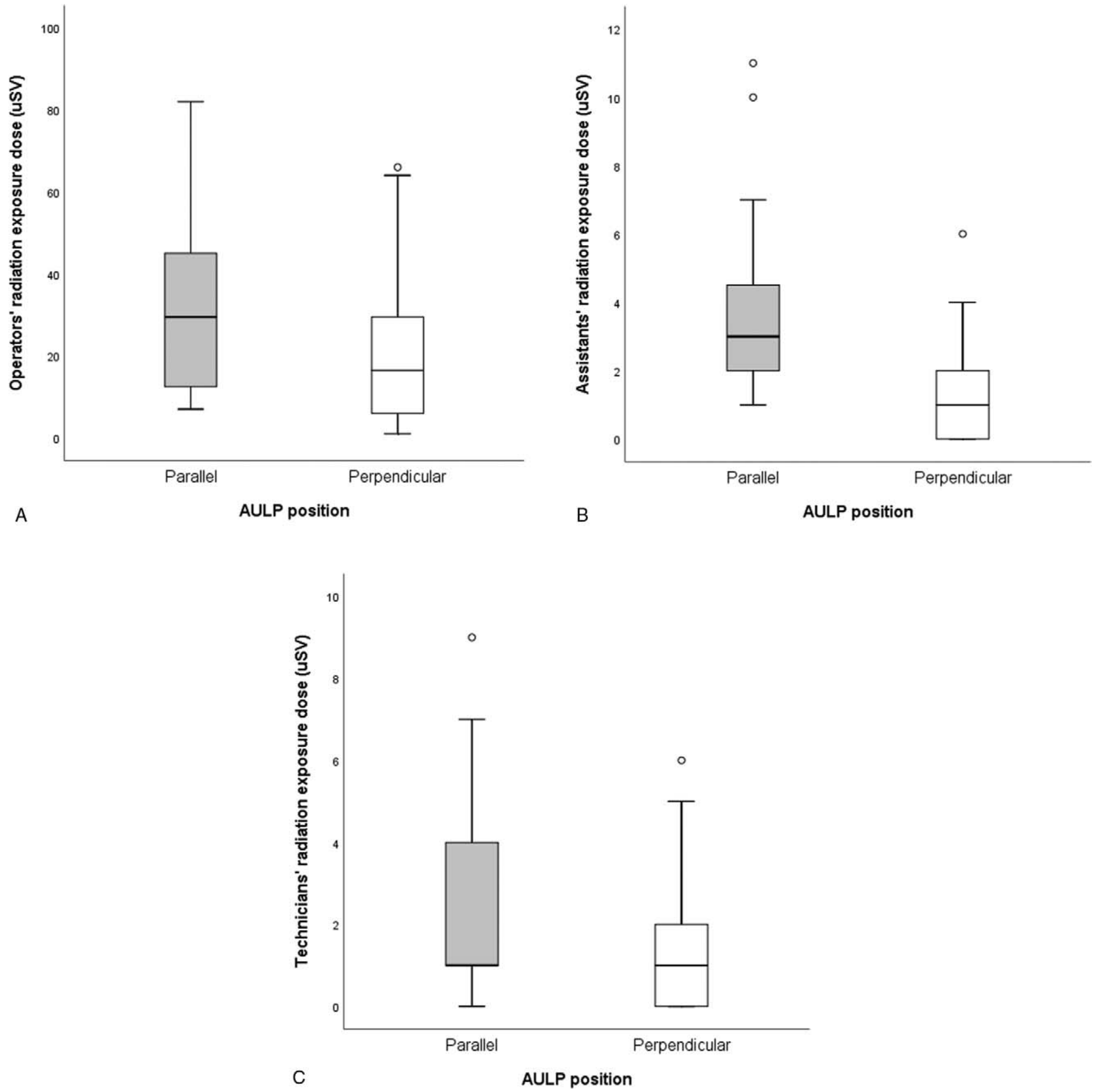

Figure 5. Radiation exposure dose for operators (A), assistants (B), and technicians (C) according to the adjustable upper-body lead protector position. AULP = adjustable upper-body lead protector.

exposure dose of the patients generally reduces the occupational dose.[10] Therefore, operators should make efforts to reduce the radiation exposure of the patients.

Our study has several strengths compared with previous studies that measured radiation dose during TACE. In previous studies, the radiation dose measured during TACE was targeted

Table 3

Multivariate linear regression of each occupational dose and the variables.

Variables	Operator Coef (95% CI)	*P*	Assistant Coef (95% CI)	*P*	Technician Coef (95% CI)	*P*
Obesity	−2.223 (−12.418–7.971)	.664	0.941 (−0.090–1.972)	.073	−0.624 (−1.558–0.309)	.186
Position of AULP	−.6.677 (−15.210–1.856)	.123	−2.139 (−3.072–−1.205)	< .001	−0.821 (−1.602–0.040)	.040
Fluoroscopic time	0.719 (−0.222–1.660)	.132	0.055 (−0.036–0.146)	.233	−0.027 (−0.103–0.048)	.471
Number of DSA	1.092 (−0.478–2.661)	.430	0.008 (−0.136–0.152)	.912	0.014 (0.127–0.155)	.845
Total DAP	0.239 (0.082–0.395)	.003	0.010 (0.005–0.021)	.068	0.031 (0.017–0.045)	< .001

AULP = adjustable upper-body lead protector, BMI = body mass index, CI = confidence interval, DAP = dose–area product, DSA = digital subtraction angiography.

only to patients and operators.[13,26] However, it may not be just the patient or operator who is exposed to the radiation environment during TACE. Therefore, it is important to manage radiation exposure for each occupational group. In this study, the radiation doses for each occupational group including the operator, assistant, and technician were measured and the influencing factors were also analyzed. Another thing is that there has been no referenced dose with real-time radiation dose; the radiation dose level in this study may be helpful for future studies.

However, this study had some limitations. It was a retrospective study conducted at a single center in Asia, and the sample size was small. TACE was performed by 2 radiologists, thus reducing the homogeneity of the procedure cohort. However, because the radiation dose was measured at 1 institution, the measurement method was consistent. Therefore, the radiation level of the staff would remain proportional even when accounting for slight variations in measurements between procedures. The real-time display monitor, which can show the radiation exposure dose in real-time during the procedure, was not referenced. However, this may have reduced the bias that may occur when the operator refers to the display monitor during the procedure.

5. Conclusion

In our study, the occupational radiation exposure dose was measured using real-time dosimetry during TACE. The operator's exposure dose was the highest, but there was no difference between the assistant's and the technician's exposure dose. These results suggest that radiation exposure influencing factors for each occupational group during TACE are diverse, and real-time radiation dosimetry could be helpful in finding the influencing factors. Perpendicularly positioning the AULP on the table, under fluoroscopy could be a simple but effective way to reduce the occupational dose. As the method of TACE may be different for each institution or country, and there may be various causative factors for radiation exposure, large-scale additional studies in various areas require further study.

Author contributions

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