Individually Body Weight-Adapted Contrast Media Application in Computed Tomography Imaging of the Liver at 90 kVp

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Objectives: The aim of the present study was to evaluate the attenuation and image quality (IQ) of a body weight–adapted contrast media (CM) protocol compared with a fixed injection protocol in computed tomography (CT) of the liver at 90 kV.

Materials and Methods: One hundred ninety-nine consecutive patients referred for abdominal CT imaging in portal venous phase were included. Group 1 (n = 100) received a fixed CM dose with a total iodine load (TIL) of 33 g I at a flow rate of 3.5 mL/s, resulting in an iodine delivery rate (IDR) of 1.05 g I/s. Group 2 (n = 99) received a body weight–adapted CM protocol with a dosing factor of 0.4 g I/kg with a subsequent TIL adapted to the patients' weight. Injection time of 30 seconds was kept identical for all patients. Therefore, flow rate and IDR changed with different body weight. Patients were divided into 3 weight categories; 70 kg or less, 71 to 85 kg, and 86 kg or greater. Attenuation (HU) in 3 segments of the liver, signal-to-noise ratio, and contrast-to-noise ratio were used to evaluate objective IQ. Subjective IQ was assessed by a 5-point Likert scale. Differences between groups were statistically analyzed ($P < 0.05$ was considered statistically significant).

Results: No significant differences in baseline characteristics were found between groups. The CM volume and TIL differed significantly between groups ($P < 0.01$), with mean values in group 1 of 110 mL and 33 g I, and in group 2 of 104.1 ± 21.2 mL and 31.2 ± 6.3 g I, respectively. Flow rate and IDR were not significantly different between groups ($P > 0.05$). Body weight–adapted protocoling led to more homogeneous enhancement of the liver parenchyma compared with a fixed protocol with a mean enhancement per weight category in group 2 of 126.5 ± 15.8, 128.2 ± 15.3, and 122.7 ± 21.2 HU compared with that in group 1 of 139.9 ± 21.4, 124.6 ± 24.8, and 116.2 ± 17.8 HU, respectively.

Conclusions: Body weight–adapted CM injection protocols result in more homogeneous enhancement of the liver parenchyma at 90 kV in comparison to a fixed CM volume with comparable objective and subjective IQ, whereas overall CM volume can be safely reduced in more than half of patients.

Key Words: multidetector computed tomography, diagnostic imaging, liver, radiation dosage, contrast media

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Contrast-enhanced computed tomography (CT) is frequently used to detect liver lesions and to (sub)classify liver tumors.[1–4] Studies show that hepatic enhancement of 50 HU or greater is considered necessary to ensure an appropriate visibility of low-attenuating lesions.[5–9] Usually, a standard fixed contrast media (CM) volume is used independent of specific patient characteristics such as height, weight, liver status (eg, cirrhosis and steatosis), and cardiac function.[6,10,11] All these factors have a direct influence on liver enhancement and, as a result, on lesion visibility. A fixed CM dose therefore results in reduced attenuation levels in the liver in heavier-weighted patients, in comparison to patients with a lower total body weight (TBW).[12] As a consequence, this might even lead to scans with an insufficient attenuation resulting in a nondiagnostic CT scan.[12] Alternatively, patients with a low TBW might receive more CM than necessary for sufficient liver attenuation, which is not preferable either.[13]

Dedicated CM injection software (P3T; Bayer Healthcare, Berlin, Germany) individualizes CM application for each patient based on body weight and the linear relationship between weight and flow rate (millimeter per second). As a result, the flow rate and the resulting iodine delivery rate (IDR) differ with a changing TBW. Injection time is constant for all patients. A higher TBW, therefore, results in a higher flow rate, with a subsequent increase in total iodine load (TIL). The advantage of an individualized CM injection protocol over a fixed CM injection protocol has already been established in various CT angiography (CTA) studies.[14–18] The effects on parenchymal enhancement, however, have not been fully investigated, especially in the light of low kV scanning and recent advances in image reconstruction (eg, iterative reconstruction).[19]

Scanner improvements aid CM volume optimization for each patient. Recent technical advances allow for CT scans to be performed at tube voltages as low as 70 kV, which decreases radiation dose significantly.[20–22] In addition, reducing the tube voltage increases CM enhancement, as the x-ray output comes closer to the 33 keV k-edge of iodine, which increases (liver) attenuation. This facilitates reduction of CM volume while decreasing radiation dose.[23,24] Most previous research on the topic of TBW and liver attenuation has been performed at a fixed tube voltage setting of 120 kV.[6,25,26] Until now, most thorough studies were performed in an Asian population, with a lower mean TBW than an average European or American population.[6,25–28]

The aim of this study was to establish a possible benefit of individualized CM injection over a fixed CM volume in liver imaging, when applying modern scanner techniques in image acquisition (90 kV protocoling) and postprocessing (raw data–based iterative reconstruction methods) in a (heavier) European population.

MATERIALS AND METHODS

Ethics

The local ethical committee and institutional review board provided a waiver of written informed consent for the study design, as

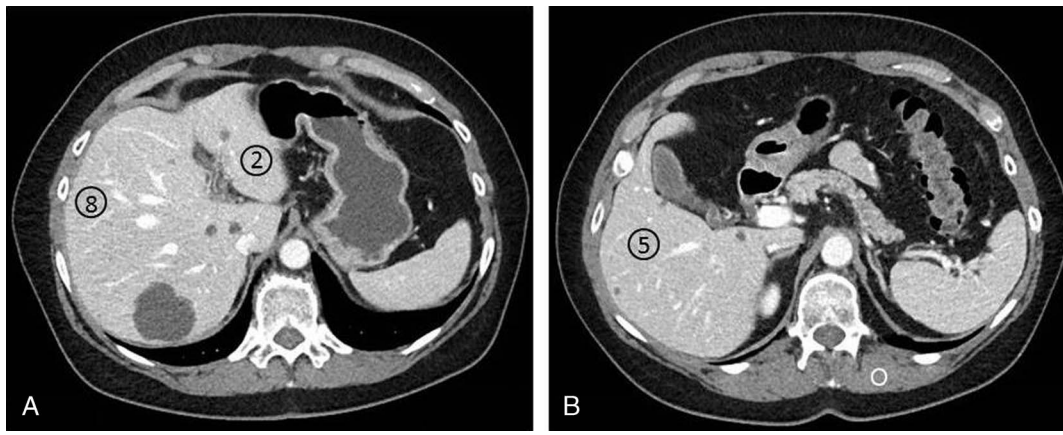

FIGURE 1. ROIs were drawn in segments 2, 5, and 8 of the liver (when available). The white circle indicates the ROI drawn to determine HU in a paraspinal muscle to determine CNR. ROI indicates region of interest; CNR, contrast-to-noise ratio.

the data were analyzed anonymously in accordance with the institutional review board guidelines (Medical Ethics Committee, ref. 16-4-161).

Study Population

All abdominal CT scans in portal venous phase or in combination with a thoracic CTA in patients aged 18 years or older were eligible for inclusion. Patients were excluded in case of hemodynamic instability, and general exclusion criteria for contrast-enhanced CT were applied (eg, pregnancy, renal insufficiency [estimated glomerular filtration rate, 30 mL/min per 1.73 m^2], iodine allergy). Technicians asked the patients' weight before the scan. In case of doubt, a weighing scale was available. Patients were excluded when the inserted intravenous catheter was not capable of reaching the necessary flow rate for the individualized CM injection or when injection data were not complete (n = 17). Two patients were excluded because of CM extravasation. In total, 199 consecutive patients were enrolled between November 2017 and May 2018.

Imaging Protocol

All scans were performed on a third-generation dual-source CT scanner (Somatom Force; Siemens Healthineers, Forchheim, Germany). Scan range was set from approximately 2 cm cranial of the diaphragm to the pubic symphysis. Scan parameters were as follows: tube voltage was 90 kV, 192 × 0.6 mm slice collimation, gantry rotation time of 0.5 second, and a quality reference tube current of 295 mAs_{ref} (CareDose 4D, Siemens). Image reconstruction was performed in the axial, coronal, and sagittal plane with 3 mm slice thickness and 2 mm increment using a Br40 kernel (Advanced Modeled Iterative Reconstruction, strength 2).

Contrast Media Injection Protocol

All patients received prewarmed CM (37°C [99°F]) (Ultravist, iopromide 300 mg/mL; Bayer Healthcare, Berlin, Germany). All scans were performed in the portal venous phase with a fixed scan delay of 70 seconds after CM administration, or approximately 35 seconds after the arterial phase of the thorax. For the latter, delay was calculated by means of bolus tracking, whereas the abdominal scan was performed after an average of 70 seconds after the start of the CM injection. Contrast media was administered using a programmable dual-head CT power injector (Stellant, Bayer) and injected through an 18, 20, or 22 gauge needle, or through a central line.

Group 1 received a standard fixed CM volume of 110 mL (TIL, 33 g I), with a flow rate of 3.5 mL/s (IDR, 1.05 g I/s) followed by a saline flush of 40 mL at the same flow rate.

Group 2 received a body weight–adapted CM injection protocol as determined by contrast injection software (P3T), which consisted of a CM phase followed by a saline flush of 40 mL at the same flow rate (maximum flow rate, 6 mL/s). The individually tailored CM injection software calculates the TIL and flow rate for each patient, depending on body weight. The dosing factor was 0.4 g I/kg, and injection time was 30 seconds for all patients.[14,15]

A dedicated data acquisition program (Certega Informatics Solution; Bayer) continuously monitored and collected all injection parameters (eg, total amount of CM [milliliter] and peak flow rate [milliliter per seconds]).

Objective Image Quality

Image quality (IQ) was evaluated by measuring the attenuation (HU) in the liver parenchyma, signal-to-noise ratio (SNR), and contrast-to-noise ratio (CNR) ratio. One experienced researcher (B.M.) measured attenuation values by manually delineating regions of interest (ROIs) within the liver parenchyma. Segments 2, 5, and 8, according to the Couinaud distribution were used where possible (Fig. 1).[29] In case liver surgery was performed, the adjacent segment was chosen. An ROI

TABLE 1. Baseline Characteristics

Patient Characteristics	Group 1 (n = 100)	Group 2 (n = 99)	*P*
Excluded patients	4	15	
Age, y	64.2 ± 16.1	64.5 ± 14.5	0.841
Sex (% male)	52 (52%)	53 (54%)	0.828
Body weight, kg	77.1 ± 15.5	77.9 ± 15.9	0.713
Height, m	1.70 ± 0.09	1.72 ± 0.09	0.188
BMI, kg m^{-2}	26.5 ± 4.3	26.3 ± 4.7	0.716
Scan indication			
Oncology	79 (79%)	81 (82%)	0.658
Infectious	7 (7%)	4 (4%)	
Other	14 (14%)	14 (14%)	
Scan protocol (Abd/Th-Abd)	52%/48%	55%/46%	0.719
Needle size			
18 gauge	4 (4%)	6 (6%)	0.828
20 gauge	86 (86%)	86 (87%)	
22 gauge	1 (1%)	1 (1%)	
Missing data	9 (9%)	6 (6%)	

No significant differences were found between groups.

BMI indicates body mass index; Abd/Th-Abd, abdominal scan/abdominal scan with a thoracic CT.

TABLE 2. Injection Parameters

		n	CM Volume ± SD, mL	TIL ± SD, g	Flow Rate ± SD, mL/s	IDR ± SD, g I/s	Grams of Iodine per kg
Group 1	≤70 kg	36	110	33	3.5	1.05	0.55 ± 0.05
	71–85 kg	36	110	33	3.5	1.05	0.42 ± 0.02
	≥86 kg	28	110	33	3.5	1.05	0.35 ± 0.03
Group 2	≤70 kg	35	82.4 ± 9.2	24.7 ± 2.8	2.7 ± 0.3	0.82 ± 0.1	0.4
	71–85 kg	35	104.3 ± 5.3	31.3 ± 1.6	3.4 ± 0.2	1.03 ± 0.1	0.4
	≥86 kg	29	130.0 ± 12.6	38.9 ± 3.4	4.2 ± 0.4	1.28 ± 0.1	0.4
P group 1 and 2			<0.01	<0.01	0.356	0.448	<0.01

CM indicates contrast media; IDR, iodine delivery rate; TIL, total iodine load.

was drawn in each segment (≥1 cm^2) without involvement of bordering vascular structures. Signal-to-noise ratio was calculated by dividing the attenuation of the liver parenchyma by the corresponding standard deviation (SD) of the attenuation.[30–34] The attenuation of the left erector spinae muscle was measured at the level of the liver to calculate CNR using the following established formula: liver segment attenuation minus intramuscular attenuation, divided by the SD of the intramuscular attenuation.[16,31–36]

Subjective Image Quality

Two radiologists (C.M. and B.M.), respectively, with 8 and 3 years of experience in abdominal radiology, evaluated the subjective IQ in consensus while blinded to the injection protocol. Subjective IQ was assessed by using a 5-point Likert scale (1, excellent; 2, good; 3, moderate; 4, poor; 5, very poor).[37]

Statistical Analysis

The Kolmogorov-Smirnov test was used to check for normal distribution. Continuous variables were reported as mean ± SD for normally distributed variables. Differences between groups were analyzed with the unpaired samples *t* test or a one-way analysis of variance with a Tukey test for post hoc comparison, depending on the number of groups. For nonnormally distributed variables, Mann-Whitney *U* or Kruskal-Wallis test was performed. Categorical variables were reported as the number of cases and the percentages per group; the χ^2 test was used to calculate differences between these groups. Statistic software (SPSS, version 24.0; IBM Corp, New York, NY) was used for the data analysis. All *P* values were 2-sided, and a *P* value less than 0.05 was considered statistically significant.

RESULTS

Baseline Characteristics

The baseline characteristics of the study population are depicted in Table 1 for both groups. No significant differences in baseline characteristics were found between groups.

Injection Parameters

Table 2 depicts the injection parameters per group and per weight category, as all patients were divided into 3 weight categories: 70 kg or less, 71 to 85 kg, and 86 kg or greater.

Figure 2 sets out the CM volume against weight for both groups. The mean CM volume for group 2 was 104.1 ± 21.2 mL (range, 60.3–165.3 mL), which was significantly lower than the CM volume in group 1 (110 mL; $P < 0.01$). A CM volume below 110 mL was used in 65.7% of the patients in group 2.

Radiation Dose

Mean effective mAs (mAs_{eff}), CT dose $index_{vol}$ ($CTDI_{vol}$), and dose length product (DLP) for group 1 were 205.3 ± 70.2 mAs_{eff}, 5.9 ± 2.1 mGy, and 288.7 ± 106.4 mGy·cm, respectively. In group 2, mean values were 204.3 ± 76.7 mAs_{eff}, 5.9 ± 2.2 mGy, and 285.9 ± 113.5 mGy·cm. No significant differences were found between groups (Table 3).

Objective Image Quality

For group 1, mean attenuation values of the liver parenchyma for each weight category (≤70 kg, 71–85 kg, ≥86 kg) were 139.9 ± 21.4 HU, 124.6 ± 24.8 HU, and 116.2 ± 17.8 HU, respectively. A significant difference in attenuation was found between the lowest and the middle weight category and between the lowest and highest weight group. In contrast, group 2 attenuation values were comparable and not significantly different between the 3 weight groups: 126.5 ± 15.8 HU, 128.2 ± 15.3 HU, and 122.7 ± 21.2 HU, respectively ($P = 0.450$; Table 4, Fig. 3). The mean SNR and CNR were not statistically different between group 1 and group 2 ($P = 0.369$ and 0.518, respectively; Table 4). The mean SNR for group 1 and 2 was 8.5 ± 2.5 (range, 1.9–14.5) and 8.2 ± 1.6 (range, 3.5–11.7). For CNR, mean values were 5.6 ± 2.9 (range, −5.4 to 16.8) and 5.4 ± 2.1 (range, 0.7–11.9) for group 1 and 2.

Subjective Image Quality

The subjective IQ was diagnostic in all scans, ranging from average to excellent with no significant difference between groups

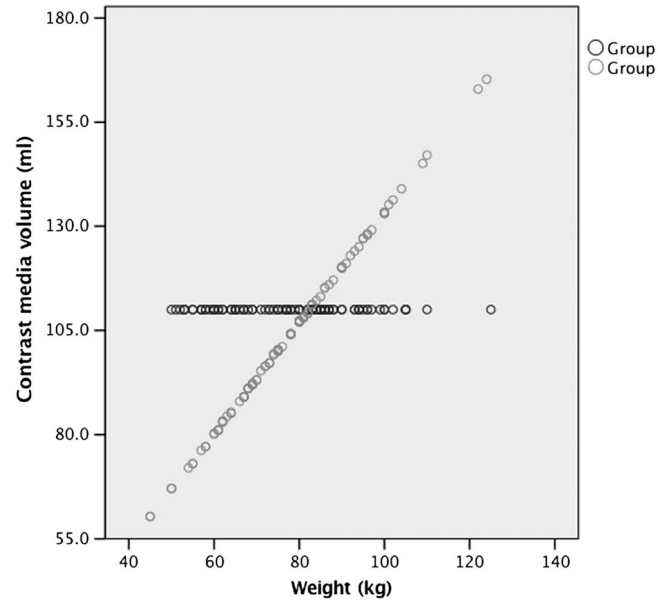

FIGURE 2. CM volume set out to weight for each group. Group 1 received a fixed CM volume of 110 mL. Group 2 received a CM volume based on total body weight. CM indicates contrast media.

TABLE 3. Mean Effective mAs, $CTDI_{vol}$ (mGy), and DLP (mGy·cm) Shown per Group and Weight Category

		Mean Effective mAs ± SD	Mean $CTDI_{vol}$ (mGy) ± SD	Mean DLP (mGy·cm) ± SD
Group 1	≤70 kg	161.6 ± 37.3	4.7 ± 1.1	217.2 ± 58.5
	71–85 kg	222.4 ± 78.1	6.3 ± 2.4	311.7 ± 105.4
	≥86 kg	239.5 ± 65.0	6.9 ± 1.9	351.2 ± 105.5
	Mean	205.3 ± 70.2	5.9 ± 2.1	288.7 ± 106.4
Group 2	≤70 kg	158.2 ± 42.1	4.6 ± 1.2	208.9 ± 50.4
	71–85 kg	203.7 ± 39.9	5.9 ± 1.2	285.3 ± 59.7
	≥86 kg	260.6 ± 102.7	7.5 ± 3.0	379.5 ± 145.5
	Mean	204.3 ± 76.7	5.9 ± 2.2	285.9 ± 113.5
Group 1 vs group 2	*P*	0.969	0.799	0.950

Values increase with an increasing weight and no significant differences were found between groups.

$CTDI_{vol}$ indicates CT dose $index_{vol}$; DLP, dose length product.

($P = 0.213$; Table 5). No significant differences in subjective IQ between the weight categories were found in both group 1 and group 2 ($P = 0.076$ and 0.358, respectively).

DISCUSSION

An individualized CM injection protocol tailored to TBW resulted in a more homogeneous enhancement of the liver parenchyma in comparison to the fixed CM volume injection protocol (Fig. 3). In the latter, a steady decline of liver enhancement with increasing TBW was observed.

In the portal venous phase, CM volume and TIL are the most important factors determining liver enhancement. Flow rate and IDR are less important, unlike in CTA where those parameters are most influential.[12,23] Because of the nature of our study design, CM volume and TIL are significantly different between group 1 and 2, whereas values for flow rate and IDR are comparable between both groups ($P > 0.05$; Table 2). The individualized protocol resulted in a CM volume reduction for nearly two third of our patients while ensuring similar IQ.

The standard deviation is smaller in group 2, which is also an indication for a more homogeneous attenuation of the liver parenchyma. Interestingly, the highest weight category shows a similar standard deviation to group 1 and a slightly lower overall attenuation than the other weight categories in group 2. A potential explanation for this finding might be a higher percentage of people with steatosis in the heavier population and therefore a greater spread in attenuation in this category.

Some studies have already established the beneficial effect of using body size parameters to individualize CM injection protocols in liver imaging. However, most previous studies were performed in an Asian population and/or at a tube voltage of 120 kV and/or with filtered back projection.[6,25,26] Mean TBW in the studies by Kondo et al and Awai et al ranged between 53.5 and 57.6 kg.[6,25,26] Mean CM volume used in those studies was between 107 and 111 mL, with a TIL between 32.1 and 33.3 g I.[6,26] Mean TBW in our population was much higher than the mean body weight in the earlier mentioned Asian studies, whereas in addition, we were able to use a lower mean CM volume. The use of a standard lower tube voltage in combination with a body weight–adapted CM injection protocol and advanced iterative image reconstruction resulted in nearly a 5% reduction of CM volume for group 2 compared with the Asian studies.

Administrating too much CM in lighter patients can result in hyperattenuation of the liver parenchyma and an unnecessarily high total injected CM volume. Although this does not necessarily lead to inadequate IQ, it is not preferable for the patients. In the heavy patient population, however, an insufficient CM volume might result in a decreased detectability of liver lesions.

Recent literature does not describe a clear cutoff value for diagnostic IQ. Mean SNR values range from 4.3 ± 0.6 to 17.9 ± 1.9 and mean CNR ranges between 5.2 ± 2.7 and 6.8 ± 3.0 in recent studies using iterative reconstructions.[4,27,28,32,33,38,39] These values show a high degree of divergence and are not comparable between studies, because different scanners, scan techniques, and CM injection protocols are used. However, in this study, SNR and CNR were not significantly different between both groups and consistent with previous published data. Previous literature states the sole use of parameters such as CNR and SNR might not be a correct representation of the IQ.[40,41] For example, the CNR only depends on contrast and noise. Factors such as the size of a lesion, its shape, and the distribution of the CM attenuation within the lesion are not taken in to account. This is considered a

TABLE 4. Attenuation Value (HU), SNR, and CNR for Each Group, Shown per Weight Category

		Mean HU ± SD	Mean SNR ± SD	Mean CNR ± SD
Group 1		127.8 ± 23.7	8.5 ± 2.5	5.6 ± 2.9
Group 2		126.0 ± 17.4	8.2 ± 1.6	5.4 ± 2.1
P		0.536	0.369	0.518
Group 1	≤70 kg	139.9 ± 21.4	10.4 ± 2.1	6.6 ± 2.7
	71–85 kg	124.6 ± 24.8	8.0 ± 2.1	5.5 ± 3.3
	≥86 kg	116.2 ± 17.8	6.6 ± 1.4	4.2 ± 1.8
	P	<0.01*	<0.01†	<0.01‡
Group 2	≤70 kg	126.5 ± 15.8	9.2 ± 1.2	6.0 ± 1.7
	71–85 kg	128.2 ± 15.3	8.3 ± 1.1	5.8 ± 2.1
	≥86 kg	122.7 ± 21.2	6.9 ± 1.7	4.3 ± 2.0
	P	0.450	<0.01†	<0.01§

No significant differences in HU, SNR, or CNR were found between the 2 groups. Although for group 1, the attenuation differed significantly between certain weight groups as described below.

*Post hoc comparison showed a significant difference between weight category ≤70 kg and 71–85 kg, and ≤70 kg and ≥86 kg.

†Post hoc comparison showed a significant difference between all 3 weight categories.

‡Post hoc comparison showed a significant difference between weight category ≤70 kg and ≥86 kg.

§Post hoc comparison showed a significant difference between weight category ≤70 kg and ≥86 kg, and 71–85 kg and ≥86 kg.

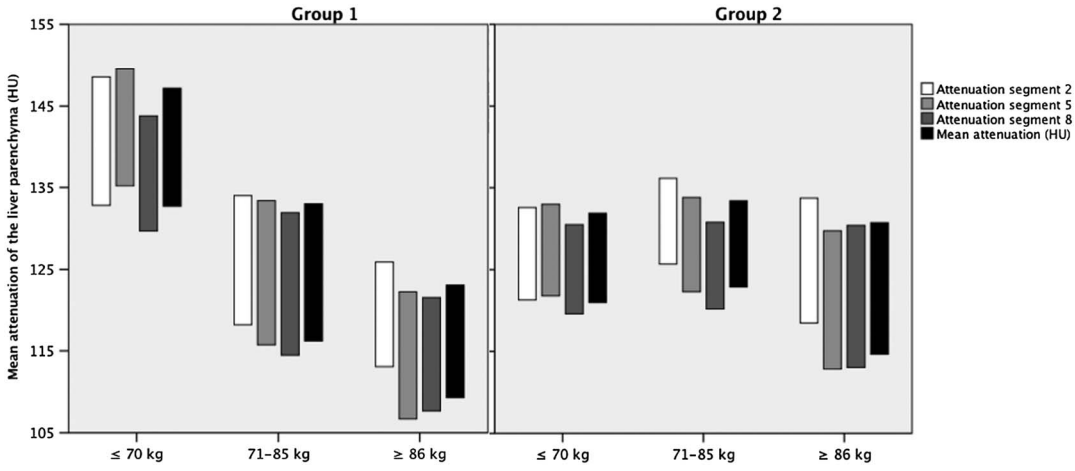

FIGURE 3. Attenuation of the liver parenchyma in segments 2, 5, and 8, according to the Couinaud distribution.[29] When liver surgery was performed, the adjacent segment was chosen. Attenuation is set out per weight category for both group 1 and group 2.

shortcoming in currently used methods for determining objective IQ in CT imaging.

Currently, abdominal CT scans in daily clinical routine are performed at lower tube voltages than the former clinical standard of 120 kV. Reducing tube voltage most importantly results in a radiation dose reduction, but also provides the possibility for CM volume reduction. Diagnostic accuracy, however, should be prioritized over radiation dose and CM volume in liver lesion detection. Maximal reduction of radiation and CM volume are of questionable value if the radiologist can no longer differentiate between the presence and absence of liver lesions. Higher tube potentials, fueled by the development of modern scanners, in combination with tube current modulation software, ensure that the tube current can be increased to a great extent, guaranteeing a constant IQ.[20] However, no research has been performed to prove that this tube voltage and CM volume reduction results in the same IQ and lesion detection potential as the ground rules set out by Heiken et al.[5] Future research should be tailored toward optimization of both radiation dose and CM volume while maintaining diagnostic IQ.

Limitations

This study has several limitations. First, this is a single-center study, investigating a limited number of patients. In our opinion, however, the baseline characteristics are a good reflection of the European population. Second, patients reported their own weight and only in case of doubt, a weighing scale was used. Therefore, some discrepancy in patients' weight could have occurred. However, this is a straightforward approach, which is comparable to the clinical setting as well. Next, lean body weight has proven to be useful in the Asian population, it would be interesting to investigate this parameter in future studies and compare it with TBW. Fourth, liver diseases (eg, steatosis and cirrhosis) and other parameters, such as cardiac function, most likely influence liver attenuation to a certain degree. These patients were not excluded here, but assumed to be randomly assigned to both groups. Therefore, it could be interesting to have a closer look into this patient subpopulation, for example, by analyzing delta HU in attenuation between unenhanced and a portal venous phase CT. This delta HU could provide a more constant parameter to determine liver enhancement, compared with HU in portal venous phase solely.

TABLE 5. Subjective IQ Rated on a 5-Point Likert Scale for Both Groups

	Excellent	Good	Moderate	Poor	Very Poor
Group 1	25 (25.0%)	63 (63.0%)	12 (12.0%)	0 (0.0%)	0 (0.0%)
Group 2	15 (15.2%)	72 (72.7%)	12 (12.1%)	0 (0.0%)	0 (0.0%)

IQ indicates image quality.

CONCLUSIONS

Usage of a body weight–tailored CM injection protocol results in more homogeneous liver enhancement at lower tube voltage (eg, 90 kV) in comparison to a fixed CM injection protocol, whereas CM volume can be reduced in a large percentage of the population.

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