A Solution for Homogeneous Liver Enhancement in Computed Tomography

A Solution for Homogeneous Liver Enhancement in Computed Tomography
Results From the COMpLEx Trial

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Objectives: The aim of the study was to reach homogeneous enhancement of the liver, irrespective of total body weight (TBW) or tube voltage. An easy-to-use rule of thumb, the 10-to-10 rule, which pairs a 10 kV reduction in tube voltage with a 10% decrease in contrast media (CM) dose, was evaluated.

Materials and Methods: A total of 256 patients scheduled for an abdominal CT in portal venous phase were randomly allocated to 1 of 4 groups. In group 1 (n = 64), a tube voltage of 120 kV and a TBW-adapted CM injection protocol was used: 0.521 g I/kg. In group 2 (n = 63), tube voltage was 90 kV and the TBW-adapted CM dosing factor remained 0.521 g I/kg. In group 3 (n = 63), tube voltage was reduced by 20 kV and CM dosing factor by 20% compared with group 1, in line with the 10-to-10 rule (100 kV; 0.417 g I/kg). In group 4 (n = 66), tube voltage was decreased by 30 kV paired with a 30% decrease in CM dosing factor compared with group 1, in line with the 10-to-10 rule (90 kV; 0.365 g I/kg). Objective image quality was evaluated by measuring attenuation in Hounsfield units (HU), signal-to-noise ratio, and contrast-to-noise ratio in the liver. Overall subjective image quality was assessed by 2 experienced readers by using a 5-point Likert scale. Two-sided *P* values below 0.05 were considered significant.

Results: Mean attenuation values in groups 1, 3, and 4 were comparable (118.2 ± 10.0, 117.6 ± 13.9, 117.3 ± 21.6 HU, respectively), whereas attenuation in group 2 (141.0 ± 18.2 HU) was significantly higher than all other groups ($P < 0.01$). No significant difference in attenuation was found between weight categories 80 kg or less and greater than 80 kg within the 4 groups ($P \geq 0.371$). No significant differences in subjective image quality were found ($P = 0.180$).

Conclusions: The proposed 10-to-10 rule is an easily reproducible method resulting in similar enhancement in portal venous CT of the liver throughout the patient population, irrespective of TBW or tube voltage.

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

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Contrast media (CM) are used in computed tomography (CT) scans to enhance vascular structures and organ parenchyma. The visibility of liver lesions depends mainly on image noise and the ratio between size and difference in attenuation of the lesion compared with the parenchyma.[1] Comparing the unenhanced parenchyma with that after CM administration (in the same patient), Heiken et al[2] found that an attenuation difference (Δ) of at least 50 Hounsfield units (HU) is necessary to safely detect liver lesions. A dosing factor of 0.521 grams of iodine per kg (g I/kg) was proposed to reach the required Δ 50 HU at a given tube voltage of 120 kV.[2] By taking the HU of the unenhanced liver into account, a correction can be performed for any liver disorder that might affect background attenuation of the liver.

Parenchymal enhancement depends on scan (eg, CT scanner, tube voltage), CM (eg, volume, concentration, flow rate, temperature), and patient characteristics. Relevant patient-related parameters include weight, height, venous access, cardiac output, age, sex, breath-hold, renal function, and comorbidity.[3] Previous research showed that individualized CM injection protocols, where the CM bolus is adapted to patient total body weight (TBW), lean body weight (LBW), or body surface area (BSA), yields better results.[1,4–8] A recent feasibility study demonstrated that a TBW adapted CM injection protocol resulted in more homogeneous liver enhancement compared with fixed iodine load.[9]

Recent technological developments in X-ray tube technology permit lower tube voltages while maintaining satisfactory image quality, which subsequently leads to lower radiation doses.[10,11] Reducing tube voltage increases attenuation of iodine, by approaching the 33 keV k-edge of iodine. This enables both a reduction of the radiation dose and CM volume.[12] This phenomenon, where changing tube voltage influences iodine attenuation, might result in clinical controversies. For example, in imaging of renal masses, attenuation may indicate whether a lesion is more likely benign or malignant.[13,14] When patients are scanned with variable tube voltages iodine attenuation is affected, consequently, conclusions cannot be derived from the magnitude of the attenuation. Therefore, it is important to find a method by which the attenuation pattern of parenchymal structures remains robust irrespective of the tube voltage or patient TBW.

In recent literature, the importance of individualized CM injection protocols reducing CM volume at a lower tube potential has been stressed in vascular studies.[15–17] To the best of our knowledge, this has not been investigated in abdominal imaging. This study tested the following hypothesis: a 10% reduction in CM dosing factor per 10 kV should yield homogeneous enhancement of the liver in portal venous CT, irrespective of TBW and at variable tube voltages (10-to-10 rule).[18,19]

The aim of the present study was to investigate whether adapting a TBW-based dosing factor to the tube voltage used results in homogeneous liver enhancement between patients.

MATERIALS AND METHODS

Ethics

This double-blind randomized controlled trial was approved by the local ethics committee as well as by the institutional review board

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and is registered on ClinicalTrials.gov (NCT03735706). Written informed consent for inclusion in the clinical trial was obtained.

Study Population

Patients were enrolled between December 2018 and June 2019 at Maastricht University Medical Center. Patients scheduled for an abdominal CT in the portal venous phase were eligible for inclusion. Possible scan indications were oncology, infection, and screening after incidental findings on ultrasound, weight loss, or abdominal pain. Exclusion criteria were age below 18 years, TBW greater than 115 kg (because of practical considerations: a CM syringe contains 200 mL), hemodynamic instability, and general contraindications for contrast-enhanced CT (eg, pregnancy, renal insufficiency [estimated glomerular filtration rate of <30 mL/min per 1.73 m^2], and iodine allergy). Scanning additional to the portal venous phase was not a reason for exclusion (other phases: eg, arterial phase, late phase; other organ region: eg, combination with thoracic scanning). Patient body weight was measured on calibrated scales in the scanner room and the patient height was asked before the CT scan. Body mass index was calculated by dividing body weight (in kg) by height (in meters) squared. Repeat inclusion was not expected to influence study outcome and was therefore allowed.

Patients were prospectively included into 1 of 4 groups. A computer random number generator prepared the randomization schedule in a 1:1:1:1 manner (ie, balanced randomization). Stratification was performed, based on age (<60 and ≥60 years) and weight (<75 and ≥75 kg). Variable block randomization distributed patients equally over the groups.

Scan and CM Protocol

All scans were performed on a third-generation dual-source CT scanner (Somatom Force; Siemens Healthineers, Forchheim, Germany). Automated tube current modulation was used (CareDose 4D; Siemens), while tube voltage was set. A 3-mm slice was scanned at the level of the main portal vein before CM administration to establish the baseline attenuation of the unenhanced liver as mentioned in the introduction. Parameters were similar to the subsequent contrast-enhanced scan: tube voltage 120, 100 or 90 kV (depending on the allocated group); slice collimation 192 × 0.6 mm; gantry rotation time 0.5 seconds; quality reference kV and mAs set respectively to 120 kV_{ref} and 150 mAs_{ref}. The abdominal scan range was set from approximately 2 cm above the diaphragm to the pubic symphysis.

Prewarmed CM (37°C [99°F]) were used at a concentration of 300 mg/mL (Iopromide; Bayer Healthcare, Berlin, Germany). CM were injected with a programmable dual-head CT power injector (Stellant, Bayer) through an 18, 20, or 22 gauge needle. Group 1 received the protocol considered the golden standard: 120 kV and 0.521 g I/kg.[2] Group 2 received an adapted protocol with CM dosing factor identical to group 1 (eg, 0.521 g I/kg), but tube voltage was reduced to 90 kV. In group 3, tube voltage was set at 100 kV and the dosing factor was reduced by 20% in accordance with the 10-to-10 rule (eg, 0.417 g I/kg). Group 4 received a 90 kV scan protocol with a 30% reduction in dosing factor compared with group 1 in accordance with the 10-to-10 rule: 0.365 g I/kg (Fig. 1). Injection duration of CM was 30 seconds in all patients, as determined by dedicated CM injection software (P3T; Bayer Healthcare, Berlin, Germany), and therefore, flow rate (in mL/s) was dependent on the weight of the patient and the allocated group.[9] The scan in the portal venous phase was performed 70 seconds after start of the CM injection in all patients. CM volume (in mL), total iodine load (g I), flow rate, and iodine delivery rate (g I/s) were monitored and collected with a dedicated data acquisition program (Certegra Informatics Solution; Bayer).

Dose-related parameters (eg, CT dose index [$CTDI_{vol}$, in mGy] and dose length product [DLP, in mGy*cm]) were recorded and collected from the dose sheet available at the PACS workstation (IMPAX version 6.6.1.5003; AGFA HealthCare N.V., Mortsel, Belgium). As mentioned above, all patients scheduled for an abdominal CT in portal venous phase were eligible for inclusion. Therefore, an additional thoracic scan or other scan phases of the liver were not reasons for exclusion. As a result, 3 different dose protocols were possible: abdominal scan in portal venous phase, abdominal scan in portal venous phase with a separated arterial thoracic CT, or a thoracic and abdominal scan in portal venous phase. Only the $CTDI_{vol}$ and DLP of the abdominal

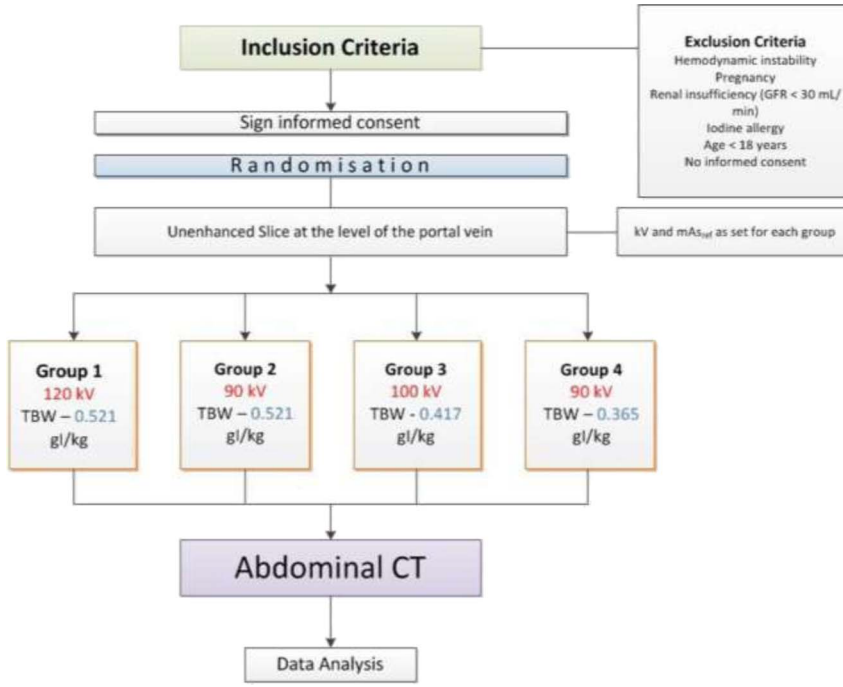

FIGURE 1. Patients were randomly assigned to 1 of 4 groups. An unenhanced slice at the level of the portal vein was scanned before contrast media injection.

scan in portal venous phase were collected from the dose sheet. In cases where the thorax and abdomen where scanned together in portal venous phase, the corresponding $CTDI_{vol}$ and DLP were collected.

Image reconstruction was performed with 3 mm slice thickness, with overlapping increment of 2 mm, in an axial, coronal, and sagittal plane with a soft tissue kernel (Br40; Siemens; Advanced Modeled Iterative Reconstruction, strength 2–3).

Data Processing

The objective image quality was evaluated by measuring attenuation (HU) in 3 different liver segments on both the unenhanced and contrast-enhanced portal venous phase scans, where possible in segments 2, 5, and 8, according to the Couinaud classification.[20] If not possible (eg previous surgery, large lesions), an adjacent location close to the respective segment was chosen. A region of interest was drawn in each liver segment (area: ≥1 cm^2), choosing the largest possible region of interest area not containing large blood vessels, bile ducts or liver lesions. Dividing the HU of each segment by its standard deviation (SD) resulted in the signal-to-noise ratio (SNR).[21–25] The mean of the measurements in segments 2, 5, and 8 is reported as the SNR. The HU and SD of the left paraspinal muscle at the level of the liver were used to calculate the contrast-to-noise ratio (CNR) as follows: the attenuation of each liver segment minus the attenuation of the left paraspinal muscle, divided by the SD of the attenuation of the paraspinal muscle.[9,22–27] The mean of 3 CNR measurements is reported.

Two abdominal radiologists (B.M. and C.M.) with respectively 4 and 9 years' experience in abdominal CT rated the scans in portal venous phase in consensus while being blinded to the protocol. The radiologists were allowed to adjust window-level settings. Overall image quality was rated on a 5-point Likert scale: 1 = excellent; 2 = good; 3 = moderate; 4 = poor; 5 = very poor.[9,28]

Statistical Analysis

Continuous variables are presented as mean ± SD and categorical variables as absolute numbers with percentages. To correct for the possible confounders, sex and iterative reconstruction (IR) strength, an analysis of covariance was performed, because all variables are continuous. Fifteen patients (5.9%) were reconstructed with IR strength 3 instead of 2. It was decided not to exclude the scans reconstructed with IR 3 but to statistically correct for this inconvenience instead, as the IR strength does not influence the attenuation of the liver parenchyma, which was our primary outcome.[29] This analysis was used for both continuous and ordinal variables, because the steps within the ordinal variables were deemed to be of comparable size. *P* values are all 2 sided and considered significant when below 0.05. Statistical software (SPSS, version 24.0; IBM Corp, New York, NY) was used for the data analysis.

RESULTS

A total of 256 patients were randomly allocated to 1 of 4 groups (group 1, n = 64; group 2, n = 63; group 3, n = 63; and group 4, n = 66) (Table 1). Despite randomization, we observed a difference in sex distribution among the groups (% male group 1 = 73.3; group 2 = 53.4; group 3 = 40.7; and group 4 = 59.7). Fifteen patients were excluded: 12 for technical reasons, 2 because only the liver was imaged and therefore radiation doses where not comparable, and 1 because of CM extravasation.

Injection Parameters and Radiation Dose

See Table 2 for an overview of CM injection parameters. As a result of the study design, significant differences were found in CM volume, total iodine load, flow rate, and iodine delivery rate with *P* values <0.01. Table 2 shows the scan protocols and the mean radiation dose for each group. As expected, with identical reference kV and mAs for each group, no significant differences in volumetric $CTDI_{vol}$ or DLP were found among groups ($P = 0.405$ and $P = 0.178$, respectively).

Objective Image Quality

The mean HU in the portal venous phase was not significantly different among groups 1, 3, and 4, whereas attenuation in group 2 was significantly higher compared with all other 3 groups (Table 3 and Fig. 2). Mean HU values in the portal venous phase were 118.2 ± 10.0, 141.0 ± 18.2, 117.6 ± 13.9, and 117.3 ± 21.6 in groups 1, 2, 3 and 4, respectively. A significant difference in HU was found between groups 1 and 2, between groups 2 and 3, and between groups 2 and 4 (all $P < 0.01$). Mean body weight was approximately 80 kg in all groups, and therefore, patients were divided into 2 weight categories (≤80 kg and >80 kg); these were slightly different from the stratification factors used for the randomization process (<75 and ≥75 kg). No significant difference in attenuation in the portal venous phase between weight categories was found within groups, with *P* values 0.371, 0.925, 0862, and

TABLE 1. Baseline Characteristics

Patient Characteristics	Group 1 (n = 64)	Group 2 (n = 63)	Group 3 (n = 63)	Group 4 (n = 66)
Excluded patients, n	4	5	4	4
Age, y	64.0 ± 11.4	66.1 ± 12.6	65.6 ± 8.5	64.3 ± 9.9
Sex, % male	73.3	53.4	40.7	59.7
Body weight, kg	79.5 ± 12.7	77.7 ± 14.0	78.5 ± 14.3	79.8 ± 14.8
Height, m	1.75 ± 0.1	1.71 ± 0.1	1.71 ± 0.1	1.74 ± 0.1
BMI, kg m^{-2}	25.8 ± 3.3	26.5 ± 4.2	26.7 ± 4.3	26.5 ± 4.5
Scan indication, %				
Oncology	95.0	89.7	94.9	96.8
Other	5.0	10.3	5.1	3.2
Needle size, %				
18 gauge	58.3	48.3	52.5	46.8
20 gauge	31.7	37.9	39.0	40.3
22 gauge	0.0	0.0	0.0	3.2
Missing data, %	10.0	13.8	8.5	9.7

Data are presented as mean ± SD, unless otherwise indicated.

Abbreviation: BMI, body mass index.

TABLE 2. Contrast Media and Radiation Dose Parameters

	Group 1 (n = 60)	Group 2 (n = 58)	Group 3 (n = 59)	Group 4 (n = 62)	*P* for Difference Among Groups
CM volume, mL	138.0 ± 22.0*	135.0 ± 24.3*	109.1 ± 19.9*	97.1 ± 18.0*	<0.01
TIL, g	41.4 ± 6.6*	40.5 ± 7.3*	32.7 ± 6.0*	29.1 ± 5.4*	<0.01
Flow rate, mL/s	4.5 ± 0.7*	4.4 ± 0.8*	3.6 ± 0.7*	3.2 ± 0.6*	<0.01
IDR, g I/s	1.4 ± 0.2*	1.3 ± 0.2*	1.1 ± 0.2*	1.0 ± 0.2*	<0.01
PvP abdomen					
Patients	13 (21.7)	17 (29.3)	12 (20.3)	15 (24.2)	
$CTDI_{vol}$ (mGy)	7.8 ± 1.0	7.8 ± 1.8	7.9 ± 2.2	6.6 ± 1.7	0.322
DLP (mGy*cm)	376.9 ± 74.5	339.0 ± 128.4	389.8 ± 136.1	303.2 ± 101.9	0.440
PvP abdomen + Art thorax					
Patients	18 (30.0)	14 (24.1)	20 (33.9)	22 (35.5)	
$CTDI_{vol}$ (mGy)	7.4 ± 1.2	7.3 ± 2.4	6.5 ± 1.5	8.0 ± 3.2	0.308
DLP (mGy*cm)	349.7 ± 63.7	360.1 ± 137.8	310.1 ± 67.7	391.9 ± 155.7	0.459
PvP thorax + abdomen					
Patients	29 (48.3)	27 (46.6)	27 (45.8)	25 (40.3)	
$CTDI_{vol}$ (mGy)	7.0 ± 1.6	6.2 ± 1.8	6.8 ± 2.2	7.0 ± 3.5	0.765
DLP (mGy*cm)	483.8 ± 121.3	386.2 ± 137.4	432.4 ± 131.6	472.2 ± 228.8	0.522
Mean					
$CTDI_{vol}$ (mGy)	7.3 ± 1.4	6.9 ± 2.0	6.9 ± 2.0	7.2 ± 3.1	0.405
DLP (mGy*cm)	420.4 ± 114.9	366.0 ± 134.1	382.3 ± 125.5	402.8 ± 189.2	0.178

Data are presented as mean ± SD or n (%).

Abbreviations: CM, contrast media; TIL, total iodine load; IDR, iodine delivery rate; PvP, portal venous phase; CTDIvol, CT dose $index_{vol}$; DLP, dose length product.

* Post hoc comparison showed a significant difference between groups 1 and 3; groups 1 and 4; groups 2 and 3; groups 2 and 4; and groups 3 and 4. Only groups 1 and 2 did not significantly differ.

0.557 for groups 1 through, 4 respectively. Figure 2 depicts mean HU values in the portal venous phase, per group and weight category. Mean HU values found for unenhanced slices of the liver at the level of the main portal vein were not significantly different between the 4 groups ($P = 0.149$).

Mean SNR was highest in groups 1 and 2 (9.3 ± 1.6 and 9.6 ± 1.9, respectively), and significantly higher than the values in groups 3 and 4 (8.8 ± 1.7 and 8.6 ± 2.1, respectively, $P < 0.01$). Contrast-to-noise ratio was significantly higher in group 2 (6.8 ± 2.2), compared with groups 1, 3, and 4 (5.8 ± 1.8, 5.4 ± 1.7 and 5.4 ± 2.7, respectively; $P < 0.01$) (Table 3).

Subjective Image Quality

The results of the subjective image quality evaluation are presented in Table 4. No significant differences were found among groups ($P = 0.180$). All scans were regarded as diagnostic, none of the CT scans were rated of poor or very poor image quality, and image quality was considered good or excellent in 93.7% of the scans.

DISCUSSION

This study showed that an individualized CM injection and scan protocol, where a 10-kV reduction in tube voltage is paired with a 10% reduction in dosing factor, resulted in homogeneous enhancement of the liver throughout the entire study population. By using this 10-to-10 rule and the CM dosing factor, portal venous abdominal CT protocols can be easily individualized based on tube voltage and patient TBW.

As hypothesized, the 10-to-10 rule results in robust enhancement of the liver at variable tube voltages irrespective of TBW. This is illustrated in Figure 3, which shows 2 scans of a patient who was included twice in the study and allocated to 2 different scan protocols, resulting in similar enhancement of the liver (first allocation to group 4: 90 kV and 0.365 g I/kg; second allocation to group 3: 100 kV and 0.417 g I/kg).

TABLE 3. Mean Attenuation (HU), SNR, and CNR Among Groups

	Group 1 (n = 60)	Group 2 (n = 58)	Group 3 (n = 59)	Group 4 (n = 62)	*P*
Mean HU unenhanced	60.6 ± 7.2	56.0 ± 11.4	56.2 ± 10.3	53.7 ± 13.5	0.149
Mean HU PvP	118.2 ± 10.0	141.0 ± 18.2	117.6 ± 13.9	117.3 ± 21.6	<0.01*
Mean SNR PvP	9.3 ± 1.6	9.6 ± 1.9	8.8 ± 1.7	8.6 ± 2.1	<0.01†
Mean CNR PvP	5.8 ± 1.8	6.8 ± 2.2	5.4 ± 1.7	5.4 ± 2.7	<0.01‡

Data are presented as mean ± SD.

Abbreviations: HU, Hounsfield units; SNR, signal-to-noise ratio; CNR, contrast-to-noise ratio; PvP, portal venous phase.

* Post hoc comparison showed a significant difference between groups 1 and 2 ($P < 0.01$); groups 2 and 3 ($P < 0.01$); and groups 2 and 4 ($P < 0.01$).

† Post hoc comparison showed a significant difference between groups 1 and 4 ($P = 0.016$); groups 2 and 3 ($P = 0.012$); and groups 2 and 4 ($P < 0.01$).

‡ Post hoc comparison showed a significant difference between groups 1 and 2 ($P < 0.01$); groups 2 and 3 ($P < 0.01$); and groups 2 and 4 ($P < 0.01$).

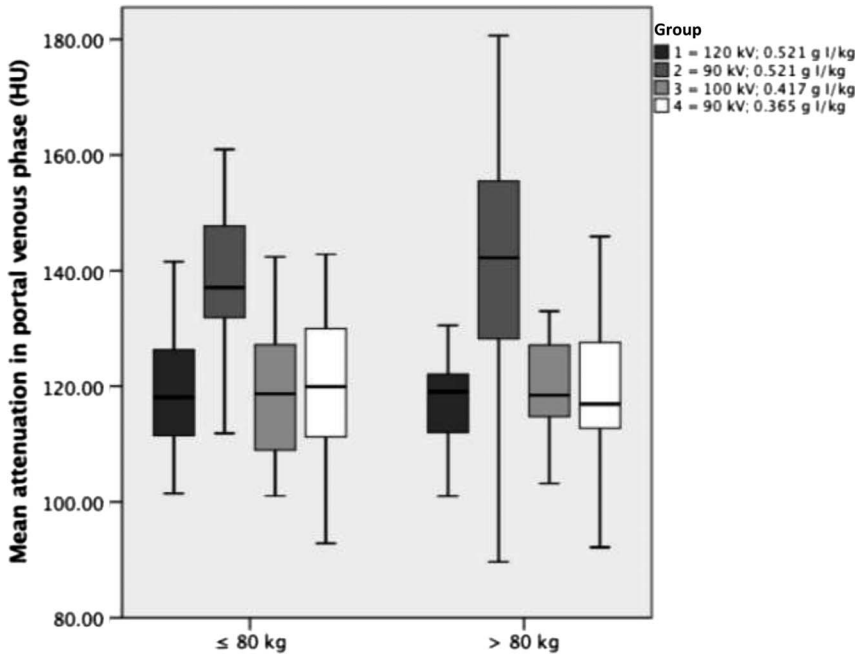

FIGURE 2. Mean attenuation of the liver parenchyma in portal venous phase set out per group and weight category.

Mean HU values in the portal venous phase were not significantly different among groups 1, 3, and 4, whereas attenuation was significantly higher in group 2 compared with the other 3 groups (Fig. 2). In addition, when this rule is applied, a 10% CM dose reduction can be achieved with every 10-kV tube voltage reduction. Mean HU values for the unenhanced slice of the liver were not significantly different among groups and we may conclude that possible factors influencing attenuation of the unenhanced liver (eg, steatosis and cirrhosis) were not noticeably different among groups and will not unduly influence attenuation in portal venous phase.

The CNR was highest in group 2 and comparable among groups 1, 2, and 3 (Table 3). The larger variation in SNR values can be explained by the study setup. A higher tube voltage with comparable tube current results in less image noise, whereas higher CM volumes result in a higher attenuation. Therefore, SNR is, as expected, highest in group 2. In group 4, the lowest tube voltage is used in comparison to the other groups and therefore a slightly lower SNR is expected and observed. Values for SNR were within the ranges reported in literature.[2,9,30–32] Furthermore, subjective image quality was considered good or excellent in 93.7% of the scans.

Numerous studies have explored the possibilities of reducing both CM volume and tube voltage.[33–37] To the best of our knowledge, no other study evaluated a rule of thumb to customize both CM and tube voltage and simultaneously individualize the protocol based on TBW in abdominal CT imaging. In this randomized controlled trial, CM injection was individualized based on TBW and no significant differences in attenuation were found between weight categories of 80 kg or lower and more than 80 kg (Fig. 2). Awai et al[8] showed that LBW might be the more reliable parameter to base the injection protocol on compared with TBW and BSA. However, LBW must be calculated using the Boer or the James formula, the first being preferred for heavier patients, and this may prove to be too time-consuming for daily clinical practice affecting daily clinical routine.[28] Therefore, considering both time and effort, TBW might be more practical. Future research can be directed toward the role of LBW in individualizing scan and CM injection protocols, while taking cost-effectiveness into account.

Nowadays, CT scans are performed at lower tube voltages, and most of the scanners incorporate techniques such as automated tube current modulation and automated tube voltage selection into their systems, thereby providing an easy method to individualize radiation dose while optimizing image quality. At present, newer CT scanners are capable of automatically adapting various scan parameters to individual patients, whereas CM are most often administered in a one-size-fits-all approach. This contradiction is easily explained by the fact that CM administration is still a manual, and therefore a more time-consuming, procedure. A connection between scanner and CM injector might be the solution to further individualization of protocols.

TABLE 4. Subjective Image Quality Scored in Consensus

	Group 1 (n = 60)	Group 2 (n = 58)	Group 3 (n = 59)	Group 4 (n = 62)	*P*
Excellent	18 (30.0%)	9 (15.5%)	16 (27.1%)	11 (17.7%)	
Good	41 (68.3%)	44 (75.9%)	38 (64.4%)	47 (75.8%)	
Moderate	1 (1.7%)	5 (8.6%)	5 (8.5%)	4 (6.5%)	0.180
Poor	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	
Very poor	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	

Limitations

This study has several limitations. First, in this single-center study, a difference was found between the number of men and women in the different groups. As this is a randomized controlled trial, it can be attributed to coincidence, but effects on outcome parameters cannot be ruled out. The distribution of fatty tissue is known to be different between genders: women in general have more fatty tissue than men, and as fat contains fewer blood vessels, it does not play an important role in the distribution of CM. However, we corrected for the difference in proportions of men in the 4 groups in the statistical analysis. Second, even though cardiac output is an important factor in CM administration, it was not taken into account in this study. Timing in portal venous CT is of lesser importance compared with arterial phase scans, and all

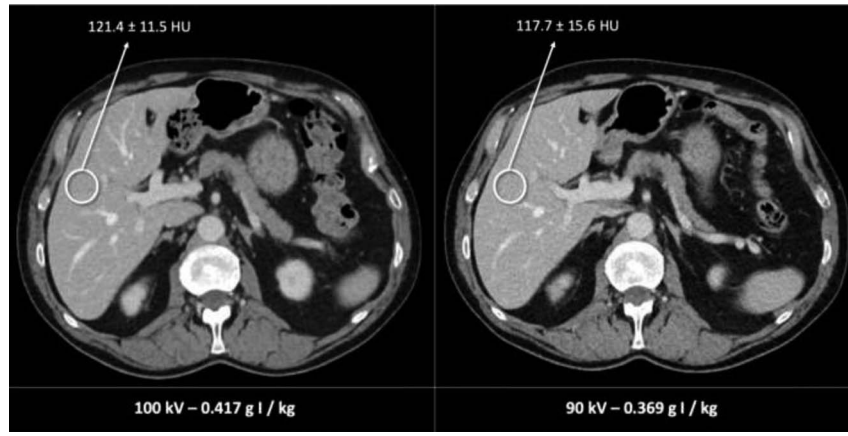

FIGURE 3. A 57-year-old man in the follow-up for metastasized urothelial cell carcinoma, included twice and randomized in 2 different groups. Images were both reconstructed with kernel BR40 and iterative reconstruction strength 2. The circle indicates the mean Hounsfield units (HU) measured in 3 different liver segments (preferable in segments 2, 5, and 8, according to the Couinaud distribution [20]), with the mean standard deviation.

patients were hemodynamically stable. It was therefore assumed that cardiac output was within normal physiological ranges in all patients.

CONCLUSION

The proposed 10-to-10 rule is an easily reproducible method for achieving homogeneous enhancement of the liver in portal venous abdominal CT, irrespective of patient TBW or tube voltage.

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