Original article

Correlation between Morphological and Functional Liver Volume in Each Sector using Integrated SPECT/CT Imaging by Computed Tomography and Technetium-99m Galactosyl Serum Albumin Scintigraphy in Patients with Various Diseases who Underwent Hepatectomy

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Running title: Sectional liver volumetry by SPECT imaging

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Abstract

Objectives To accurately examine the functional volume (RI-vol) of the hepatic segments of SPECT/CT fusion imaging with technetium-99m galactosyl human serum albumin (^{99m}Tc-GSA) scintigraphy, we examined the RI-vol and morphological volume by computed tomography (CT-vol).

Methods In 60 patients with various liver background statuses who underwent hepatectomy, the RI- and CT-vol were examined in each sector using imaging analysis. The values from a control group (n=91) were used as reference data.

Results The mean RI- and CT-vol of the right liver were 64±10% and 63±6%, respectively, whereas the values for the left liver were 36±10% and 37±6%, respectively. Compared with the control group, the ratios in each hemi-liver were similar. The mean RI- and CT-vol for each sector were also similar, and significant positive correlations were identified between both volumes ($p<0.01$). In 4 patients with hepatic tumors involving the main hepatic vessels or the bile duct and in 10 patients who had undergone portal vein embolization (PVE), the actual RI-vol in the injured sector was significantly decreased compared with CT-vol ($p<0.05$). There were marked changes of functional volume in segment 6+7 and segment 2+3 after PVE ($p<0.05$).

Conclusions Volumetric measurement by SPECT/CT imaging with ^{99m}Tc-GSA scintigraphy is useful for evaluating functional volume in separated livers and offers a good reflection of background liver status.

Keywords Liver resection, technetium-99m-galactosyl human serum albumin liver scintigraphy, functional volume, biliary obstruction, hepatic segment

Introduction

To avoid postoperative hepatic failure resulting from excessive hepatectomy beyond the functional liver reserve, hepatic functions before operation and estimated resected liver volume were carefully evaluated (1,2). Liver volume is usually measured with computed tomography (CT) (3,4) , which provides a morphological liver volume. Volumetric measurement of the liver using CT (CT-vol) has usually been applied in the field of hepatic resection (3-5) or living-related liver transplantation (6). Morphological liver volume does not always reflect true healthy liver status because this method includes areas such as ischemic or congestive liver and biliary congestion due to obstructive jaundice (7). Furthermore, portal vein embolization (PVE) to reduce the resected right liver volume might reduce the functional liver volume (8). Recently, technetium-99m galactosyl human serum albumin (99mTc-GSA) scintigraphy has been applied to determine regional functional volume (9,10).

Targeted asialoglycoprotein receptors on hepatocytes reflect functional liver cells (11). The use of 99mTc-GSA liver scintigraphy has been recognized as a reliable new test for assessing hepatic functional reserve and is now commonly used in patients with liver diseases (12,13). This method has been shown to allow measurement of functional hepatic volume (RI-vol) in the hemi-liver (14-16). As 99mTc-GSA scintigraphy provides information on regional liver function, this modality should be useful in deciding the appropriate hepatectomy for an injured liver. With recent advances in radiological imaging technology, accurate functional liver volume could be examined using SPECT/CT imaging of RI-vol and CT-vol (17). Previously, when examining RI-vol, the attenuation correction for photons emitted from radioisotopes in the deeper part of liver was performed using Chang’s procedure (18). Recently, the CT attenuation correction method, which is a more advanced procedure, has been applied for accurate measurement of liver volume (19). In comparison, SPECT/CT imaging allows more precise volumetric analysis. We previously clarified the clinical significance of measuring RI-vol and measured larger volumes in the hemi-liver (16,20). In the previous study, the regional RI-vol could not be accurately measured because fusion imaging technology was not yet available at our institute in 2004. However, more precise volumetric analysis in liver sectors could be achieved by developing a new workstation for imaging. We hypothesized that more accurate examination of RI-vol could be achieved using SPECT/CT imaging.

In the present study, the new SPECT/CT imaging modality was used to preliminary examine RI-vol, functional and morphological hepatic volume in 60 patients with or without injured livers who underwent hepatic resection, and correlations between those volumes were examined. We also examined the discrepancies between functional and morphological volume and major vascular invasion of the tumor and portal vein embolization.

Materials and methods

Patients

The subjects included 60 patients (36 men, 24 women) with or without an injured liver who underwent hepatectomy in the Division of Surgical Oncology and Department of Surgery, in Nagasaki University Hospital (NUH) between April 2009 and July 2012. The mean (standard deviation (SD)) age at the time of surgery was 70.3±10.8 years (range, 37-85 years). Liver diseases included hepatocellular carcinoma in 29 patients, intrahepatic cholangiocarcinoma in 8 patients, metastatic liver carcinomas in 13 patients and bile duct carcinoma in 10 patients. Background liver diseases included normal liver function in 16 patients, fatty liver in 6 patients, chronic viral liver disease in 28 patients (cirrhosis in 2 patients, hepatitis B virus in 15 patients and hepatitis C virus in 11 patients) and obstructive jaundice in 10 patients.

As control data, RI-vol and CT-vol were respectively determined in the hemi-livers of 91 patients who were treated between 2004 and March 2009 and did not undergo SPECT/CT imaging. Functional volumetric analysis was calculated only in the hemi-liver (segment 2+3+4 and segment 5+6+7+8) by setting the borderline along the Rex-Cantlie line of the ^{99m}Tc-GSA images.

In our hospital, the volume of liver to be resected is determined before surgery based on the results of indocyanine green (ICG) retention rate at 15 min (ICG-R15) using Takasaki’s formula (19). For the ICG-R15 test, a dose of 0.5 mg ICG/kg body weight was injected intravenously, and the 15-min retention rate was measured using a photopiece applied to the fingertip (Sumitomo Electric, Tokyo, Japan) without blood sampling. The estimated resected liver volume, excluding tumor volume, was measured by CT volumetry (4). In cases where the permitted resection volume was lower than the estimated volume, or the estimated volume was >65% for a normal liver or 50% for a cirrhotic liver, preoperative portal vein embolization was selected. The uptake ratio of the liver count to the heart and liver count at 15 min (LHL15) and a retention index (HH15) by 99mTc-GSA scintigraphy was determined as well as the ICG-R15 and other liver function parameters preoperatively (20); however, these parameters were not included in the assessment of the present study because the purpose of the present manuscript is to evaluate the regional functional parameter. Hemihepatectomy or more extended hepatectomy was performed in 18 patients, segmental or sectional resection in 33 patients and limited resection in 9 patients. All study protocols were approved by the Ethics Review Board at NUH and signed consent for clinical analysis was obtained from all patients. Data were retrieved from both anesthetic and patient charts as well as from the NUH database for the duration of the hospitalization following the hepatectomy.

Volumetric measurement using SPECT/CT imaging of ^{99m}Tc-GSA liver scintigraphy

Morphological volume was measured using contrast-enhanced CT (21, 22). For imaging of CT-volumetry, serial transverse scans at a 0.5-mm thickness with 0.4-mm intervals were using a 64-row multi-detector CT system (Aquilion™ 64; Toshiba Medical Systems Co., Tokyo, Japan), and the resulting images were stored. Using workstation software (Ziostation System 1000, version 1.31; Ziosoft Inc., Tokyo, Japan), actual areas without tumors and large vessels in the liver area were traced and measured. The hepatic CT-vol for each sector was then measured 3-dimensionally (Fig. 1A). For SPECT/CT imaging of RI-volumetry, all patients received 3 mg (185 MBq) of ^{99m}Tc-GSA (Nihon Medi-Physics, Nishinomiya, Japan) as a bolus dose into an antecubital vein. The images were obtained using an integrated SPECT/CT system with a large field-of-view gamma camera (Symbia T; Siemens AG, Malvern, PA) equipped with a high-resolution, parallel-hole collimator centered on the liver and precordium. Sequential abdominal digital images (128×128 matrix) were acquired and sent to an on-line nuclear data processor (Symbia T Series Processing Workplace; Siemens Medical Solutions USA, Inc., Hoffman Estates, IL) at 30 s/frame for the first 20 min after injection. Hepatic single-photon emission CT (SPECT) images were acquired after dynamic study (Fig. 1B) (23). Each set of projection data was obtained in a 128×128 matrix, and 60 projections (6°/step, 20 s/projection) were acquired. Transaxial SPECT images were reconstructed with 4.8-mm slice thickness. Following SPECT acquisition, CT image acquisition was performed on the same SPECT/CT scanner. Attenuation correction was applied on SPECT images using this CT data. Finally, CT and ^{99m}Tc-GSA SPECT fusion images were obtained, and the RI-vol in each sector was determined. To determine the surface boundary of ROI, a cut-off level was set at 26% of the maximum counts of the liver, as the result closest to the actual volume was obtained in a phantom study (not published). The boundary of ROI between adjacent sectors was determined manually.

Anatomical segmentation based on Couinaud's anatomy using 3-dimensional CT was performed (24), and hepatic volume was measured in each of 4 sectors: the left lateral (segment 2+3), median (segment 4), anterior (segment 5+8) and posterior (segment 6+7) sectors (Fig. 1A).

Portal vein embolization (PVE) and evaluation

Preoperative PVE (25) was performed in 9 of 44 patients. The approach to the portal vein was achieved by direct catheterization through percutaneous transhepatic puncture. The substances used for embolization was 15-20 ml of 5% ethanolamine oleate iopamidol (Oldamin; Fuji Chemical, Toyama, Japan), and permanent embolization materials were not used. At 14 days after PVE, the hepatic volumes of the unembolized lobe and embolized liver (liver to be resected) were reassessed by CT volumetry and ^{99m}Tc-GSA scintigraphy (18).

Statistical analysis

All continuous data are expressed as the mean ±SD. Differences were examined using one-way analysis of variance (ANOVA) and Student's *t*-test. The correlations between the two parameters were examined by calculating the Pearson's correlation coefficient. A two-tailed value of $P<0.05$ was considered significant. SPSS for Windows version 18.0 (SPSS, an IBM Company, Chicago, IL) was used for all statistical analyses.

Results

Correlation between RI-vol and CT vol in the right and left hemi-liver

Table 1 shows the correlation between RI-vol and CT vol in the right (segments 5+6+7+8) and left (segments 2+3+4) hemi-liver. Data from the control group were used as reference data for the 60 patients subjected to SPECT/CT imaging. There were no significant differences in the mean preoperative RI-vol and CT-vol of the right liver in the 60 patients. The mean RI-vol and CT-vol of the left liver in the 44 patients also indicate no significant differences between volumes. A significant positive correlation was identified between the RI-vol and CT-vol in the right and left liver (Table 1). Control data from 91 previous patients indicated no significant differences for ratios or actual volume of RI-vol and CT-vol in each hemi-liver among the 60 patients in the present study.

Correlation between RI-vol and CT-vol in each sector in the 60 patients

Table 2 shows the correlation between RI-vol and CT-vol in each sector in the 60 patients. The mean ratio and actual volumes of RI-vol and CT-vol for each sector were not significantly different between both volumes. Significant positive correlations were identified between RI-vol and CT-vol in each 4 sectors (Table 2). In these patients, four patients presented a large difference of segmental volume between RI-vol and CT-vol caused by tumor invasion into the major vessels in the hepatic hilum. One patient had a large intrahepatic cholangiocarcinoma in segments 6+7 invading the main right portal vein and bile duct (Fig. 2A). In that case, the actual volumes and ratio of RI-vol in segments 6+7 and segments 5+8 were markedly decreased in comparison with CT-vol (Fig. 2B; Table 3). One patient had hepatocellular carcinoma in segments 5+8 infiltrating the anterior branch and right trunk of the portal vein. In that case, actual volume and ratio of RI-vol in segments 5+8 was decreased in comparison with CT-vol (Table 3). The last two cases had hilar bile duct carcinoma infiltrating the left portal vein and the left hepatic duct. RI-vol in the lateral and median segment was decreased in comparison with CT-vol in the same segments.

Volumetric analysis in patients undergoing portal vein embolization

Ten cases underwent preoperative PVE, and volumetric analysis was also performed after PVE (Table 4). A change of hypertrophy in the non-embolized liver (segments 2+3+4) was similar between RI-vol and CT-vol in each case. However, Cases 1, 4 and 5 displayed a greater decrease of over 100 cm^3 in RI-vol of the embolized liver (segments 5+6+7+8) in comparison with CT-vol after PVE. In segments 6+7, there was a significantly greater decrease of RI-vol (-107±114 cm^3) compared with the decrease of CT-vol (-36±73 cm^3) after PVE (p=0.049, Table 4). In segments 5+8, the decrease of RI-vol (-109±95 cm^3) was not significantly different than the decrease of CT-vol (-75±58 cm^3) after PVE (p=0.35). In segment 4, the increase of RI-vol (35±58 cm^3) was significantly greater than the increase of CT-vol (48±61 cm^3) after PVE (p=0.67, Table 4). In segments 2+3, the increase of RI-vol (182±50 cm^3) was significantly greater compared with the increase of CT-vol (52±37 cm^3) after PVE (p=0.045).

Discussion

The use of 99mTc-GSA scintigraphy offers a reliable and non-invasive method for evaluating hepatic functional reserve without testing blood samples (9-18). Asialoglycoprotein is exclusively internalized into hepatocytes by receptor 11, and thus a decrease in the number of asialoglycoprotein receptors is specifically observed in injured livers (23). Since 1996, our department has applied 99mTc-GSA scintigraphy preoperatively in combination with ICGR15 and conventional liver function tests. The measurement of functional hepatic volume by 99mTc-GSA scintigraphy in targeted regions of the liver has recently become available (16, 18, 20,25), and correlations between CT-vol and functional volume using RI-vol in the hemi-liver have been reported (16, 18). In those reports, precise measurement of smaller regions of the liver could not been achieved because setting the borders at the segment or section level remains difficult. Therefore, only the hemi-liver level was examined up to March 2009 in our series. As shown in both previous reports (16, 18) and the present study, correlations between RI-vol and CT-vol were strongly positive, and no differences were seen between the previous results and the present data using the new imaging technique. The hepatic volume of the hemi-liver level can thus be evaluated by 99mTc-GSA scintigraphy alone. The aim of this preliminary study was to clarify the possibility of measuring hepatic volume at the sectional level using an integrated SPECT/CT system with attenuation correction and to determine its clinical significance in liver surgery.

Our institute introduced a new imaging system for liver scintigraphy using a SPECT/CT imaging system in April 2009. This system can produce 3-dimensional CT fusion imaging with exact attenuation correction but not using the previous RI system. Using the new SPECT/CT imaging system allowed us to improve attenuation correction in the deeper part of the liver and to set more precise liver regions, outlines and borders in ^{99m}Tc-GSA scintigraphy imaging using reference CT images. The method for counting uptake amounts in ^{99m}Tc-GSA scintigraphy was important. We measured functional volume using 26% of the maximum uptake of liver as a threshold determining a functional liver (data not published). We clinically measured the summed counts of the each segment or sector using manually determined regions of interest. This method is similar to the three-dimensional quantification GSA density method. We assumed that the ratio of each segment measured with this method was similar to the results with CT volumetry, although the measuring GSA density might demonstrate a large inter- or intra- observer variance. Thus, we used the volume measurement method determined by 26% maximum uptake as a threshold in the present study. Using this threshold, the healthy liver tissue presenting good GSA uptake was included in the functional volume. On the other hand, the liver tissue presenting poor GSA uptake was automatically removed from the functional liver volume. Thus, the determine volume was not a simple morphological volume but, instead, a parameter of regional liver function. This system examines functional volume in greater detail in comparison with the previous system. In cases of sectionectomy, trisectionectomy and central hepatectomy, the precise evaluation of hepatic volume is necessary to decide operative indications. Using the newly introduced imaging system, we compared actual volume and percentage of hepatic volume in the hemi-liver with previous results. The ratios and actual RI-vol and CT-vol were similar between the present and previous studies. Significant correlations between CT-vol and RI-vol as well as with the previous results were confirmed in the present series; however, the actual data between both volumes was not always consistent. Although 38of 60 patients had liver injury (chronic hepatitis, cirrhosis and obstructive jaundice), correlations remained similar in each disease (data not shown). Even with liver injury, the functional mass detected using the asialoglycoprotein receptor was similar to the morphological volume in the stable state, as reported previously (16,18). In addition to our previous reports, the usefulness of ^{99m}Tc-GSA scintigraphy and the measurement of functional liver volume has been reported by other investigators.(17,26) Iimuro et al. indicated the clinical application and significance of functional volumetric analysis in hepatic sections (17). When large tumors occupy the liver segment or sector, the RI volume might not reflect the actual liver volume compared with morphological measurement because the hepatic function of the surrounding liver parenchyma near the tumor might be decreased by the influence of vascular infiltration. Therefore, the real hepatic function can be more accurately estimated by measurement of RI-vol compared to CT-vol alone. We stress that the discrepancy between both volumes is possible and, in such a case, RI-volumetry would be clinically significant for evaluating surgical indication. To the best of our knowledge, no investigators have yet reported sectional volumetric analyses using the new integrated SPECT/CT imaging system. In the present series, four cases presented main vascular involvement of the hepatic tumor. A sectional decrease in RI-vol was observed in cases with segmental liver injury in the present study. Our previous study and other reports indicate that RI-vol in patients with biliary obstruction or main vascular involvement tends to be decreased in comparison with CT-vol in the same hemi-liver.(16-18,25) Uesaka et al. reported that hepatic functional reserve was decreased in cases of hilar bile duct carcinoma with biliary obstruction (27). As expected, liver pathology may result in a loss of normal hepatic function. This information is quite important in deciding operative indications or the need for additional treatments such as biliary drainage or PVE. To evaluate the hepatic functional reserve, ^{99m}Tc-GSA scintigraphy must be a reliable modality (9-18).

After PVE, the morphology of the embolized (segments 5+6+7+8) and unembolized liver (segments 2+3+4) changes over the course of a few weeks (28,29). Our previous results revealed that RI-vol was significantly lower than CT-vol in embolized hemi-livers (16,18,25). In the present series, three of ten patients who underwent PVE displayed greater decreased (>100 cm^3) sectorial RI-vol compared with CT-vol in the same sector. The impairment of liver function might have occurred in each sector in the embolized hemi-liver. In the case of trisegmentectomy, we need to evaluate changes to functional volumes in the anterior or medial segment, but this information could not be obtained by previous imaging modalities without CT fusion images. On the other hand, as reported previously, hypertrophy of the unembolized medial and lateral segments as seen by RI-vol was similar to CT-vol. (16,18) In the present sectorial analysis of hepatic volume, changes of segments 6+7 and segments 2+3 (both peripheral area of the liver) were more significant compared with changes of segments 5+8 and segment 4 (both central areas of the liver). These result indicate that dynamic changes of atrophy or hypertrophy might be expressed in the peripheral liver after PVE, which has not been reported to our knowledge. Thus, the new imaging modality allowed new findings in the field of liver surgery. As Sugai et al. and Beppu et al. also reported, functional volume in the unembolized liver section did not increase significantly after PVE (30, 31). Thus, RI volumetry is useful for evaluation of only atrophic (i.e., injured) areas of liver. By using this imaging modality, precise evaluations of hepatic functional volume in sectionectomy, central bisectionectomy or trisectionectomy can be accomplished (5).

Even in the present study, functional volumetry techniques such as a GSA liver scintigraphy have not been fully applied. Our present study results are quite useful in the consideration of the operative indications in functionally borderline cases. We demonstrated that for some patients with discrepancies and invasion to major vessels and patients undergoing PVE, we could obtain clinically good outcomes by applying functional volumetry. The relationship between the functional volumes and the conventional laboratory data was already reported in our previous reports (20, 32), in which the functional volume was well correlated with other functional liver reserves or portal pressure but not with morphological CT volumetry in patients who underwent PVE. Thus, this useful method to aid in deciding operative indication should be spread worldwide.

In conclusion, the present study demonstrated the measurement of hepatic volume by integrated SPECT/CT imaging of ^{99m}Tc-GSA scintigraphy in each segment of the liver, a new imaging modality. However, functional volume by ^{99m}Tc-GSA was decreased in injured areas of the liver such as areas with tumor involvement of the main hepatic vessels or post-PVE status as compared with CT volumetry. Changes of hepatic functional volume after PVE might have dominantly occurred in the posterior and lateral segments of the liver. Functional volumetry in each section of the liver by SPECT/CT imaging of ^{99m}Tc-GSA scintigraphy is useful for evaluating hepatic function in separate areas of the whole liver and for evaluation of injured regions. This new imaging analysis method is clinically useful for the evaluation of surgical indications before hepatectomy.

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Figure legends

Figure 1. (a) Three-dimensional CT volumetry in each sector of the liver. (b) Three-dimensional single-photon emission CT (SPECT) images of ^{99m}-Tc GSA liver scintigraphy were acquired after dynamic study.

FIGURE 2. (a) A case of intrahepatic cholangiocarcinoma in segments 6+7 invading the hepatic hilum. (b) Actual RI volume in segments 6+7 and segments 5+8 was markedly decreased in comparison with hepatic morphological volume.

Figure 1A

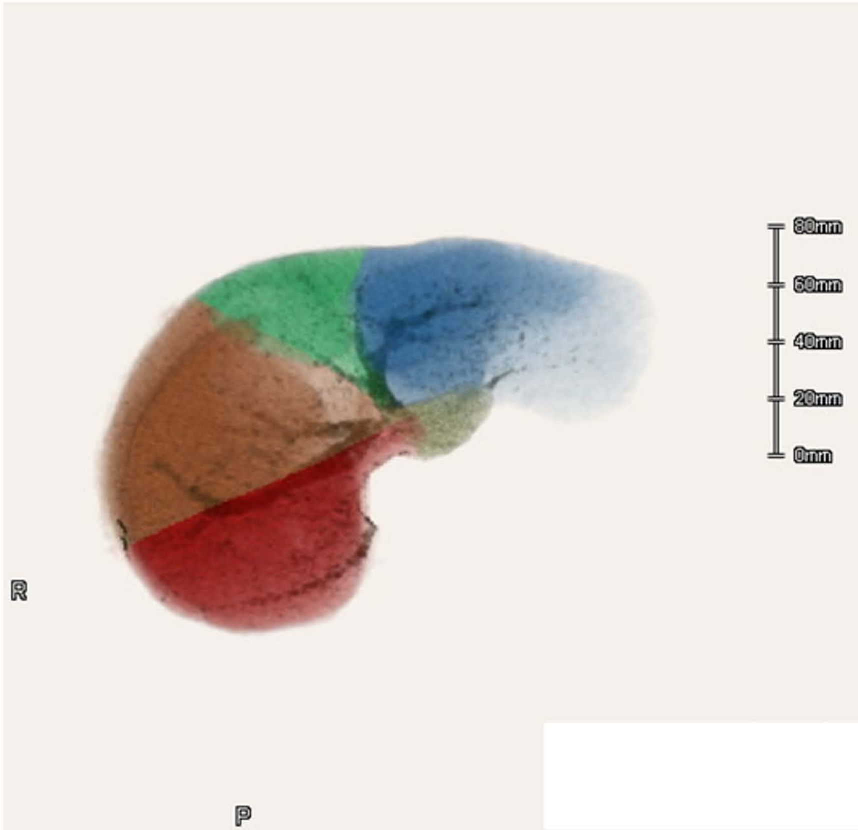

Figure 1B

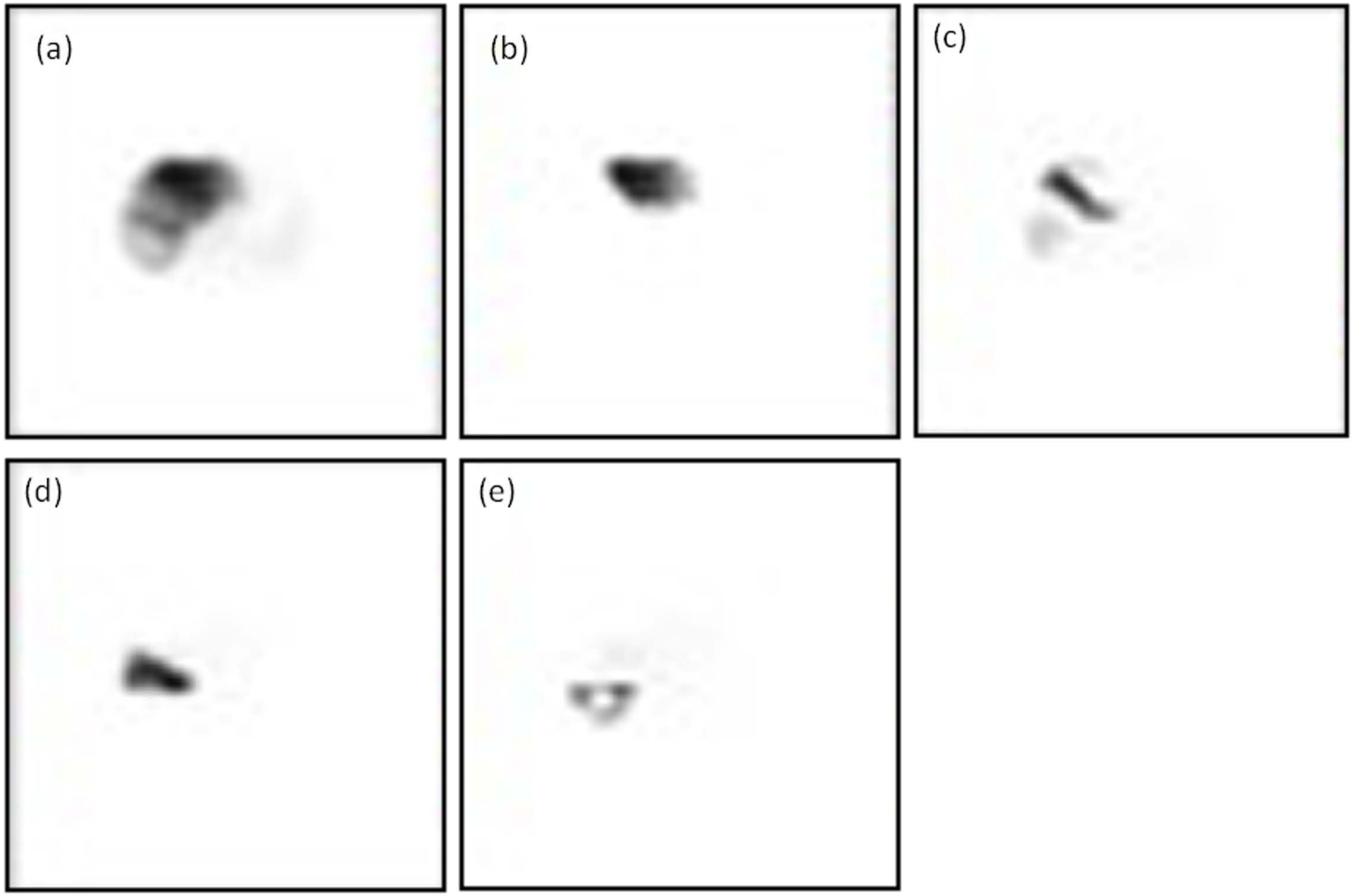

Figure 2A

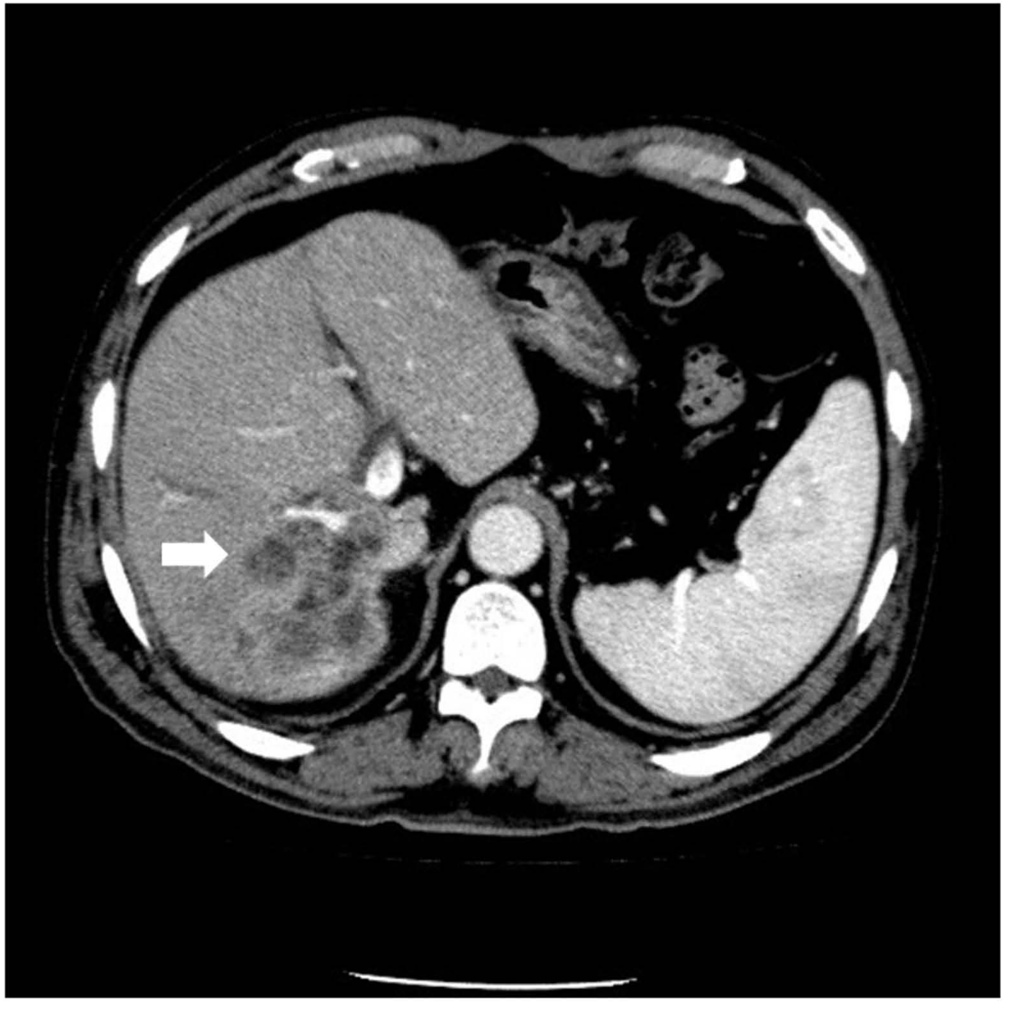

Figure 2B

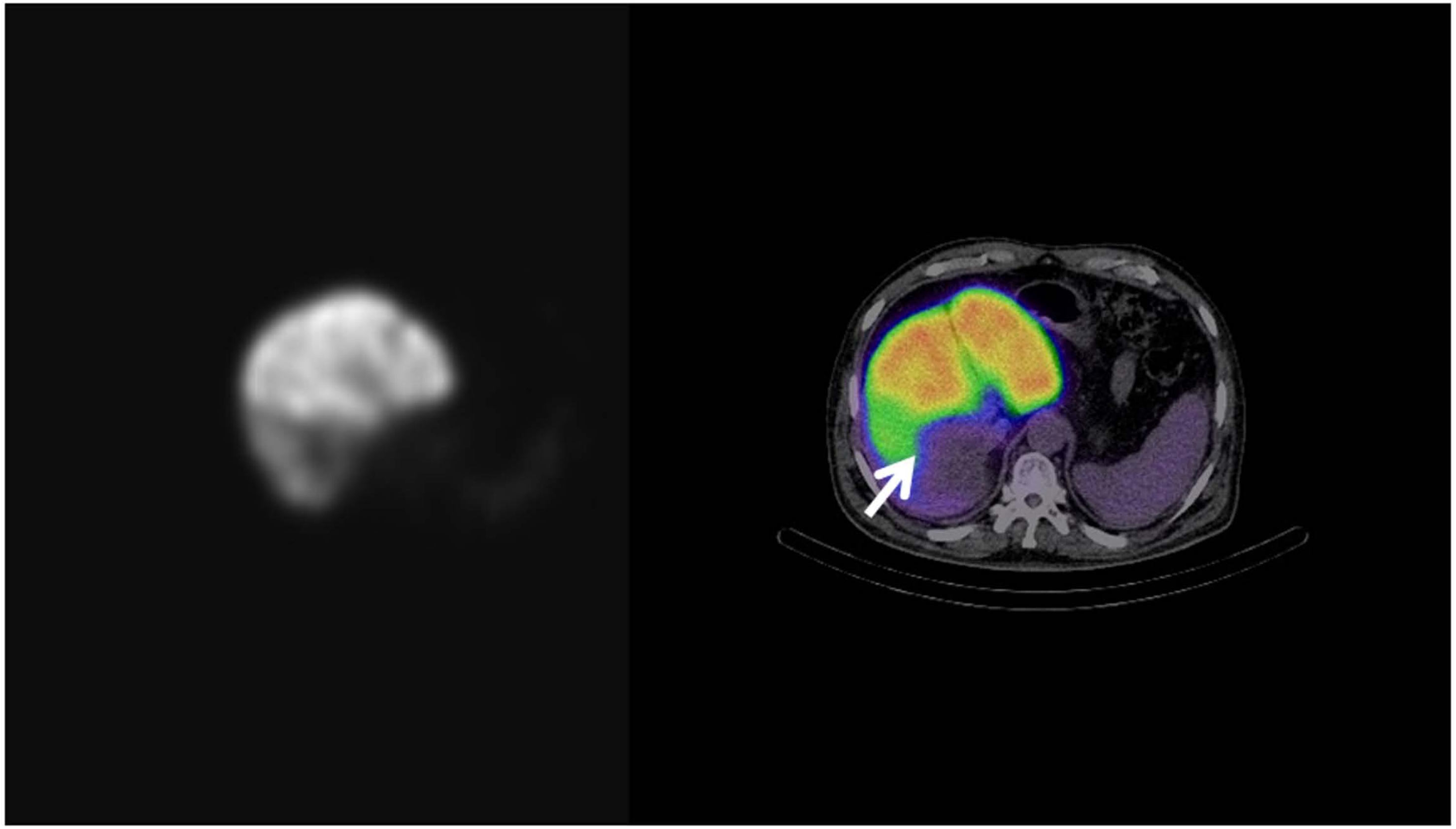

TABLE 1 Correlation between CT-vol and RI-vol in each hemi-liver using the new imaging modality

	RI volume	CT volume	correlation (r)	P value
Present series (n=60)				
Right liver				
ratio (%)	64+/-10	63+/-6	0.612	<0.001
actual volume (cm^3)	789+/-210	765+/-141	0.665	<0.001
Left liver				
ratio (%)	36+/-10	37+/-6	0.628	<0.001
actual volume (cm^3)	438+/-154	423+/-92	0.786	<0.001
Control group (n=91)				
Right liver				
ratio (%)	63+/-19	61+/-12	0.659	<0.001
actual volume (cm^3)	698+/-241	669+/-192	0.679	<0.001
Left liver				
ratio (%)	37+/-19	39+/-12	0.668	<0.001
actual volume (cm^3)	411+/-207	410+/-160	0.663	<0.001

TABLE 2 Correlation between CT-vol and RI-vol in each segment using the new imaging modality

	RI volume	CT volume	correlation (r)	P value
(n=60)				
Segments 6+7				
ratio (%)	31+/-10	28+/-6	0.539	<0.001
actual volume (cm^3)	388+/-158	324+/-106	0.623	<0.001
Segments 5+8				
ratio (%)	33+/-10	35+/-7	0.596	<0.001
actual volume (cm^3)	419+/-138	409+/-93	0.550	<0.001
Segment 4				
ratio (%)	17+/-6	18+/-6	0.445	0.021
actual volume (cm^3)	220+/-93	211+/-70	0.604	<0.001
Segments 2+3				
ratio (%)	19+/-8	19+/-8	0.740	<0.001
actual volume (cm^3)	238+/-111	227+/-97	0.753	<0.001

TABLE 3 Demographics and volumetric data in patients with tumor invasion to a main vessel

Gender Age	Disease	Invaded vessel	RI (cm^3)				CT (cm^3)			
			Seg. 6+7	Seg. 5+8	Seg. 4	Seg. 2+3	Seg. 6+7	Seg. 5+8	Seg. 4	Seg. 2+3
72 Male	ICC	right portal vein right hepatic duct	119 (9%)	257 (18%)	569 (42%)	419 (31%)	394 (31%)	339 (28%)	349 (29%)	141 (12%)
66 Male	HCC	anterior portal vein	353 (32%)	247 (22%)	199 (18%)	498 (45%)	232 (22%)	302 (29%)	214 (21%)	290 (28%)
78 Female	HBDC	left portal vein left hepatic duct	400 (47%)	269 (32%)	153 (18%)	24 (3%)	208 (20%)	385 (38%)	203 (20%)	205 (22%)
68 Male	HBDC	right portal vein right hepatic duct	123 (15%)	167 (20%)	332 (40%)	211 (25%)	266 (25%)	307 (29%)	299 (28%)	198 (8%)

Seg.: segment

ICC: intrahepatic cholangiocarcinoma

HCC: hepatocellular carcinoma

HBDC: hilar bile duct carcinoma

TABLE 4 Demographics and volumetric data in 10 patients who underwent portal vein embolization before hepatectomy

	Gender Age	Disease	Embolized liver		RI (cm^3)				CT (cm^3)			
					Seg. 6+7	Seg. 5+8	Seg. 4	Seg. 2+3	Seg. 6+7	Seg. 5+8	Seg. 4	Seg. 2+3
1	63 Female	BDC	left liver	prePVE	334 (23%)	483 (32%)	283 (19%)	387 (26%)	390 (33%)	344 (30%)	269 (23%)	336 (14%)
				postPVE	421* (32%)	505* (39%)	166 (13%)	210 (16%)	332* (22%)	342* (29%)	214 (21%)	290 (28%)
2	83 Male	HCC	right liver	prePVE	152 (14%)	545 (51%)	139 (14%)	222 (21%)	211 (19%)	524 (46%)	170 (15%)	216 (20%)
				postPVE	282 (26%)	376 (35%)	161* (15%)	263* (24%)	293 (25%)	392 (33%)	219* (19%)	277* (23%)
3	69 Female	GBC	right liver	prePVE	352 (26%)	436 (32%)	292 (22%)	302 (22%)	248 (21%)	356 (30%)	326 (28%)	242 (21%)
				postPVE	236 (18%)	357 (28%)	365* (28%)	327* (26%)	215 (19%)	321 (26%)	356* (34%)	311* (24%)
4	75 Male	BDC	right liver	prePVE	334 (23%)	380 (29%)	241 (18%)	386 (29%)	208 (20%)	427 (40%)	184 (17%)	242 (23%)
				postPVE	302 (23%)	247 (18%)	299* (22%)	498* (37%)	232 (22%)	302 (29%)	214* (21%)	290* (28%)
5	84 Male	HCC	right liver	prePVE	284 (23%)	463 (37%)	190 (16%)	291 (24%)	251 (25%)	351 (34%)	177 (18%)	214 (23%)
				postPVE	108 (13%)	198 (18%)	174 (23%)	420* (46%)	273 (30%)	297 (26%)	178 (18%)	265 (268%)
6	77 Male	BDC	right liver	prePVE	556 (40%)	401 (29%)	241 (17%)	192 (14%)	451 (39%)	349 (29%)	226 (19%)	160 (14%)

				postPVE	379 (26%)	437 (31%)	295 (21%)	312* (22%)	349 (18%)	365 (18%)	260 (18%)	202* (18%)
7	67 Male	BDC	right liver	prePVE	411 (33%)	489 (39%)	147 (12%)	193 (16%)	302 (28%)	435 (40%)	157 (16%)	170 (16%)
				postPVE	258 (21%)	348 (29%)	338* (28%)	278* (23%)	300 (29%)	260 (21%)	270* (25%)	272* (25%)
8	53 Female	GBC	right liver	prePVE	300 (25%)	480 (40%)	252 (21%)	168 (14%)	264 (26%)	431 (43%)	133 (13%)	186 (18%)
				postPVE	228 (19%)	428 (36%)	229 (19%)	294* (25%)	219 (19%)	374 (33%)	250* (22%)	294* (26%)
9	72 Female	BDC	right liver	prePVE	448 (28%)	424 (27%)	347 (22%)	380 (24%)	497 (31%)	532 (33%)	250 (15%)	346 (21%)
				postPVE	248 (20%)	323 (26%)	254 (31%)	401 (33%)	295 (24%)	397 (32%)	218 (18%)	332 (26%)
10	71 Male	BDC	right liver	prePVE	348 (27%)	448 (34%)	250 (19%)	261 (20%)	302 (26%)	430 (38%)	200 (18%)	211 (18%)
				postPVE	237 (21%)	326 (29%)	248 (22%)	332 (29%)	276 (24%)	342 (30%)	261 (23%)	278 (24%)
	Average			prePVE	351±121 (27±8%)	452±53 (36±8%)	231±71 (18±4%)	267±86 (21±5%)	304±110 (26±6%)	426±73 (37±6%)	203±62 (18±5%)	222±59 (20±3%)
				postPVE	238±76[#] (20±5%)	339±83[#] (28±6%)	252±75 (23±6%)	349±82[†] (31±9%)	272±47 (20±5%)	339±50[#] (29±4%)	259±89[#] (22±5%)	281±36[#] (24±3%)

Sg.: segment

BDC: bile duct carcinoma, HCC: hepatocellular carcinoma, GBC; gallbladder carcinoma

PVE; portal vein embolization

*: Hepatic volume in the non-embolized (hypertrophy) liver after PVE

#: $P<0.05$, †: $P<0.01$