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Original article

The most appropriate formula for accurate calculation of standard liver volume for Thai population

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Background: Living donor liver transplantation has been used for the treatment of end-stage liver disease due to the decline in organ donations. Living donor graft volume (GV) to recipient standard liver volume (SLV) ratio should be estimated before surgery to assess the degree of graft size disparity. In order to avoid post-operative liver failure, it is important to calculate SLV as a reference point for the minimal volume necessary for the recipient.
Objective: We determined which formula is the most appropriate and accurate for calculating SLV in the Thai population.
Materials and methods: One hundred twenty patients with multi-detector computed tomography (MDCT) of the upper or whole abdomen for conditions unrelated to hepatobiliary system with normal liver images between August 1, 2009 and March 31, 2010 were enrolled into the study. TLV measurements obtained from MDCT were compared to the SLV calculation based on the previously reported formulae.
Results: The formula derived from the Thai population by Hatthapornsawan S et al. was based on the body weight and its SLV estimation was the closest to TLV (ICC = 0.703). However, this formula underestimated SLV on average by 69.8 cc. The formula derived from the Japanese population by Urata et al. underestimated SLV by 97.7 cc with an ICC of 0.44. The body weight was found to correlate most closely with TLV ($R^2 = 0.972$, $P<0.001$). The new linear regression formula used to estimate SLV was modifies to SLV = 20.67 × body weight.
Conclusion: From the six previously reported formulae for the calculation of SLV, values obtained from the formula by Hatthapornsawan S et al. was the closest in estimating the liver volume in the Thai population but also slightly underestimated SLV. We have modified the formula. We recommend that Thai physicians use this new formula to calculate SLV because it is more accurate than the previously reported formula.

Keywords: Liver volume, MDCT, measurement, standard liver volume, Thai population

Major liver resections are on the rise for the treatment of primary or metastatic liver cancer. The remnant liver gradually regenerates back to the standard liver volume (SLV) which is the optimal liver volume required to meet the body's metabolic demand but regenerations were at a slower rate compared to the recipient's graft [1, 2]. There has been an upsurge in number of liver transplantations being performed even through the number of available organs has not increased.

Living donor and split-liver transplantation have been established for the treatment of end-stage liver disease. The strategy can be used when there is a shortage of organs [1]. In adult-to-adult living donor liver transplantation, the graft volume (GV) is inevitably much smaller compared to SLV. Therefore the ratio of GV obtained from multi-detector computed tomography (MDCT) scanning images to SLV in recipients obtained from body surface area (BSA) (GV:SLV ratio) should be estimated before surgery to assess the degree of graft size disparity [2-5]. Kawasaki et al. recommended that predicted GV: SLV ratio should not be below 30% in both donor and recipient [3]. Previous studies reported that future liver remnant (FLR) <25% of SLV could increase the incidence of postoperative hepatic dysfunction in patients with a normal liver [2-5]. In several studies, it has been recommended that pre-operative portal vein embolization (PVE) should be done to increase the liver volume when FLR was less than 25 to 35%

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of the whole liver in patients with normal liver parenchyma and less than 40% in patients with chronic liver disease or damaged liver [2-5]. Furthermore, in order to avoid post-operative liver failure, it is important to calculate SLV as a reference point to determine the minimal volume required for successful living donor liver transplantation [3].

Estimation of SLV has been used to predict the hepatic metabolic demand of each patient. It has been shown that patient characteristics such as body weight, body height, body surface area (BSA) or body mass index (BMI) may affect SLV [6]. Because of this, several formulae used to calculate the liver volume have been based on the recipient's body weight, body height, BSA and BMI [7, 8]. Even through these formulae have been verified to precisely estimate SLV in healthy adults however, it is important to remember that these studies utilized different populations to measure liver volume. This may affect the accuracy of these formulae [7-14] for calculation of the SLV in Thai population.

The accuracy of the current Thai formula has never been retested by other researchers despite the fact that this was all derived from only 20 patients. Any under- or over-estimates of the SLV can jeopardize the success of the living donor liver transplantation. Therefore, this study decided to assess the accuracy of all the formulae previously reported for SLV calculation in the Thai population to avoid post-operative liver failure.

Materials and methods

Our institutional review board approved this cross-sectional study. The sample size of this study was based on a previous study [11]. We used the program PASS 2008 to calculate the sample size. A total sample size of 120 was sufficient to reach 90% power. All patients undergoing MDCT studies of the upper or whole abdomen for the condition unrelated to hepatobiliary system with normal liver radiology between August 1, 2009 and March 31, 2010 were recruited into the study. All MDCT results were analyzed by experienced radiologists. Patients were excluded if they had any liver lesion, diffuse liver disease such as malignancy or lymphoma, abnormal liver function test, bile duct disease (bile duct tumor or dilatation), cholangitis or vascular obstruction**,** significant rapid weight loss (>10% weight loss in three months), on parenteral nutrition, were bedridden and under 16 years old [15-17].

Contrast-enhanced MDCT scanning was performed by using the standard protocol when respiration was suspended by using a Somatome Sensation 4 or 16 (SIEMENS). Scanning started at the diaphragm through the whole liver. The MDCT data was transferred to a work-station to assess the liver volume. The border of the liver in the portovenous phase was manually outlined by using a track ball. Gallbladder, inferior vena cava, interlobar fissure, and portal vein were excluded from the image data. All MDCT data were performed by the researcher of the study. The volume program for MDCT scan was able to limit the optimum upper and lower Hounsfield unit thresholds for liver parenchyma. To increase the accuracy of the liver volume estimation, data from the intrahepatic vessels were extrapolated. We used the upper and lower limits of 160 to 180 and 40 to 60 Hounsfield units, respectively [18]. Total liver volume (TLV) was calculated by summing up the volume of each slice of liver with a thickness of 5 mm. By using this volume program, we were able to calculate the total liver volume in cubic centimeters (cm^3) as shown in **Figure 1**.

Patient height and weight were recorded at the time of MDCT examination. Du Bois formula was used to calculate the body surface area (BSA) [19]: [BSA (m^2) = body weight (kg) $^{0.425} \times$ body height (cm)$^{0.725}$ $\times$ 0.00718]. Body mass index (BMI) was calculated by using Quetelet's formula: [BMI (kg/m^2) = (10,000 $\times$ body weight (kg)/body height (m)^2]. SLV was calculated by using six previously published formulae that were validated in different populations [9-14].

Data analysis was performed by using SPSS version 16.0. We used intraclass correlation power analysis (ICC) to assess the correlation between calculated SLV from each equation and TLV measured from MDCT images. If the ICC was close to 1.0, then it was considered to be in agreement with 90% power and at 5% level of significance (p <0.05). The relationships between liver volume and age, body weight, body height, BSA or BMI were also analyzed by using univariate and multivariate linear regression statistic analysis.

Results

One hundred twenty patients (42 male and 78 female) were analyzed. The mean age, weight, height, BSA and BMI were 57 years (range 23-90), 59.2 kg (range 30-106), 159 cm (range 135-178), 1.60 m^2

(range 1.12-2.08) and 23.34 kg/m^2 (range 14.27-43), respectively. The descriptive data is summarized in **Table 1**.

TLV was measured by MDCT images with a range of 746.7 to 3212.8 cm^3. Mean TLV was 1230.2 cm^3 as shown in **Table 2**.

The TLV was analyzed by correlation coefficient. **Table 3** shows the comparison between TLV as measured by MDCT scans and SLV from six previously mentioned formulae. The formula derived from the Thai population was based on the recipient's body weight and was found to estimate SLV more closely to TLV (ICC = 0.703).

The new regression formulae were obtained from our population based on the body indices that are shown in **Table 4.** The body weight was found to correlate most closely with TLV (R^2 = 0.972, p <0.001). The new linear regression formula used to estimate SLV was derived from body weight of the recipient as follows: SLV = 20.67 × body weight (kg) (**Figure 2**).

When age and gender were excluded from the multivariate linear regression analysis, liver volume was slightly correlated with age (age; R^2 = 0.055, 0.001< p <0.05) and was insignificantly correlated with gender (gender; R^2 = 0.018, p >0.05). The significant multivariate regression formula for SLV was [48.32 × BMI (kg/m^2)] + [11.14 × BH (cm)] – 1670.90 (R^2 = 0.535, p <0.001).

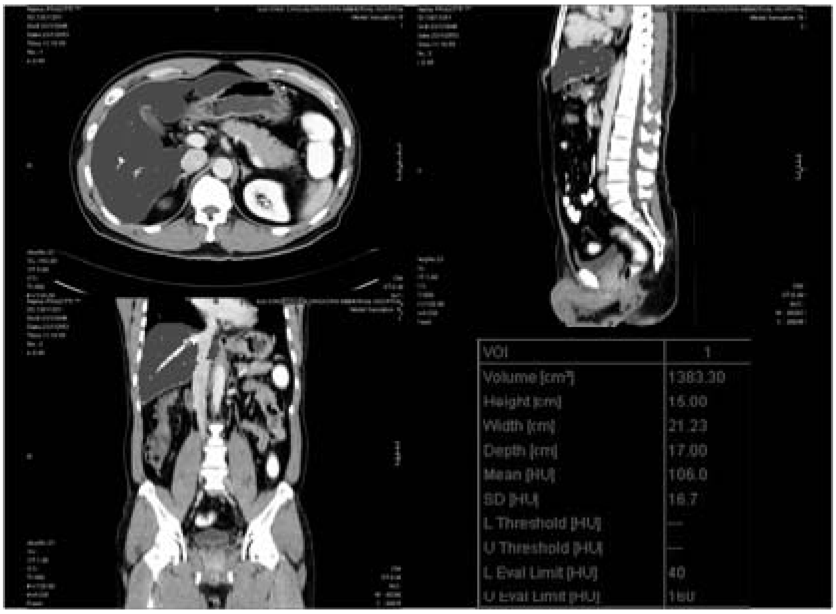

Figure 1. The MDCT scan using the volume program. The total liver volume was obtained by summing up the volumes of the individual slices of liver as cubic centimeters (cm^3). TLV does not include the gallbladder, inferior vena cava, interlobar fissure, and portal vein.

Table 1. Descriptive data of 120 patients.

	Male		Female		Total	
	Mean±SD	**Range**	**Mean±SD**	**Range**	**Mean±SD**	**Range**
Age (years)	58.5±13.8	(26-86)	56.1±15.4	(23-90)	56.9±14.8	(23-90)
Body weight (kg)	63.2±12.7	(30-102)	57.1±11.5	(38.5-106)	59.2±12.2	(30-106)
Height (cm)	165.5±7.4	(145-178)	155.8±6.0	(135-168)	159.2±8.0	(135-178)
BSA (m^2)	1.69±0.18	(1.12-2.08)	1.55±0.15	(1.29-2.04)	1.60±0.17	(1.12-2.08)
BMI (kg/m^2)	22.96±3.9	(14.27-37.47)	23.54±4.56	(16.65-43.0)	23.34±4.4	(14.27-43)

Table 2. Measurements of the total liver volume [TLV, cubic centimeters (cm^3)] using MDCT images.

Sex	Number (%)	Minimum (cm^3)	Maximum (cm^3)	Mean (cm^3)
Male	42 (35)	863.17	1896.81	1,285.5
Female	78 (65)	746.69	3212.82	1,200.4
Total	120 (100)	746.69	3212.82	1,230.2

Table 3. Correlation between standard liver volume [SLV, cubic centimeters (cm^3)] calculated by each formula and total liver volume [TLV, cubic centimeters (cm^3)] as measured by MDCT images.

Formula	ICC	Mean of SLV (cm^3)	Difference between TLV-SLV (Mean±SD), (cm^3)
Japanese population-based study $SLV = (706.2 \times BSA) + 2.4$	0.442	1132.52	97.67±22.55
Western population-based study $SLV = 191.8 + (18.51 \times BW)$	0.693	1288.22	-58.03±19.33
Thai population-based study $SLV = 19.59 \times BW$	0.703	1160.40	69.79±19.38
Korean population-based study $SLV = 21.585 \times BW^{0.732} \times BH^{0.225}$	0.656	1335.48	-105.19±19.84
Indian population-based study $SLV = 375.2 + (14.2 \times BW)$	0.621	1216.33	13.87±19.85
Chinese population-based study $SLV = (12.5 \times BW) + 536.4$	0.578	1276.83	-46.64±20.37

ICC=intraclass correlation, BW=body weight [kilograms (kg)], BH=body height [centimeters (cm)], BSA=body surface area [square meters (m^2)], BMI=body mass index (kg/m^2)

Table 4. New regression formulae obtained from our population based on the body indices.

Univariate regression	Formula	R	R2	*P* value
Age (years)	$(-4.88 \times age) + 1508.3$	0.235	0.055	<0.05
BW (kg)	$20.67 \times BW$	0.986	0.972	<0.001
BH (cm)	$7.73 \times BH$	0.972	0.945	<0.001
BSA (m2)	$(1151.16 \times BSA) - 612$	0.646	0.417	<0.001
BMI (kg/m^2)	$52.53 \times BMI$	0.984	0.968	<0.001
Multivariate	$(48.32 \times BMI) + (11.14 \text{ x } BH) - 1670.90$	0.731	0.535	<0.001

BW = body weight [kilograms (kg)], BH=body height [centimeters (cm)], BSA = body surface area [square meters (m^2)], BMI=body mass index (kg/m^2)

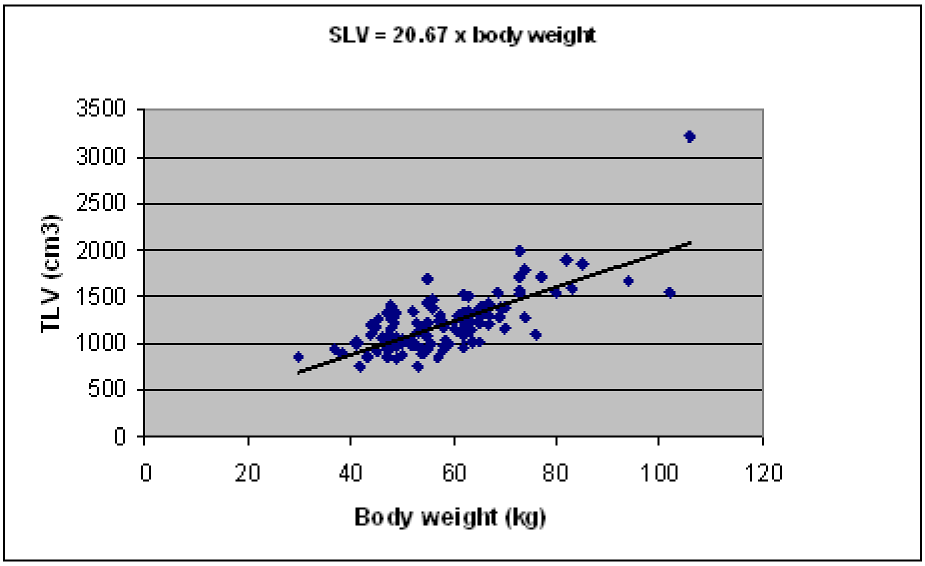

Figure 2. Correlation between body weight (kg) and total liver volume [TLV, cubic centimeters (cm^3)], SLV (cm^3) = 20.67 × body weight (kg); R^2=0.972, p<0.001.

Discussion

The use of MDCT scanning is on the rise to measure liver volume. Previous studies have shown that MDCT images had a high rate of accuracy in measuring the liver volume [3, 18]. Tanpowpong N et al. revealed that there was a strong correlation between the liver volume measured by using MDCT images and actual liver volume by water replacement method. MDCT scan to be the gold standard for assessing the liver volume.

Hatthapornsawan S et al. found that SLV correlated most closely with the recipient's body weight in the Thai population. However, this study was done in only 20 autopsied livers without excluding patients with any liver disease. This study lacked variations in the patients' weight and height that limited the use of the formula in a very fat or very tall person [12].

In order to compensate for the limitations found in Hatthapornsawan S et al.'s study, we decided to have a larger study with a wider range of people with different body weights and heights. When we compared all six formulae, we found that Hatthapornsawan S et al.'s formula estimated most closely to the SLV (ICC=0.703). However, this formula underestimated SLV on average by 69.8 cm^3. This underestimation may be due to the way they measured the liver volume. Liver volumes were measured by water replacement and were not accurate because there was some loss of fluid in the liver tissue, which caused it to shrink.

We found that the Japanese formula by Urata et al. [9] underestimated SLV on average by 97.67±22.55 (SD) cm^3 (ICC = 0.44) in the Thai population. Chandra MA et al. [11] also showed that the Japanese formula underestimated SLV by 63 cm^3 in the Indian population. Another study conducted by Heinemann A et al. reported [7] that the liver volume obtained from the Japanese formula underestimated SLV by 322.6 +/- 335.8 cm^3 (SD) in the Caucasian population. These underestimations of the SLV can compromise the graft volume. These underestimations are due to the low mean BSA of Urata et al.'s study population. Most of the patients in their study were children (N = 96, pediatric = 65, mean BSA 1.5 m^2). Thus, in our study, we excluded anyone under 16 years old because it has been shown that the ratio of estimated SLV to BW gradually decreases with age up to approximately 16 years [7-8].

On the other hand, the Western, Korean, and Chinese formulae overestimated SLV in the Thai patients on average by 46.64-105.19 cm^3, which may compromise donor safety.

From the univariate and multivariate linear regression, we derived three formulae to calculate SLV in the Thai population based on body weight, height, and BMI as follows: SLV = 20.67 × BW (kg), SLV = 7.73 × BH (cm), and SLV = 52.53 × BMI (kg/m^2). These formulae showed a strong correlation with the liver volume. The R^2 of these formulae were more than 0.9. This study confirmed that the liver volume correlated well with the body weight, height, BSA and

BMI as previously reported [11, 12]. Age and gender did not affect the calculation for SLV [11, 12]. The body weight was found to correlate most closely with TLV ($R^2 = 0.972$, $p < 0.001$). Consequently, the multivariate regression formula was derived as follows: SLV = [48.32 × BMI (kg/m^2)] + [11.14 × BH (cm)] – 1670.90 ($R^2 = 0.535$, $p < 0.001$). This formula should be interpreted with caution because it is moderately correlated with liver volume ($R^2 \sim 0.535$).

Conclusion

Among the six previously reported formulae for SLV calculation, only Hatthapornsawan S et al.'s formula, derived from the Thai population based on the recipient's body weight, estimated most closely to the liver volume in the Thai population (ICC = 0.703) but slightly underestimated SLV. We have modified the formula to accurately calculate SLV in the Thai population. The new formula should be helpful in decreasing morbidity from graft size disparity after having living donor liver transplantation.

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