Estimation of Right Hemiliver Graft Weight for Living Donor Liver Transplantation using Portal Vein Diameter - A "Second Checkpoint"

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ABSTRACT

Background: Estimation of graft weight for live donor liver transplant using portal vein diameter has not been validated widely.

Objective: To observe the accuracy of portal vein diameter based formula in predicting graft weight.

Methods: Graft weight was estimated using standard liver volume (SLV) multiplied by the ratio of portal vein branch diameter (Lee's formula). SLV was calculated using different formulae described in the literature. The most accurate formula was compared with three dimensional computed tomography volumetry in terms of accuracy of prediction of actual graft weight. Factors which predicted percentage error of more than 15 in computed tomography were analyzed.

Results: In 307 right hemiliver grafts, SLV calculation by Urata's method in Lee's formula was the most accurate (P=0.60 in Analysis of Variance) among all SLV methods. Lee's formula with Urata and computed tomography volumetry had a good correlation with actual graft weight (r=0.77 vs. r=0.8) which was confirmed by Bland Altman analysis. On volumetry 45 patients had a percent error of more than 15. On logistic regression analysis, an estimated graft volume of greater than 800cc was a significant factor (p=0.008, odds ratio 2.99) and, in these patients Lee's formula was better(mean error 9.2 ±7.8 vs. 20.2±4.5, p<0.001).

Conclusion: Lee's formula with SLV by Urata's method was accurate and can act as the second checkpoint after three dimensional computed tomography volumetry. Computed tomography estimate of graft weight more than 800 is associated with higher inaccuracy and in those patients portal vein diameter based formulae fared better.

KEYWORDS: Portal vein; Living donors; Liver transplantation; Hepatectomy

INTRODUCTION

Estimation of graft weight preoperatively is mandatory before live donor liver transplant (LDLT) and has a bearing on transplant outcome. Based on the hypothesis that the volume of each lobe is proportional to the portal blood flow, Lee et al. [1] derived the ratio of right and left portal vein flow using their diameter and multiplied it by standard liver volume (SLV) derived using Urata's formula [2]. Using this method they accurately estimated graft volume in split liver transplant setting [1]. An extrapolation of this method to a cohort of living donors produced similar results [3].

Addressing the issue of using single SLV formula in the equation, which might not be applicable to other patient population, and trifurcation anomaly of the portal vein in which

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Table 1: Demographic characteristics (n=307).

Characteristics	Mean ± SD (range)
Age (years)	30.4 ± 9.1 (18-55)
Sex Male: Female	135:172
Body weight (kg)	63.3 ± 8.3 (45-91)
Height (cm)	165.1 ± 5.4 (151-180)
Body Mass Index (kg/m^2)	24.1 ± 2.5 (18-30.2)
BSA (m2)	1.7 ± 0.1 (1.5-2.0)
Portal vein type (Cheng's classification)	Type 1- 286 Type 2- 16 Type 3- 5

diameter of right portal vein cannot be precisely measured, Tongyoo et al.[4] calculated estimated graft weight using a similar formula, but right anterior and posterior portal vein diameter was used separately and the standard liver volume was calculated using several formulae described in the literature.

In this study, we compared the portal vein diameter based formulae for estimation of graft weight using different SLV formulae described in the literature and compared it with actual graft weight and three dimensional computed tomography (3DCT) volumetry. We further analyzed the factors which predicted error in CT volumetry.

MATERIALS AND METHODS

All consecutive subjects undergoing right hemi liver donor hepatectomy during the study period from March 2012 to October 2018 were included in the study (n=307). The study was approved by the ethical committee of the institute and has therefore been performed in accordance with the ethical standards laid down in the Declaration of Helsinki 1975(revised in 2000). Written informed consent was taken from all the participants.

Donor Selection

We have previously published on our donor selection process [5]. Contrast enhanced computed tomography (CECT) abdomen with volumetry was done in step 2 of donor evaluation. The CECT was seen by a radiologist and a transplant surgeon and discussed in a multidisciplinary meeting.

CT Volumetry

In the initial 69 patients, two-dimensional volumetry was performed and in the rest, 238 patients underwent three-dimensional volumetry.

The imaging data obtained from multi detector contrast enhanced computed tomography (CECT) were processed with the help of Myrian XP Liver 3D software (France). Segmentation algorithms were used to isolate entire hepatic vascular systems as well as healthy parenchyma and to calculate liver parenchyma volume. The contours of intermediate slices in hepatic venous phase were automatically interpolated and optimized by the software and ultimately by the radiologist (with manual correction if needed). For right hemi liver volume estimation a plane was drawn along the middle hepatic vein (MHV) on the venous phase of the CECT abdomen. Parenchymal

Table 2: Calculated standard liver volumes, donors, using various SLV formulae (n=307) in ascending order of the values.

Formula	SLV* in ml (Mean ± SD)
Chan [10]	1008 ± 112
Fu-Gui [11]	1063 ± 96
Urata [2]	1199 ± 86
Hashimoto [7]	1250 ± 117
Lee [12]	1266 ± 84
Noda [13]	1273 ± 131
Chandramohan [14]	1281 ± 117
Yoshizumi [15]	1309 ± 94
Yuan [16]	1313 ± 113
Vauthey [28]	1354 ± 155
Vauthey [18]	1364 ± 155
Lin [9]	1377 ± 151
Yu [17]	1417 ± 143
Heinemann [18]	1473 ± 131
Deland [19]	1509 ± 124
Chouker [20]	1715 ± 212

*Standard Liver Volume

volumetric calculations (in ml) were obtained after excluding extrahepatic vessels (portal vein, hepatic artery, and inferior vena cava).

Operative Procedure

We have previously published on our technique of donor hepatectomy [6]. In short, after the demarcation line is marked with electrocautery, the parenchymal transection is performed using a cavitronic ultrasonic surgical aspirator. The MHV is left in the remnant and transection proceeds as close to MHV as possible. The segment 5 and 8 veins are taken down after applying clips which are later opened on the bench at the time of perfusion. Hanging maneuver is used in the posterior most part of transection.

Actual Graft Weight

The weight of the graft was measured before perfusion with an electronic weighing machine. Actual volume was considered the same as graft weight assuming a unit density.

Formulae used in the Study

Standard liver volume was calculated according to different formulae described in literature [2, 7-20]. Portal vein anatomy was classified using Cheng's classification [21].

Graft weight estimation formulae using SLV

Lee's formula: used in cases of type 1 portal vein anatomy

$$RHLV = SLV^* [R2/ (R2+L2)]$$

Modified Lee's formula used in cases of type 2 (trifurcation) and 3 (staged) portal vein anatomy

$$RHLV = SLV^* [(RA2+RP2)/(RA2+RP2+L2)]$$

Table 3: The right hemiliver volumes of donors estimated by the method of Lee /modified Lee's using the previously calculated SLV formulas (n=307) as compared to actual graft weight (ANOVA with repeated measures).

	Mean Difference	Std. Error	P-value	95% Confidence Interval
Urata [2]	-12.958	4.41	0.6069	-29.115 to 3.200
Deland [19]	-182.368	5.308	<0.0001	-201.816 to -162.920
Chan [10]	113.659	4.926	<0.0001	95.609 to 131.709
Chandramohan [14]	-46.938	5.132	<0.0001	-65.742 to -28.133
Chouker [20]	-305.384	8.711	<0.0001	-337.304 to -273.464
Fui Gui [11]	81.209	4.942	<0.0001	63.101 to 99.318
Hashimoto [7]	-34.71	4.945	<0.0001	-52.828 to -16.592
Lee [12]	-39.385	4.976	<0.0001	-57.619 to -21.150
Lin [9]	-104.257	5.346	<0.0001	-123.846 to -84.669
Heinman [18]	-160.975	5.299	<0.0001	-180.391 to -141.560
Vauthey [18]	-95.917	5.617	<0.0001	-116.500 to -75.334
Vauthey 2 [8]	-90.723	5.385	<0.0001	-110.454 to -70.993
Yoshizumi [15]	-64.307	4.995	<0.0001	-82.611 to -46.003
Yu [17]	-127.263	5.477	<0.0001	-147.333 to -107.193
Yuan [16]	-66.776	5.028	<0.0001	-85.199 to -48.353
Noda [13]	-42.053	5.274	<0.0001	-61.379 to -22.726

RHLV (Right hemi liver volume), SLV (standard liver volume), R (right portal vein diameter), L (Left portal vein diameter), RA(right anterior portal vein diameter), RP (right posterior portal vein diameter)

Measurement of Portal Vein Diameter

The main R, RA, RP and LPV diameters were measured using the measuring "ruler" tool imbedded in the computed tomography software. Diameters were measured just distal to the branch point perpendicular to the axis of the vessel and recorded in the database.

Statistical Analysis

All analytical tests were performed using SPSS-20 software (IBM; SPSS, Chicago, IL, USA). Descriptive data were reported as mean ± SD The repeated measures analysis of variance (ANOVA) was used to compare the actual graft weight with estimated live donor right hemiliver graft volumes using Lee's/modified Lee's formula with SLV derived from different formulae in literature(n=307). Percentage error was calculated by the formula (estimated graft weight –actual graft weight /actual graft weight) x100. The statistical significance was set at a P value <0.05 for all tests. The formulae which had no significant difference with actual graft weight in ANOVA was compared to 3DCT volumetry using correlation scatter plots and Bland Altman analysis (n=238). Logistic regression analysis was performed to look for predictors of percent error of more than 15 in 3DCT volumetry.

RESULTS

A total of 307 right lobe live donor liver transplants were performed during the current study period. Donor demographics and anthropometric data, including gender, age, re

Table 4: Logistic regression analysis of factors which predicts error percentage of >15% on CT volumetry.

Factors	P-value	Adjusted Odds Ratio	95% Confidence Interval
BSA	0.266	0.165	0.007 to 3.946
BMI	0.329	1.076	0.929 to 1.246
Height	0.211	1.064	0.965 to 1.173
Weight	0.910	0.997	0.943 to 1.054
Age	0.495	1.014	0.975 to 1.055
Estimated CT volume of>800cc	0.008	2.993	1.328 to 6.747
Gender	0.808	1.091	0.541 to 2.197

lation, weight, and height were gathered and shown in Table 1. 3DCT volumetry was done in 238 patients and rest had 2-dimensional volumetry.

The standard liver volume of all 307 donors was calculated by all 16 formulae [2, 7-20] and expressed as mean and standard deviation (SD) in Table 2. Estimated SLV varied widely depending on the formula used and ranged from the smallest using the formula of Chan et al. [10] 1008±112 ml compared with the largest using the formula of Chouker et al. [20] 1715±212 ml.

In 21 patients' calculation of Lee's formula was not possible because of type 2 (trifurcation) or 3 (staged) portal vein anatomy (according to Cheng's classification) where measurement of the right portal vein diameter was not feasible, modified Lee's formula (as proposed by Tongyoo et al. [4]) was used.

The graft volumes of all 307 donors estimated by Lee's/modified Lee's formula using the previously calculated SLV are shown in Table 3. The statistical result from repeated measure ANOVA was P<0.005, which confirmed a significant difference between groups in this comparison. Compared to actual graft volumes, the most accurate method for estimating live-donor graft volume was Lee's/modified Lee's formula with SLV calculated by the method of Urata (P=0.6).

Correlation scatter plot were constructed between actual graft weight, 3D CT volumetry

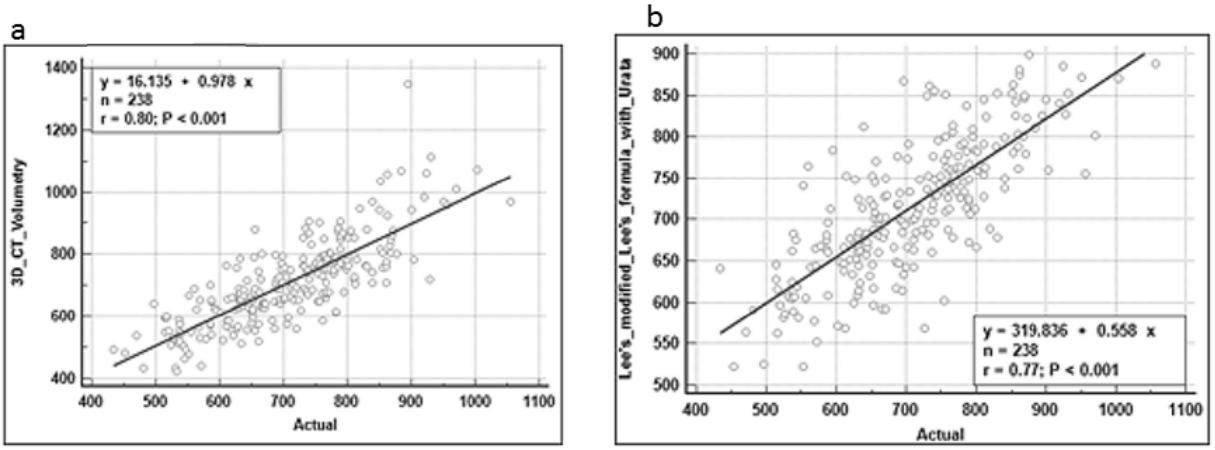

Figure 1: Scatter plot showing comparison of actual graft weight with 3D CT Volumetry (a), Lee's/Modified Lee's formula with SLV calculated by Urata's method (b).

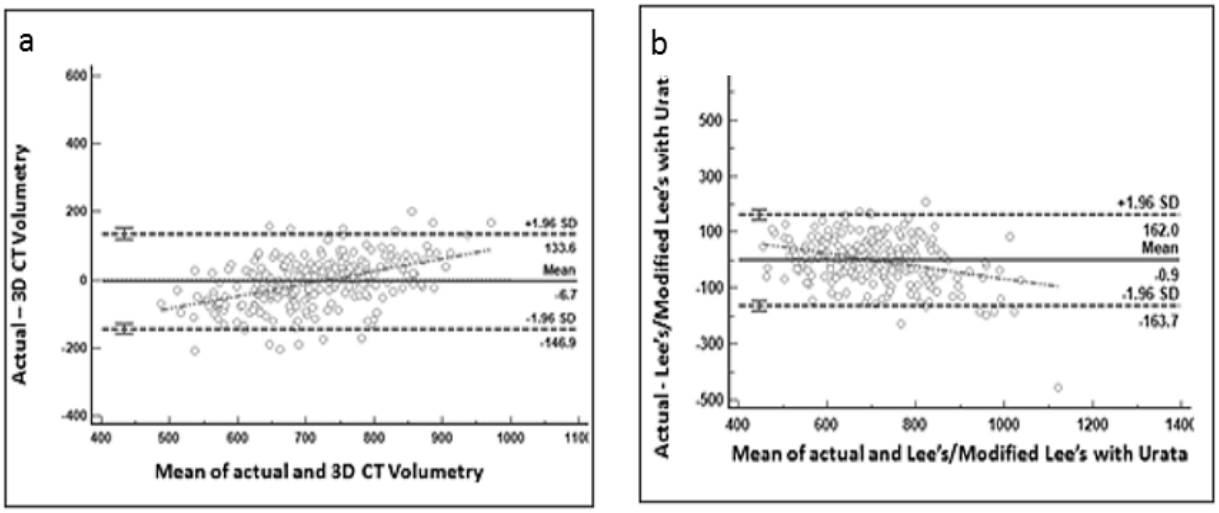

Figure 2: Bland Altman plot showing agreement of actual graft weight with 3D CT Volumetry (a), Lee's/Modified Lee's formula with SLV calculated by Urata's method (b).

(n=238) and Lee's and modified Lee's formula with SLV calculated by the method of Urata (n=238). Both the methods were accurate (r=0.8 for CT vs. r=0.77 for Lee's and modified Lee's formula with SLV calculated by the method of Urata), shown in Fig 1. Bland Altman plots were constructed to see the validity of the agreement and it was found that 3DCT volumetry had the narrower limit of agreement (-146 to 133) followed by Lee's and modified Lee's formula with SLV calculated by method of Urata (-163 to 162) as shown in Fig 2.

In 19% patients (45/238), percentage error of CT was more than 15%. Percentage error of Lee's and modified Lee's formula with SLV calculated by method of Urata in those patients was compared. The mean error was 20.2±4.5 for 3DCT vs. 9.2 ±7.8 for the portal vein-based formula, p<0.001. Factors which predicted error of more than 15% on 3DCT were analyzed by logistic regression analysis. Factors taken for analysis were donor age, gender, body surface area (BSA), body mass index (BMI), height, weight and estimated 3DCT graft volume of more than 800cc. Among all estimated 3DCT graft volume of more than 800 came out to be significant with p=0.008 and odds ratio of 2.99 shown in Table 4.

DISCUSSION

Pliability To the best of our knowledge, this is the largest study on validation of portal vein diameter-based formulae for estimation of graft weight in live donor liver transplant. Lee and modified Lee formulae with SLV calculated using Urata's formula was accurate and was complementary to 3D CT volumetry.

Portal vein-based formulae are based on the hypothesis that the amount of blood flow to a hemiliver is directly proportional to its mass. These formulae have two components, the first is the ratio of the portal vein flow and other is the total liver volume calculated as SLV using anthropometric parameters. This physiological basis theoretically provides information about the function of the hemiliver. We used Lee's formula for type 1 portal vein anatomy and modified Lee's formulae for type 2 and 3 portal vein anatomy where Lee formula cannot be used. It has been shown previously that there is no difference between Lee's and modified Lee's formulae if used in the same patient. It is the feasibility that decides which formulae are to be used [4]. The other component is SLV, which was calculated using different formulae described in the literature [2, 7-20]. There was a significant difference in the volumes calculated using different SLV formulae and graft weight was most accurately pre-

dicted when SLV was calculated using Urata's formula (p=0.6 in ANOVA with repeated measures) as compared to other SLV formulae. It had a good correlation and narrow limits of agreement in Bland Altman analysis as shown in figure 1 and figure 2. Therefore, it is important to have an SLV formula established for a patient population using retrospective data and then apply it prospectively to estimate the graft weight.

Three-dimensional computed tomography volume calculation was accurate in estimating the graft weight and had the narrowest limits of agreement (figure 1, 2). Although it is operator dependent and its accuracy depends upon the quality of images procured, it is consistently found to be accurate and almost all of live donor transplant centers use it for graft weight estimation [4]. It remains as the primary modality of graft weight estimation.

There was a subset of patients (n=45, 19%) in which CT volumetry had an error percentage of more than 15%. We have taken 15% as the cutoff because this amount of variation can have clinical implications. In these patients' portal vein, diameter-based formulae fared better. We tried to find out the factors which could predict this error as one can be more cautious in interpreting the volumetry results, and confirm it with portal vein diameter-based formula. One observation was in those with higher error the CT estimate was higher than usual graft weight we get. We included donor anthropometric parameters and age as they can have a bearing. On logistic regression analysis, a CT estimate of more than 800 cc came out to be a significant factor. So, if a patient had a 3DCT estimate of more than 800 cc, it was 3 times likely that he will have an error estimate of more than 15%. In this subset of patients' portal; vein diameter-based formula should be used to confirm the findings and in case of wide discrepancy, volumetry should be repeated.

Portal vein diameter-based formulae have a physiological basis as opposed to volumetry where the calculation is based on anatomical data. These two entirely different methods can complement each other and in the case of wide discrepancy, further evaluation can be carried out. In a situation like live liver donor evaluation where the margin of error is very low, having a second checkpoint is always desirable. One has to be more careful in interpreting the volumetry results if the estimated volume is higher than what is normally seen in the patient population like more than 800cc in this series. In these situations, this method can be reassuring to the surgeon.

One of the limitations was that the study could not capture any factor which predicted error in portal vein diameter-based formulae.

In conclusion, portal vein-based formulae give a fairly accurate estimation of right hemiliver graft volume when Urata formulae are used for calculation of SLV in this cohort of patients. Portal vein diameter-based formula predict better when estimated volume by 3DCT is more than 800cc.

CONFLICTS OF INTEREST: None declared.

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