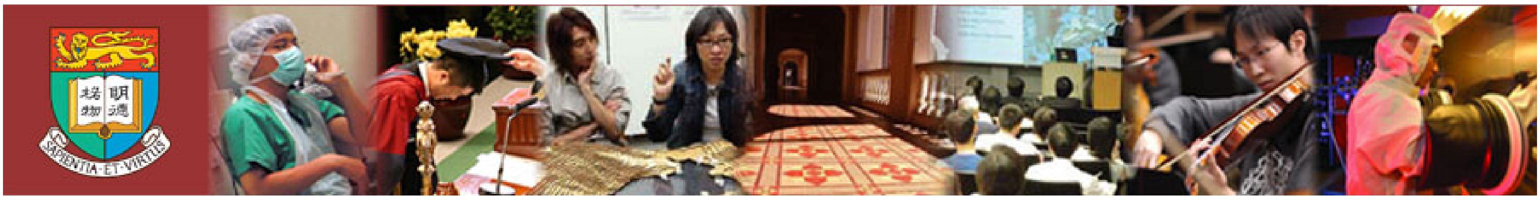

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CLINICAL RESEARCH

Estimating liver weight of adults by body weight and gender

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Abstract

AIM: To estimate the standard liver weight for assessing adequacies of graft size in live donor liver transplantation and remnant liver in major hepatectomy for cancer.

METHODS: In this study, anthropometric data of body weight and body height were tested for a correlation with liver weight in 159 live liver donors who underwent donor right hepatectomy including the middle hepatic vein. Liver weights were calculated from the right lobe graft weight obtained at the back table, divided by the proportion of the right lobe on the computed tomography.

RESULTS: The subjects, all Chinese, had a mean age of 35.8 ± 10.5 years, and a female to male ratio of 118:41. The mean volume of the right lobe was 710.14 ±131.46 mL and occupied 64.55%±4.47% of the whole liver on computed tomography. Right lobe weighed 598.90±117.39 g and the estimated liver weight was 927.54 ±168.78 g. When body weight and body height were subjected to multiple stepwise linear regression analysis, body height was found to be insignificant. Females of the same body weight had a slightly lower liver weight. A formula based on body weight and gender was derived: Estimated standard liver weight (g) = 218 + BW (kg) x 12.3 + gender x 51 (R^2 = 0.48) (female = 0, male = 1). Based on the anthropometric data of these 159 subjects, liver weights were calculated using previously published formulae derived from studies on Caucasian, Japanese, Korean, and Chinese. All formulae overestimated liver weights compared to this formula. The Japanese formula overestimated the estimated standard liver weight (ESLW) for adults less than 60 kg.

CONCLUSION: A formula applicable to Chinese males and females is available. A formula for individual races appears necessary.

Key words: Estimated standard liver weight; Liver tranplantation

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INTRODUCTION

Small-for-size graft is a common problem in live donor liver transplantation[1]. In major hepatectomy, a small remnant liver is a key factor attributing to hospital mortality[2], even in the non-cirrhotic liver[3]. Size of the partial liver graft or the remnant liver is often expressed as a percentage of the estimated standard liver weight (ESLW) of the patient. Very often, the native liver of a transplant recipient is small and cirrhotic, and that of a patient undergoing major hepatectomy houses a large tumor. The size of the patient's liver, therefore, has little bearing on the preoperative assessment. Under both circumstances, reference to ESLW has a clinical relevance. The Shinshu group of Japan deduced a formula by drawing a relationship between the estimated standard liver volume (ESLV) and body surface area (BSA) from 96 patients who underwent abdominal computed tomography (CT), yet without liver diseases: ESLV (mL) = 706.2 × BSA (m^2) + 2.4[4]. BSA was derived from the clinical parameters of body weight (BW) and body height (BH) as described by DuBois and DuBois[5]. In view of the low mean age (11.1 years) of the patients in the study, the Shinshu group subsequently validated the formula by the same methodology in an independent sample of 96 adult live liver donors[6]. Nonetheless, this formula when applied to Caucasians underestimates the liver volume from studies based on autopsy data[7] and CT of patients without liver diseases[8].

Underestimation of liver volume was even found in another group of Asian population, the Koreans. In this Korean group the increase in liver volume in relation to BSA showed a nonlinear relationship. A piecewise linear model and a nonlinear model have thus been developed in Korea[9]. In another study, a sample of 33 Chinese in-patients admitted for abdominal ailments apart from liver diseases were evaluated by CT. The main purpose of the study was to use them as control in comparison with cirrhotic livers and not intended for a broader application of liver size estimation[10]. As early as the sixties, it was pointed out that females of the same body size as males have a smaller liver[11]. A study of a wider scale recently has affirmed this concept[12]. Our study was to clarify the above issues by analyzing the right lobe graft weight which was measured directly on the back-table during donor right hepatectomy in healthy live liver donors. The weight of the whole liver was calculated by the measurements of the liver volumes from CT.

MATERIALS AND METHODS

Study design

From May 10, 1996 to October 25, 2004, 182 consecutive right lobe live donor liver transplants were performed at the University of Hong Kong, Queen Mary Hospital. These 182 live liver donors being evaluated and operated were healthy with normal liver biochemistry. None of them was hepatitis B or C carriers, or had the habit of alcohol consumption. Donor anthropometric data including age, gender, BW (measured to the nearest 0.5 kg), and BH (measured to the nearest 1 cm) were recorded prospectively and entered into a liver transplantation database by 2 designated liver transplant research assistants. BSA was calculated by the formula by DuBois and DuBois: BSA (m^2) = BW (kg)$^{0.425}$ × BH (cm)$^{0.725}$ × 0.007184[5]. Body mass index = BW/BH × BH. CT of the donors was performed before the donor operation. Estimation of the liver volumes on CT was done by 3 dedicated radiologists using the Heymsfield method[13]. They had no information of the body size of the live liver donors or the liver transplant recipients. All subjects underwent single slice spiral CT (HiSpeed Advantage System; General Electric Health Care, Milwaukee, WI) and multi-slice CT study (LightSpeed QX/i 4-MDCT or LightSpeed 16-MDCT, General Electric Health Care, Milwaukee, WI) from 2000. Cuts were made at 5 to 7.5 mm intervals and continuously. Demarcation of the right and left portions of the liver was made by tracing along the middle hepatic vein, corresponding to the Cantlie's line. Volumes of the right lobe plus right caudate lobe (segment 1r) and the left lobe plus left caudate lobe (segment 1l)[14,15], were measured independently. All but 1 donor underwent donor right hepatectomy including the middle hepatic vein. This donor's right lobe graft did not include the middle hepatic vein for anatomical reason (case no. 85). The donor was a non-Chinese, and was therefore excluded. Details of the donor right hepatectomy have been described elsewhere[16]. In short, the transection line was determined by temporary inflow control. Transection by Cavitron ultrasonic surgical aspirator (CUSA; Valleylab, Boulder, CO), was just onto the left of the middle hepatic vein, including the latter into the right lobe liver graft. The right lobe liver grafts were perfused with University of Wisconsin Solution (NPBI, Emmer-Compascuum, the Netherlands), and from case no. 110 of the series, with histidine-tryptophan-ketoglutarate solution (Dr. Franz Köhler, Chemie GmbH, Alsbach-Hähnlein, Germany). The gallbladder was removed in the early phase of the hepatectomy during hilar dissection. No parts of the inferior vena cava, triangular ligament, or coronary ligament were included. The right lobe liver grafts were then weighed at the back-table. The weight of the whole donor liver was calculated by the right lobe graft weight (GW) divided by the volume fraction of the right lobe in relation to the entire liver as measured on the CT.

Exclusion criteria

We excluded 23 donors over this entire period of 8 years from this study. These included fatty change of the liver over 10% as documented by biopsy of the liver graft intraoperatively (n = 9). Non-Chinese donors (n = 6) were also excluded. The above 2 conditions occurred in 1 of the donors (n = 1). Donors with missing data of height were also excluded (n = 4). Donors with BW (n = 2) or BH (n = 1) lying beyond 97.5% were excluded. The number of subjects for analysis thus became 159.

Statistical analysis

Following testing for normal distribution (Kurtosis and Skewness tests), data were expressed as mean ± SD. Simple linear regression analysis by the least-squares fit method was used to plot the relation between calculated liver weight against BSA. This was then done with BW, and also BH as independent variables. Male and female subjects were analyzed separately. By stepwise multiple linear regression analysis, the correlation between calculated liver weight as a dependent variable and with BW and BH as independent variables, and gender as a binary factor, was tested. Goodness of fit of the formula was tested by analysis of residuals. Formulae deduced from other studies and this study were used to calculate the ESLW using BW, BH, BSA, and gender of these 159 subjects as appropriate[4,7-9,11,12,17,18]. ESLV derived from the respective formulae[4,7-10,18] was converted to ESLW by a factor of 1.19 mL/g as derived from analysis of data from this study. This was obtained by plotting liver volume on CT against calculated liver weight of these 159 subjects. The ESLW so derived was compared with the calculated liver weight of this series by 2-sided paired-samples t test. P < 0.05 was considered statistically significant. Regression lines of representative series were drawn and compared with the regression line of this study[4,8,9,12]. All statistical analyses were performed by SPSS Version11.0 program (SPSS, Chicago, IL).

RESULTS

Baseline characteristics

Characteristics of the 159 subjects and their livers are listed in Table 1. They were young. Females outnumbered males by 2 fold. Such a female preponderance was attributed to a higher proportion of male recipients (n = 118), and their wives volunteered as the donor (n = 58). Donors who were healthy had normal built as reflected from the BMI.

Liver weights and volumes

From the measurements made on the preoperative CT,

Table 1 Characteristics of subjects (mean ± SD, n = 159)

Age (yr)	35.8 ± 10.5 (18-57)
Gender (M : F)	53 : 106
Body weight (kg)	56.3 ± 8.4 (41.0-78.5)
Body height (cm)	161.7 ± 7.5 (144.5-181.3)
Body mass index (kg/m^2)	21.5 ± 2.6 (16.5-29.1)
Body surface area (m^2)	1.59 ± 0.14 (1.30-2.13)
Computed tomography liver volume (mL)	1,099.10 ± 181.51
Right lobe graft volume on CT (mL)	710.14 ± 131.46
Right lobe to total liver volume on CT (%)	64.55 ± 4.47 %
Right lobe graft weight (g)	598.90 ± 117.39
Estimated whole liver weight (g)	927.54 ± 168.78

CT: computed tomography.

the mean volume of the right lobe was 710.14 ± 131.46 mL and the whole liver was 1099.10 ± 181.51 mL. On the back-table, the right lobe grafts after being perfused with preservation solution, weighed 598.90 ± 117.39 g. The right lobe accounted for an average of 64.55% ± 4.47% of the entire liver on the CT. The total liver weight calculated was 927.54 ± 168.78 g.

Regression models

When the calculated liver weight was plotted against BSA for males (R^2 = 0.37) and females (R^2 = 0.26), the linear relationships were distinctly different (Figure 1A). Those females with the same BSA as males had a lower calculated liver weight. When BW was used instead of BSA, a similar pattern occurred for males (R^2 = 0.38) and females (R^2 = 0.34) (Figure 1B). The correlation of calculated liver weight with BH was much weaker for males (R^2 = 0.13) and in particular for females (R^2 = 0.02) (Figure 1C).

By stepwise multiple linear regression analysis, the relation of calculated liver weight with BW, BH, and gender (male = 1, female = 0) was tested. BH was excluded by the collinearity statistics of tolerance from the following formula so derived:

ESLW (g) = 218.32 + BW (kg) × 12.29 + gender × 50.74 (R^2 = 0.48)

or more conveniently:

ESLW (g) = 218 + BW (kg) × 12.3 + gender × 51

The ESLW is predictably correlated with ESLV. Based on linear regression analysis, the relation between ESLW and ESLV is as follows: ESLV (mL) = 302.34 + ESLW (g) × 0.859 (R^2 = 0.64), ESLW (g) = 111.25 + ESLV (mL) × 0.743 (R^2 = 0.64). For simplicity, the conversion factor is 1.19 mL/g (Figure 1D).

Comparison of different formulae to estimated liver size

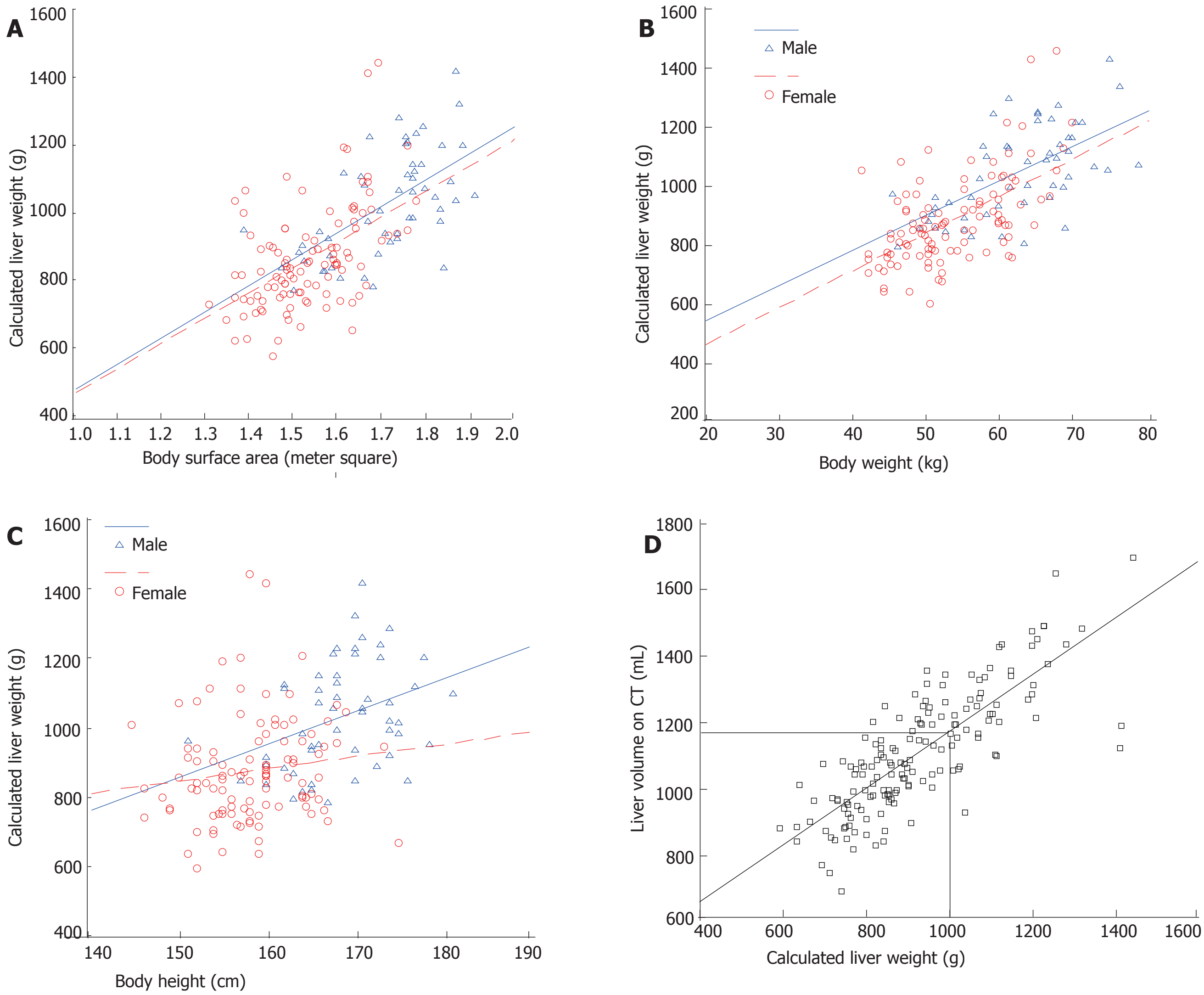
Using the formulae for ESLV and ESLW from other studies[4,7-9,11,12,17,18], and the anthropometric data of the 159 subjects of this study, the ESLV and ESLW were calculated. The ESLW was converted from ESLV by factor of 1.19 mL/g. The ESLWs calculated from each formula were compared with the calculated liver weight of these 159 subjects by two-sided paired-samples t test. All except that calculated from the Urata formula (P = 0.098) were found to deduce a higher ESLW, with statistically significant differences (P < 0.000, Table 2). Amongst these, 4 regression models were selected for comparison using the regression line of best-fit method. In one German study using autopsy data, the ESLW was markedly higher[12], whereas the other series had fairly close ESLWs[4,8,9]. The regression line of the model from Urata correlated nicely in subjects of the middle range of body weights. Nonetheless, divergence was seen in subjects with body weight less than 60 kg, resulting in a higher ESLW.

DISCUSSION

The results of this study demonstrate that in healthy Chinese adults, ESLW was positively related to BW, and such correlation was also gender-dependent. The liver of the male was slightly heavier than that of the female of the same body weight. Furthermore, BH was found to be not required in the estimation of the standard liver weight. Statistically, by the test of collinearity for tolerance, BH was eliminated as an independent factor. Though many studies have used BSA as the independent factor for liver size estimation, in which BH is a key component in calculating BSA, our findings here corroborate with those studies which evaluated BW, BH , and BSA independently[8,12]. This is also in concordance with the use of only body weight as reference in determining the adequacy of the size of the liver graft from studies of North America[19] and Europe[20]. In such convention, the graft weight to recipient body weight ratio is expressed as graft recipient weight ratio (GRWR). However, the intercept of the regression line in this study did not meet at zero, using body weight as denominator as in GRWR, accuracy may be compromised in subjects who deviate much from the mean body weight of the population.

The DuBois formula for calculating BSA[5] has been used for estimating liver size in 4 formulae[4,7,11,18]. The deficiency of the BSA formula is that it is published in 1916 and deduced from planometric measurements of the body castings made on 9 subjects spanning a wide age range[5]. Larger series of BSA estimation by geometric methods revealed that the DuBois equation can predict lower BSA values[21]. The Mosteller equation which illustrates that BSA (m^2) = square root BH (cm) × BW (kg) /3600[22] has been used in 2 series for the sake of easier calculation[8,17]. On the whole, convenience of using BSA is in using the simple formula from linear regression. The easy access to personal computer nowadays may make this point relatively invalid. Using BW and BH from which BSA is derived also evades all possibilities of using data not applicable to the local population from which BSA formulae are deduced. One study showed that liver volume had a curvilinear relation with BSA[9]. The formula for calculating BSA itself has a curvilinear nature with BW and BH. Thus, a pure relation with BW and BH should rather be addressed.

The gender factor in relation to liver weight is alluded to as early as in the sixties[11]. This has been recently validated by another study which included gender in the formula deduced in estimating the ESLW[12]. Such phenomenon of gender difference can be anticipated as the female has a smaller fat-free mass given the same BW and BH[23-25]. A slightly small liver is therefore required to



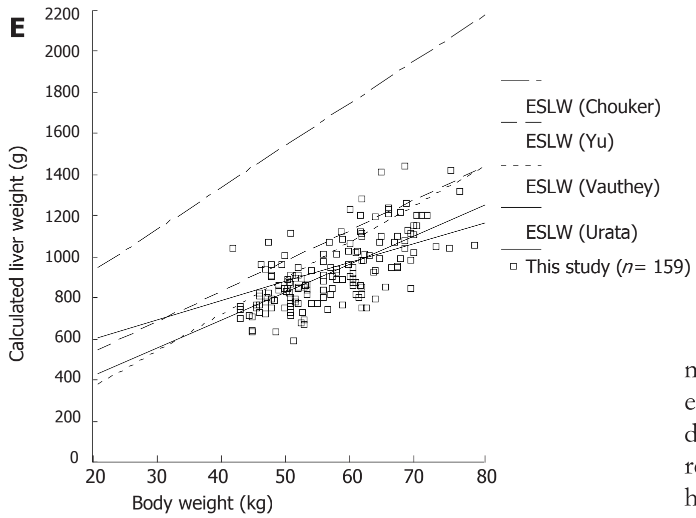


Figure 1 Relationship between estimated liver weight and body surface area (**A**), between estimated liver weight and body weight (**B**), between estimated liver weight and body height (**C**), between liver volume on computed tomography and estimated liver weight (**D**) and regression lines derived from data of the 159 Chinese adults using formulae from Chouker *et al*[11], Yu *et al*[8], Vauthey *et al*[7], Urata *et al*[3], and this study (**E**).

meet her metabolic need. The gender factor is also age-dependent, and becomes less important as the subjects become older[12]. This helps to explain why the gender factor was significant in our series in which the mean age of the subjects was 35.8 years.

Weight in gram is the common unit used in liver transplantation for quantifying the size of the liver graft. Handiness at the back-table enables this unit of measurement to prevail. Otherwise, the graft size is expressed either as GW/ESLW or as GRWR. A formula determining the ESLW in the unit of gram is direct and requires no further conversion. In our center, donor right hepatectomy is performed along the Cantlie's line, and the graft includes the middle hepatic vein. At operation, the line of demarcation between the right and left lobes is determined by temporary inflow control and marked by diathermy. It is our experience that the middle hepatic vein is predictably encountered during the course of liver transection employing the CUSA from the demarcation line to the mid portion of the inferior vena cava. Intraoperative ultrasonography certainly helps to define this plane and navigates the liver transection[26]. Weighing of the right lobe graft obviates the reliance on volume

Table 2 Comparison of regression models

Study	Formula	Mean ESLW (ESLV)	Difference in ESLW	*P*
Deland and North[11]	ESLW = 1020 × BSA[1] – 220	1400.41 g	- 472.86 g	0.000[a]
Heinemann[7]	ESLV = 1072.8 × BSA[1] - 345.7	1141.67 g (1358.59 mL)	- 214.12 g	0.000[a]
Yoshizumi[17]	ESLV = 772 × BSA[2]	1225.50 g	- 297.95 g	0.000[a]
Yu[9]	ESLV = 21.585× $BW(kg)^{0.732}$ × $BH(cm)^{0.225}$	1087.32 g (1293.91 mL)	- 159.77 g	0.000[a]
Choukér[12]	ESLW = 452 + 16.434 × BW(kg) + 11.85 × age – 166 × gender (F=1, M=0)	1690.90 g	- 763.35 g	0.000[a]
Urata[4]	ESLV = 706.2 × BSA[1] + 2.4	944.79 g (1124.30 mL)	- 17.24 g	0.098
Vauthey[8]	ESLV = 1267.28 × BSA[2] -794.41	1022.95 g (1217.30 mL)	- 95.40 g	0.000[a]
Lee[18]	ESLV = 691 × BSA[1] + 95	1002.31 g (1192.75 mL)	- 74.76 g	0.000[a]
Lin[10]	ESLV = BH × 13 + BW × 12 - 1530	1048.85 g (1248.13 mL)	- 121.30 g	0.000[a]
This study	ESLW = 218.32 + BW × 12.29 + gender × 50.74 (M=1, F=0)	927.47 g	7.60E-2	0.994
Calculated liver weight		927.54 g		
Conversion factor 1.19 mL/g			paired samples *t* test	[a]*P* < 0.05

ESLV: estimated standard liver volume; ESLW: estimated standard liver weight; BSA: body surface area; BW: body weight; BH: body height; F, female; M, male.
[1]DuBois and DuBois[5]
[2]Mosteller[22]

determination of the liver by CT. Instead, it is the volume ratio of the right versus the left lobe that calculates the weight of the entire liver.

There is no perfect way of measuring the liver volume as this cannot be done with the organ *in-situ* in a healthy human subject. Many attempts have been made to get closest to the actual liver volume. ESLV can be obtained from measurement of the cadaveric internal organs. By definition, these measurements are acquired from non-healthy subjects with age bias, and influenced by sequelae of either the major illness leading to the demise, or the treatments like fluid resuscitation. Autopsy data excluding those with severe postmortem changes, extensive burns, blood transfusion, fluid infusion, and injury and pathological changes of the organ can minimize such errors[27]. By the principle of Archimedes, the liver volume is measured. An average tissue density of 1.04 kg/L[9] to 1.08 kg/L[7] is derived from correlation with the liver weight. Heinemann *et al*[7] have not pointed out the findings of the increase in liver volume in those with longer periods of survival before death. Furthermore, a gradual increase in liver volume has also been observed during the time interval between death and postmortem[7]. Deceased donor livers might be weighed with deduction of 2.3% for the weight of the gallbladder. The time from brain death to organ harvesting is usually short. Nonetheless, changes of volume status as a result of diabetes insipidus and fluid resuscitation, which are common in donors with intracerebral pathologies and perfusion with preservation solution, can still affect the liver size.

The accuracy of CT in assessing the liver volume has been evaluated. Inflow and outflow vessels of the liver from cadavers can be retrieved and dissected free of fascia and fat. They are weighed and underwent CT scan *ex-vivo*. A high correlation between the actual liver volume and the volume assessed by CT has been identified by Heymsfield *et al*[13]. Urata *et al*[4], reported that 19 children with end-stage liver disease undergoing liver transplantation also have their liver volume assessed preoperatively by CT. The liver volume obtained from CT is accurate. Another study reported the livers of fresh sheep can be scanned *in-vitro* and the volume can be measured by water displacement method[28]. All these 3 studies showed that the error of the CT is less than 5%. Nevertheless, it is worth noting that these are measurements of organs excised from deceased or diseased subjects. Misregistration errors made in tracing the peripheries of the liver on CT occur particularly in the thin portions such as the left lateral segment. Partial volume effect and respiratory movements are also possible sources of error. Overestimation for small livers and underestimation for large livers have also been observed[28]. Spiral CT which requires a shorter breath-holding period theoretically should minimize artifacts from breathing movements. This has, however, shown to be of no significance[29].

A potential major source of error in this study might come from the measurement of BW and BH in the ward. As donors were weighed wearing clothes, BW could be expected to have a systematic error of overestimation due to the weight of the clothes. As the BW and BH were measured in different wards over a long period, potential systematic errors from the equipments could be expected to be random instead of systematic. With continuous data collection, accuracy of the formula could be improved by more meticulous recording of BW and BH.

In comparison with ESLW/ESLV derived from other formulae, except that from Urata, the ESLW of the subjects in the current study was significantly smaller. Though statistically not significant, the Urata formula did overestimate liver weight in our adults less than 60 kg. The discrepancy between our formula and the others might be attributed to the fact that our liver grafts were weighed blood-free on the back-table. The liver already flushed with perfusion solution and devoid of back-perfusion via hepatic vein as *in-situ* is smaller and lighter. This nonetheless is the state at which the liver graft harvested is weighed. The conversion factor of 1.19 mL/g could be used for converstion of weight to volume. It is also possible that a smaller liver may be required to meet the metabolic need of the adult Chinese. The racial difference in the amount of visceral adipose tissue has been demonstrated by whole-body magnetic resonance imaging.

Asian Americans have a higher amount of visceral adipose tissue, thus less lean mass for the same body size[30]. A word of caution ought to be made in the application of data obtained from healthy and relatively young subjects to patients with various morbidities like wasting, edema, ascites, and perhaps to those of an older age.

In conclusion, these data demonstrate that ESLW can be derived from simple clinical parameters of weight and gender. The formulae for Caucasians may not be applicable to Chinese adults. Additional studies of more age- and weight-diverse subjects can provide additional information to this subject of interest.

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