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ORIGINAL ARTICLE

Validation of graft and standard liver size predictions in right liver living donor liver transplantation

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Abstract

Purpose To assess the accuracy of a formula derived from 159 living liver donors to estimate the liver size of a normal subject: standard liver weight (g) = 218 + body weight (kg) × 12.3 + 51 (if male). Standard liver volume (SLV) is attained by a conversion factor of 1.19 mL/g.

Methods The total liver volume (TLV) of each of the subsequent consecutive 126 living liver donors was determined using the right liver graft weight (RGW) on the back table, right/left liver volume ratio on computed tomography, and the conversion factor. The estimated right liver graft weight (ERGW) was determined by the right liver volume on computed tomography (CT) and the conversion factor. SLV and ERGW were compared with TLV and RGW, respectively, by paired sample *t* test.

Results Donor characteristics of both series were similar. SLV and TLV were 1,099.6 ± 139.6 and 1,108.5 ± 175.2 mL, respectively, ($R^2 = 0.476$) ($p = 0.435$). The difference between SLV and TLV was only −8.9 ± 128.2 mL (−1.0 ± 11.7%). ERGW and RGW were 601.5 ± 104.1 and 597.1 ± 102.2 g, respectively ($R^2 = 0.781$) ($p = 0.332$). The conversion factor from liver weight to volume for this series was 1.20 mL/g. The difference between ERGW and RGW was 4.3 ± 49.8 g (0.3 ± 8.8%). ERGW was smaller than RGW for over 10% (range 0.21–40.66 g) in 18 of the 126 donors. None had the underestimation of RGW by over 20%.

Conclusion SLV and graft weight estimations were accurate using the formula and conversion factor.

Keywords Liver transplantation · Living donor · Size · Standard

Introduction

The desperate shortage of deceased donor liver grafts has driven living donor liver transplantation (LDLT) to become an acceptable life-saving treatment alternative for recipients with end-stage liver diseases and small irresectable hepatocellular carcinoma. This is on the premise that donor-risk is acceptably low. Even in the situation, when the living donor's liver is large, in order to maximize donor safety, a just enough portion of the donor liver is obtained as a graft for implantation provided that recipient survival is predictably high. The estimated mortality rate for a donor right hepatectomy is 0.5% and for a donor left hepatectomy is 0.1% [1]. Thus, an accurate estimation of the minimal graft size in relation to recipient body size is crucial. This process entails, at first, estimation of the standard liver volume (SLV) of the recipient since the volume of the deceased native liver almost invariably has a little value for reference. Secondly, the graft size as measured from preoperative imaging and the actual weight of the liver graft as obtained by the donor hepatectomy are often different. In major hepatectomy for liver tumor, the remnant liver volume in relation to the SLV is also crucial. A liver with fatty change or cirrhosis and a sizeable tumor has a volume with a little correlation of the SLV.

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From an earlier study of our series of 159 living donors, a formula for estimating the SLV was derived: standard liver weight (g) = 218 + body weight (kg) × 12.3 + 51 (if male). In brief, the weight of the whole liver of the donor was calculated by the weight of the right liver graft. This was then divided by the volume fraction of the right liver in relation to the entire liver as measured by volumetric analysis of the computed tomography (CT).

A gender difference was also noticed. For a given body weight, the liver of the male is slightly heavier by a mean of 51 g. The SLV is attained by a conversion factor of 1.19 mL/g [2].

The validity and thus applicability of the above formula is to be verified by calculating the SLV of the subsequent consecutive donors of our series using their body weight and gender. This was correlated with the liver volume as calculated from the right liver graft weight (RGW) on the back table and the right-to-left liver volume ratio from CT volumetric analysis.

Also important is the accuracy of predicting the graft weight for the standard living donor right hepatectomy including the middle hepatic vein [3]. Factor that may compromise such prediction is also elucidated. The question is how close the final graft size to recipient ratio to the preoperative prediction is elucidated in order to know the safety margin and to identify possible factors affecting this prediction.

Patients and methods

From 183 cases of right liver LDLT at our centre, 139 donor-recipient pairs were identified. The donors with liver, with fatty change of over 10% as documented by histopathology of liver graft biopsy after implantation ($n = 8$) were excluded. Donors with body weight lying beyond 97.5% were excluded ($n = 2$). Non-Chinese donors ($n = 3$) were also excluded. The number of subjects for analysis was thus 126.

Based on donor body weight and gender, using the formula derived earlier, the SLV was calculated for each donor. The total liver weight of each donor was also calculated from the RGW divided by the ratio of the right liver to whole liver proportion. The total liver volume (TLV) was then derived by multiplying the total liver weight by 1.19 mL/g. This was compared with the SLV from the previous formula case by case.

The estimated right liver graft weight (ERGW) was estimated from the right liver volume on CT divided by the factor 1.19 mL/g. This was compared with the RGW on the back table. Factors that may contribute larger discrepancy of the graft weight predicted were analyzed. They included small remnant left liver and marginal graft-to-recipient SLV.

Following the testing for normal distribution of data by Kurtosis and Skewness tests, data were expressed as mean ± standard deviation. The SLV was compared with the TLV; the RGW was compared with the ERGW by paired sample t test. $p < 0.05$ was considered statistically significant. All statistical analyses were performed by SPSS for Windows Version 16.0 (SPSS, Chicago, IL, USA).

Results

This series of 126 donors had similar characteristics as the previous series of 159 donors (Table 1).

The SLV and TLV were 1,099.6 ± 139.6 and 1,108.5 ± 175.2 mL, respectively, ($p = 0.435$). The SLV minus TLV was −8.9 ± 128.2 mL and −1.0 ± 11.7%, respectively. A linear correlation was seen ($R^2 = 0.476$) ($p = 0.000$) (Fig. 1).

The right liver volume on CT was 715.8 ± 123.8 mL. Using the conversion factor of 1.19 mL/g from the previous study, the ERGW was 601.5 ± 104.1 g, whereas the RGW was 597.1 ± 102.2 g ($p = 0.332$) with a linear correlation ($R^2 = 0.781$) ($p = 0.000$) (Fig. 2). A conver-

Table 1 Characteristics of the previous and current series

	Previous series $n = 159$	Current series $n = 126$	p
Gender ratio (M:F)	55:104	43:83	1.0
Age (years)	35.6 ± 10.6	33.9 ± 10.3	0.180
Body weight (kg)	56.6 ± 8.5	56.0 ± 8.4	0.561
Body height (cm)	161.8 ± 7.6	163.0 ± 8.0	0.218
Body mass index (kg/m^2)	21.6 ± 2.6	21.0 ± 2.5	0.080
TLV on CT (mL)	1,100.7 ± 180.9	1,115.6 ± 173.7	0.480
Right liver volume on CT (mL)	711.5 ± 130.6	715.8 ± 123.8	0.781
Left liver volume on CT (mL)	389.1 ± 76.8	399.9 ± 74.8	0.236
RGW (g)	601.2 ± 117.3	602.2 ± 107.1	0.941
Right liver/TLV ratio on CT (%)	64.6 ± 4.4	64.1 ± 4.2	0.343

CT computed tomography

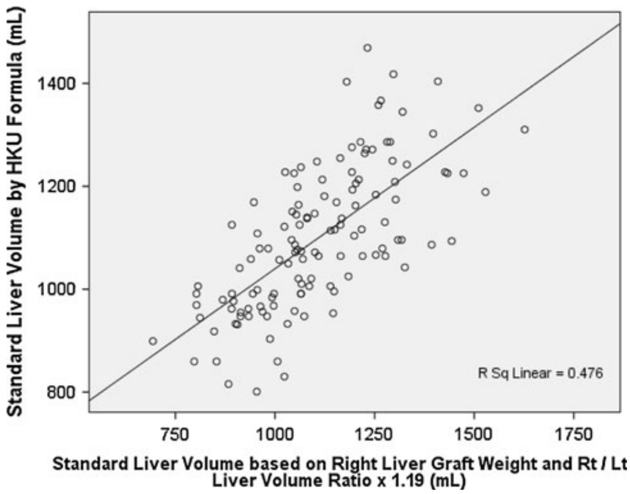

Fig. 1 Relation between SLV estimated by the University of Hong Kong formula and by RGW, right/left liver volume ratio, and conversion factor of 1.19 mL/g

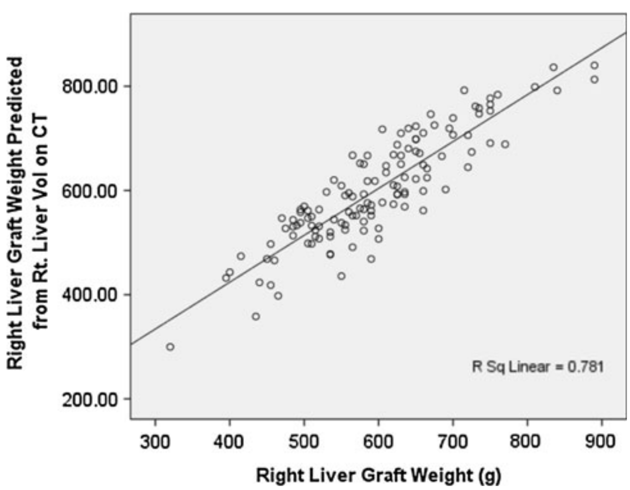

Fig. 2 Relation between right graft weight estimated from right liver volume on CT and conversion factor of 1.19 mL/g and RGW on the back table

sion factor of 1.20 mL/g was elucidated in this current series. The difference between the ERGW and RGW was 0.3 ± 8.8% (range −26.2–15.7%).

By one-way analysis of variance, factors possibly related to discrepancy of RGW to graft weight estimated from right liver volume on CT did not show any statistical significance (Table 2). Nevertheless, a tendency was noticeable. When the ratio of right liver graft to SLV of the recipient was small, a tendency of obtaining a larger right liver graft was noticeable (Fig. 3). When the remnant left liver volume to TLV ratio was well above 30%, a tendency of the RGW being larger than the ERGW was also noticeable (Fig. 4). Nevertheless, as deviations to both directions were present, it tended to cancel out the biases.

Table 2 Univariate analysis of factors that may affect real graft weight

	p
Donor body weight (kg)	0.794
TLV (mL)	0.163
Right liver volume on CT (mL)	0.117
Left liver volume on CT (mL)	0.186
Right liver to TLV (%)	0.073
Left liver to TLV (%)	0.073
Graft to recipient SLV (Urata) (%)	0.340
Graft to recipient SLV (HKU) (%)	0.361

HKU The University of Hong Kong

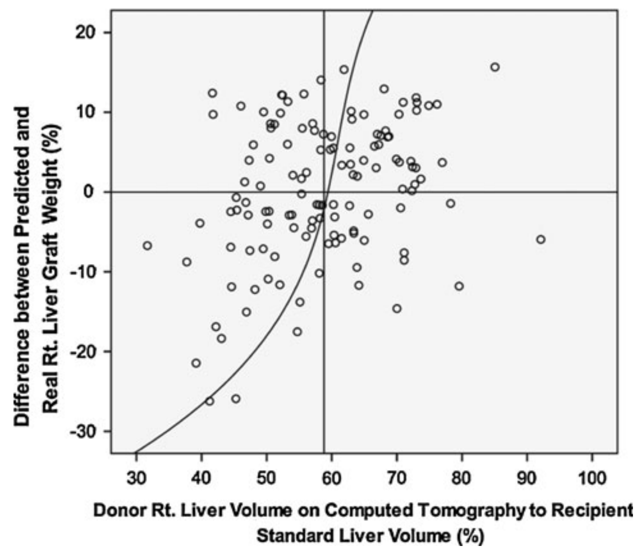

Fig. 3 Difference between predicted and real RGW in relation to donor right liver volume on CT to recipient standard liver volume

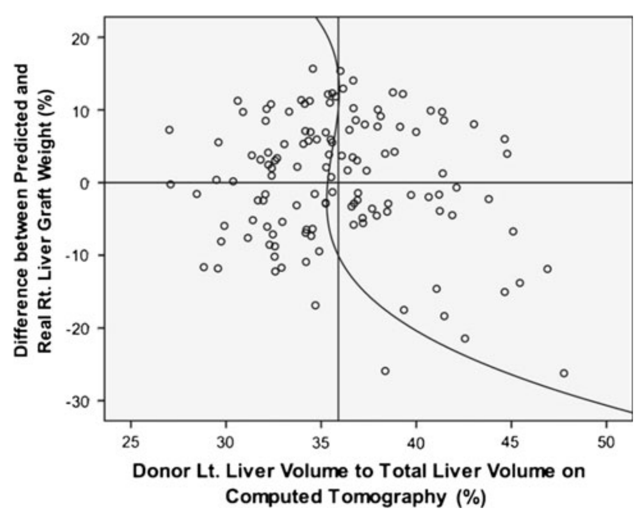

Fig. 4 Difference between predicted and real RGW and donor remnant left liver volume to TLV on computed tomography

In practice, only 18 of the 126 right liver grafts obtained were smaller than the predicted graft weight by over 10% and were at a range of 0.21–40.66 g. None of the right liver graft had a weight 20% less than predicted.

Discussion

The formula for estimation of the SLV and conversion factor (1.19 mL/g) for prediction of RGW were validated in this cohort of 126 donors. From our previous study, this formula was derived from the right graft weight, conversion ratio of 1.19 mL/g, and the right-to-left liver volume ratio, and TLV on CT. The SLV derived from this formula correlated well with the TLV as derived from the RGW, right and left liver volume ratio, and the conversion factor 1.19 mL/g. The ERGW as predicted from the right liver volume on CT and divided by the conversion factor 1.19 mL/g also had a good correlation with the RGW on the back table.

The conversion factor from this cohort was 1.20 mL/g and was very close to 1.19 mL/g derived from the previous study. The blood-fill right liver graft volume to blood-free graft weight had a conversion factor of 1.22 mL/g in a smaller study of 12 subjects [4]. Although one study determined a 1.0 mL/g equivalence of graft weight and volume, the comparison of the formulae estimating liver volume [5] and weight [6] was not made with any conversion [7]. Only 18 of the 126 right liver grafts were smaller than the predication by more than 10%. None was smaller by 20% of the prediction. For cases with a graft to SLV ratio above 40%, a good margin of safety was provided.

A donor hepatectomy, in particular, of obtaining a right liver, is a very major operation for the donor. The human factor of the operating surgeon is inevitable and undeniable. When the donor's left liver to TLV ratio was small and close to only 30%, our data showed that a tendency of a RGW lower than predicted was observed. This reflects the operating surgeon's concern and worries that not keeping enough of the left liver remnant would be conducive to liver failure after donation. A higher safety margin for hepatectomy for LDLT in contrast to tumor removal is generally accepted by the transplant community as exemplified by a recent survey that would allow a minimal remnant liver volume of 25% in cases of normal liver [8]. Nevertheless, donor mortality from inadequate remnant liver has not been reported [9]. On the other hand, when the graft to SLV ratio was marginal, there was also a tendency of the surgeon obtaining a right liver graft larger than predicted. This was out of the intention of lowering the chance of development of small-for-size syndrome though with no sound evidence. The advantage of including or preserving liver parenchyma beyond the Cantlie line determined by temporary inflow control is dubious, but the good intention of the surgeon is understandable.

The discrepancy between the ERGW and RGW ought to be addressed in more detail. As the conversion factor of 1.19 mL/g is consistently true, this is not due to the human factor. Volume of the right liver on CT is a liver filled with circulating blood, whereas the RGW on the back table is flushed with preservation solutions and exsanguinated. Though the liver parenchyma and the other soft tissues, except fat are of higher density than water, the exsanguination results in a liver mass weight in grams lower than the right liver volume on CT assuming a 1 mL/g conversion, that of water. In the published series, unless the graft to body weight was used for the graft size to body size ratio, when the graft weight to SLV ratio was used, one has to make a distinction of whether the author used the right liver volume on CT or the RGW for graft size. As in our series, we lowered the minimum graft to SLV ratio requirement from 40 to 35%. This was used when preoperative assessment of the right liver graft volume on CT to SLV was over 40% [10]. We found that when the RGW to SLV ratio of >35% became satisfactory; we then lowered the requirement to 35% [11].

The real liver weight for a given body size of weight and height in the human subject has never been and cannot be validated. There are systemic errors for imaging and volumetric analysis of the liver. Volume assessment of a solid organ by CT as described by Heymsfield et al. [12] may have systemic errors from demarcation of the periphery of the organ. This could be particularly problematic for structures for the left liver that may have a thin and slender left lateral section. We used RGW and volume, and right to left liver volume ratio instead. Though there could be errors from volume assessment of the left liver, the formula did not rely on volume assessment of the TLV on CT which could only be as accurate as tracing of the surface of the liver from imaging. The weight of a deceased liver is also erroneous, because of the major systemic changes before death and postmortem changes. To date, there are two ways to circumvent these problems. One is to use body weight. Another way is to estimate the liver volume using body weight with height to come to a body surface area. In our case, we used the body weight and gender. Therefore, the essence and value of any liver size estimation is in the reproducibility and reliability in reflecting the increase in liver size with increase in body size, especially, from a utilitarian point of view.

There is still ambiguity of graft size in relation to recipient body size in the literature. Graft size is usually the weight of the graft as on the back table [13–15]. The graft weight either with reference to the SLV as determined by a formula [13] or body weight of the recipient [14, 15] is used for determining the minimal graft size requirement. Given the discrepancy as reflected from the conversion factor of 1.19 mL/g,[2] or 1.20 mL/g as in this series, an allowance of around 20% is needed when the right liver volume on CT is used for preoperative planning. This corroborates other series [4, 16].

The formula and conversion factor are validated by this series of 126 living donors. The accuracies of such are adequate to guide safe clinical practice of estimating the graft size requirement of a recipient based on body weight and gender. More complicated and non-linear models had been developed [5, 17]. However, in those series, inclusion of subjects is either pediatric [5] or with low body weight, and a body surface area below 1.2 m^2 [17] possibly contributed to the curvilinear relationship of SLV and body size. The right liver graft including the middle hepatic vein obtained from donor right hepatectomy has a weight predicted accurately from right liver volume on CT and converted to weight by the conversion factor.

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