Preoperative computed tomography volumetry and graft weight estimation of left lateral segment in pediatric living donor liver transplantation

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Abstract

Introduction: Liver volumetry based on a CT-Scan is widely used for estimating liver volume before any liver resection, especially for pediatric living donor liver transplantation (LDLT). The "One-to-one" conversion rule for liver volume to weight has been widely adopted worldwide for many years. However, most recent analyses discuss this approach.

Methods: The study retrospectively included consecutive donors undergoing left lateral hepatectomy for pediatric LDLT between December 2008 and September 2020. All donors were healthy adults who met the evaluation criteria for pediatric LDLT and underwent a preoperative contrast-enhanced CT scan. Manual segmentation of the left lateral liver lobe for volume (GV) estimation and intraoperative measurement of an actual graft weight (AGW) was performed. A relationship between estimated GV and AGW was analyzed.

Results: 94 living liver donors were included in the study. The mean AGW was approximately 283.4 ± 68.5 grams, and the mean GV was 244.9 ± 63.86 ml. There was a strong correlation between the GV and AGW (r = 0.804, p < 0.001). The Bland-Altman analysis revealed an interreader agreement of 38.0 ± 97.25 and an intraclass correlation coefficient showed an almost excellent agreement (0.840, p < 0.001). The conversion formula for calculating graft weight (GW) based on computed tomography volumetry was determined based on regression analysis: 0.88 x GV + 41.63.

Conclusion: Estimating left liver GW using "one-to-one" rule is subject to measurable variability in calculated graft weights and tends to underestimate it. Instead, a conversion formula should be used to determine donor GW more accurately.

Introduction

Liver volumetry is a widely used imaging modality for estimating liver volume before any liver resection. More importantly, it is used for the preoperative evaluation of donors in living donor liver transplantation (LDLT) 1. The major concern of LDLT is not just the graft quality but, more importantly, the adequate graft volume (GV) that could fully satisfy the recipient's metabolic demands 2. However, in the context of living liver donation, the weight of the graft seems to be much more important. Graft weight is used to calculate the most important prognostic factor - donor graft weight-to-recipient body weight ratio (GRBWR) - this should ideally be between 2.0% and 4.0% 3,4. Too high (>6–8%) or too low (<0.8%) GRBWR may also become a contraindication to transplantation depending on the individual situation 5,6. Therefore, the relationship between volume and weight is crucial.

A radiologist performs computed tomography volumetry (CTV), a gold standard method for estimating GV in LDLT 7. However, as mentioned before, to calculate a GRBWR, it is mandatory to have not volume but the weight of the graft. "One-to-one" has been a widely adapted approach worldwide for many years.
However, most recent analyses of right liver grafts show that by applying this rule, a significant error could arise for some patients. 

Our study analyzed the relationship between the left liver GV and actual graft weight (AGW). Using this relations analysis, we also aimed to define a conversion formula between volume and weight for the left lateral liver.

**Methods**

Between December 2008 and September 2020, ninety-four (41 men; 53 women) consecutive donors undergoing left lateral hepatectomy for pediatric LDLT were retrospectively reviewed. Before data collection, an ethics vote was obtained from the University of Duisburg-Essen ethics committee (No. 20-9294-BO). All donors were healthy adults and underwent a preoperative contrast-enhanced computed tomography (CT) scan during donor candidacy selection for LDLT. CT images included in the study had to show normal anatomic features of the liver, gallbladder, and vasculature. All individuals evaluated as candidates who did not meet the donor evaluation criteria for LDLT were excluded.

The CT examinations were performed on 16-slice computer tomography (LightSpeed 16®, General Electrics Medical Systems, Milwaukee, USA) according to a standard internal protocol for the liver. The CT images used for CTV have been reconstructed on 5 mm slices before segmentation. A radiologist performed the segmentation.

The ligamentum teres, the ligamentum venosum, and the bifurcation of the left portal vein were used as reference points to depict segments II-III as accurately as possible. These structures are also used intraoperatively to perform a left lateral hepatectomy as they separate segment IV from segments II-III. A venous phase of CT scans was used for this study.

The segmentation is carried out by coloring the voxels in the abovementioned segmentation program ITK-SNAP (http://www.itksnap.org). After manual segmentation, the individual layers were joined three-dimensionally by the software. After that, a 3D image of the organ was displayed. Furthermore, the volume is presented in cm³ as the sum of all segmented areas on the axial CT slices (Fig. 1).

An experienced hepatobiliary surgeon performed all surgeries. Before the liver resection, every patient underwent a standard evaluation of intra-abdominal organs for any possible pathologies (including intra-abdominal tumors and chronic liver diseases). The typical surgical incision plane is approximately 0.5-1.0 cm to the right of the falciform ligament. Therefore, in all the cases, the cutting plane was slightly lateral to the left lateral hepatic lobe. After removing grafts, they were weighted intraoperatively on a pre-calibrated digital scale to determine an AGW. Each case estimated GV obtained by CTV was compared to the AGW.

The classification of postoperative complications is based on the Clavien-Dindo "Classification of Surgical Complications". For further statistical analysis, complications were divided into two groups.
All complications from category IIIb, according to Clavien, were classified as serious complications, and all below IIIb were classified as non-serious complications. For better comparability of recipient complications among centers and countries, surgical complications were converted to the comprehensive complication index (CCI) ¹¹.

• **Statistical Analysis**

Values are shown as mean ± standard deviation. Categorical variables are reported as numbers and percentages. Statistical analysis was performed using SPSS version 27.0 (IBM® SPSS®-Software Platform for Windows). A value of p < 0.05 was considered significant. The relation between estimated GV and AGW was determined using linear regression analysis. Furthermore, the linear correlation of Spearman and its 95% confidence interval were presented, and Bland-Altman analysis and an intraclass correlation coefficient (ICC) were also measured to assess the reliability of the above data. The quartile method was used to identify the outliers. The data points below Q1–3*IQR or above Q3 + 3*IQR are outliers ¹².

**Results**

A total of 94 living liver donors were included in the study. Most donors were women (56.4%). The mean age of the donors at the time of transplantation was 32.52 ± 6.69 years. Among them, the youngest donor was 21 years old, and the oldest was 52 years old. The mean body mass index was 24.8 ± 3.78 kg/m². The mean duration of surgery in the donor was 293.2 ± 68.77 minutes. Postoperative complications were observed in a total of 9 donors (9.6%), of which one donor (1.0%) had a biliary leak, which required surgical treatment and thus counted as a severe postoperative complication according to the Clavien-Dindo classification (Grade IIIB). The follow-up exam was on average after 25.95 ± 16.65 months (Table 1). Donor demographic and clinical data for the training and validation sets were compared. There were no statistically significant differences (p > 0.05).
Table 1
Clinical and demographic data of the donors

<table>
<thead>
<tr>
<th>Gender</th>
<th>Woman (n = 53)</th>
<th>56.4%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Man (n = 41)</td>
<td>43.6%</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Age at Tx</th>
<th>32.52 ± 6.69 (21–52)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMI (kg/m²)</td>
<td>24.80 ± 3.78 (17.99–37.98)</td>
</tr>
<tr>
<td>Future liver remnant (%)</td>
<td>81.72 ± 5.85 (65.28–93.51)</td>
</tr>
<tr>
<td>Operation duration (Minutes)</td>
<td>293.19 ± 68.77 (162–490)</td>
</tr>
<tr>
<td>ASA class at the Tx</td>
<td></td>
</tr>
<tr>
<td>Class I (n = 51)</td>
<td>54.2%</td>
</tr>
<tr>
<td>Class II (n = 43)</td>
<td>45.8%</td>
</tr>
<tr>
<td>Postoperative complications (Classification according to Clavien-Dindo)</td>
<td></td>
</tr>
<tr>
<td>No complications (n = 85)</td>
<td>90.4%</td>
</tr>
<tr>
<td>Grade I (n = 4)</td>
<td>4.3%</td>
</tr>
<tr>
<td>Grade II (n = 4)</td>
<td>4.3%</td>
</tr>
<tr>
<td>Grade IIIa (n = 1)</td>
<td>1.0%</td>
</tr>
<tr>
<td>Comprehensive Complication Index (CCI)</td>
<td>1.67 ± 5.99 (0–39.5)</td>
</tr>
<tr>
<td>ICU stay (days)</td>
<td>1.12 ± 0.51 (0–4)</td>
</tr>
<tr>
<td>Hospital stay (days)</td>
<td>7.79 ± 1.86 (5–16)</td>
</tr>
</tbody>
</table>

The mean weight of a liver segment II-III was approximately 283.4 ± 68.5 grams, and the mean volume was 244.9 ± 63.86 ml. There was a statistically significant difference between the volume and weight ($p < 0.001$). A strong correlation between the left lateral liver graft was observed ($r = 0.804, p < 0.001$) (Fig. 2). For a more detailed and accurate analysis of the agreement between left lateral liver volumes and weights, and determination of the probability of error in each measurement we have performed a Bland–Altman analysis. The analysis revealed an interreader agreement of 38.0 ± 97.25 (Fig. 3). Moreover, an intraclass correlation coefficient (ICC) between volume and AGW was calculated, which has an almost excellent agreement (0.840, $p < 0.001$).

After determining an almost excellent agreement between CTV and AGW, a linear regression analysis was performed based on the volume and weight of the left lateral liver. After removing a few outliers (n = 6, 6.4%), the formula for calculating the left lateral liver weight from CTV was determined:

$$
\text{Liver segment II-III weight} = 0.88 \times [\text{II-III volume(ml)}] + 41.63.
$$

By this formula, 77.2% of the variance in AGW could be explained. The regression coefficient of the variable size is 0.88, and it is statistically significant ($t(88) = 17.275; p < 0.001$). Statistical requirements for the regression analysis or Gauss-Markov assumptions were met when the formula was created.
Discussion

Estimation of the donor liver volume preoperatively is an essential factor that affects not just a surgical strategy but also recipient mortality and morbidity after LDLT. However, in the context of a living liver donation, the weight of the organ or graft to be transplanted is much more important because not volume but graft weight is used to calculate the most important prognostic factor – GRBWR. Therefore, the relation between volume and weight is crucial, especially in pediatric living donor liver transplantation. Unfortunately, the data situation in the sense of this relation for the left lateral liver segment is very sparse and not conclusive.

Most transplant centers still use an approach for liver volume-weight conversion by interpreting a mean density of healthy liver tissue as 1.00 g/ml. The current discussion points out that one milliliter in CTV may not correspond to one gram of liver tissue. Moreover, many authors analyzing the liver and their segments (mostly right liver grafts) density have already presented many different conversion coefficients. Therefore, based on these data, the conversion factor should be somewhere between 0.8 and 0.95, depending on which part of the liver the weight is to be calculated from, whether the surgical section plane matches the plane used for segmentation, and whether the GV is calculated with or without intrahepatic vessels.

By not considering around 5% to, in some cases, 20% of conversion error by using a “one-to-one” rule, we risk some LDLT recipients receiving smaller organs as expected. Therefore, such a miscalculation may put some recipients at risk for small-for-size syndrome. On the other hand, big grafts may result in pressure necrosis to the graft because of the smaller intra-abdominal cavity, outflow occlusion, or possibly the need for delayed abdominal closure to prevent compartment syndrome. However, many authors suggest that a good surgical strategy for bigger grafts leads to no inferior results. Also, they have denied the major concerns of delayed abdominal closure, such as the increased possibility of a local wound and abdominal infections. In conclusion, an underestimation of liver graft size and associated recipient risks should be considered by using a “one-to-one” rule.

In our study, we analyzed the left lateral liver lobe. To date, only one formula, a BSA-based formula for calculating the volume of the left lateral liver lobe, has been published (left lateral liver lobe = 139×BSA). However, it was recently demonstrated that no demographic or anthropometric data correlates with left lateral hepatic lobe volume. Therefore, it can be concluded that to date, no reliable conversion formula offers a standardized calculation of the left lateral liver graft weight based on CTV.

Our patient collective’s average weight of the left lateral liver lobe (approximately 283.4 grams) did not differ from the published data (Goja et al., 2018). In our study, we demonstrated a strong correlation between AGW and measured volume, which was significantly stronger compared to the published data, where only a moderate correlation was demonstrated ($r = 0.804$ vs. $r = 0.49, p < 0.001$). Moreover, intraclass correlation coefficients analysis revealed almost excellent agreement ($0.840, p < 0.001$).
Therefore, we could conclude that there is a strong and significant relation between the AGW and GV and that a conversion formula could be determined.

In our study, we established for the first time the formula for calculating the standard weight of the left lateral liver graft: weight (liver segment II-III) = 0.88 x [II-II volume (ml)] + 41.63. We also found that volume is a significant predictor of weight, and the suggested formula explains 77.2% of the variance. With a standardized collection of the preoperative volumetric data (possibly without liver vessels) and the intraoperative data, including a surgical procedure with a clear-cutting plane, it would be possible to create an even more precise and better variance-explaining formula for calculating the standard weight. This could also significantly improve the evaluation of possible donor organs in calculating the GRBWR, eliminating the risk of underestimating liver graft size.

**Conclusion**

Estimating left liver graft weight using only the "one-to-one" rule is subject to measurable variability in calculated graft weights and tends to underestimate it. Instead, a conversion formula should be used to calculate graft weight to more accurately determine GRBWR and reduce the risk of underestimating liver graft weight in a donor selection process before LDLT.

**Declarations**

**Data Availability**

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

**Author contributions statement**

M.T. designed the study, collected, and analyzed data, and wrote the paper. S.K., J.M.T., A.Z., D.P.H., F.F., J.H., N.F., F.N., J.T., E.M. mentored the study and contributed important reagents. All authors reviewed the manuscript.

**Competing interests**

The author(s) declare no competing interests.

**Ethics declarations**

The study was performed in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The ethics committee of the University of Duisburg-Essen approved the study and its protocol as well as waived the need of informed consent for present study (No. 20-9294-BO).

**References**


Figures

![Figure 1](image_url)
Manual liver segmentation (blue: left lateral liver lobe (liver segment II-III); green: liver segment IV; red: right liver lobe (liver segment V-VIII).

Figure 2

Scatter plot of the relationship between actual graft weight and graft volume.
Figure 3

Bland-Altman-Plot of segmented liver volume and actual liver weight.