Estimation of Standard Liver Volume for Japanese Adults

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ABSTRACT

Introduction. Accurate pretransplant estimation of the recipient's standard liver volume (SLV) is important. The purpose of this study was to compare reported formulas for clinical estimation of liver volume among Japanese adults.

Methods. We reviewed data on 70 healthy adults (46 men, 24 women, ages 20 to 65 years old) evaluated for living donor liver transplantation. Liver volume (LV) was measured using two- or three-dimensional computed tomography volumetry (CTV). The formulas of DeLand ($LV = 1020 \times$ body surface area $[BSA] - 220$), Urata ($LV = 706.2 \times BSA + 2.4$), Noda ($LV = 50.12 \times BW^{0.78}$), Heinemann ($LV = 1072.8 \times BSA - 345.7$), Vauthey ($LV = 18.51 \times BW + 191.8$) and Yoshizumi ($LV = 772 \times BSA$) were applied to estimate LV. We calculated the differences for individual donors betwen CTV and LV estimated by each formula.

Results. Mean LVs as estimated by the formulae of DeLand and Heinemann et al were significantly greater ($P < .01$) than the mean CTV, while LV estimated by the formula of Urata was significantly less ($P < .05$) than the CTV. The formulas of DeLand and Heinemann overestimated LV, while the formula of Urata underestimated it. The formulae of Noda et al and Yoshizumi et al tended to underestimate the LV when the CTV was greater than 1600 cm^3. When the Yoshizumi formula was applied, the number of donors with an acceptable difference ($\pm 15\%$) between CTV and estimated LV was 55 (78.6%).

Conclusions. The Yoshizumi formula was applicable, especially for patients with a $BSA < 2.0$, whereas the well-known Urata formula made LV underestimates.

LIVING DONORS and split grafts have been used to help solve the shortage of cadaveric livers for transplantation.[1–3] Small-for-size graft syndrome, which causes graft failure, has been a severe complication in this setting.[4,5] Accurate pretransplant estimation of the recipient's standard liver volume (SLV) is crucial.[6] For example, overestimation of recipient SLV impairs the safety of the living donor due to excessive hepatic resection. Whereas, underestimate recipient SLV causes small-for-size graft syndrome (Fig 1).[3,5,7] Recently, the minimal graft volume to avoid small-for-size graft syndrome has been proposed by our center to be at least 40% of the recipient SLV for patients with liver cirrhosis.[7]

Our center has used left lobe grafts for living donor liver transplantation when possible, seeking avoid donor complications.[4,7,8] In such a situation, preoperative evaluation of the correct SLV is critical for both donors and recipients, because left lobectomy may be ideal for healthy volunteers.[4]

Recently, we reported a new formula to estimate SLV using the data from 1413 cadaveric liver grafts of multiple races.[6] Five other formulae have been reported from Western or Japanese centers.[9–13] The formula described by DeLand and North in 1968[9] to calculate standard liver weight (LW) on the basis of body surface area (BSA) is:

$$LW(kg) = 1.02 \times BSA - 0.22$$

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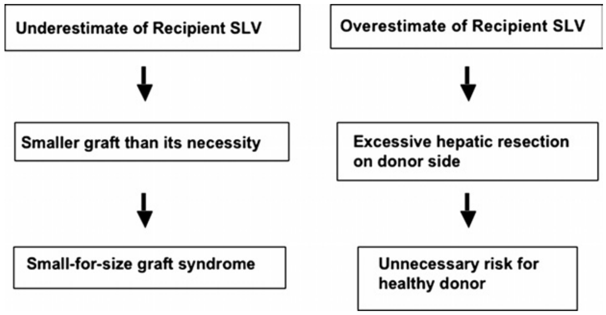

Fig 1. Flowchart, which shows what is happening with misunderstood standard liver volume (SLV). Underestimated SLV can lead small-for-size graft syndrome on recipient side (left line), whereas overestimated SLV can give unnecessary risk for healthy donor (right line).

DeLand and North developed their formula using 550 autopsy cases. They found, however, that the relationship between LW and BSA was limited when BSA was $\leq 1.0\ m^2$.

In Japan, Noda et al[10] and Urata et al[11] studied patients without liver disease using computed tomography (CT) and reported formulae to calculate liver volume (LV). Noda et al[10] proposed the following formula:

$$LV(cm^3) = 50.12 \times \text{body weight}(BW)(kg)^{0.78}$$

The formula suggested by Urata et al[11]:

$$LV(mL) = 706.2 \times BSA + 2.4$$

is useful both for pediatric and adult patients. Many centers have accepted it. Urata's patients, however, were 1 month to 27 years old. It has been used worldwide; however, detail supplementary examination has never been reported.

From Western centers, Heinemann et al[12] and Vauthey et al[13] developed formulae to calculate SLV in Caucasians. Heinemann et al[12] developed the following formula using 1332 autopsy livers:

$$LV(mL) = 1072.8 \times BSA - 345.7$$

Table 1. Reported Formulae for Standard Liver Volume

Author (published year)	Formula	Material Used (race, number)
DeLand (1968)	LV = 1020 × BSA − 220	Autopsy (unknown, 550)
Urata et al (1995)	LV = 706.2 × BSA + 2.4	CT volumetry (Japanese, 96)
Noda et al (1997)	LV = 50.12 × $BW^{0.78}$	CT volumetry (Japanese, 54)
Heinemann et al (1999)	LV = 1072.8 × BSA − 345.7	Autopsy (Caucasian, 1332)
Vauthey et al (2002)	LV = 18.51 × BW + 191.8	CT volumetry (Western, 292)
Yoshizumi et al (2003)	LV = 772 × BSA	Cadaveric graft (multiple, 1413)

LV, liver volume; BSA, body surface area; BW, body weight; CT, computed tomography.

Table 2. Donor Characteristics

Gender (male:female)	46:24
Age (y)	35 (20–65)
Body height (cm)	167.5 (147–179)
Body weight (BW, kg)	63.0 (37–92)
Body surface area (BSA, m^2)	1.70 (1.23–2.13)
Body mass index (kg/m^2)	22.4 (15.8–30.3)
CT volumetry (CTV, g)	1290 (827–1999)
CTV/BW (%)	2.07 (1.59–3.02)
CTV/BSA (g/m^2)	772.0 (559.0–1020.4)

Data are expressed by median.

They concluded that LV in Caucasians was larger than that calculated with Urata's formula. This study excluded children whose BW was less than 15 kg; however, the value of the coefficient of determination was low ($r^2 = .30$).

Vauthey et al[13] recommended a formula calculated based upon body weight using 292 cases of CT volumetry:

$$LV(mL) = 18.51 \times BW + 191.8.$$

Both formulae have been recommended for Western populations. In the study described herein, we compared the six formulas to estimate LV.

PATIENTS AND METHODS

We reviewed data on 70 healthy adults (46 men, 24 women, ages 20 to 65 years old) evaluated for living donor liver transplantation. LV was measured using two- or three-dimensional CT volumetry (CTV), as the accuracy of volumetry has been already reported.[14,15] Body weight and height recorded on the donor charts were used to calculate BSA and body mass index (BMI). Equations for BSA[16] and BMI[17] were as follows:

$$BSA(m^2) = \text{sqrt}[BW(kg) \times \text{height (cm)}/3600]$$

$$BMI\ (kg/m^2) = BW(kg)/\text{height}\ (m)^2$$

We then applied the formulas of DeLand, Urata, Noda, Heinemann, Vauthey, and Yoshizumi to estimate LV among our donors. The details of previously reported formulae are shown in Table 1. We calculated the differences for individual donors between CT volumetry and LV as estimated by each formula. The ultimate clinical issue is whether the estimated LW was sufficiently accurate to distinguish cases to avoid small-for-size graft syndrome on the

Table 3. Mean Value of CTV and Estimated LV in Each Formula

Formula	Mean ± SD	*P* Value Compared to CTV
DeLand	1505 ± 202	<.01
Urata et al	1196 ± 140	<.05
Noda et al	1257 ± 194	NS
Heinemann et al	1469 ± 213	<.01
Vauthey et al	1348 ± 228	NS
Yoshizumi et al	1306 ± 153	NS
CT volumetry	1310 ± 242	ND

CTV, computed tomography volumetry; LV, liver volume; SD, standard deviation; NS, not significant; ND, not determined.

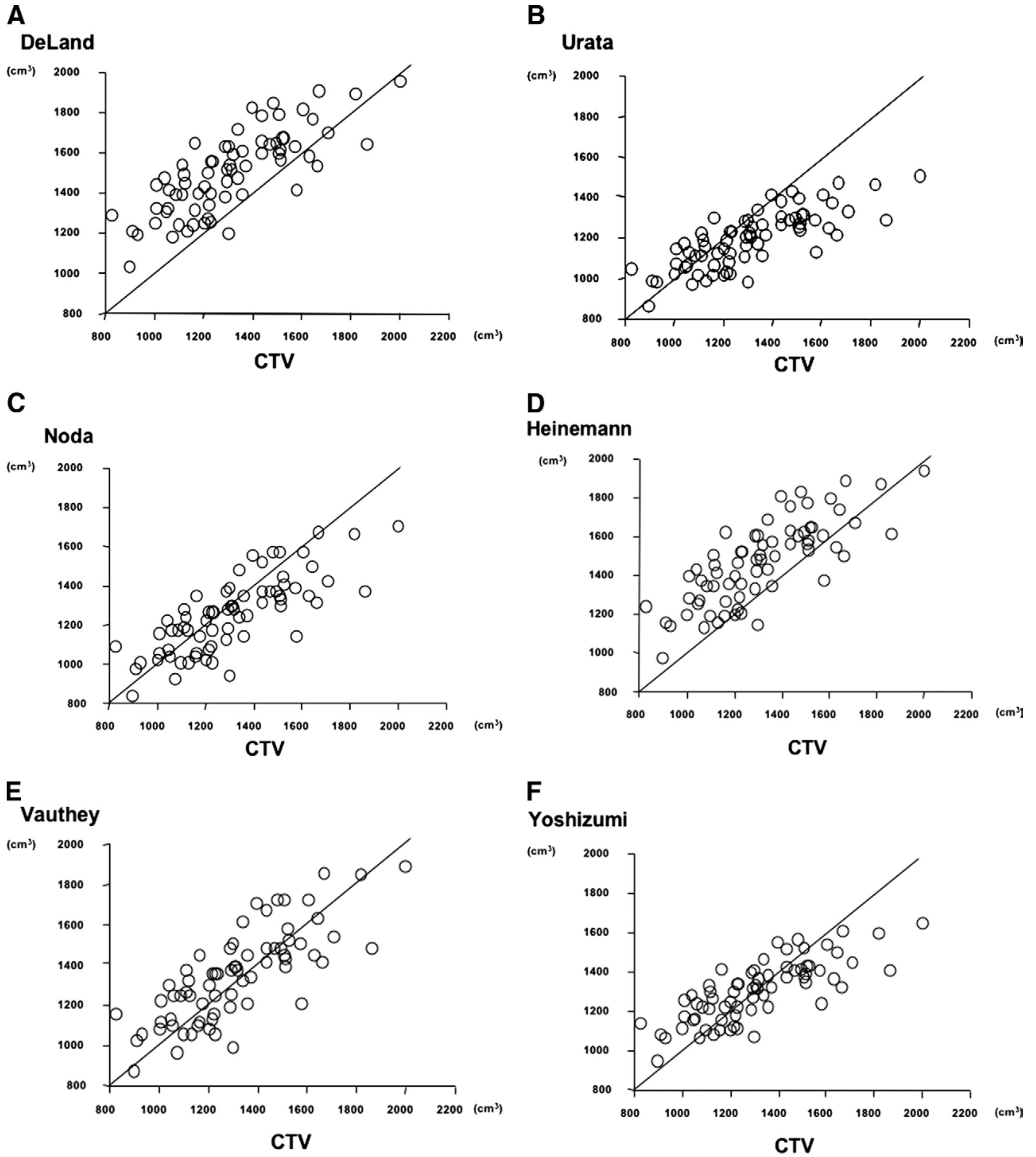

Fig 2. Correlation between CT volumetry (CTV) and estimated liver volume (LV) by each formula. When both would be same, a dot would be on the linear line. Formulas of DeLand (**A**), and Heinemann (**D**) overestimate LV than CTV. Urata formula underestimates LV (**B**). Formulas of Noda (**C**) and Yoshizumi (**F**) seem to fit; however, they tend to underestimate LV when those are greater than 1600 cm^3.

recipient side or avoid overresection on the donor side. Our standard for this analysis was that an estimated LW was acceptable if it was within 15% of the true value.[6] Estimation methods were compared for meeting the criterion using McNemar's test.[18] SPSS 10.0 (SPSS Inc, Chicago, Ill, USA) was used for this test. For comparisons with formulae that estimated LV, the tissue density of the liver was considered to be 1.0 g/mL.[6,11]

The significance of group differences was determined by Tukey-Kramer test. A P value $<.05$ was considered significant. Data were expressed as mean values ± standard deviation.

RESULTS

The characteristics of donors are shown in Table 2. Remarkably, the median value of CTV/BSA was 772.0 (the mean value of which was 772.3), which is the same coefficient as in our previous report (Table 1).

Table 3 shows mean values and standard deviations of CTV and estimates of LV according to each formula. There was no significant difference between CTV and estimated mean LV as calculated by Noda, Vauthey, or Yoshizumi. Mean LV as estimated by the formulas of DeLand and Heinemann et al was significantly greater ($P < .01$) than mean CTV, while LV estimated by the formula of Urata was significantly less ($P < .05$) than CTV.

The data of CTV, and the estimated LV, by each formula were plotted (Fig 2). Using the formulas of DeLand (Fig 2A) and Heinemann et al (Fig 2B) tended to overestimate the LV, while the formula of Urata (Fig 2B) tended to underestimate the LV. The formulas of Noda et al and Yoshizumi et al tended to underestimate the LV when the CTV was greater than 1600 cm^3.

When the Yoshizumi formula was applied, the number of donors with an acceptable difference (±15%) between CTV and estimated LV was 55 (78.6%; Table 4). The formulas of DeLand and Heinemann et al showed significantly lower rates of acceptable differences (Table 4). The other four formulae had comparable results with no significant differences. It should be noted that the Urata formula may underestimate SLV, especially for men.

DISCUSSION

Surgical techniques and immunosuppression for living donor liver transplantation have progressed[1–3] since the procedure was first reported in 1989.[19] Small-for-size graft syndrome is a major problem to overcome to achieve good results.[20,21] Although patient status, recipient portal hypertension, venous return of the graft, or graft quality may cause the syndrome,[7,20–22] graft size is the most important factor.[7,20] It is not easy to obtain a graft with sufficient size from a living donor, because donor safety is the principal in this setting.[4,7] Recently, it was reported that the mortality rate of living donors has reached 0.5%.[23] This will imperil us to keep performing the procedure. Therefore, we believe correct preoperative evaluation for LV should be performed on both donors and recipients.[6,13]

Table 4. Number of Donors With an Acceptable Difference (±15%) Between CTV and Estimated LV, by Formula

Formula	Overall (n = 70)	Male (n = 46)	Female (n = 24)
DeLand	35 (50.0%)*	24 (52.2%)†	11 (45.8%)
Urata et al	52 (74.3%)	33 (71.7%)	19 (79.2%)
Noda et al	56 (80.0%)	37 (80.4%)	19 (79.2%)
Heinemann et al	39 (55.7%)*	27 (58.7%)†	12 (50.0%)
Vauthey et al	54 (77.1%)	35 (76.1%)	19 (79.2%)
Yoshizumi et al	55 (78.6%)	38 (82.6%)	17 (70.8%)

CTV, CT volumetry; LV, liver volume.
*$P < .01$, †$P < .05$, compared to Yoshizumi's formula.

Table 2 shows that the the median value of CTV/BSA of our donors was 772.0. When we developed the Yoshizumi formula at Mount Sinai Hospital, we made the formula quite simple.[6] The intercept was set to zero (LV = 772 × BSA). It was very interesting, because the present study showed the same result (CTV = 772 × BSA). Some formulae examine differences of races among the patients.[12,13]

The data from this study indicated that the formulae of DeLand and Heinemann et al overestimated LV, while the Urata formula underestimated it as shown in Fig 2. The two formulas developed from autopsy cases might have included some microscopic fatty liver among their data. This may be the reason that the LV was overestimated by their formula, because fatty changes can increase the volume. The Urata formula was developed mainly using data from pediatric and young age populations. This may have influenced their data, because the ratio between LV and BSA changes according to age.[24] This consideration might make their formula underestimate LV. The formulas of Noda et al and Yoshizumi et al seemed applicable; however, they underestimate LV when it is 1600 mL or more. Several formulas should be used properly according to the patients' BSA. For instance, the Yoshizumi formula would be adequate for the patients with BSA 2.0 or less. The other formulas might be appropriate for patients with BSA > 2.0.

The SLV for patients who are obtaining living donor liver transplantations is relatively complicated. It is well known that patients with liver cirrhosis have malnutrition,[25] which may decrease BSA, and display ascites, which may affect body weight as well.

In conclusion, we compared six reported formulae to calculate LV using data from living donors, observing that the Yoshizumi formula was applicable, especially for patients with BSA < 2.0.

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