ELSEVIER

DONOR AND RECIPIENT TRANSPLANT EVALUATION

A Simple New Formula to Assess Liver Weight

T. Yoshizumi, G.E. Gondolesi, C.A. Bodian, H. Jeon, M.E. Schwartz, T.M. Fishbein, C.M. Miller, and S. Emre

ABSTRACT

Introduction. In cadaveric or segmental liver transplantation, accurate assessment of graft volume is desirable but not always easy to achieve based on donor morphometric data. We sought to establish a simple, reliable formula for accurate prediction of liver volume.

Methods. Data from 1,413 cadaveric adult and pediatric liver donors were analyzed using simple and multiple regression analysis. Liver weight (LW) was plotted against age, height, body weight (BW), body surface area (BSA) or body mass index (BMI); a formula was developed using simple regression: LW (g) = 772 (g/m^2) $\times$ BSA, r = 0.73, $P < .01$. For donors with BSA $\leq$1.0, a pediatric factor (PF) of 1.0 was included, resulting in the formula: LW (g) = 772 (g/m^2) $\times$ BSA $-$ 38PF, r = 0.73, $P < .01$. We then applied our formula on 5 published formulae to estimate LW of our donors.

Results. Among donors with BSA >1.0, there was no significant difference between the actual and the estimated mean LW as calculated by the new formula. For pediatric donors, there was no significant difference between estimated and actual mean liver weight with any formula. When the new formula was applied, the difference between the actual and the estimated liver weight was acceptable (<20%) in 1040 (73.6%) cases. In all races, there was no significant difference between actual and estimated mean liver weight as calculated by this formula.

Conclusion. A simple formula to calculate liver weight in donors with BSA >1.0 is: LW = 772 $\times$ BSA, and for donors with BSA $\leq$1.0: Liver Weight = 772 $\times$ BSA $-$ 38.

THE SHORTAGE of cadaveric livers for transplantation continues to limit the therapy,[1–3] but the use of living donors and split grafts has helped to solve this problem.[4–6] In cadaveric or segmental liver transplantation, accurate pretransplant estimation of donor standard liver volume is crucial to avoid severe mismatches or the small-for-size syndrome.[3,7–11] A simple, reliable formula to accurately predict liver volume would be invaluable.

Several formulas have been developed. DeLand and North calculated standard liver weight on the basis of body

From the Recanati/Miller Transplantation Institute (T.Y., G.E.G., H.J., M.E.S., T.M.F., C.M.M., S.E.), and the Department of Biomathematical Sciences (C.A.B.), Mount Sinai School of Medicine, New York, New York.

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Address reprint requests to Dr Sukru Emre, Mount Sinai Hospital, Box 1104, One Gustave L. Levy Place, New York, NY 10029. E-mail: sukru.emre@msnyuhealth.org

360 Park Avenue South, New York, NY 10010-1710

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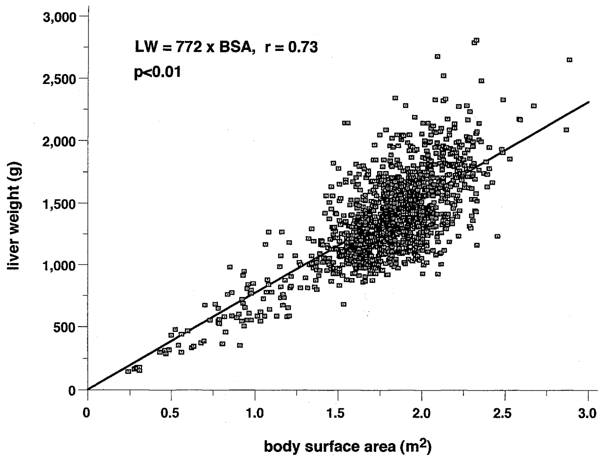

Fig 1. Relationship between BSA and actual liver weight in 1413 donors used for orthotopic liver transplantation.

surface area (BSA) using 550 autopsy cases[12]: liver weight (kg) = 1.02 × BSA − 0.22. Although this formula has been used by some centers, the relationship between liver weight and BSA is limited when BSA is $\leq$1.0 m^2.

In Japan, Noda et al and Urata et al studied patients without liver disease using computed tomography (CT). They reported formulas for calculating liver volume. Noda et al[13] proposed the following formula: liver volume (cm^3) = 50.12 × body weight $(kg)^{0.78}$. The formula suggested by Urata et al[14]: liver volume (mL) = 706.2 × BSA + 2.4, is useful for both pediatric and adult patients; many centers accept it for use.[5,8,9,15] Urata's cohort, however, ranged in age from 1 month to 27 years; it did not include any elderly individuals, a limiting factor in the application of this formula. Livers from donors >70 years can be used safely.[16] As reported by Schmucker, liver volume declines between maturity and senescence in humans.[17] Therefore, it is important to assess liver volume formulas over wide age ranges.

Heinemann et al[18] recently developed a formula for calculating standard liver volume (LV) in white subjects using 1332 autopsy livers: LV (mL) = 1072.8 × BSA − 345.7. They concluded that liver volume in whites was larger than that calculated with Urata's et al's formula. Their study excluded children whose body weight was <15 kg; however, the value of the coefficient of determination was low (r^2 = 0.30).

Finally, we previously reported a formula based on data from 500 cadaveric donor livers used for transplantation[19,20]: LW (g) = 6 × body weight (lb.) + 4 × age + 350. This formula was valid for livers from donors >11 years. In the present study, we sought to establish a new, clinically useful formula to estimate liver volume in adult and pediatric donors as well as recipients before transplantation, to appropriately match donors and recipients. We compared the new formula with the five previously published formulas mentioned earlier.

MATERIALS AND METHODS

Data were obtained on 1413 cadaveric liver donors (851 men, 562 women; aged 2 months to 87 years) for orthotopic liver transplantation between April 1990 and March 2001. Causes of donor deaths were: subarachnoid hemorrhage (n = 391); stroke (n = 280); motor vehicle accident (MVA; n = 269); gunshot wound (n = 171); non-MVA head injury (n = 98); or other (n = 204). Liver weight was measured just after the backtable procedure. Because the liver weight included the weight of the gall bladder, 2.3% of the measurement[18] was subtracted. Donor body weight and height were used to calculate BSA and body mass index (BMI), using the following equations[21,22]:

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

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

Livers from pregnant donors or livers used for reduced-size or split-liver transplantation were excluded, because the precise body weight and/or liver weight could not be obtained.

Our goal was to develop a simple formula relating a single factor to liver weight, preferably describing a line passing through the origin. Correlation coefficients were estimated for several potential donor factors. The correlations with liver weight were higher for BSA (r = 0.73) and weight (r = 0.72) than age (r = 0.27), height (r = 0.62), or BMI (r = 0.51).

The regression line for LW against donor weight displayed a

Table 1. Body Size and Liver Weight by Gender

	Male	Female
n	851	562
Age* (y)	38.6 ± 20.6 (0–87)	47.0 ± 19.7 (0–85)
Body height* (cm)	172.3 ± 19.4 (50.8–213.4)	160.8 ± 14.6 (55.0–190.5)
Body weight* (BW; kg)	73.4 ± 20.3 (4.1–158.9)	63.7 ± 16.5 (5.0–116.2)
Body surface area* (BSA, m^2)	1.86 ± 0.36 (0.24–2.88)	1.68 ± 0.28 (0.28–2.38)
Body mass index‡	24.2 ± 4.9 (10.2–49.6)	24.3 ± 5.2 (12.1–49.1)
Liver weight* (LW; g)	1438.0 ± 379.8 (150–2817)	1290.1 ± 324.3 (166–2697)
LW/BW† (%)	2.04 ± 0.49 (1.08–4.92)	2.09 ± 0.44 (1.03–4.31)
LW/BSA# (g/m^2)	770.7 ± 140.8 (392.7–1383.7)	767.1 ± 138.5 (419.7–1400.3)

Data expressed as mean ± SD (range).
*P < .01;
†P < .05;
‡Not significant.

Table 2. Mean Actual and Estimated Liver Weight, by Formula

		Estimated LW					
	Actual LW	772 × BSA	DeLand and North	Heinemann et al	Noda et al	Mt Sinai Hospital	Urata et al
Overall data (N = 1413)	1379.1 ± 365.9	1379.5 ± 266.6	1604.1 ± 345.7*	1572.8 ± 363.6*	NA	1436.6 ± 294.2*	1265.3 ± 239.4*
Patients with BSA >1.0 (N = 1353)	1417.0 ± 322.4	1417.3 ± 197.9	1652.1 ± 261.4*	1623.3 ± 274.9*	NA	1473.0 ± 242.4*	1298.5 ± 181.0*
Patients with BSA <1.0 (N = 60)	524.4 ± 215.1	526.3 ± 174.3†	522.7 ± 230.2	435.5 ± 242.1	483.6 ± 154.3	616.5 ± 106.1	516.6 ± 159.4

LW, liver weight; BSA, body surface area; NA, not applicable (used only for pediatric group).
*$P < .01$ compared with actual LW.
†For these patients, 772 × BSA − 38 was used.

statistically significant intercept term ($P < .001$). BSA was considered preferable for our purposes, because simple linear regression showed that its intercept was not significant ($P = .28$). The original formula was:

$$\text{LW (g)} = 785\ (\text{g/m}^2) \times \text{BSA} - 23.3\ (P < 0.001)$$

Setting the intercept to zero, the results of the regression of BSA on liver weight are:

$$\text{LW (g)} = 772\ (\text{g/m}^2) \times \text{BSA}\ (P < .001;\ \text{Fig 1})$$

The latter formula is simple, and its results are not statistically different than results with the original one with an intercept at 23.3 (g).

Donors were then divided into groups according to whether the BSA was greater or less than 1.0, to test the suitability of this formula for the pediatric population. Using this formula, the average estimated liver weight for donors with a BSA ≤1.0 was much greater than the actual liver weight (data not shown). Therefore, for donors with a BSA ≤1.0, a pediatric factor (PF) was included in a new formula. The PF was set at 1.0 for pediatric donors with a BSA ≤1.0 (n = 60) and PF was set at 0 for donors with a BSA >1.0 (n = 1353). Multiple regression analysis with two independent factors (BSA and PF) was then performed. The final formula was as follows:

$$\text{Liver weight (g)} = 772\ (\text{g/m}^2) \times \text{BSA} - 38\text{PF}\ (r = 0.73,\ P < .01)$$

We then applied the new formula and the formulas of DeLand and North, Urata et al, Heinemann et al, and Mount Sinai Hospital to estimate liver weight of donors based on body weight, BSA, and/or age. Noda's formula was used to estimate liver weight for pediatric donors. For comparisons with formulas that estimated liver volume, tissue density of the liver was considered as 1.0 g/mL.[14] For individual donors we calculated the difference between actual and estimated liver weight using each formula. Individual differences were plotted against actual liver weight with a modified Bland–Altman method.[23] The ultimate clinical issue was whether the estimated liver weight is sufficiently accurate to distinguish cases, in terms of whether the donor liver is of acceptable size for the procedure to be performed. Our standard for this analysis was an estimated liver weight within 20% of the true value. Estimation methods were compared for meeting the criterion by McNemar's test[24] using SPSS version 10.0 (SPSS, Inc, Chicago, Ill).

The reliability of the formula was considered separately for racial groups.

The significance of differences between groups was determined by Student's *t* test for unpaired populations or ANOVA. $P < .05$ was considered statistically significant. Data are expressed as mean ± standard deviation (SD).

RESULTS

Age, body size parameters, and liver weight of the donors are shown in Table 1. Except for BMI, body size parameters were significantly greater in men than women (Table 1). Remarkably, however, liver weight/BSA ratio was not significantly different between the genders. This finding is consistent with the result that BSA displayed the most robust relationship to LW.

Table 2 shows mean values and standard deviations of actual liver weight and estimated liver weight according to each formula. Overall, and in donors with a BSA >1.0, there was no significant difference between actual and estimated mean liver weight as calculated by our new formula (Table 2). For the same populations, mean liver weight, as estimated by the formulas of DeLand and North,

Table 3. Number of Donors With an Acceptable Difference (±20%) Between Estimated and Actual Liver Weight, by Formula

	772 × BSA	DeLand and North	Heinemann et al	Mt Sinai Hospital	Urata et al
Overall (N = 1413)	1040 (73.6%)	725* (51.3%)	785* (55.6%)	967* (68.4%)	1048 (74.2%)
Donors with BSA >1.0 (N = 1353)	1002 (74.1%)	694* (51.3%)	756* (55.9%)	940* (69.5%)	1011 (74.7%)
Donors with BSA <1.0 (N = 60)	38† (63.3%)	31 (51.7%) (*P* = .065)	29 (48.3%) (*P* = .12)	27‡ (45%)	37 (61.7%)

BSA, body surface area.
*$P < .01$ compared with 772 × BSA by McNemar's test for matched pair.
†For these patients, 772 × BSA − 38 was used.
‡$p < .05$ compared to 772 × BSA by McNemar's test for matched pair.

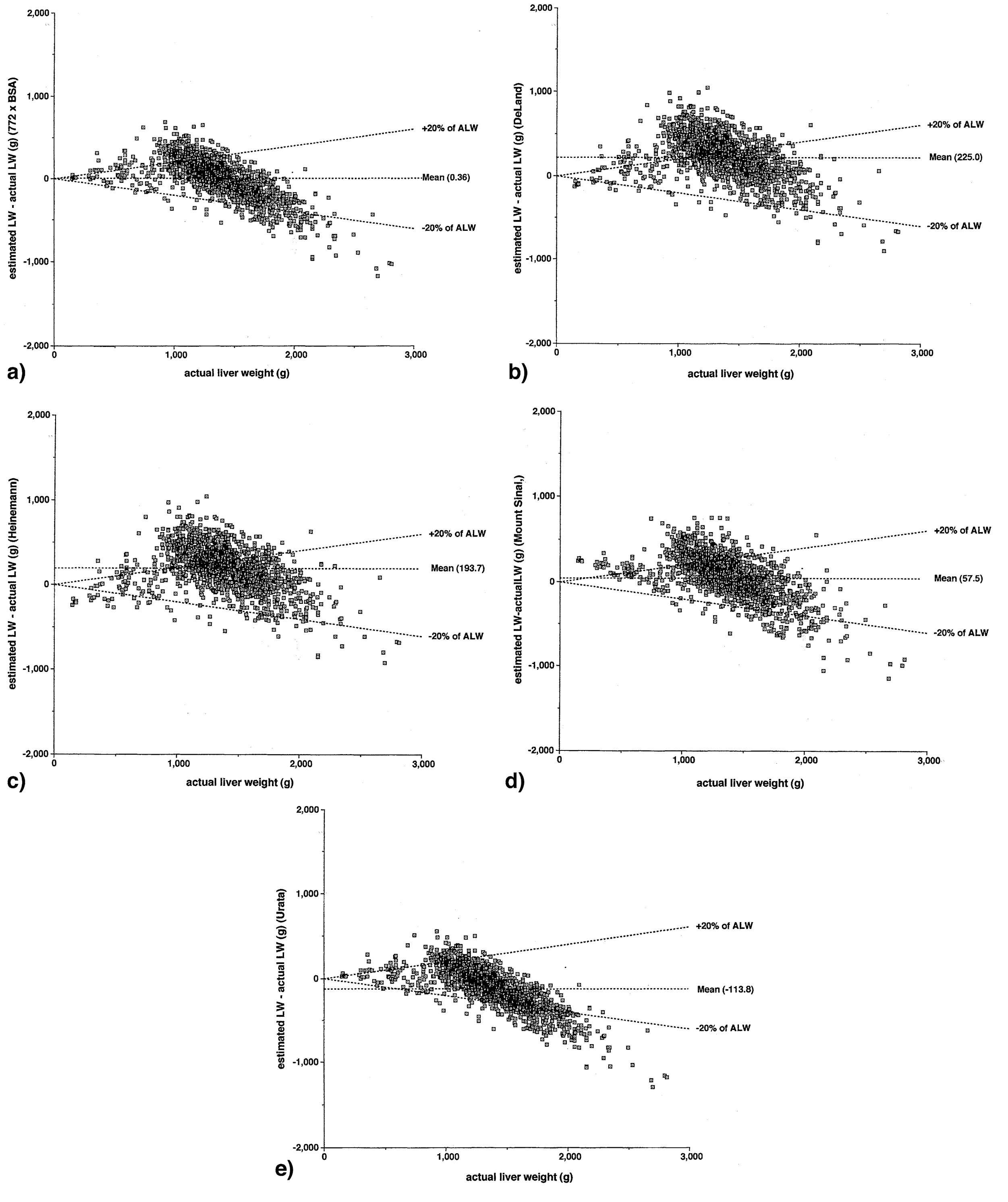

Fig 2. Individual differences between actual liver weight and estimated liver weight, as calculated by each formula. The line on each figure showing the mean value of the differences illustrates the bias in some of the formulas. The two dotted oblique lines in each trace indicate bounds within which the estimated value is within 20% of the true value, under the assumption that these are acceptable criteria in the clinical setting. ELW, estimated liver weight; ALW, actual liver weight.

Table 4. Average of Actual Liver Weight or Calculated Liver Weight in Each Race

	Actual LW	772 × BSA*	DeLand and North	Heinemann et al	Mt Sinai Hospital	Urata et al
White (N = 986)	1417.9 ± 359.1	1393.3 ± 260.0	1621.9 ± 326.5†	1591.5 ± 343.4†	1459.8 ± 285.4‡	1277.6 ± 226.1†
Black (N = 237)	1296.3 ± 382.5	1378.7 ± 317.3	1604.2 ± 410.1†	1572.9 ± 431.3†	1410.5 ± 332.2‡	1265.4 ± 283.9
Hispanic (N = 166)	1290.3 ± 351.5	1314.4 ± 271.5	1519.6 ± 348.5†	1483.9 ± 366.6†	1349.5 ± 274.0	1206.8 ± 241.3
Others (N = 24)	1218.7 ± 295.4	1268.6 ± 227.6	1457.6 ± 295.1‡	1418.8 ± 310.3‡	1343.7 ± 246.1	1163.9 ± 204.3

LW, liver weight; BSA, body surface area.
*For children with a BSA of <1.0, 772 × BSA − 38 was used.
†$P < .01$ compared with actual LW.
‡$P < .05$ compared with actual LW.

Heinemann et al, and Mount Sinai Hospital, was significantly greater ($P < 0.01$) than mean actual liver weight, whereas liver weight estimated by the formula of Urata et al was significantly lower ($P < 0.01$) than actual liver weight. For pediatric donors, there was no significant difference between estimated and actual mean liver weight with any of the formulas.

Fig 2a–e shows individual differences between actual liver weight and estimated liver weight, calculated using each formula. When our formula was applied, the number of donors with an acceptable difference (≤20%) between actual and estimated liver weight was 1040 (73.6%) (Table 3). The formulas of DeLand and North, Heinemann et al, and Mount Sinai Hospital had significantly lower rates of acceptable differences (Table 3).

Table 4 shows the mean actual and estimated liver weights by race. In all races, there was no significant difference between actual and estimated mean liver weight as calculated by our new formula. By contrast, in whites, mean liver weight, as estimated by the formulas of DeLand and North, Heinemann et al, and Mount Sinai Hospital, was significantly greater than mean actual liver weight, whereas mean liver weight estimated by the formula of Urata et al was significantly lower than the actual mean LW.

The number of cases within the acceptable 20% rate was also calculated for each race. Our new formula was compared with five previously described formulas in terms of proportions of livers within acceptable limits (Table 5). Our formula showed a >70% acceptability rate in each race except blacks. The acceptable rate in our formula was significantly higher than those of DeLand and North, Heinemann et al and Mount Sinai Hospital for whites. For blacks, Urata et al; formula had the highest acceptability rate.

DISCUSSION

The aim of our study was to develop a simple, broadly applicable formula for estimating liver weight. Our new formula (liver weight = 772 × BSA) was calculated from the largest series thus far reported in the literature. As shown in Table 1, no significant difference in LW/BSA ratio was observed between men and women, a finding that supports the observation that BSA had the best relationship to LW, signifying this formula is applicable to both genders.

Table 2 shows that, of all the formulas the one presented herein showed, the closest match to the mean of the actual liver weight for the overall data or in cases with a BSA of >1.0 or <1.0. Several formulas have been established using data from subjects of a single race.[13,14,18] Our formula, 772 × BSA, was established using data from several races. Because it requires the use of only one factor, it may be the most suitable for use in the USA and other multiracial nations. Furthermore, our data indicate that 772 × BSA is more applicable than the formulas of DeLand and North and Heinemann et al. Estimates using Noda et al's formula, as described for pediatrics, are not significantly different from estimates achieved with our formula in pediatric donors. The Noda formula format with an exponential function detracts from its usefulness in the clinical setting. The Urata formula is the most popular and has even been used in the USA[9,15]; however, using our donor data, the Urata formula underestimates liver weight, as shown in Fig 2 and Tables 2 and 4. Furthermore, the original descrip-

Table 5. Number of Cases Within Acceptable Range (±20%) Against Individual Actual Liver Weight by Race

	772 × BSA*	DeLand and North	Heinemann et al	Mt Sinai Hospital	Urata et al
White (N = 986)	753 (76.4%)	550† (55.8%)	592† (60.0%)	693† (70.3%)	734 (74.4%)
Black (N = 237)	152 (64.1%)	83† (35.0%)	88† (37.1%)	147 (62.0%)	172‡ (72.6%)
Hispanic (N = 166)	117 (70.5%)	80† (48.2%)	8† (53.6%)	111 (66.9%)	124 (74.7%)
Others (N = 24)	17 (70.8%)	12 (50.0%)	16 (66.7%)	16 (66.7%)	18 (75.0%)

BSA, body surface area.
*For children with a BSA <1.0, 772 × BSA − 38 was used.
†$P < .01$ compared with 772 × BSA by McNemar's test for matched pair.
‡$P < .05$ compared with 772 × BSA by McNemar's test for matched pair.

tion[14] did not assess LW in the elderly population as does our formula.

In conclusion, we analyzed LW using data from a large group of cadaveric donors, observing that the average donor estimated LW is 772 g/m^2. Therefore, the new formula to calculate liver weight in donors with a BSA $>$1.0 is: LW $= 772 \times$ BSA; and for donors with a BSA $\leq$1.0, the formula is: LW $= 772 \times$ BSA $- 38$. This formula is clinically simple and useful for all donor populations, regardless of gender, age, or race.

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