


Baseline living-donor kidney volume and function associate with 1-year post-nephrectomy kidney function

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Abstract

Living donors may develop kidney dysfunction more often than equally healthy populations. The purpose of this study was to determine whether computed tomography-assessed remaining kidney volume indexed to body surface area (RKV/BSA) was associated with 1-year post-nephrectomy renal function independent of baseline renal function. Using multivariable regression, we modeled 1-year estimated glomerular filtration rate (eGFR) and eGFR <60 mL/min/1.73 m² and considered pre-determined baseline eGFR subgroups in 151 consecutive donors. Mean ± SD baseline age, eGFR, RKV, BSA, and RKV/BSA were 38 ± 11 years, 97 ± 16 mL/min/1.73 m², 153 ± 29 mL, 1.9 ± 0.2 m², and 80.0 ± 12.8 mL/m², respectively; 50% were female and 94% were white. Mean baseline eGFR was greater with increasing RKV/BSA tertiles (92 ± 14, 97 ± 16, 107 ± 16 mL/min/1.73 m²; *P* < 0.001). Post-nephrectomy eGFR remained separated by RKV/BSA tertiles. At baseline, each SD greater RKV/BSA and eGFR was independently associated with higher adjusted 1-year eGFR by 2.4 and 9.2 mL/min/1.73 m². Each SD greater age associated with 2.2 mL/min/1.73 m² lower adjusted 1-year eGFR. Adjusted odds of 1-year eGFR <60 increased significantly for donors with RKV/BSA <80 mL/m². With baseline eGFR <90, probability of 1-year eGFR <60 increased to >80% with decreasing RKV/BSA values below 80 mL/m². Those with baseline eGFR >100 rarely developed 1-year eGFR <60 if RKV/BSA remained >60 mL/m². RKV/BSA independently associated with 1-year eGFR <60, especially with lower baseline eGFRs. Additional studies should evaluate the predictive utility of this measure and its potential role in donor evaluations and informed consent.

KEYWORDS

glomerular filtration rate, kidney function, kidney transplantation, kidney volume

1 | INTRODUCTION

Living-donor kidney transplantation is a preferred treatment option for individuals with end-stage kidney disease. Those with access to living-donor kidneys can undergo planned transplant surgery and avoid years of chronic dialysis on the deceased-donor

kidney waiting list, which associates with improved survival and lower healthcare costs.^{1,2} Because the kidneys are typically procured from healthy living donors and then transplanted with very little ischemia time, they tend to have lower rates of delayed graft function, primary non-function and premature graft failure compared with deceased-donor kidney transplants.⁵ In recent years,

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however, epidemiologic studies have revealed increased risk for subsequent kidney disease in living donors compared with similarly healthy non-donors.^{6,7} Epidemiologic data have also shown substantial variation in risk based on individual donor characteristics,⁸ but more information is needed to improve prediction tools to further personalize the informed consent process for living kidney donor candidates.

Organ Procurement and Transplantation Network (OPTN) Policy 14.4 describes the minimal medical evaluation requirements for living kidney donors in the United States. In addition to a detailed history, physical examination and extensive laboratory testing, anatomic assessment of the kidneys must be performed to determine potential masses, cysts, stones, defects, whether the kidneys are of equal size, and which one is more "anatomically suited for transplant." Computed tomography (CT) angiography is commonly utilized for this purpose because it also provides comprehensive visual information about the renal vessels as well as surrounding anatomic structures. In terms of assessing kidney size, the three-dimensional (3D) volume of each kidney can be accurately estimated from these CT scans using post-processing software.

A few studies of living kidney donors have assessed pre-donation kidney volume and subsequent post-donation outcomes^{9,10}; however, it remains unclear whether the individual volume of the remaining kidney is independently associated with post-donation kidney function. The degree to which remaining kidney volume may associate with post-donation kidney function in relation to other donor factors is also poorly understood. In particular, data from several large general population (ie, non-donor) cohorts suggest that baseline estimated glomerular filtration rate (eGFR) is one of the strongest independent predictors of future kidney disease.¹⁴ On the other hand, analyses from a large French cohort of healthy living kidney donors recently showed that "lifetime-standardized renal reserve" was no different between baseline GFR groups of <80, 80-90, or >90 ml/min/1.73 m².¹⁵

The French cohort study also noted that baseline eGFR was associated with age, leading the authors to conclude that baseline values <90 mL/min/1.73 m² are reasonable for older donors.¹⁵ A prior study by our group at the University of Utah found that living-donor kidney volume assessed via CT angiography and divided by recipient weight (the "volume dose" for the recipient) was associated with allograft kidney function in the recipients of those kidneys 1 year after transplantation.¹⁶ Because of the clinical need for more information about factors for future prediction tool development in living donors themselves, we performed the current study in the living kidney donors of this cohort to determine the independent association between remaining kidney volume and eGFR at 1-year post-nephrectomy. Given the importance of baseline eGFR with regard to future renal function within general populations¹⁴ and to account for the potential for remaining kidney volume to meet the metabolic demands of the donor as well as prior evidence that CT-assessed kidney volumes correlate best with BSA,¹⁷ we specifically controlled for baseline eGFR, divided remaining kidney volume by BSA, and included age and other donor characteristics in multivariable models

to determine the independent magnitudes of association for these potential predictors.

2 | MATERIALS AND METHODS

2.1 | Cohort and data collection

This study was approved by the institutional review board at the University of Utah, and we adhered to the ethical principles of the Declaration of Helsinki.¹⁸ The clinical and research activities reported here are also consistent with the principles outlined in the Declaration of Istanbul on Organ Trafficking and Transplant Tourism.¹⁹ Living donors and matching kidney recipients underwent standard evaluation based on an established institutional protocol. As part of the donor evaluation process, bilateral kidney volumes were assessed as described below, and additional baseline and follow-up data were retrospectively collected in consecutive adult kidney donors between January 2005 and December 2009. Donors with missing serum creatinine values at 1 year were excluded. During the study period at our institution, the presence of comorbidities, including hypertension, obesity, and prediabetes, was considered contraindications to living kidney donation regardless of donor candidate age.

2.2 | Renal function and kidney volume assessment

The Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) equation was used to calculate baseline and 1-year post-donation eGFR.²⁰ Potential living kidney donors were evaluated with a 64-row multi-detector CT scanner (Somatom Sensation 64; Siemens Medical Solutions, Erlangen, Germany) or Dual-Source CT (Definition; Siemens Medical Solutions). Triphasic renal images were obtained using unenhanced, arterial phase, and nephrographic phase data sets to determine total and cortical volumes for both kidneys separately. During the scan, each patient received 115 mL of intravenous contrast containing 370 mg of iodine per mL (iopamidol, 76%; Isovue 370; Bracco Diagnostics, Princeton, NJ) at a rate of 4 mL per sec via a power injector (MEDRAD, Warrendale, PA). Arterial and nephrographic phase scans were performed 30 and 70 seconds after the start of contrast injection, respectively. Unenhanced images were constructed using 3 × 3 mm slice thicknesses and increments. Arterial and nephrographic phase images were constructed using 2 × 2 mm slice thicknesses and increments.

3D volume-rendered images were obtained at an independent workstation by dedicated technologists using an automated software tool (Syngo Volume Calculation; Siemens Medical Solutions). The software system automatically defines a volume around a defined seed point within the 3D model of the kidney by searching for directly connected voxels within a defined Hounsfield unit range. Renal cortical volumes were obtained from arterial phase data during maximum separation between the enhancing cortex and less-enhancing medulla. We used a predefined Hounsfield unit range of 100-400 with adjustment to obtain the best visual separation

between the cortex and medulla for renal cortical volume measurements. Whole renal parenchymal volume was obtained from the delayed phase data excluding the renal sinus fat. We used a predefined Hounsfield unit range of 0-400 for whole renal parenchymal volume measurements.

2.3 | Statistical analysis

Descriptive statistics were reported as mean \pm standard deviation or frequency (percentage). We calculated BSA using the formula by Mosteller.²¹ We calculated the ratio of remaining whole parenchymal kidney volume divided by BSA (RKV/BSA, mL/m²). We compared the cohort distributions of baseline donor characteristics across tertiles of RKV/BSA via analysis of variance for continuous variables and chi-square or Fisher exact tests for categorical variables. We also generated violin plots to explore differences in the change in eGFR from baseline to 1 year between RKV/BSA tertiles. We calculated Pearson correlation coefficients between age, RKV/BSA, baseline eGFR, and 1-year eGFR.

We fit a linear regression model to estimate the relationship between continuous RKV/BSA and 1-year eGFR. For multivariable adjustments, we included the following pre-determined covariates: baseline eGFR, age, sex, race, and body mass index (BMI, kg/m²). To enable comparisons between covariates regarding strength of association, increases in these continuous variables were assessed per standard deviation. Using variance inflation factor tests, we found no evidence for multicollinearity problems between covariates.

To further explore the relationship between RKV/BSA and kidney function 1-year after donor nephrectomy, we used a restricted cubic regression spline basis matrix to graphically model the odds of

having an eGFR <60 mL/min/1.73 m² at 1 year based on RKV/BSA adjusted for age, sex, race, and BMI. Because the cubic splines provided smooth functions over the range of RKV/BSA in the data set, the results were relatively insensitive to the selection of the knot points. We then predetermined baseline eGFR cutoffs (<90, 90-100, >100 mL/min/1.73 m²) that could be considered clinically meaningful during healthy donor candidate evaluations. Using logistic regression models, we determined the probability of eGFR <60 mL/min/1.73 m² at 1 year by RKV/BSA for each of these baseline eGFR subgroups. We considered two-sided *P*-values <0.05 as statistically significant. Analyses were performed with Stata 14 (Stata Corp, College Station, TX).

3 | RESULTS

There were a total of 205 consecutive living-donor nephrectomies at our program during the study period. Information about baseline eGFR was not available for 1 of these donors, 7 of those remaining did not have available kidney volume measurements, and 46 of those remaining did not have available eGFR assessments at 1 year. A total of 151 living kidney donors were available for analysis. Mean age was 38 \pm 11 years (median age 38 [range: 19-62] years), 50% were female and 94% were white. Mean baseline eGFR was 97 \pm 16 mL/min/1.73 m². Mean RKV/BSA was 80 \pm 12.8 mL/m² (Table 1). Continuous donor age was modestly and inversely correlated with RKV/BSA (ρ = -0.163, *P* = 0.05). Baseline eGFR was significantly greater by increasing tertile of RKV/BSA at 92 \pm 14, 98 \pm 16 and 108 \pm 16 mL/min/1.73 m², respectively (*P* < 0.001). There were no other significant differences in baseline characteristics by tertiles of RKV/BSA. As depicted by a scatterplot in Figure 1,

TABLE 1 Baseline characteristics by RKV/BSA tertile

Characteristic	All (47.0-114.2) N = 151	Tertile 1 (47.0-74.1) N = 51	Tertile 2 (74.2-85.2) N = 50	Tertile 3 (85.3-114.2) N = 50	<i>P</i> -value
RKV/BSA, mL/m ²	80 \pm 12.8	66.2 \pm 6.3	80 \pm 3.1	94 \pm 7	
Age, y	37.9 \pm 11.2	39.5 \pm 10.7	39 \pm 11.3	35.2 \pm 11.4	0.11
Female	75 (50)	26 (51)	27 (54)	22 (44)	0.59
White race	142 (94)	49 (96)	46 (92)	47 (94)	0.69
Height, cm	171.3 \pm 9.7	171.5 \pm 9.6	170.5 \pm 9.7	172.0 \pm 9.8	0.75
Weight, kg	78.1 \pm 14.1	80.7 \pm 13.5	76.6 \pm 13.2	76.9 \pm 15.4	0.26
Body mass index, kg/m ²	26.5 \pm 3.7	27.3 \pm 2.9	26.3 \pm 3.6	25.9 \pm 4.3	0.13
Body surface area, m ²	1.9 \pm 0.2	2.0 \pm 0.2	1.9 \pm 0.2	1.9 \pm 0.2	0.37
Serum creatinine, mg/dL	0.87 \pm 0.16	0.93 \pm 0.16	0.87 \pm 0.16	0.82 \pm 0.14	<0.001
eGFR, mL/min/1.73 m ²	99.3 \pm 16.8	91.9 \pm 14.3	98 \pm 16	108.3 \pm 15.9	<0.001
Creatinine clearance, mL/min	116.6 \pm 23.5	114.2 \pm 17.7	111.7 \pm 25.6	124.1 \pm 25.0	0.02
Remaining kidney volume, mL	153.3 \pm 28.6	129.2 \pm 16.3	151.8 \pm 16.3	179.4 \pm 25.6	<0.001

eGFR, estimated glomerular filtration rate.

Values are mean \pm standard deviation or frequency (%). The cutoff values used to determine tertiles for remaining kidney volume divided by body surface area (RKV/BSA, mL/m²) are provided.

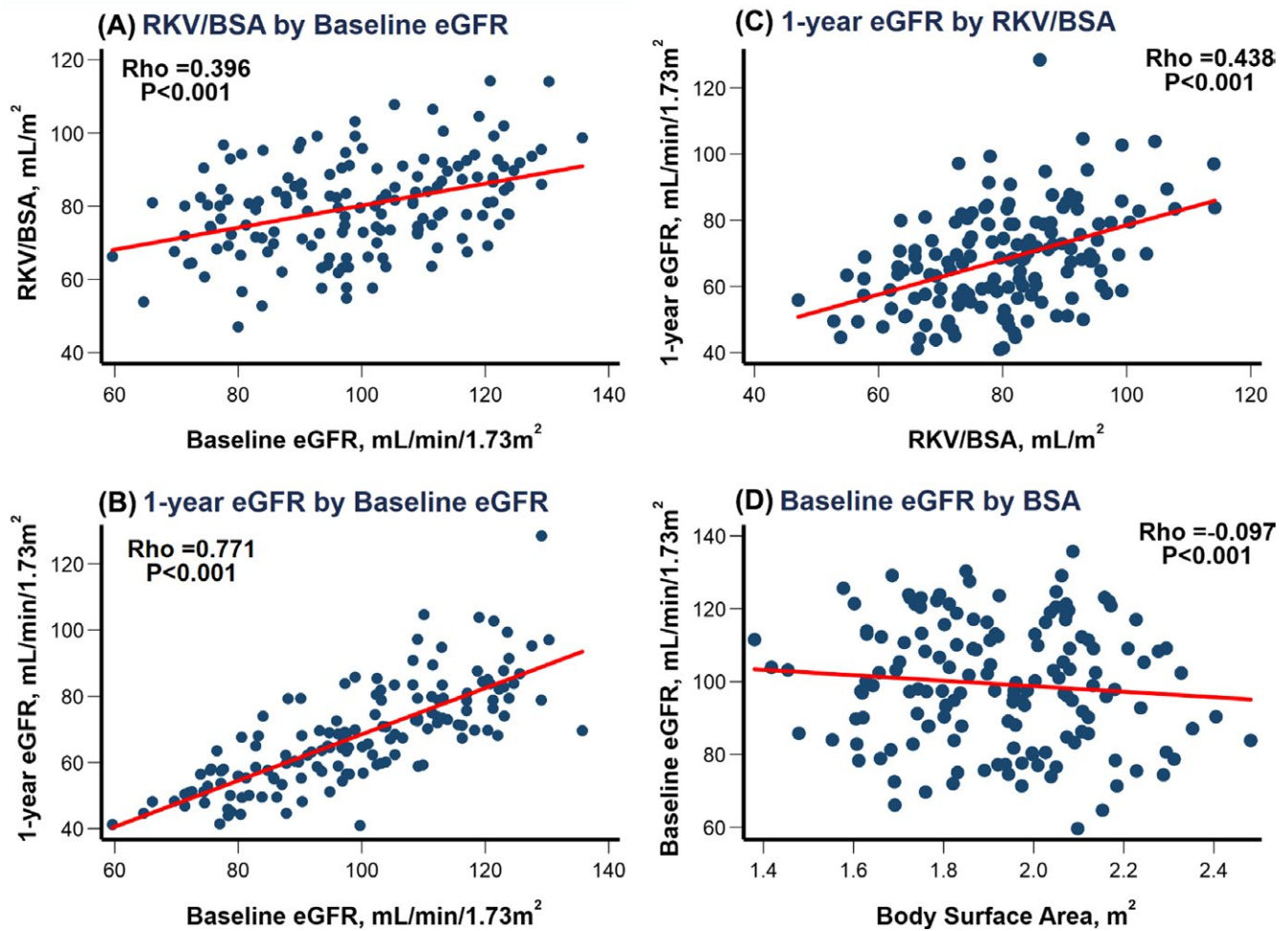


FIGURE 1 Correlations between RKV/BSA, BSA, baseline eGFR, and 1-year eGFR. A, Remaining kidney volume divided by body surface area (RKV/BSA) vs baseline (pre-donation) estimated glomerular filtration rate (eGFR). B, 1-year eGFR vs baseline eGFR. C, 1-year eGFR vs RKV/BSA. D, Baseline eGFR vs BSA

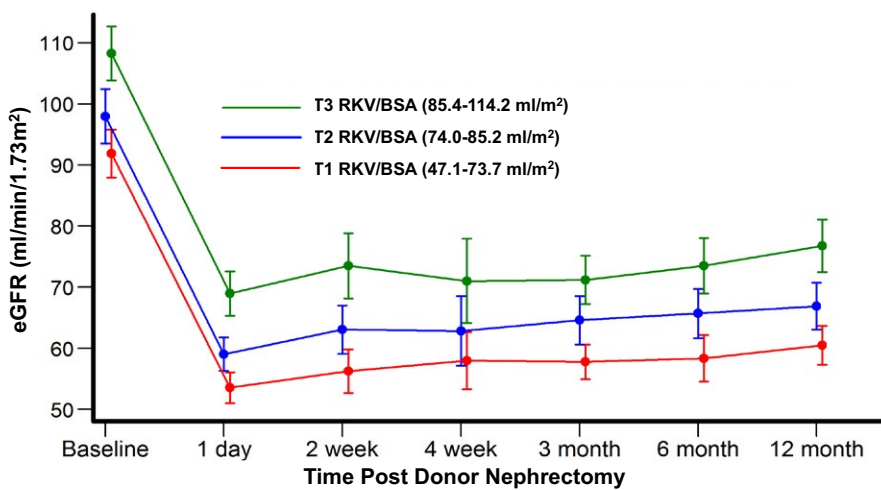


FIGURE 2 Kidney donor eGFR over the first year by RKV/BSA tertile. The number of donors with missing values at each follow-up were as follows: baseline none, 1-day none, 2-week 56, 4-week 97, 3-month 54, 6-month 29, 12-month none. Via analysis of variance, values were statistically different between tertiles at each time point, except at 4 weeks with $P = 0.02$. eGFR, estimated glomerular filtration rate; RKV/BSA, remaining kidney volume divided by body surface area

there was moderate positive correlation between baseline eGFR and RKV/BSA.

Figure 1 also shows that both baseline eGFR and RKV/BSA were significantly and positively correlated with 1-year eGFR. Figure 2 demonstrates sharp and similar declines in eGFR immediately after

nephrectomy in all RKV/BSA tertiles. Donor renal function increased steadily and remained significantly separated throughout the first year between RKV/BSA tertiles. The overall reduction in eGFR from baseline to 1 year was not statistically different between RKV/BSA tertiles ($P = 0.98$, Figure 3).

Via multivariable linear regression, RKV/BSA remained significantly associated with 1-year eGFR (Table 2). For each standard deviation greater RKV/BSA, adjusted 1-year eGFR was greater by 2.4 (95% confidence interval: 0.7, 4.1; $P = 0.01$) mL/min/1.73 m². Baseline eGFR had an even stronger independent association with 1-year eGFR, which increased by 9.2 (95% confidence interval: 7.2, 11.3; $P < 0.001$) mL/min/1.73 m² per standard deviation greater baseline eGFR. Older age was independently associated with a decline in 1-year eGFR [adjusted linear coefficient -2.2 (95% confidence interval: $-4.2, -0.2$; $P = 0.02$)]; however, sex, race, and BMI were not independently associated with changes in kidney function at 1 year in this cohort.

The adjusted odds of eGFR <60 mL/min/1.73 m² at 1 year after nephrectomy were significantly increased for donors with RKV/BSA values below 80 mL/m² (Figure 4). In the subgroup of donors with baseline eGFR <90 mL/min/1.73 m², the probability of eGFR <60 mL/min/1.73 m² at 1 year increased substantially to over 80% with decreasing RKV/BSA values below 80 mL/m² (Figure 5). On the other hand, the probability of eGFR <60 mL/min/1.73 m² did not increase above 30% in the subgroup of donors with baseline eGFR >100 mL/min/1.73 m² unless RKV/BSA was <60 mL/m².

4 | DISCUSSION

Living-donor kidney transplantation is a vitally important treatment option for the more than 95 000 individuals currently waiting for kidneys in the United States according to OPTN data as of June 2018. However, the number of living-donor kidney transplants has remained relatively flat since 2011 at around 5500-5800 per year, down from a peak of over 6600 in 2004. The demographics of living kidney donors have also recently changed with declining proportions

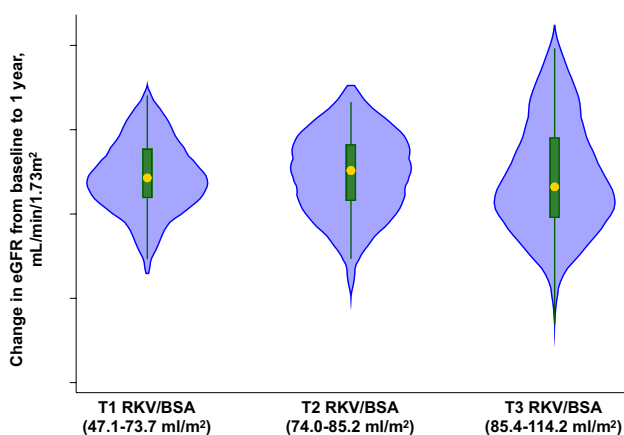


FIGURE 3 Violin plots for change in eGFR from baseline to 1 year by RKV/BSA tertile. Each plot depicts the median (yellow dot), interquartile range (blue violin shape), and non-outlier values (green bars, values within 1.5 times above and below the interquartile range). The width of each plot represents the estimated kernel density at that particular value. Via analysis of variance, change in eGFR was not statistically different between RKV/BSA tertiles ($P = 0.98$)

of younger as well as black donors.⁵ What has led to the current state of living-donor kidney transplantation is not fully understood but may be related in part to concerns about the long-term risks of donor nephrectomy, especially for certain patient populations.

In this single-center cohort study of healthy living kidney donors, we have shown that the volume of the remaining kidney, measured via pre-donation CT angiography software and indexed to BSA, is independently associated with eGFR 1 year after donation. We found that the adjusted strength of association for RKV/BSA on 1-year eGFR was similar to that of age at the time of donation, while it was much stronger and likely more clinically meaningful for baseline eGFR. We showed that the adjusted odds of having eGFR <60 mL/min/1.73 m² 1 year after donation were significantly higher with RKV/BSA <80 mL/m². We also noted that the risk of this outcome increased sharply and progressively starting at even greater RKV/BSA values for donors with baseline eGFR <90 mL/min/1.73 m².

It is important to consider the findings from this living kidney donor study in relation to those previously reported for the recipients of these kidneys.¹⁶ The volume of the donated kidney indexed to the recipient's weight, referred to as the "volume dose," correlated significantly with 1-year eGFR in the recipient. An earlier study of pre-donation kidney volume and function noted similar associations with post-transplant allograft outcomes.²² Considering these prior recipient studies in conjunction with the current analysis of donor outcomes, our hypothesis about the potential importance of kidney volume in transplantation appears to be supported. A large donated kidney volume is likely best for the recipient but may not be for the donor with regard to post-nephrectomy kidney function. Notwithstanding, being overly concerned about subsequent living-donor kidney function in the range of 60 mL/min/1.73 m² without regard to donor age could have unintended and detrimental consequences for the field and especially for future transplant candidates. In fact, there has been considerable debate over whether it is justifiable to consider otherwise healthy kidney donors with isolated eGFR values below 60 mL/min/1.73 m² as having chronic kidney disease (CKD).^{23,24} As such, we have purposely chosen to avoid the term CKD with regard to this research.

A handful of other studies have also evaluated the relationship between kidney volume and post-nephrectomy kidney function. In 189 Korean living donors, Jeon et al⁹ found that age, BMI, pre-donation GFR and RKV/BSA were modestly but independently associated with Modification of Diet in Renal Disease (MDRD)-estimated GFR <60 mL/min/1.73 m² at 6 months post-nephrectomy. Taner et al¹⁰ evaluated compensatory increases in remaining kidney volume and measured GFR in 46 living donors from the Mayo Clinic, including 30 considered medically complex due to hypertension, age >55 years, or BMI >35 kg/m². At a mean follow-up of 5.8 years and regardless of risk factors, remaining kidney volume increased by 29% and GFR increased (from pre-donation GFR divided by 2) by 36%. The researchers did not, however, report associations based on remaining kidney function. Narasimhamurthy et al¹¹ evaluated 85 donors and found those with larger combined kidney volumes adjusted for BSA were more likely and more quickly

Donor factors	Univariate linear coefficient (95% CI)	P-value	Multivariable linear coefficient (95% CI)	P-value
Baseline eGFR per SD	11.7 (10.2, 13.3)	<0.001	9.2 (7.2, 11.3)	<0.001
RKV/BSA per SD	6.7 (4.5, 8.9)	<0.001	2.4 (0.7, 4.1)	0.01
Age per SD	-8.6 (-10.6, -6.6)	<0.001	-2.2 (-4.2, -0.2)	0.02
Male gender	0.17 (-4.7, 5.1)	0.94	-1.1 (-4.2, 2.1)	0.50
White race	-11.5 (-21.7, -1.3)	0.03	-5.6 (-11.9, 0.8)	0.08
BMI per SD	-3.3 (-5.7, -0.90)	0.007	-0.9 (-2.3, 0.8)	0.30

BMI, body mass index; eGFR, estimated glomerular filtration rate; RKV/BSA, remaining kidney volume divided by body surface area; SD, standard deviation.

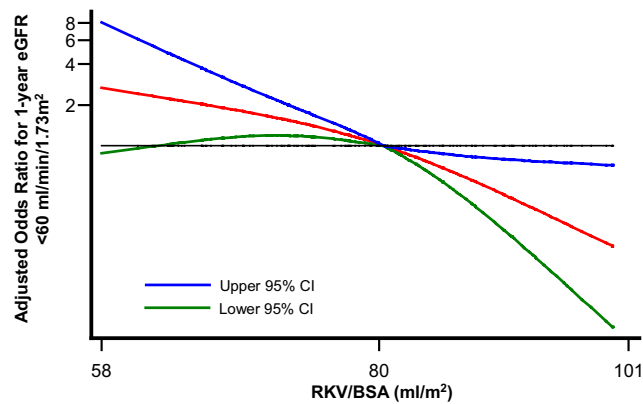


FIGURE 4 Spline plot for the adjusted odds of eGFR <60 mL/min/1.73 m² at 1 year by RKV/BSA. Variables for adjustment were age, sex, race, and body mass index. CI, confidence interval; eGFR, estimated glomerular filtration rate; RKV/BSA, remaining kidney volume divided by body surface area

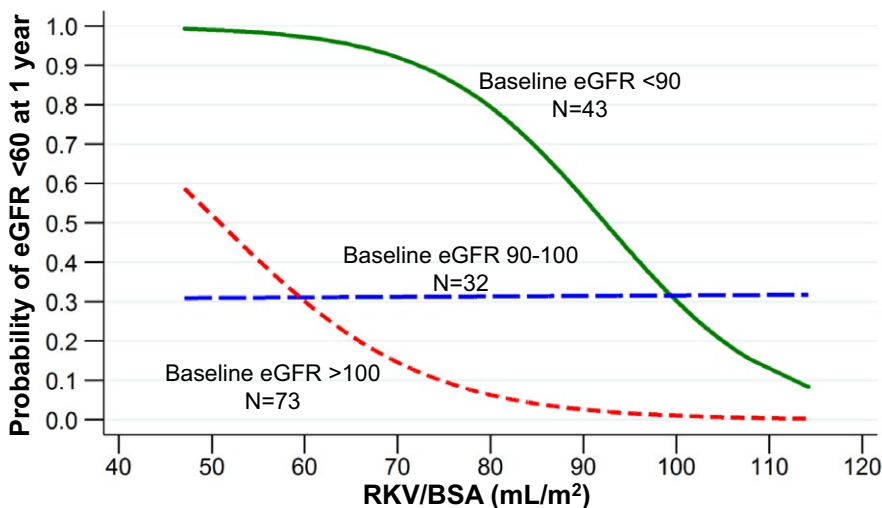


TABLE 2 Linear regression for baseline donor factors on continuous 1-y eGFR

receiver-operating characteristic curve of 0.80.¹² Most recently, Lange et al¹³ used contrast-enhanced magnetic resonance imaging (MRI) to measure pre-donation kidney volumes compared with split renal function as assessed by ^{99m}Tc-labelled mercapto-acetyl-triglycin (MAG3) scintigraphy in a German cohort of 100 living kidney donors. The investigators noted that MRI-measured remaining kidney volume independently correlated with Cockcroft-Gault-estimated GFR over 3 years of post-donation follow-up better than MAG3 scintigraphy-assessed remaining split renal function.

The current study has obvious limitations. Though we controlled for important demographic factors and baseline eGFR, the retrospective, observational nature of the study design makes residual confounding possible. This cohort consisted predominantly of young, very healthy donors with normal BMIs and may not be generalizable to much older or obese donors. As is the case in many transplant centers in the United States, long-term follow-up for living kidney donors is not available. In 2005, the OPTN began re-

to achieve eGFR values of 60 mL/min/1.73 m² or more, but the researchers did not report associations for remaining kidney volume nor did they adjust for baseline eGFR or other donor factors. In a French cohort of 105 donors, Gardan et al found that the unadjusted cortical volume of the remaining kidney predicted measured GFR <60 mL/min/1.73 m² at 1 year with an area under the

questing submission of living-donor follow-up forms at 6, 12, and 24 months post-donation. Since February 2013, however, the OPTN began mandating minimum thresholds for the proportion of donors with complete information at each follow-up time point. The current cohort was assembled without losses to follow-up at 1 year,

but more than half did not return at 2 years. Similarly, follow-up data on proteinuria were available in less than half of the cohort. Importantly, nearly all available urine albumin/creatinine ratios at 1 year were <30 mg/g, except for two donors with values of 35 and 38 mg/g, respectively.

An additional study limitation is the lack of measured GFRs before and after donation. The most recent international guideline on living kidney donor evaluation and care recommends using serum creatinine-based estimating equations and then to “confirm” GFR via direct measurement techniques, creatinine clearance, combined serum creatinine-cystatin C equations, or simply repeating serum creatinine-based GFR estimation.²⁵ We used the CKD-EPI equation, which may underestimate measured GFR but has been shown to be more accurate than the MDRD equation in living kidney donors.²⁶ In an earlier study that included much higher proportions of racial and ethnic minorities than our cohort, however, MDRD was found to perform better than CKD-EPI.²⁷ Apart from creatinine-based GFR estimations, an interesting study from Korea showed that kidney volume-based GFR estimation by CT may prove to be accurate enough to replace creatinine-based eGFR or even measured GFR for assessing kidney function in donor candidates.²⁸ Lastly, studies have shown potential prognostic benefit for donors when implantation kidney biopsies are performed at the time of transplantation,^{29,30} but this has not been the practice at our transplant center.

In conclusion, our findings add to the growing body of literature on living-donor kidney volume by describing the independent strength of association between remaining kidney volume and 1-year eGFR utilizing standard deviations for comparisons. The decision to remove one kidney over the other often involves multiple and complicated anatomical and surgical considerations. Given these potential complexities in light of the current findings, we believe adequate and open discussion to plan donor nephrectomy laterality should be part of the comprehensive interdisciplinary donor selection meetings. With mounting evidence about the importance of remaining kidney volume, additional and larger studies are warranted to evaluate different methods of measurement in donor candidates along with their predictive utility based on long-term follow-up. Just as importantly, however, we believe future studies should evaluate the potential need for disclosing information about kidney volume during the donor evaluation and informed consent process.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTION

Isaac E. Hall (MD, MS): Dr Hall participated in interpreting results and drafted the manuscript; Akram Shaaban (MBBCH): Dr Shaaban participated in the performance of the research by reading the computed tomography scans and volume-rendered images, interpreting results and helping with manuscript revisions; Guo Wei (MS): Mr Wei participated by performing the statistical analyses and helping with manuscript revisions; Magdalena B. Sikora (MD): Dr Sikora participated by performing chart reviews, interpreting results and helping with manuscript revisions; Hassan Bourija: Mr Bourija participated by obtaining the computed tomography scans, compiling the volume-rendered images and helping with manuscript revisions; Srinivasan Beddhu (MD): Dr Beddhu participated in study design, provided important planning and feedback about statistical analyses, helped interpret results, and helped with manuscript revisions; Fuad Shihab (MD): Dr Shihab conceived of the study, participated in its design, interpreted the results and helped write the manuscript.

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REFERENCES

- Gill JS, Lan J, Dong J, et al. The survival benefit of kidney transplantation in obese patients. *Am J Transplant.* 2013;13(8):2083-2090.
- Massie AB, Luo X, Chow EK, Alejo JL, Desai NM, Segev DL. Survival benefit of primary deceased donor transplantation with high-KDPI kidneys. *Am J Transplant.* 2014;14(10):2310-2316.
- Barnieh L, Manns BJ, Klarenbach S, McLaughlin K, Yilmaz S, Hemmelgarn BR. A description of the costs of living and standard criteria deceased donor kidney transplantation. *Am J Transplant.* 2011;11(3):478-488.
- Jarl J, Desatnik P, Peetz Hansson U, Prutz KG, Gerdtham UG. Do kidney transplantations save money? A study using a before-after design and multiple register-based data from Sweden. *Clin Kidney J.* 2018;11(2):283-288.
- Hart A, Smith JM, Skeans MA, et al. OPTN/SRTR 2016 annual data report: kidney. *Am J Transplant.* 2018;18(suppl 1):18-113.
- Mjoen G, Hallan S, Hartmann A, et al. Long-term risks for kidney donors. *Kidney Int.* 2014;86(1):162-167.
- Muzaale AD, Massie AB, Wang MC, et al. Risk of end-stage renal disease following live kidney donation. *JAMA.* 2014;311(6):579-586.
- Massie AB, Muzaale AD, Luo X, et al. Quantifying postdonation risk of ESRD in living kidney donors. *J Am Soc Nephrol.* 2017;28(9):2749-2755.
- Jeon HG, Lee SR, Joo DJ, et al. Predictors of kidney volume change and delayed kidney function recovery after donor nephrectomy. *J Urol.* 2010;184(3):1057-1063.
- Taner T, Iqbal CW, Textor SC, Stegall MD, Ishitani MB. Compensatory hypertrophy of the remaining kidney in medically complex living kidney donors over the long term. *Transplantation.* 2015;99(3):555-559.

11. Narasimhamurthy M, Smith LM, Machan JT, et al. Does size matter? Kidney transplant donor size determines kidney function among living donors. *Clin Kidney J.* 2017;10(1):116-123.
12. Gardan E, Jacquemont L, Perret C, et al. Renal cortical volume: high correlation with pre- and post-operative renal function in living kidney donors. *Eur J Radiol.* 2018;99:118-123.
13. Lange D, Helck A, Rominger A, et al. Renal volume assessed by magnetic resonance imaging volumetry correlates with renal function in living kidney donors pre- and postdonation: a retrospective cohort study. *Transpl Int.* 2018;31:773-780.
14. Grams ME, Sang Y, Levey AS, et al. Kidney-failure risk projection for the living kidney-donor candidate. *N Engl J Med.* 2016;374(5):411-421.
15. Gaillard F, Courbebaisse M, Kamar N, et al. The age-calibrated measured glomerular filtration rate improves living kidney donation selection process. *Kidney Int.* 2018;94(3):616-624.
16. Sikora MB, Shaaban A, Beddhu S, et al. Effect of donor kidney volume on recipient outcome: does the "dose" matter? *Transplantation.* 2012;94(11):1124-1130.
17. Tan JC, Paik J, Chertow GM, et al. Validity of surrogate measures for functional nephron mass. *Transplantation.* 2011;92(12):1335-1341.
18. World Medical Association. WMA Declaration of Helsinki – Ethical Principles for Medical Research Involving Human Subjects. <http://www.wma.net/en/30publications/10policies/b3/>. Accessed September 10, 2013.
19. The declaration of Istanbul on organ trafficking and transplant tourism. Istanbul Summit April 30-May 2, 2008. *Nephrol Dial Transplant.* 2008;23(11):3375-3380.
20. Levey AS, Stevens LA, Schmid CH, et al. A new equation to estimate glomerular filtration rate. *Ann Intern Med.* 2009;150(9):604-612.
21. Mosteller RD. Simplified calculation of body-surface area. *N Engl J Med.* 1987;317(17):1098.
22. Poggio ED, Hila S, Stephany B, et al. Donor kidney volume and outcomes following live donor kidney transplantation. *Am J Transplant.* 2006;6(3):616-624.
23. Poggio ED, Rule AD. A critical evaluation of chronic kidney disease – should isolated reduced estimated glomerular filtration rate be considered a 'disease'? *Nephrol Dial Transplant.* 2009;24(3):698-700.
24. Srinivas TR, Poggio ED. Do living kidney donors have CKD? *Adv Chronic Kidney Dis.* 2012;19(4):229-236.
25. Lentine KL, Kasiske BL, Levey AS, et al. Summary of Kidney Disease: Improving Global Outcomes (KDIGO) clinical practice guideline on the evaluation and care of living kidney donors. *Transplantation.* 2017;101(8):1783-1792.
26. Burballa C, Crespo M, Redondo-Pachon D, et al. MDRD or CKD-EPI for glomerular filtration rate estimation in living kidney donors. *Nefrologia.* 2018;38(2):207-212.
27. Bhuvanakrishna T, Blake GM, Hilton R, Burnapp L, Sibley-Allen C, Goldsmith D. Comparison of estimated GFR and measured GFR in prospective living kidney donors. *Int Urol Nephrol.* 2015;47(1):201-208.
28. Choi DK, Choi SM, Park BH, et al. Measurement of renal function in a kidney donor: a comparison of creatinine-based and volume-based GFRs. *Eur Radiol.* 2015;25(11):3143-3150.
29. Denic A, Alexander MP, Kaushik V, et al. Detection and clinical patterns of nephron hypertrophy and nephrosclerosis among apparently healthy adults. *Am J Kidney Dis.* 2016;68(1):58-67.
30. Saito T, Uchida K, Ishida H, Tanabe K, Nitta K. Changes in glomerular filtration rate after donation in living kidney donors: a single-center cohort study. *Int Urol Nephrol.* 2015;47(2):397-403.

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