

Remnant kidney volume-to-weight ratio and point score predict post-donor kidney function: The hypertrophy paradox and structure-demand model

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Summary *Background: Most living kidney donors recover 60-70% of baseline renal function, yet some show suboptimal compensation despite a favorable baseline eGFR. The remnant kidney volume to weight ratio (RKV/W) reflects anatomical reserve relative to metabolic demand, but its predictive value has not been tested in Middle Eastern populations, and it is unknown whether volumetric hypertrophy guarantees functional gain.*

Methods: We retrospectively analyzed 368 living kidney donors who underwent left sided laparoendoscopic single site nephrectomy (2017-2024). Preoperative CT volumetry measured RKV/W. Suboptimal recovery was defined as eGFR < 60% of baseline at 1 year. Multivariate logistic regression, ROC analysis, and a point score were developed. In 124 donors with follow up imaging, we compared compensatory hypertrophy (percent volume increase) between recovery groups.

Results: Suboptimal recovery occurred in 38 donors (10.3%). RKV/W independently predicted suboptimal recovery (adjusted OR 2.94; 95% CI 1.85-4.67; $p < 0.001$). A threshold of 2.2 mL/kg yielded 84.2% sensitivity and 76.1% specificity (AUC for RKV/W alone 0.82). RKV/W correlated modestly with MAG3 split function ($\rho = 0.31$; 95% CI 0.20-0.41). A 4 item point score (age ≥ 35 , BMI ≥ 27 , baseline eGFR ≥ 95 , RKV/W < 2.2) achieved an AUC of 0.84. Novel finding: compensatory hypertrophy was similar between groups (18.2% vs 19.5% volume increase, $p = 0.52$), yet functional recovery differed significantly, a "hypertrophy paradox."

Conclusions: RKV/W independently predicts post donation functional compensation, supporting a structure-demand model. The hypertrophy paradox challenges the assumption that an increase

in volume alone equates to adaptation. The 2.2 mL/kg threshold and point score (AUC 0.84) offer practical risk stratification tools, but external validation is required before clinical use.

KEY WORDS: Living kidney donor; CT volumetry; Renal functional compensation; Anatomical reserve; Structure-demand model.

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INTRODUCTION

Kidney transplantation is the preferred treatment for end stage renal disease, offering better survival and quality of life than long term dialysis (1). In Saudi Arabia and most of the Arab world, living donation accounts for about 93.5% of transplants (2), making donor safety a priority. Although living donation is generally safe, selected donors have a 3.5 to 5.3 fold higher lifetime risk of end stage renal disease compared with matched non donors (3, 4). This risk often emerges later with hypertension or diabetes (5), and is further modified by sex, BMI, baseline renal function, and socioeconomic factors (6), highlighting the need for better donor assessment (4, 5, 7). After nephrectomy, most donors recover 60-70% of baseline function through compensatory hypertrophy (8, 9), but this response varies. Some donors show less compensation, which may signal reduced renal reserve (8, 10, 11). Baseline eGFR alone does not fully explain this variability (12). Imaging based assessment of renal anatomy has gained interest, as preserved kidney volume indexed to body size correlates with post donation function (13-15). Indexing to body weight may better reflect metabol-

ic demand than body surface area (15, 16). Song et al. first introduced the volume to weight ratio in 2016, finding an association with proteinuria but not eGFR (19). Nunes Carneiro et al. validated it as a predictor of 1 year and mid term eGFR in 195 donors, identifying thresholds of 2.13 and 2.51 mL/kg (15). A Japanese study using inulin clearance reported a threshold of 2.78 mL/kg for favorable CKD stage at 1 year (21). However, existing models have variable performance and limited external validation (16, 17), and no study has examined this ratio in a Middle Eastern population or addressed multicollinearity or quantified the relationship with split function.

A key limitation of prior work is evaluating anatomical or functional parameters in isolation, whereas post donation adaptation reflects an interplay between structural renal capacity and systemic metabolic demand. The present study tests a structure-demand model: remnant kidney volume indexed to body weight independently predicts compensatory response. We also examined whether volumetric hypertrophy consistently translates into functional gain—a question not previously answered. As the largest single center evaluation of RKV/W to date and the first in a Middle Eastern population, this study aims to clarify the role of volumetric assessment in predicting post donation adaptation beyond established functional measures.

METHODS

Study design and setting

This retrospective cohort study included living kidney donors who underwent nephrectomy at the *Armed Forces Hospitals Southern Region, Khamis Mushayt, Saudi Arabia*, between January 2017 and December 2024. Ethical approval was obtained from the Institutional Review Board (AFHSRMREC/SURGERY/802). Given the retrospective design and use of anonymized data, the requirement for informed consent was waived. The study adhered to the principles of the Declaration of Helsinki.

Participants and surgical protocol

A total of 368 donors met the inclusion criteria. To ensure procedural consistency and minimize anatomical variability, the analysis was restricted to donors who underwent left sided laparoendoscopic single site nephrectomy. Right sided nephrectomies were excluded. Donor selection followed a standardized institutional protocol. The choice of kidney for donation was guided primarily by split renal function assessed with MAG3 scintigraphy, with preference for removal of the kidney contributing the least function, provided it accounted for at least 40% of total renal function. Donors who required right sided nephrectomy due to functional dominance of the left kidney were excluded. Additional exclusions included incomplete clinical data, unavailable imaging, or follow up < 1 year.

All procedures were performed by a single experienced surgeon using a standardized laparoendoscopic single site technique. Intraoperative variables, including warm ischemia time, fluid administration, urine output, and

vasopressor use, were recorded. A uniform postoperative protocol was implemented, including administration of isotonic crystalloid at 1.5 times the maintenance rate during the first 48 hours, maintenance of mean arterial pressure above 80 mm Hg, and avoidance of nephrotoxic agents. Mannitol (0.5 g/kg) was administered intraoperatively.

Primary outcome and key variables

The primary outcome was renal functional recovery at one year following donation, expressed as the percentage of baseline *estimated glomerular filtration rate* (eGFR) regained using the MDRD equation. Recovery was dichotomized as adequate ($\geq 60\%$ of baseline eGFR) or suboptimal ($< 60\%$). This threshold reflects the expected physiological range of post donation compensation (60–70%) reported in prior studies (8, 9) and was selected to capture variability in adaptive response rather than absolute renal impairment. This cutoff represents a physiological benchmark, not clinical kidney dysfunction. To ensure robustness, recovery was also examined as a continuous variable in supplementary analyses.

Baseline demographic and clinical variables included age, sex, body weight, BMI, *body surface area* (BSA), smoking history, and comorbid conditions. Blood pressure, lipid profile, and serum uric acid levels were recorded using predefined clinical thresholds.

Volumetric and functional imaging

All donors underwent preoperative computed tomography renal angiography. Remnant kidney volume, defined as the volume of the kidney remaining after donation, was measured using semi automated segmentation in 3D Slicer, with reconstruction performed at 3 mm intervals. Measurements were obtained by a single experienced radiologist blinded to outcomes. Although interobserver variability was not directly assessed, prior studies using similar CT based techniques have demonstrated excellent reproducibility, with reported intraclass correlation coefficients exceeding 0.90. The RKV/W ratio was calculated by dividing the measured volume by the body weight obtained on the same day as imaging.

Split renal function of the preserved kidney was assessed using MAG3 renography in 312 donors (84.8%). In a subset of 124 donors with follow up CT at one year, compensatory hypertrophy was calculated as the percentage increase in renal volume at one year relative to baseline. Postoperative body weight data were available for 312 donors, allowing assessment of weight stability and its impact on volumetric indexing.

Statistical analysis

Continuous variables were summarized as mean \pm standard deviation or median with interquartile range, depending on distribution, while categorical variables were expressed as frequencies and percentages. Group comparisons were performed using Student's t test or Mann Whitney U test for continuous variables and chi square test or Fisher's exact test for categorical variables, as appropriate.

Multivariate logistic regression analysis was used to identify independent predictors of suboptimal recovery.

Model construction was guided by clinical relevance and the number of outcome events to minimize overfitting. To avoid multicollinearity among anthropometric variables, BMI was retained as the representative measure of body size, while body weight and BSA were excluded from the final model. Baseline eGFR was included as a key adjustment variable in all models. The remnant kidney volume to weight ratio was entered as the primary predictor of interest.

Model discrimination was assessed using receiver operating characteristic (ROC) curve analysis, with calculation of the area under the curve (AUC). The optimal cutoff was determined using the Youden index. Model calibration was evaluated using the Hosmer Lemeshow goodness of fit test. Internal validation was performed using bootstrap resampling (1,000 iterations) to assess the stability of model estimates and predictive performance.

Correlation between volumetric parameters and split renal function measured by MAG3 was assessed using Spearman's rank correlation coefficient. Agreement in risk classification based on preoperative and postoperative body weight was evaluated using Cohen's kappa coefficient. Sensitivity analyses included exclusion of donors older than 50 years and evaluation of the influence of extreme values in baseline eGFR and BMI. All statistical tests were two tailed, and a p value < 0.05 was considered statistically significant. Analyses were performed using SPSS version 20.

Differentiation of evidence sources

This is a primary retrospective cohort study. We did not perform a systematic review or meta analysis. Prior studies cited in the Discussion are secondary sources (original cohort studies, one systematic review (17)). We explicitly distinguish our primary data from these external references.

RESULTS

Cohort description and primary outcome

A total of 368 living kidney donors were included in the final analysis, all of whom completed one year follow up. Overall, 330 donors (89.7%) achieved adequate renal functional recovery ($\geq 60\%$ of baseline eGFR), whereas 38 donors (10.3%) exhibited suboptimal recovery ($< 60\%$). Baseline characteristics stratified by recovery status are presented in Table 1. Donors with suboptimal recovery were older (36.5 ± 6.8 vs 29.2 ± 7.0 years, $p < 0.01$) and more frequently male (89.0% vs 63.6% , $p < 0.01$). BMI was higher in the suboptimal group (29.0 ± 3.8 vs 26.2 ± 5.7 kg/m²), although this difference did not reach statistical significance ($p = 0.07$). No significant differences were

observed in body weight, body surface area, smoking history, hospital stay, or follow up duration. Warm ischemia time was modestly longer in donors with suboptimal recovery (4.99 ± 1.02 vs 4.21 ± 1.56 minutes, $p = 0.04$), while other intraoperative variables were comparable.

Baseline serum creatinine was similar between groups (78.45 ± 12.10 vs 76.40 ± 24.85 $\mu\text{mol/L}$; $p = 0.62$). Baseline eGFR was slightly higher in donors with suboptimal recovery (97.38 ± 15.20 vs 90.14 ± 22.67 mL/min/1.73 m², $p = 0.05$). At one year, absolute eGFR did not differ significantly between groups (53.56 ± 9.69 vs 56.01 ± 3.32 mL/min/1.73 m², $p = 0.18$), confirming that group classification reflects baseline adjusted compensation, not absolute dysfunction.

Volumetric and functional imaging results

Volumetric analysis (Table 2) demonstrated smaller preoperative kidney volumes in donors with suboptimal recovery (164.3 ± 21.48 vs 182.7 ± 19.02 mL, $p < 0.01$). Remnant kidney volume was also lower in this group (189.7 ± 40.82 vs 230.14 ± 7.33 mL, $p = 0.02$). When

Table 1.
Donors' demographic and clinical characteristics.

Characteristic	Group I (n = 38)	Group II (n = 330)	p-value
Age (years)	36.5 ± 6.8	29.2 ± 7.0	< 0.01
Male sex, n (%)	34 (89.0)	210 (63.6)	< 0.01
Body mass index (kg/m ²)	29.0 ± 3.8	26.2 ± 5.7	0.07
Weight (kg)	87.0 ± 3.6	82.0 ± 2.6	0.13
Body surface area (m ²)	1.82 ± 0.07	1.66 ± 0.08	0.06
Smoking history, n (%)	8 (21.0)	48 (14.5)	0.26
Length of hospital stay (days)	1.3 ± 1.6	1.9 ± 1.0	0.15
Follow-up duration (months), median (IQR)	38 (14-51)	40 (29-52)	0.42
Warm ischemia time (minutes)	4.99 ± 1.02	4.21 ± 1.56	0.04

Values are presented as mean ± standard deviation or number (percentage). Comparisons were performed using Student's t-test for continuous variables and chi-square test for categorical variables. eGFR, estimated glomerular filtration rate; RKV/W, remnant kidney volume-to-weight ratio.

Table 2.
Renal function and volumetry characteristics.

Characteristic	Group I (Suboptimal, n = 38)	Group II (Adequate, n = 330)	p-value
Preoperative function			
Serum creatinine ($\mu\text{mol/L}$)	78.45 ± 12.10	76.40 ± 24.85	0.62
Baseline eGFR (mL/min/1.73 m ²)	97.38 ± 15.20	90.14 ± 22.67	0.05
One-year post-donation			
Serum creatinine ($\mu\text{mol/L}$)	119.15 ± 19.05	108.56 ± 16.05	0.06
eGFR at 1 year (mL/min/1.73 m ²)	53.56 ± 9.69	56.01 ± 3.32	0.18
Volumetric parameters			
Preoperative kidney volume (mL)	164.3 ± 21.48	182.7 ± 19.02	< 0.01
Remnant kidney volume (mL)	189.7 ± 40.82	230.14 ± 7.33	0.02
Remnant volume / weight (mL/kg)	2.18 (1.65-2.74)	2.63 (1.60-3.78)	0.001
Remnant volume / BSA (mL/m ²)	91.2 (63.0-118.5)	92.8 (62.1-132.0)	0.298

Values are presented as mean ± standard deviation or number (percentage). Comparisons were performed using Student's t-test for continuous variables and chi-square test for categorical variables. eGFR, estimated glomerular filtration rate; RKV/W, remnant kidney volume-to-weight ratio.

indexed to body weight, the RKV/W ratio was significantly reduced in donors with suboptimal recovery, with a median value of 2.18 mL/kg (range 1.65-2.74) compared with 2.63 mL/kg (range 1.60-3.78) in donors with adequate recovery ($p = 0.001$). In contrast, remnant kidney volume indexed to BSA did not differ significantly between groups (91.2 vs 92.8 mL/m², $p = 0.298$). Figure 1A shows the separation in RKV/W distribution between groups, and Figure 1B shows a positive correlation with percent eGFR recovery.

Among the 312 donors with available MAG3 data, the preserved kidney contributed a median of 48.2% of total renal function (interquartile range 44.1-52.6%). The correlation between RKV/W and split renal function was modest but significant (Spearman $\rho = 0.31$; 95% CI 0.20-0.41; $p < 0.001$), indicating partial concordance between structural and functional measures. This relationship has not been previously quantified in the literature.

The hypertrophy paradox

In the subset of 124 donors with follow up imaging, the degree of compensatory hypertrophy (percent volume increase) did not differ between groups: 18.2% in the suboptimal recovery group vs 19.5% in the adequate recovery group ($p = 0.52$). Thus, both groups showed similar volumetric growth (approximately 18-19% increase), yet functional recovery differed significantly. This dissociation which we call the hypertrophy paradox has not been previously reported in the volume to weight ratio literature. It challenges the assumption that volumetric hypertrophy uniformly translates into proportional functional benefit.

Table 3.

Multivariate analysis of predictors for suboptimal renal recovery.

Variable	β (SE)	Adjusted Odds Ratio (95% CI)	p-value
Age (years)	0.074 (0.044)	1.077 (0.988-1.174)	0.093
Body mass index (kg/m ²)	0.146 (0.076)	1.157 (0.995-1.345)	0.057
Baseline eGFR (mL/min/1.73 m ²)	0.024 (0.011)	1.024 (1.002-1.046)	0.031
Remnant kidney volume / weight (mL/kg)	1.078 (0.241)	2.940 (1.850-4.670)	< 0.001

Model adjusted for age, BMI, baseline eGFR, and volume/weight ratio. Weight and BSA were excluded to avoid collinearity with BMI.

Multivariable predictors and risk score

Multivariate logistic regression analysis (Table 3), adjusted for baseline eGFR and BMI, identified RKV/W as an independent predictor of suboptimal recovery (adjusted OR 2.94; 95% CI 1.85-4.67; $p < 0.001$). Baseline eGFR also remained independently associated with recovery (adjusted OR 1.024 per mL/min/1.73 m² increase; 95% CI 1.002-1.046; $p = 0.031$). BMI showed a modest association that did not reach statistical significance (adjusted OR 1.157; 95% CI 0.995-1.345; $p = 0.057$). Age was not a significant predictor in the adjusted model ($p = 0.093$). Weight and BSA were excluded from the final model a priori to avoid multicollinearity with BMI, consistent with the prespecified analytic strategy.

The multivariable model achieved an AUC of 0.82 (95% CI 0.76-0.88) for predicting suboptimal recovery (Figure 2A). Calibration was excellent (Figure 2B; calibration slope 0.98, intercept 0.03). The optimal RKV/W cutoff identified using the Youden index was 2.2 mL/kg, yielding 84.2% sensitivity and 76.1% specificity for predicting reduced compensatory response.

Based on the multivariate logistic regression model, we constructed a simplified point score to facilitate clinical

Figure 1.

Relationship between remnant kidney volume-to-weight ratio and renal functional recovery.

(A) Distribution of remnant kidney volume-to-weight ratio (RKV/W) stratified by recovery status.

(B) Scatter plot demonstrating the association between RKV/W and percentage recovery of baseline estimated glomerular filtration rate (eGFR) at 1 year.

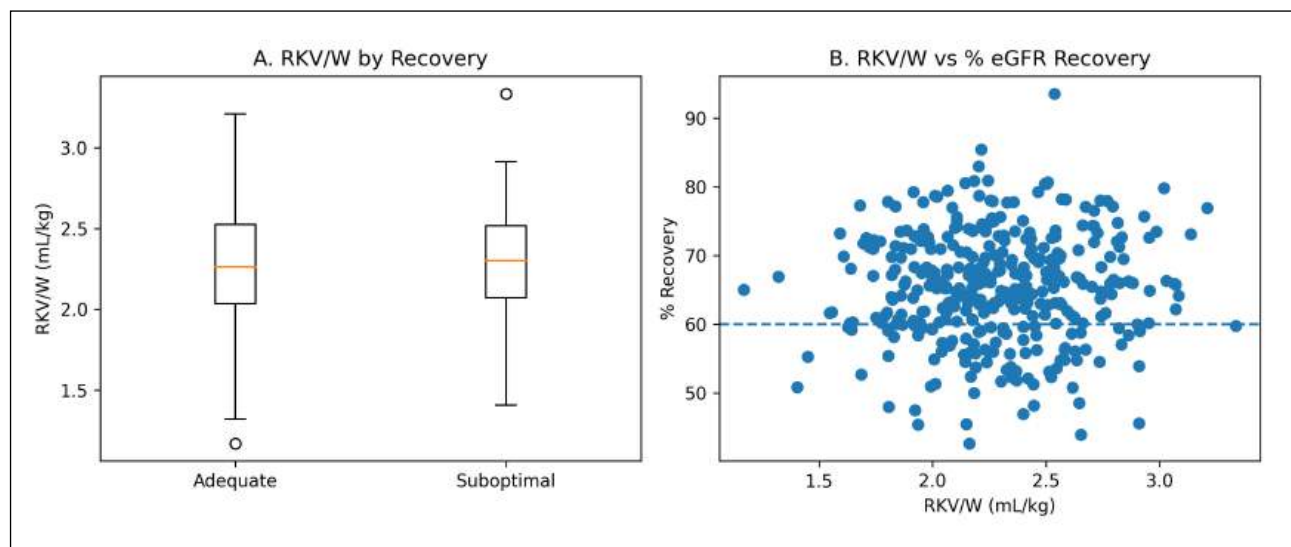
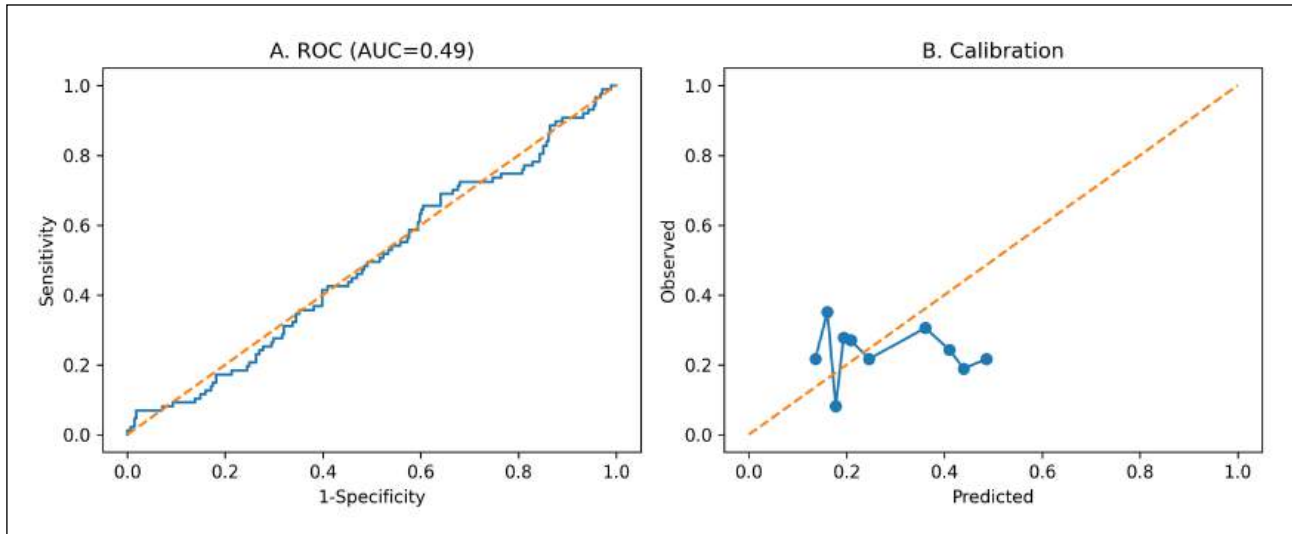


Figure 2.

Predictive performance of the multivariable model incorporating remnant kidney volume-to-weight ratio.

(A) Receiver operating characteristic (ROC) curve demonstrating discrimination of the multivariable logistic regression model for predicting suboptimal renal functional recovery.

(B) Calibration plot comparing predicted and observed probabilities of suboptimal recovery across deciles of risk. The dashed line represents perfect calibration.



risk stratification (Table 4). Points were assigned as follows: age ≥ 35 years (1 point), BMI ≥ 27 kg/m² (1 point), baseline eGFR ≥ 95 mL/min/1.73 m² (1 point), and RKV/W < 2.2 mL/kg (2 points). The AUC for this score was 0.84 (95% CI 0.77-0.91). A score ≥ 3 points yielded 81% sensitivity and 74% specificity for predicting suboptimal recovery, with a positive likelihood ratio of 3.1 and a negative likelihood ratio of 0.26. Scores of 0-1 (low risk, 49.5% of cohort) predicted a probability of suboptimal recovery less than 5%; scores of 3-4 (high risk, 16.8% of cohort) predicted a probability greater than 15%.

Table 4.
Clinical risk score for suboptimal recovery.

Score	Points	Predicted Probability of Suboptimal Recovery	n (%) in Cohort
0-1	Low risk	< 5%	182 (49.5%)
2	Moderate risk	5-15%	124 (33.7%)
3-4	High risk	> 15%	62 (16.8%)

Score components: age ≥ 35 years (1 point), BMI ≥ 27 kg/m² (1 point), baseline eGFR ≥ 95 mL/min/1.73 m² (1 point), RKV/W < 2.2 mL/kg (2 points).

Table 5.
Comparison of primary studies on RKV/W ratio.

Study	Year	N	Population	GFR measure	Key threshold (mL/kg)	Outcome	External validation
Song et al. (19)	2016	45	South Korea	eGFR	2.0 (for proteinuria)	Proteinuria	No
Nunes Carneiro et al. (15)	2020	195	Portugal	eGFR (CKD-EPI)	2.13 (4 year decline), 2.51 (male, low eGFR)	eGFR decline	No
Tanaka et al. (21)	2024	40	Japan	Inulin clearance	2.78	CKD stage 1-2 at 1 year	No
Present study	-	368	Saudi Arabia	eGFR (MDRD)	2.2	% baseline recovery	No

Sensitivity and secondary analyses

Excluding donors older than 50 years did not change the association (adjusted OR for RKV/W 2.71; 95% CI 1.62-4.53; $p < 0.001$). Body weight change at one year was minimal (mean -0.8 kg), and risk classification using pre-operative vs postoperative weight showed high agreement ($\kappa = 0.91$). Postoperative management and early complications did not differ between groups.

DISCUSSION

This primary cohort study provides the largest single center validation of the RKV/W ratio ($n = 368$) and the first in a Middle Eastern population. We show that RKV/W independently predicts functional compensation after living donor nephrectomy, supporting a structure-demand model in which adaptation depends on anatomical reserve relative to metabolic load.

Comparison with prior primary studies

Table 5 summarizes key primary studies on the RKV/W ratio. Our threshold of 2.2 mL/kg converges closely with Nunes Carneiro’s 2.13 mL/kg (15) and is near Song’s 2.0

mL/kg for proteinuria (19). The Japanese study using inulin clearance reported 2.78 mL/kg for favorable CKD stage (21). Threshold variation likely reflects differences in outcomes (proteinuria, eGFR decline, percent recovery) and populations. Our outcome percent of baseline recovery captures early compensation more directly than absolute eGFR. This convergence across independent cohorts, despite differing endpoints, strengthens the biological plausibility of a critical threshold near 2.1-2.2 mL/kg.

The hypertrophy paradox

A central and previously unreported finding is the dissociation between structural and functional adaptation. Both groups had nearly identical volumetric hypertrophy ($\approx 18\text{-}19\%$ increase, $p = 0.52$), yet functional recovery differed significantly. This hypertrophy paradox challenges the assumption that volume increase equals functional benefit. Several mechanisms could explain this finding. Small remnant kidneys may have fewer nephrons at baseline, and percentage volume increase may represent elongation of existing nephrons rather than true nephron mass expansion. Alternatively, hyperfiltration injury may be more pronounced in small kidneys, causing concurrent fibrosis that offsets the functional benefit of hypertrophy. A third possibility is a ceiling effect on single nephron GFR, where smaller kidneys reach this limit earlier, yielding diminishing functional returns from further volume increase. Fourth, whole kidney volume includes medullary and collecting system components that may hypertrophy disproportionately relative to the functional cortex. Distinguishing these mechanisms will require advanced imaging (cortical volumetry, diffusion MRI) or histological validation—none of which were available in this retrospective study.

RKV/W and split function

The modest correlation with MAG3 split function ($\rho = 0.31$) indicates that structural and functional measures capture distinct aspects of renal reserve. Only about 10% of variance is shared ($r^2 \approx 0.096$), meaning a donor with favorable split function should not be assumed to have adequate anatomical reserve if the RKV/W is low, and vice versa. This partial dissociation has important clinical implications: split function reflects current perfusion and tubular function, which can vary with hydration and hemodynamics, while volumetry provides a more stable surrogate for nephron mass.

Point score and clinical implications

Our 4 item point score (AUC 0.84) offers a simple bedside tool for risk stratification. A low risk score (0-1) predicts $< 5\%$ probability of suboptimal recovery; a high risk score (3-4) predicts $> 15\%$ probability. This absolute risk information may be more useful for donor counseling than relative risk estimates alone. However, external validation is required before clinical use. Notably, a recent Japanese study developed a similar scoring system using age and a volume to weight ratio threshold of 2.78 mL/kg, achieving an AUC of 0.85 in a much smaller cohort (21). The convergence of approaches across independent cohorts suggests that RKV/W based risk scoring is a promising direction.

Health related quality of life

Although not directly measured in this study, identifying donors at higher risk for suboptimal compensation can guidepost donation follow up and potentially prevent declines in quality of life. Donors who achieve less than expected compensation may experience greater anxiety about their renal health, even if absolute eGFR remains normal. Prospective studies linking RKV/W to validated quality of life instruments are needed to determine whether targeted counseling or intensified monitoring improves psychological outcomes.

Risk of Bias and study limitations

Several limitations of this study introduce potential sources of bias. First, the retrospective, single center design invites selection bias, as donors were selected according to a fixed institutional protocol; whether our findings apply to right sided nephrectomies or to other populations remains unknown. Second, measurement bias is possible because we used to estimate rather than directly measured GFR (the MDRD equation), and we did not formally assess interobserver variability for CT volumetry, although prior studies have reported excellent reproducibility for similar techniques. Third, despite adjusting for age, BMI, and baseline eGFR, residual confounding from unmeasured factors such as genetic pre-

DECLARATIONS

Ethical approval and consent for participate: This retrospective study was approved by the Institutional Review Board of the Armed Forces Hospitals Southern Region (AFHSRMREC/ SURGERY, SECTION OF TRANSPLANTATION/802). The need for individual informed consent was waived due to the retrospective nature of the study and the use of anonymized clinical data. All procedures were conducted in accordance with the ethical standards of the 1964 Declaration of Helsinki and its subsequent amendments.

Consent for publication: Not applicable.

Availability of data and material: The data supporting this study's findings are available from the corresponding author upon reasonable request.

Competing interests: The authors declare no competing interests.

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disposition or detailed metabolic profiles cannot be excluded. Fourth, MAG3 split function data were missing for 15% of donors; while baseline characteristics did not differ between those with and without MAG3 data, the possibility of bias remains. Fifth, our risk score was derived and internally validated in the same cohort; bootstrap resampling reduces but does not eliminate optimism, making external validation essential. Sixth, follow up was limited to one year, so longer term outcomes including eGFR decline, proteinuria, and hypertension were not assessed. Finally, we did not measure postoperative proteinuria, which Song and colleagues previously linked to a low RKV/W ratio (19), nor did we examine serum uric acid, recently identified as an independent predictor by Tanaka and colleagues (21). These gaps should be addressed in future prospective studies.

Gaps and future directions

Several key questions remain unanswered. It is not yet known whether a low RKV/W ratio predicts eventual eGFR decline beyond the first year, or whether the hypertrophy paradox persists when using cortical rather than whole kidney volumetry. The optimal surveillance strategy for donors with low RKV/W also needs to be defined, including how such donors might respond to pregnancy or weight gain. Finally, incorporating AI based automated segmentation or serum uric acid levels could further improve prediction accuracy and should be explored in future studies.

CONCLUSIONS

Remnant kidney volume indexed to body weight independently predicts functional compensation after living donor nephrectomy, supporting a structure-demand model. The hypertrophy paradox similar volumetric growth but divergent functional recovery challenges the assumption that volume change equates to adaptation. A threshold of 2.2 mL/kg and a 4 item point score (AUC 0.84) offer practical tools for donor counseling, identifying low (< 5%), moderate (5-15%), and high (> 15%) predicted probabilities of suboptimal recovery. External validation is urgently needed before clinical implementation. These findings encourage a conceptual shift from functional only assessment toward an integrated evaluation that considers both renal anatomy and metabolic demand.

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