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# Screening and prognostic roles of renal volumetry and scintigraphy in the assessment of living kidney transplant donors, considering the early recovery of the residual renal function

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## Abstract

**Background** The existing criteria for living kidney donors (LKDs)in Japan are controversial. We evaluated the roles of computed tomography volumetry (CTV) and 99 m Tc-diethylenetriamine penta-acetic acid (DTPA) scintigraphy in assessing preoperative and postoperative renal function and predicting early recovery of residual renal function.

**Methods** We retrospectively reviewed the medical charts of 175 consecutive LKDs who underwent donor nephrectomy (DN) at our institution between 2006 and 2022. Preoperative renal volume was assessed using enhanced CTV, and screening of renal functions was performed using 99 m Tc-DTPA scintigraphy. We evaluated the estimated glomerular filtration rate (eGFR), single-kidney eGFR (skeGFR), and recovery rate three months after DN.

**Results** We included 55 men and 81 women (median age, 59 years; median follow-up period, 73 months). Age > 60 years, hypertension, and total kidney volume/body surface area (TKV/BSA) < 170 mL/m$^2$ independently predicted preoperative eGFR < 80 mL/min/1.73 m$^2$, whereas total measured GFR < 80 mL/min/1.73 m$^2$ independently predicted preoperative eGFR < 70 mL/min/1.73 m$^2$. Regarding postoperative renal function, residual KV/BSA < 85 mL/m$^2$ and ΔskeGFR ≤ 9 mL/min/1.73 m$^2$ independently predicted postoperative eGFR < 60% of preoperative eGFR, and TKV/BSA < 170 mL/m$^2$ independently predicted early recovery of skeGFR.

**Conclusions** CTV may be used as a reliable prognostic screening tool to select LKDs and assess their split renal functions before DN, and renal scintigraphy may help select the optimal LKD.

**Keywords** Computed tomography volumetry, Donor nephrectomy, Early recovery, Living donor kidney transplantation, Residual renal function, Renal scintigraphy

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## Background

In terms of the prognosis of end-stage renal disease (ESRD), living donor kidney transplantation (LDKT) is superior to deceased donor kidney transplantation and maintenance dialysis [1–3]. Therefore, if potential living kidney donors (LKDs) are available, LDKT is recommended for the treatment of ESRD. Although the priority is to ensure safety and minimal harm to LKDs, detailed criteria for LKDs are still debated in Japan. Transplant centers and surgeons are responsible for making decisions by balancing the potential LKD's desire to donate with the future risk of ESRD and associated morbidity.

Japanese guidelines define the following eight factors for a standard LKD: age, infectious diseases, blood pressure, body mass index (BMI), renal function, proteinuria, diabetes mellitus (DM), and malignancy [4]. However, no assessment tools for preoperative renal function or algorithm for determining the side of the selected kidney exist.

Renal scintigraphy and computed tomography volumetry (CTV) have been reported as valuable tools for screening LKDs and determining the side of the procured kidney based on residual renal function (RRF) after donor nephrectomy (DN) [5–10]. Our previous studies demonstrated that although CTV could be a predictive factor for RRF, it could not accurately assess preoperative renal function in some LKDs, whereas 99 m Tc-diethylenetriamine penta-acetic acid (DTPA) scintigraphy was helpful in evaluating those LKDs for whom clinically significant split renal function (SRF) is not accurately reflected in CTV [11, 12]. Therefore, screening tools for renal function are still debated, and combining CTV and renal scintigraphy may enable improved screening of preoperative renal function and prediction of RRF. In addition, patients with early recovery of RRF after DN were reported to have improved long-term renal functions irrespective of preoperative renal function and age [13].

The present study aimed to clarify the roles of CTV and 99 m Tc-DTPA scintigraphy in assessing LKDs before DN and investigate the associations between the objective parameters of these assessments and early recovery of RRF after DN.

## Methods

### Participant selection and data collection

This retrospective study reviewed consecutive LKDs who underwent DN at our institution between January 2006 and December 2022. We retrospectively reviewed the medical charts of these LKDs and obtained their clinical information. The estimated glomerular filtration rate (eGFR), calculated using the Chronic Kidney Disease Epidemiology Collaboration equation [14], was evaluated three and 12 months after DN and analyzed. The study protocol was approved by the Institutional Review Board for Clinical Studies at Nara Medical University (Medical Ethics Committee ID: 3176). The requirement for informed consent was waived owing to the retrospective nature of the study. The study was conducted in compliance with the study protocol and provisions of the Declaration of Helsinki (2013).

### Protocols for computed tomography volumetry and 99 m Tc-diethylenetriamine penta-acetic acid scintigraphy

Enhanced computed tomography (CT) images obtained for preoperative screening and examination of vascular structures were analyzed using the Volume Analyzer SYNAPSE VINCENT image analysis system (Fujifilm Medical, Tokyo, Japan) to quantify renal volume, as described previously [11]. Briefly, all LKDs were evaluated using a 64-slice multi-detector CT scanner (SOMATOM Definition AS, Siemens Medical Solutions, Erlangen, Germany), and triple-phase CT images (plain, arterial phase, and nephrographic phase) were obtained. The images showing abnormal structures, including space-occupying lesions, such as renal cysts, infarctions, aneurysms, or masses, were excluded from the analysis. The measured values were adjusted for body surface area (BSA), which was calculated according to the DuBois-DuBois formula. In addition, 99 m Tc-DTPA scintigraphy was used to assess SRF. All LKDs were examined in the supine position with their backs against a gamma camera (SYMBIAE, Canon Inc., Tokyo, Japan), and 99 m Tc-DTPA was injected intravenously. Scintigraphy can measure bilateral glomerular filtration rate (GFR) (measured GFR [mGFR]) based on the excretion of DTPA from the glomerulus.

### Definition of renal function and its early recovery

We chose eGFR $<80$ and $<70$ mL/min/1.73 $m^2$ as endpoints of preoperative renal function, according to the criteria for standard and marginal LKDs in Japan [4]. RRF was defined as eGFR 12 months after DN. The LKDs were classified into good and poor preservation groups (good preservation group, eGFR $>60\%$ of the preoperative eGFR; poor preservation group, eGFR $\leq 60\%$ of the preoperative eGFR). Furthermore, the single-kidney estimated glomerular filtration rate (skeGFR) was evaluated with reference to previous reports published by van der Weijden et al. [13]., and ΔskeGFR was calculated using the following formula: ΔskeGFR = eGFR three months after DN – (preoperative eGFR/2). Early and non-early recovery of RRF were defined as ΔskeGFR $\geq 9$ and $<9$ mL/min/1.73$m^2$, respectively.

### Outcomes

The primary outcomes were the effects of CTV and scintigraphy parameters on preoperative and postoperative renal functions. As a secondary outcome, the association of CTV and scintigraphy parameters with early recovery of RRF was evaluated.

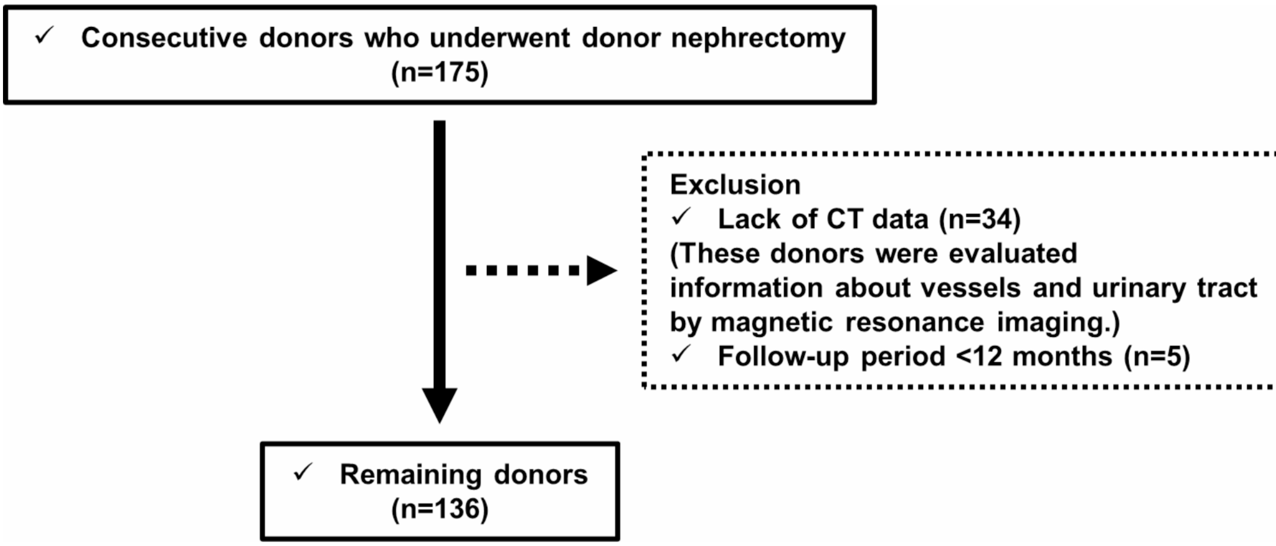


**Fig. 1** Study workflow. Of the 175 consecutive living kidney donors who underwent donor nephrectomy, 39 were excluded from the study because of a lack of data or a follow-up period of less than 12 months. The data of the remaining 136 living donors were evaluated. CT, computed tomography

**Table 1** Patient's clinical information at donor nephrectomy (*n*=136)

| Variables | Median (IQR) or number of patients (%) |
|---|---|
| Age (years) | 59 (50 - 64) |
| Follow-up period (months) | 73 (34 - 110) |
| Sex | |
| Male | 55 (40.4) |
| Female | 81 (59.6) |
| Body mass index (kg/m$^2$) | 23.0 (20.9 - 25.1) |
| Body surface area (m$^2$) | 1.64 (1.50 - 1.74) |
| Systolic blood pressure (mmHg) | 120 (115 - 130) |
| Diastolic blood pressure (mmHg) | 70 (70 - 80) |
| Hypertension | |
| Yes | 28 (20.6) |
| Diabetes mellitus | |
| Yes | 6 (4.4) |
| Dyslipidemia | |
| Yes | 18 (13.2) |
| Smoking | |
| Yes | 41 (30.1) |
| Serum creatinine (mg/mL) | 0.65 (0.58 - 0.8) |
| estimated GFR (ml/min/1.73m$^2$) | 79.0 (69.7 - 88.1) |
| 24 h creatinine clearance | 101.5 (88.2 - 118.0) |
| measured GFR | 90.9 (78.4 - 105.1) |
| Total kidney volume (mL) | 292.8 (262.8 - 339.0) |
| Donated kidney volume (mL) | 147.6 (131.3 - 170.4) |
| Remaining kidney volume (mL) | 144.8 (131.4 - 169.3) |

IQR = interquartile range; GFR = glomerular filtration rate

### Statistical analysis

Continuous variables are reported as median and interquartile range (IQR) values. Categorical variables are reported as numbers and percentages. The Mann–Whitney U test, Fisher's exact test, or chi-square test was used for comparisons between groups, as appropriate. Statistical analyses were performed, and figures were plotted using GraphPad Prism 9.0 (GraphPad Software, San Diego, CA, USA). The interrelationships among the assessed factors were analyzed using Spearman's rank correlation coefficients. Receiver operating characteristic curve analysis was performed to identify the optimal cutoff value of each factor for maximizing the sum of sensitivity and specificity, which was determined as the point closest to the upper left corner. Multivariate logistic regression analysis was performed using the Statistical Package for the Social Sciences (SPSS) version 19 (SPSS Inc., Chicago, IL, USA), and donor factors were evaluated as adjustors with significant differences in univariate analysis. Two-sided tests were used in all cases, and a P-value $< 0.05$ was considered statistically significant in all analyses.

## Results

### Donor characteristics

A total of 175 consecutive LKDs who underwent DN were investigated. Among them, 39 LKDs (22.3%) were excluded from the analysis because of a lack of preoperative CT images ($n = 34$) or a follow-up period of $< 12$ months ($n = 5$). Finally, we evaluated the medical data of 136 LKDs (Fig. 1). Table 1 shows the baseline clinical characteristics of the study cohort. The median age and follow-up period were 59 (IQR, 50–64) years and 73 (IQR, 34–110) months, respectively. The cohort comprised 55 men (40.4%) and 81 women (59.6%). The median BMI and BSA were 23.0 (IQR, 20.9–25.1) kg/m$^2$ and 1.64 (IQR, 1.50–1.74) m$^2$, respectively. Hypertension, DM, and smoking habits were observed in 28 (20.6%), six (4.4%), and 41 (30.1%) LKDs, respectively. Preoperative eGFR and mGFR were 79.0 (IQR, 69.7–88.1) and 90.9 (IQR, 78.4–105.1) mL/min/1.73m$^2$, respectively. Regarding the findings of CTV, total kidney volume (TKV) and residual kidney volume (RKV) were 292.8 (IQR, 262.8–339.0) and 144.8 (IQR, 131.4–169.3) mL, respectively.

#### Predictive factors of preoperative renal function

Multivariate analysis revealed that age > 60 years (odds ratio [OR], 2.94; 95% confidence interval [CI], 1.32–6.52), hypertension (OR, 3.80; 95% CI, 1.35–10.68), and TKV/BSA < 170 mL/m$^2$ (OR, 4.97; 95% CI, 1.98–12.47) were independent predictive factors for preoperative eGFR < 80 mL/min/1.73m$^2$. Although male sex and total mGFR were not associated with preoperative eGFR < 80 mL/min/1.73m$^2$, male sex (OR, 0.22; 95% CI, 0.093–0.54) and total mGFR < 80 mL/min/1.73m$^2$ (OR, 3.52; 95% CI, 1.41–8.80) were independent predictive factors for preoperative eGFR < 70 mL/min/1.73m$^2$ (Table 2).

#### Correlation analyses with age

Lower preoperative eGFR and total mGFR were correlated with older age ($P$ = 0.0004 [Fig. 2a] and $P$ = 0.0053 [Fig. 2b], respectively), whereas no association was found between serum creatinine and age ($P$ = 0.58). TKV/BSA was also not correlated with age ($P$ = 0.10). In men, the lower total mGFR was correlated with older age ($P$ = 0.0036 [Fig. 2c]), whereas TKV/BSA was not correlated with age ($P$ = 0.91). Conversely, in women, the total mGFR showed no correlation with age ($P$ = 0.14), whereas lower TKV/BSA was correlated with older age ($P$ = 0.012 [Fig. 2d]).

#### Predictive factors of residual renal function

Postoperative eGFR < 60% of preoperative eGFR was evaluated as endpoints (Table 3). Multivariate analysis revealed that RKV/BSA < 85 mL/m$^2$ (OR, 2.81; 95% CI, 1.19–6.66) and ΔskeGFR ≤ 9 mL/min/1.73 m$^2$ (OR, 5.43; 95% CI, 2.27–13.01) were independent predictive factors of postoperative eGFR < 60% of preoperative eGFR.

#### Correlation analyses of renal function with computed tomography volumetry and scintigraphy findings

Lower preoperative eGFR was correlated with lower total mGFR and TKV/BSA ($P$ < 0.0001 [Fig. 3a] and $P$ < 0.0001 [Fig. 3b], respectively). A significant association was found between mGFR and the three variables involved in the CTV assessment (TKV/BSA: $P$ < 0.0001 [Fig. 3c], donated KV/BSA: $P$ < 0.0001 [Fig. 3d], and RKV/BSA: $P$ = 0.0024 [Fig. 3e], respectively). Older age was correlated with lower postoperative eGFR (Fig. 3f; $P$ < 0.0001), whereas lower total mGFR, residual mGFR, TKV/BSA, and RKV/BSA were correlated with lower postoperative eGFR ($P$ < 0.0001 [Fig. 3g], $P$ < 0.0001 [Fig. 3h], $P$ < 0.0001 [Fig. 3i], and $P$ < 0.0001 [Fig. 3j], respectively).

#### Predictive factors of early recovery of residual renal function

Predictive factors of early recovery of postoperative skeGFR were evaluated for assessing eGFR 12 months after DN (Table 4). Multivariate analysis was used to evaluate factors that were significantly different in univariate analysis and revealed that TKV/BSA < 170 mL/m$^2$ was an independent predictive factor of early recovery of skeGFR (OR, 2.56; 95% CI, 1.20–5.46).

## Discussion

The present study demonstrated that volume parameters calculated using CTV and mGFR obtained using 99 m Tc-DTPA scintigraphy enabled screening of preoperative renal function in potential LKDs and predicting RRF after DN. In addition, early recovery of RRF was an important factor that predicted RRF. If possible, both CTV and 99 m Tc-DTPA scintigraphy should be performed to assess preoperative renal function in potential LKDs, although radiation exposure should be considered. CTV and 99 m Tc-DTPA scintigraphy can provide valuable information, including preoperative renal function and RRF, to enable transplant surgeons in the personalized selection of LKDs and follow-up frequency after DN.

In most transplant institutes, the criteria for determining optimal LKDs and the side of the procured kidney are controversial, and the accuracy of the decisions by transplant surgeons is critical in determining prognosis after LDKT. Transplant surgeons are required to evaluate current renal functions and predict renal functions after surgery. Traditionally, renal scintigraphy has been used to assess SRF; however, several studies have reported that volume parameters calculated using CTV are as helpful or even better than mGFR obtained using renal scintigraphy in assessing SRF [5–11]. A large-scale study from the United States on healthy adults also showed that CTV reflected renal function, which changes with age and sex, and that albuminuria, smoking history, and decreased high-density lipid cholesterol were strongly associated with increased cortical or medullary volume [15]. Therefore, CTV may currently be sufficient to evaluate renal function in LKDs. However, in the present study, mGFR was helpful in assessing preoperative renal function in especially LKDs with low eGFR preoperatively, whereas the volume parameter RKV/BSA played a significant role in predicting RRF. Therefore, CTV may be recommended as a screening tool for anatomical features and renal functions in all LKDs. However, renal scintigraphy may be recommended for assessing potential LKDs with borderline renal functions, and it may be omitted in LKDs with good renal function to avoid radiation exposure.

In the present study, early recovery of RRF was associated with the prediction of RRF, and RKV/BSA was significantly associated with the recovery rate. According to

**Table 2** Univariate and multivariate analysis for predicting preoperative renal function

| Variables | preoperative eGFR <80 | | | | | | preoperative eGFR <70 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Univariate analysis | | | Multivariate analysis | | | Univariate analysis | | | Multivariate analysis | | |
| | OR | 95%CI | *P* value | OR | 95%CI | *P* value | OR | 95%CI | *P* value | OR | 95%CI | *P* value |
| Age | | | | | | | | | | | | |
| ≤60 | 1 | | | 1 | | | 1 | | | | | |
| >60 | 3.37 | 1.63 - 7.13 | 0.0015 | 2.94 | 1.32 - 6.52 | 0.008 | 1.99 | 0.91 - 4.43 | 0.11 | | | |
| Sex | | | | | | | | | | | | |
| Male | 1 | | | | | | 1 | | | 1 | | |
| Female | 0.51 | 0.26 - 1.00 | 0.079 | | | | 0.31 | 0.14 - 0.69 | 0.0052 | 0.22 | 0.093 - 0.54 | 0.001 |
| BMI | | | | | | | | | | | | |
| ≤25 | 1 | | | | | | 1 | | | | | |
| >25 | 1.96 | 0.89 - 4.49 | 0.12 | | | | 2.00 | 0.85 - 4.41 | 0.12 | | | |
| Hypertension | | | | | | | | | | | | |
| No | 1 | | | 1 | | | 1 | | | | | |
| Yes | 3.23 | 1.31 - 8.11 | 0.018 | 3.80 | 1.35 - 10.68 | 0.011 | 2.15 | 0.90 - 5.23 | 0.096 | | | |
| Diabetes mellitus | | | | | | | | | | | | |
| No | 1 | | | | | | 1 | | | | | |
| Yes | 0.42 | 0.077 - 1.85 | 0.42 | | | | 0.54 | 0.045 - 4.25 | >0.99 | | | |
| Smoking history | | | | | | | | | | | | |
| No | 1 | | | | | | 1 | | | | | |
| Yes | 0.99 | 0.49 - 2.05 | >0.99 | | | | 1.72 | 0.78 - 3.93 | 0.21 | | | |
| Total mGFR | | | | | | | | | | | | |
| ≥80 | 1 | | | 1 | | | 1 | | | | | |
| <80 | 2.49 | 1.17 - 5.64 | 0.024 | 1.82 | 0.74 - 4.45 | 0.19 | 2.26 | 1.03 - 4.82 | 0.054 | 3.52 | 1.41 - 8.80 | 0.007 |
| TKV/BSA | | | | | | | | | | | | |
| ≥170 | 1 | | | 1 | | | 1 | | | | | |
| <170 | 4.43 | 1.93 - 10.50 | 0.0003 | 4.97 | 1.98 - 12.47 | 0.001 | 1.29 | 0.54 - 2.97 | 0.67 | | | |

OR = odds ratio; CI = confidence interval; eGFR = estimated glomerular filtration rate; BMI = body mass index; mGFR = measured glomerular filtration rate; TKV = total kidney volume; BSA = body surface area

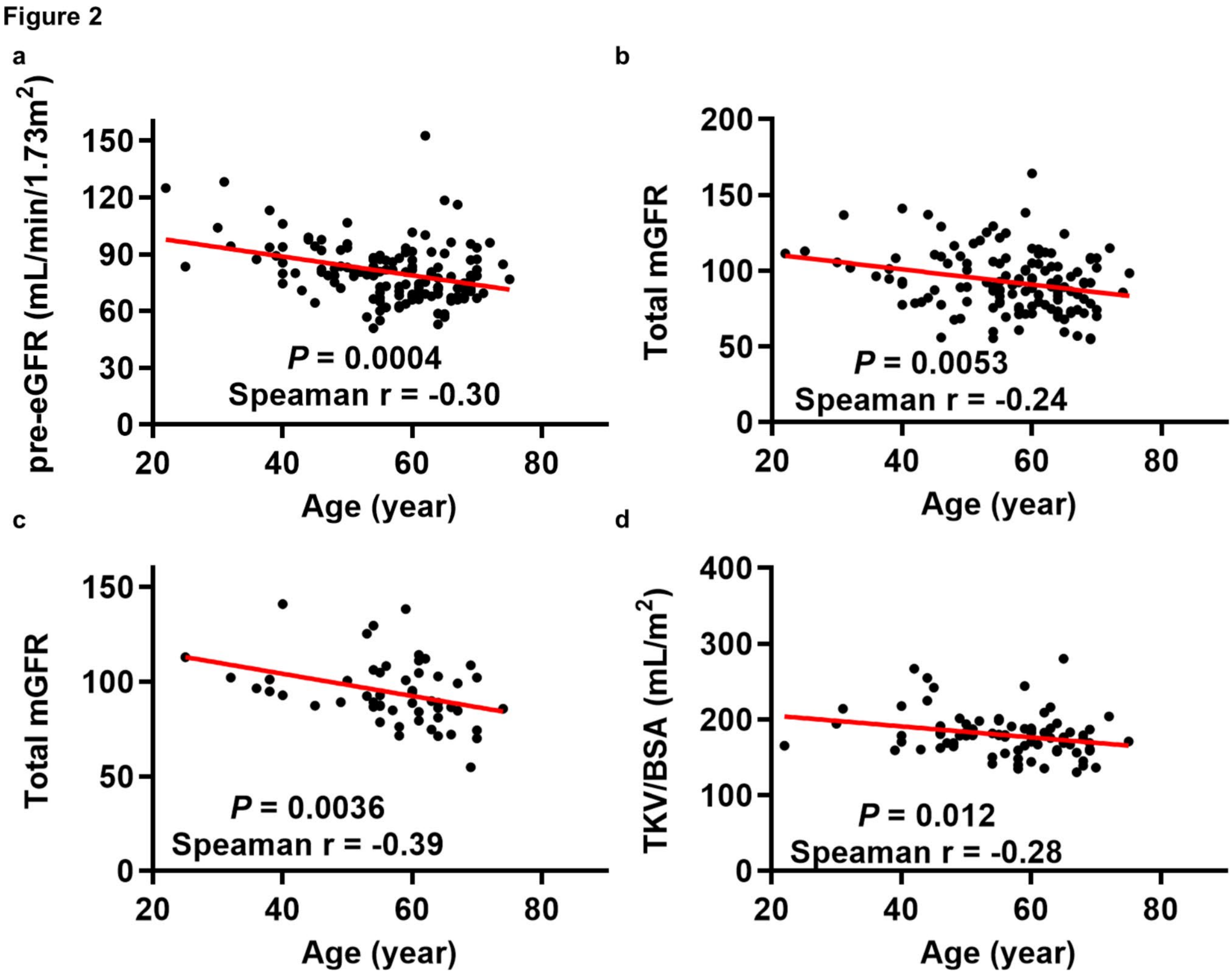


**Fig. 2** Correlations among age and volume parameters and measured glomerular filtration rate. The preoperative estimated glomerular filtration rate (**a**) and measured glomerular filtration rate (mGFR) obtained using scintigraphy (**b**) are correlated with age. In men, mGFR is correlated with age (**c**), whereas total kidney volume/body surface area are correlated with age in women (**d**). mGFR, measured glomerular filtration rate

RKV/BSA, LKDs can be divided into two groups, namely early or non-early recovery groups, and transplant surgeons may be able to intervene in those with non-early recovery of RRF to prompt an increase in the recovery rate via renal rehabilitation, medications, and nutritional management before and after DN. As individualized follow-up after DN, LKDs in the non-early recovery group may need to be followed more carefully and frequently than those in the early recovery group. Previous randomized controlled studies have reported that both home-based and center-based exercises inhibited the decrease in eGFR and the incidence of renal replacement therapy in patients with chronic kidney disease (CKD) [16–19]. Therefore, considering the Japanese insurance system, home-based exercises may help preserve RRF in LKDs at a high risk of non-early recovery of RRF. Furthermore, as previously reported [20, 21], nutritional education can contribute to avoiding a decrease in RRF; thus, transplant surgeons should include nutritional education to prevent the progression of CKD in their busy clinical practice.

The greatest concern is the risk of ESRD development in LKDs after DN. A previous study reported that LKDs had an increased risk of developing ESRD compared with the healthy population, although the number of cases was small [22–25]. In Japan, patients with postoperative persistent proteinuria, acute cardiovascular events, severe infections, or a history of hospitalization due to conditions accelerating the progression of CKD were reported to have a high risk of ESRD [26]. A meta-analysis also reported that 12% of LKDs had a GFR between 30 and 59 mL/min/1.73m$^2$, while 0.2% of LKDs had a GFR $\leq$ 30 mL/min/1.73m$^2$, and LKDs tended to develop proteinuria more often than the control group during the average follow-up period of seven years after DN [27]. The decline in RRF over time usually remains stable after DN;

**Table 3** Univariate and multivariate analysis for predicting postoperative renal function 12 months after surgery

| Variables | | 60% preservation | | | | | |
|---|---|---|---|---|---|---|---|
| | | Univariate analysis | | | Multivariate analysis | | |
| | | OR | 95%CI | *P* value | OR | 95%CI | *P* value |
| Age | | | | | | | |
| | ≤60 | 1 | | | | | |
| | >60 | 1.98 | 0.88 - 4.15 | 0.11 | | | |
| Sex | | | | | | | |
| | Male | 1 | | | | | |
| | Female | 1.34 | 0.59 - 3.11 | 0.48 | | | |
| BMI | | | | | | | |
| | ≤25 | 1 | | | | | |
| | >25 | 0.85 | 0.35 - 2.04 | 0.82 | | | |
| Hypertension | | | | | | | |
| | No | 1 | | | | | |
| | Yes | 1.00 | 0.39 - 2.62 | >0.99 | | | |
| Diabetes mellitus | | | | | | | |
| | No | 1 | | | | | |
| | Yes | 0.59 | 0.049 - 4.62 | >0.99 | | | |
| Smoking history | | | | | | | |
| | No | 1 | | | | | |
| | Yes | 0.79 | 0.33 - 1.93 | 0.67 | | | |
| Total mGFR | | | | | | | |
| | ≥80 | 1 | | | | | |
| | <80 | 1.81 | 0.78 - 3.93 | 0.19 | | | |
| Residual kidney mGFR | | | | | | | |
| | ≥40 | 1 | | | | | |
| | <40 | 2.01 | 0.85 - 4.44 | 0.12 | | | |
| TKV/BSA | | | | | | | |
| | ≥170 | 1 | | | 1 | | |
| | <170 | 2.89 | 1.31 - 6.34 | 0.016 | 1.14 | 0.35 - 3.78 | 0.83 |
| Residual KV/BSA | | | | | | | |
| | ≥85 | 1 | | | 1 | | |
| | <85 | 3.35 | 1.46 - 7.39 | 0.0036 | 2.81 | 1.19 - 6.66 | 0.019 |
| Preoperative eGFR | | | | | | | |
| | ≥80 | 1 | | | | | |
| | <80 | 0.60 | 0.28 - 1.32 | 0.23 | | | |
| ΔskeGFR | | | | | | | |
| | >9 | 1 | | | 1 | | |
| | ≤9 | 6.04 | 2.52 - 14.30 | <0.0001 | 5.43 | 2.27 - 13.01 | <0.0001 |

OR = odds ratio; CI = confidence interval; eGFR = estimated glomerular filtration rate; BMI = body mass index; mGFR = measured glomerular filtration rate; TKV = total kidney volume; BSA = body surface area; KV = kidney volume; skeGFR = single kidney estimated glomerular filtration rate

however, new-onset renal or systemic diseases accelerate CKD progression and result in ESRD.

In the Japanese guidelines for LKDs, no criteria or algorithms exist for SRF and selection of the kidney to be procured [4], while the Organ Procurement and Transplantation Network Policy of the United States describes detailed medical evaluation requirements for LKDs and the considerations pertaining to SRF and anatomical suitability of the kidney to be procured [28]. The British Transplantation Society also has published guidelines for LKDs, with detailed statements regarding criteria, notably age- and sex-specific mGFR criteria [29]. In the present study, preoperative renal functions tended to decrease in male LKDs compared with female LKDs, and mGFR was significantly associated with age in men, whereas TKV/BSA was significantly associated with age in women. Age was also associated with renal functions evaluated using CTV, scintigraphy, and blood examinations. Differences in renal functions may exist among different sex and age groups; therefore, in Japan, optimal criteria should be established according to sex and age. Further research to establish detailed criteria is expected.

Avoiding the deterioration of RRF, which may lead to ESRD, can improve prognosis in LKDs. Differences in the

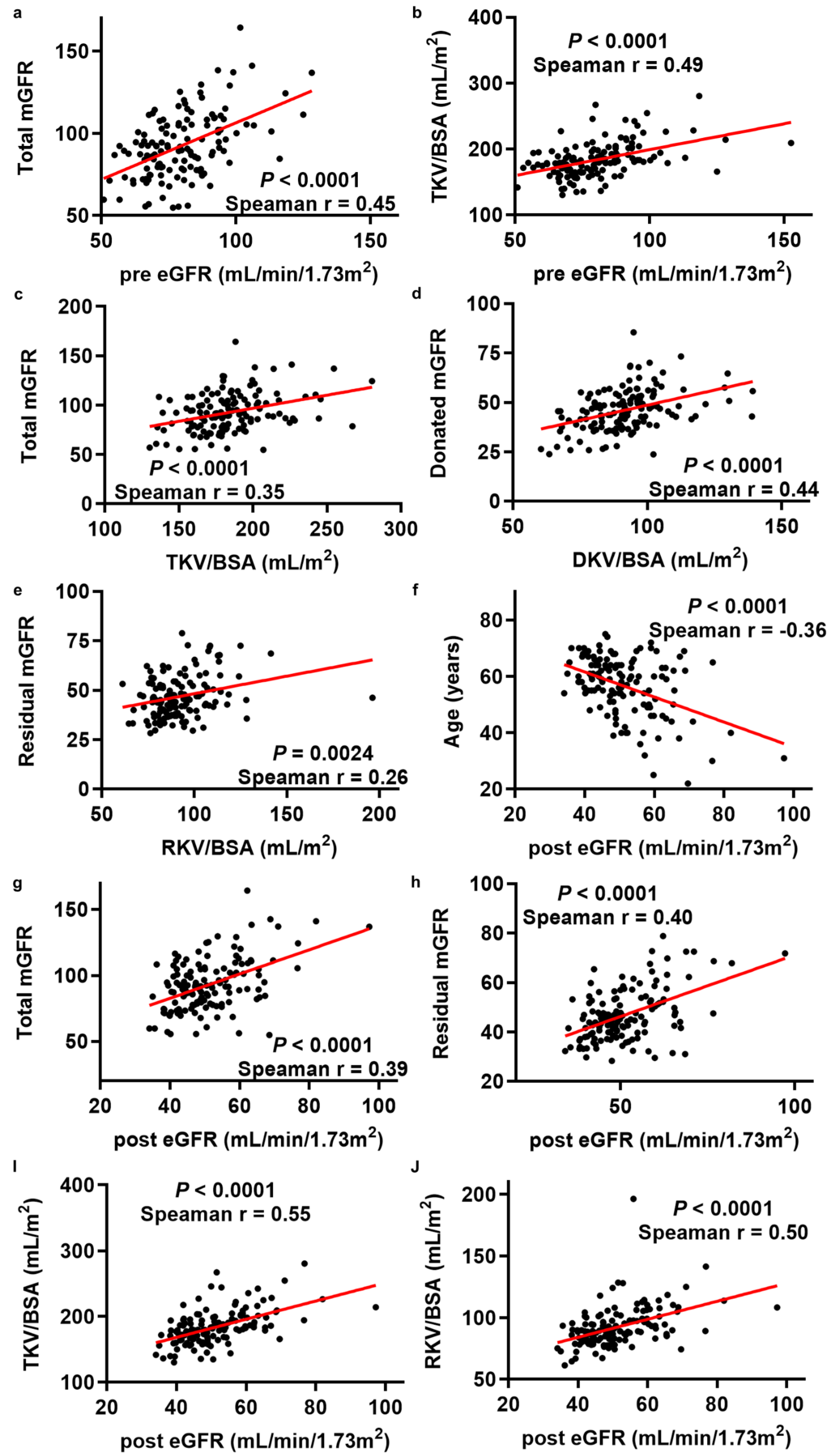


**Fig. 3** (See legend on next page.)

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**Fig. 3** Correlation analysis of renal function with volume parameters and measured glomerular filtration rate. The preoperative estimated glomerular filtration rate (eGFR) is correlated with the measured glomerular filtration rate (mGFR) obtained using scintigraphy (**a**) and total kidney volume/body surface area (TKV/BSA) (**b**). The mGFR is correlated with TKV/BSA (**c**), and donated and residual kidney volumes are correlated with donated and residual mGFRs, respectively (**d**, **e**). Age is negatively correlated (**f**) and mGFR, residual mGFR, TKV/BSA, and residual kidney volume/body surface area are positively correlated (**g**, **h**, **i**, and **j**, respectively) with postoperative eGFR. mGFR, measured glomerular filtration rate; post-eGFR, postoperative estimated glomerular filtration rate; pre-eGFR, preoperative estimated glomerular filtration rate; TKV/BSA, total kidney volume/body surface area; DKV/BSA, donated kidney volume/body surface area; RKV/BSA, residual kidney volume/body surface area

onset of ESRD and mortality rates in LKDs are observed beyond 10 years after DN; therefore, systematic and long-term follow-up after DN is important [23, 25]. Preoperative medical examinations of LKDs are also essential to improve surgical outcomes. CTV has an important role in evaluating preoperative renal function and predicting RRF. In addition, even after DN, optimal intervention may enable early recovery of RRF, resulting in good preservation of RRF.

The present study had some limitations. The medical data of LKDs were obtained from a single institution, and the sample size was small due to the exclusion criteria in this study, resulting in poor analysis. The follow-up period was not sufficiently long to evaluate the RRF in LKDs adequately. In our previous study, the median follow-up period was 73 months, and it showed that 5- and 10-year follow-up rates were approximately 75% and 55%, respectively [30]. Furthermore, due to the

**Table 4** Univariate and multivariate analysis for predicting early recovery of residual renal function

| Variables | | Univariate analysis | | | Multivariate analysis | | |
|---|---|---|---|---|---|---|---|
| | | OR | 95%CI | *P* value | OR | 95%CI | *P* value |
| Age | | | | | | | |
| | ≤60 | 1 | | | | | |
| | >60 | 1.79 | 0.89 - 3.68 | 0.11 | | | |
| Sex | | | | | | | |
| | Male | 1 | | | | | |
| | Female | 0.93 | 0.46 - 1.91 | 0.86 | | | |
| BMI | | | | | | | |
| | ≤25 | 1 | | | | | |
| | >25 | 1.24 | 0.59 - 2.73 | 0.69 | | | |
| Hypertension | | | | | | | |
| | No | 1 | | | | | |
| | Yes | 1.23 | 0.54 - 2.80 | 0.67 | | | |
| Diabetes mellitus | | | | | | | |
| | No | 1 | | | | | |
| | Yes | 1.6 | 0.36 - 7.04 | 0.68 | | | |
| Smoking history | | | | | | | |
| | No | 1 | | | | | |
| | Yes | 0.87 | 0.41 - 1.78 | 0.85 | | | |
| Total mGFR | | | | | | | |
| | ≥80 | 1 | | | | | |
| | <80 | 1.31 | 0.61 - 2.74 | 0.56 | | | |
| Residual kidney mGFR | | | | | | | |
| | ≥40 | 1 | | | | | |
| | <40 | 1.45 | 0.68 - 3.20 | 0.33 | | | |
| TKV/BSA | | | | | | | |
| | ≥170 | 1 | | | 1 | | |
| | <170 | 2.56 | 1.23 - 5.55 | 0.020 | 2.56 | 1.20 - 5.46 | 0.015 |
| Residual KV/BSA | | | | | | | |
| | ≥85 | 1 | | | 1 | | |
| | <85 | 2.16 | 1.02 - 4.32 | 0.043 | 1.34 | 0.49 - 3.61 | 0.57 |
| Preoperative eGFR | | | | | | | |
| | ≥80 | 1 | | | | | |
| | <80 | 1.21 | 0.61 - 2.45 | 0.60 | | | |

OR = odds ratio; CI = confidence interval; eGFR = estimated glomerular filtration rate; BMI = body mass index; mGFR = measured glomerular filtration rate; TKV = total kidney volume; BSA = body surface area; KV = kidney volume; skeGFR = single kidney estimated glomerular filtration rate exclusion criteria in this study, the number of LKDs was extremely small, resulting in poor analysis. Therefore, we need to evaluate whether the results are accurate during long-term follow-up in the future. In this study, 99 m Tc-DTPA was used for renal scintigraphy; however, additional analysis using a MAG3 scan might be required to provide evidence-based recommendations. Furthermore, previous reports showed that TKV/BSA was relatively stable with age until the age of 50 years with a subsequent decline, and these changes differed by gender [15]; their report was slightly inconsistent with our results. Therefore, careful interpretation is needed. Considering the long-term prognosis, further research is warranted to establish an optimal assessment protocol for potential LKDs and the side of the procured kidney.

## Conclusions

CTV may be a reliable and prognostic screening tool for selecting LKDs and assessing SRF in LKDs before DN, whereas renal scintigraphy may help select optimal LKDs, especially those with a low eGFR. Further research is required to establish systematic criteria for LKDs in Japan. Knowledge and understanding of the potential use of CTV and the clinical significance of the early recovery of RRF may help develop improved selection criteria, including those for the kidney to be procured, resulting in the preservation of RRF and improved prognosis in LKDs.

### Abbreviations

| | |
|---|---|
| CT | Computed tomography |
| 24HCCR | 24 h creatinine clearance |
| eGFR | Estimated glomerular filtration rate |
| ESRD | End-stage renal disease |
| mGFR | Measured glomerular filtration rate |
| ΔskeGFR | Δsingle-kidney estimated glomerular filtration rate |
| mGFR | Measured glomerular filtration rate |
| pre-eGFR | Preoperative estimated glomerular filtration rate |
| TKV/BSA | Total kidney volume/body surface area |

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### Author contributions

S. H, T. Y, and K. F contributed to conception and design. S. H, M. T, K. I, K. O, Y. M, D. G, Y. N, M. M, and K. T contributed to acquisition of patients' data, analysis of data, and interpretation of data. S. H, M. T, N. T, and T. Y performed the treatment. All authors have been involved in drafting the manuscript and revising it critically for important intellectual content and have approved the version to be published. All authors have participated sufficiently in this work to take public responsibility for appropriate portions of the content.

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### Data availability

The datasets generated and/or analyzed during the current study are not publicly available due to our hospital policy but are available from the corresponding author on reasonable request.

## Declarations

### Ethical approval and consent to participate

This retrospective chart review study involving human participants was approved by the Institutional Review Board for Clinical Studies at Nara Medical University (Medical Ethics Committee ID: 3176). The study was conducted in compliance with the study protocol and provisions of the Declaration of Helsinki (2013). The requirement for informed patient consent was waived by the institutional review board owing to the retrospective nature of the study.

### Competing interests

The authors declare no competing interests.

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