TRANSPLANT INTERNATIONAL

Transplant International ISSN 0934-0874

ORIGINAL ARTICLE

Volume matters: CT-based renal cortex volume measurement in the evaluation of living kidney donors

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Keywords
CT-based renal cortex volume, kidney transplantation, living kidney donation, scintigraphy.

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Conflict of interest
The authors declare no conflict of interest.

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Received: 6 June 2013
Revision requested: 21 July 2013
Accepted: 15 September 2013
Published online: 19 October 2013

doi:10.1111/tri.12195

Summary

Currently, no international standard for the pre-transplant evaluation of living donor renal function exists. Following a standardized questionnaire on current practice in all Eurotransplant (ET) centers, we compared a new CT-based technique to measure renal cortex volume with our standard of DTPA-clearance combined with MAG3-scintigraphy (DTPA × MAG3) and with creatinine-based methods in 167 consecutive living kidney donors. Most ET centers use creatinine-clearance (64%) to measure total renal function and radioistopic methods (82%) to assess split renal function. Before transplantation, CT-measured total cortex volume ($r = 0.67$; $P < 0.001$) and estimated GFR using the Cockcroft-Gault formula [eGFR(CG)] ($r = 0.55$; $P < 0.001$) showed the strongest correlation with DTPA-clearance. In contrast, the correlation between DTPA-clearance and creatinine clearance was weak ($r = 0.21$; $P = 0.02$). A strong correlation was observed between CT-measured split cortex volume and MAG3-measured split renal function ($r = 0.93$; $P < 0.001$). A strong correlation was also found between pre-transplant split renal function assessed by eGFR(CG) together with cortex volume measurement and post-transplant eGFR(CG) of both, the donor ($r = 0.83$; $P < 0.001$) and the recipient ($r = 0.75$; $P < 0.001$). In conclusion CT-based assessment of renal cortex volume bears the potential to substitute existing methods to assess pre-transplant living donor split renal function.

Introduction

As a result of an increasing number of patients with end stage renal disease (ESRD) and the obvious shortage of deceased donor kidneys, living kidney donation (LKD) has become increasingly important. The prognosis of living kidney donors was found to be similar to the general population with an excellent quality of life and without an excessive risk of ESRD [1]. Due to better long-term results of living donor transplants compared to deceased donor transplants, LKD also provides the best medical treatment for patients with ESRD [2,3]. Although pre-transplant living kidney donor evaluation is of utmost importance, no clear international guidelines exist [4], mainly due to a lack of adequate studies.

Throughout the past decades different ways to assess living donor renal function have been established. Glomerular filtration rate (GFR) is either measured as endogenous creatinine clearance (CrCl) by 24-h urine collection or estimated (eGFR) based on serum creatinine measurement by various formula such as Cockroft-Gault (CG), modification of diet in renal disease (MDRD) and the chronic kidney disease epidemiology collaboration equation (CKD-EPI). Due to the recommendations of the KDIGO guidelines [5] and its simplicity the MDRD formula is routinely calculated in many laboratories including our own hospital (Charité), although these guidelines also discuss the limitations of the method, especially for patients with normal renal function. Methods that measure renal function with a

higher precision use radioisotopic markers such as technetium-99 m-labeled diethylenetriamine-pentaacetate (DTPA), chrome-51 m-labeled ethylene-diaminetetraacetate (EDTA) and technetium-99 m-labeled mercaptoacetyltriglycine (MAG3) [6,7]. In addition to these functional tests, imaging techniques such as ultrasound, computed tomography (CT) and magnetic resonance imaging (MRI) are used to determine the vasculature, kidney size and volume [8].

A recent study on current practice in 72 United Network for Organ Sharing (UNOS)-approved centers showed that the majority of centers (71%) use 24-h urine creatinine clearance as screening method for GFR measurement [9]. Most centers (84%) use a second confirmatory method, if the initial measurement is unclear. Current guidelines of the British Transplantation Society recommend a GFR measurement using a reference procedure like EDTA-clearance, whereas eGFR assessment is not advised [10]. In contrast, the Caring for Australasians with Renal Impairment (CARI) guidelines allow GFR measurement with exogenous markers as well as creatinine clearance using 24-h urine collection and eGFR assessment according to CG or MDRD [11]. According to the Amsterdam Guidelines, creatinine-based methods to estimate eGFR can be used, but should be replaced or supplemented by isotopic GFR measurement in case of borderline GFR determination [12].

After conducting a questionnaire on current practice of pre-transplant living donor evaluation in Eurotransplant (ET), we evaluated the potential utility of a new CT-based technique to measure pre-transplant renal cortex volume in living kidney donors by comparison with our current standard method, a combination of DTPA-clearance and MAG3-scintigraphy, and with different creatinine-based methods to estimate or measure GFR. In addition, pre-transplant analyses were related to post-transplant renal function of the donor and the recipient. To our knowledge, this is the first study to investigate the use of renal cortex volume measurement by CT-density-reconstruction as a predictor of donor and recipient renal function following living donor renal transplantation.

Patients and methods

First, we conducted a structured questionnaire among all ET transplant centers on their current practice of pre-transplant evaluation of total and split living donor kidney function. Next, we performed a retrospective analysis on all adult living donor renal transplantations performed at our center between 2005 and 2011. Altogether, 167 consecutive LKD pairs were performed. Follow-up at 6 months after transplantation was completed in 144 donors and 155 recipients. Out of the 167 LKD pairs, follow-up at 6 months after donation was not available in 23 donors and 12 recipients: three recipients suffered from early graft loss within the first 6 months after transplantation, one recipient died due to severe postoperative complications, two recipients provided no 6-month follow-up, and six paediatric recipients (<16 years) were excluded from the analysis. CT-examination and the assessment of renal function of all donors were carried out within 3 months before transplantation. Renal function of both, donors and recipients was assessed at 6 ± 1 months after transplantation. In addition, the best eGFR of each recipient after transplantation was noted.

Assessment of pre-transplant renal function in the donor

DTPA-clearance and MAG3-scintigraphy were routinely carried out in all donors to assess total and split pre-transplant renal function. Clearances were determined using Bubeck's procedure [13,14]. Endogenous CrCl was measured based on repeated 24-h urine collection. GFR was estimated using the following formulas: Cockcroft-Gault [15], MDRD [16], and CKD-EPI [17].

Assessment of pre-transplant cortex volume in the donor

Pre-operative CT-examinations were performed on 16- to 320-slice CT-scanners with 1.0 or 0.5 mm slice collimation (*Aquilion-16*, *Aquilion-64*, *AquilionONE*; all from Toshiba Medical Systems, Otawara, Japan). The examination protocol included the application of 120 ml of an iodinated contrast agent (Ultravist, 370 mg iodine/ml, Bayer HealthCare Pharmaceuticals, Berlin, Germany; Xenetix, 350 mg iodine/ml, Guerbet, Roissy, France) at a flow of 2.5–3.5 ml/s. Examinations were performed in arterial and venous phases with a delay after the start of contrast injection of 30s and 60s, respectively. Images were reconstructed for thin slice data sets at 0.5–1.0 mm for post-processing (Fig. 1).

For assessment of renal cortex volume CT images were copied to a post-processing workstation (*Vitrea core*, Vital images, Minnetonka, MN, USA). As a first step, images were reconstructed in axial, sagittal and coronal views using the thin slice data sets. Then the software measured the cortex volume of the kidney by automatical volume rendering function based on density differences of the cortex compared to the surrounding tissues. Adjustments of the segmentations were done manually using the multiplanar reconstructions.

Calculation of pre-transplant split renal function and split cortex volume in the donor

Pre-donation split renal function, e.g., the side-specific GFR of each kidney, was calculated via multiplying the percentage of either CT-measured split cortex volume (Vol%) or MAG3- measured split renal function (MAG3%) by

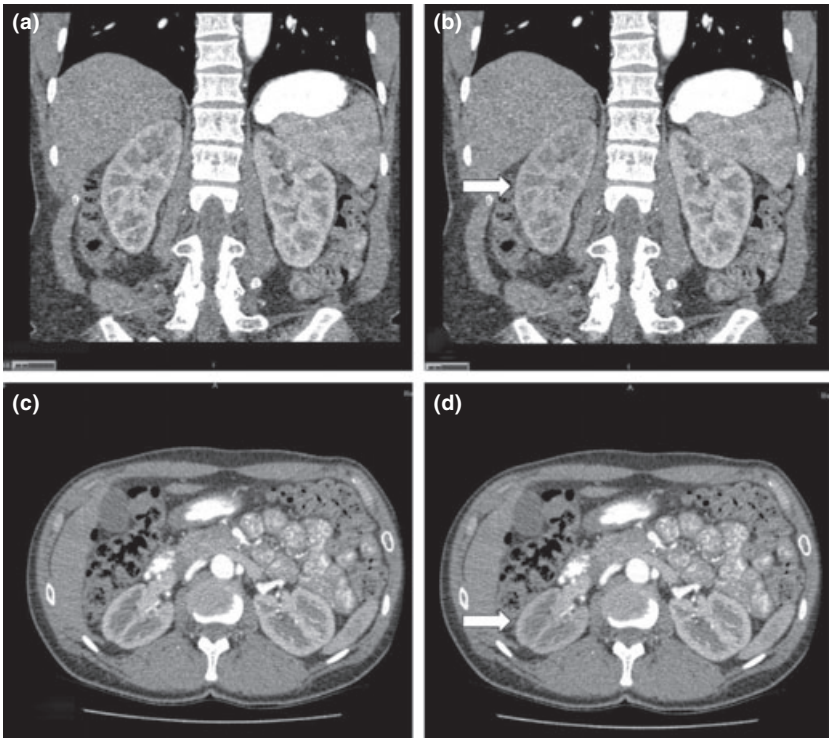

Figure 1 Pre-operative coronal (a,b) and axial (c,d) CT-images for assessment of renal cortex volume of a donor. The cortex was evaluated by using automatic segmentation software which is capable to detect and measure the cortical volume three-dimensionally within few mouse clicks. Images 'a' and 'c' show both kidneys after scanning, images 'b' and 'd' show the cortex segmentation of the right kidney (white arrows) after post-processing.

total GFR. Pre-donation split cortex volume was calculated via multiplying the percentage of CT-measured split cortex volume (Vol%) or MAG3-measured split renal function (MAG3%) by total cortex volume.

Statistical analysis

Statistical analysis was performed using SPSS statistical software (version 19.0; IBM Corp., Armonk, NY, USA) and GRAPHPAD PRISM software (version 5.0; GRAPHPAD Software, Inc., LA Jolla, CA, USA). Data are shown as mean ± SD. Cortex volume and all GFR values in donors pre-transplant and recipients post-transplant were adjusted to body surface area (BSA) using the Du Bois formula [18]. Relationship between two parameters was analyzed by correlation analysis (Pearson) and linear regression analysis. Bland-Altman test was employed to assess reliability and agreement between the different methods of GFR assessment. A probability of <0.05 was considered as statistically significant.

Results

Current practice of pre-transplant living donor evaluation in Eurotransplant

A standardized survey among all ET transplant centers that performed living donor kidney transplantations in 2012, revealed considerable country- as well as center-specific disparities concerning the pre-transplant evaluation of living donor renal function (Table 1). The majority of centers use CrCl (64%) to assess total renal function and radioisotopic techniques (82%) to assess split renal function. Besides, radiological techniques such as CT and ultrasound are applied to analyze split kidney size.

Pre-transplant evaluation of total cortex volume and total renal function

In our present study, mean donor age was 49 ± 11 years (range 24–76 years) and 65% of the donors were female. Compared to DTPA-clearance all other methods underestimated GFR (Table 2). Correlation between DTPA-clearance and total cortex volume (TCV) measured by CT ($r = 0.67$; $P < 0.001$) was superior to any of the applied methods to evaluate renal function (Table 2). The strongest correlation between DTPA-clearance and any of the other applied methods to assess GFR was found with eGFR(CG) ($r = 0.55$; $P < 0.001$). Only a weak correlation was observed between DTPA-clearance and CrCl ($r = 0.21$; $P = 0.02$). These results were confirmed by Bland-Altman analysis (Fig. 2).

Investigation of the relationship between TCV and different methods to assess renal function revealed that the strongest correlation was present between TCV and

Table 1. Evaluation of the pre-transplant donor renal function in Eurotransplant.

	Austria	Belgium	Croatia	Germany	Luxembourg	Netherlands	Slovenia	Total*
Transplant centers (*n*)	5	6	3	39	1†	7	1	61
Responding centers (*n*,%)	5 (100%)	6 (100%)	3 (100%)	39 (100%)	n.a.	7 (100%)	1 (100%)	61 (100%)
Total renal function								
Radioisotopic measurement (*n*,%)	1 (20%)	5 (83%)	1 (33%)	11 (28%)	n.a.	1 (14%)	0	19 (31%)
Inulin clearance (*n*,%)	1 (20%)	0	0	0	n.a.	0	0	1 (2%)
CrCl by 24 h-urine collection (*n*,%)	3 (60%)	1 (17%)	2 (67%)	26 (67%)	n.a.	6 (86%)	1 (100%)	39 (64%)
Cystatin clearance (*n*,%)	0	0	0	2 (5%)	n.a.	0	0	2 (3%)
Split renal function								
Radioisotopic measurement (*n*,%)	5 (100%)	5 (83%)	1 (33%)	39 (100%)	n.a.	0	0	50 (82%)
Size by CT (*n*,%)	0	1 (17%)	2 (67%)	0	n.a.	7 (100%)	0	10 (16%)
Size by ultrasound (*n*,%)	0	0	0	0	n.a.	0	1 (100%)	1 (2%)

Current standard methods for the pre-transplant evaluation of total and split donor renal function in Eurotransplant according to country.
CrCl, creatinine clearance; CT, computed tomography; n.a., not applicable.
*Total number and percentages without Luxembourg.
†No living kidney donation performed in 2012.

Table 2. Pre-transplant evaluation of total cortex volume and total renal function in 167 living kidney donors at our center.

		Correlation with DTPA clearance	Correlation with total cortex volume
DTPA clearance	124 ± 26 ml/min/1.73 m^2	n.a.	$r = 0.67$; $P < 0.001$
Total cortex volume by CT	225 ± 56 cm^3	$r = 0.67$; $P < 0.001$	n.a.
eGFR(CG)	106 ± 27 ml/min/1.73 m^2	$r = 0.55$; $P < 0.001$	$r = 0.64$; $P < 0.001$
eGFR(MDRD)	90 ± 18 ml/min/1.73 m^2	$r = 0.37$; $P = 0.009$	$r = 0.39$; $P = 0.007$
eGFR(CKD-EPI)	95 ± 12 ml/min/1.73 m^2	$r = 0.30$; $P < 0.001$	$r = 0.47$; $P < 0.001$
CrCl by 24 h-urine collection	107 ± 27 ml/min/1.73 m^2	$r = 0.21$; $P = 0.02$	$r = 0.35$; $P < 0.001$
Serum creatinine	0.79 ± 0.11 mg/dl	$r = 0.07$; $P = 0.4$	$r = 0.04$; $P = 0.35$

Pre-transplant evaluation of CT-measured total cortex volume and total renal function according to the applied methods.
CG, Cockroft-Gault; CKD-EPI, chronic kidney disease epidemiology collaboration equation; CrCl, creatinine clearance; CT, computed tomography; DTPA, diethylenetriamine-pentaacetate; eGFR, estimated glomerular filtration rate; MDRD, modification of diet in renal disease; n.a., not applicable.

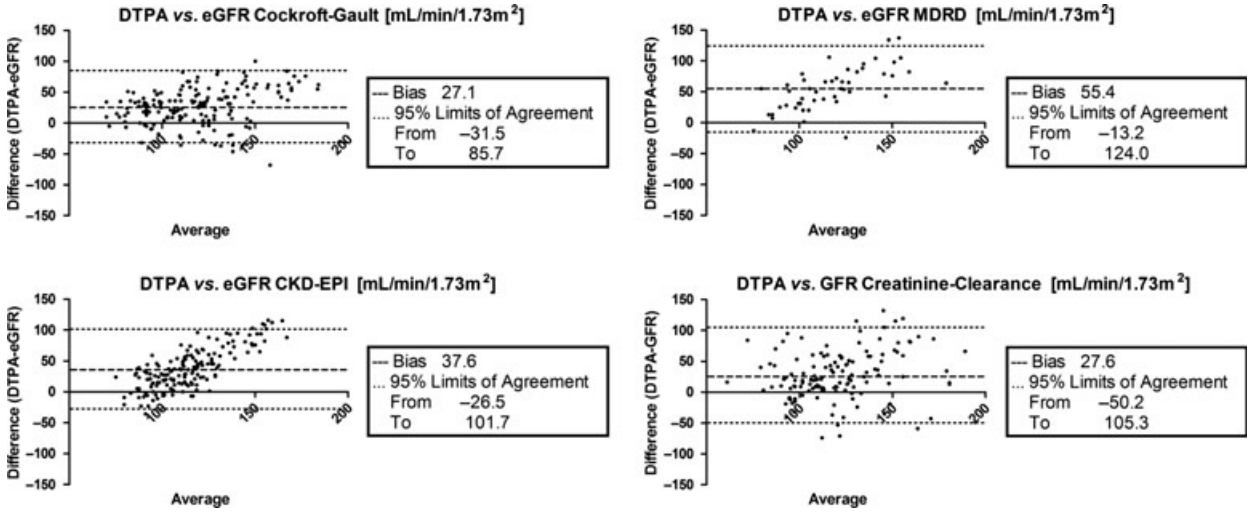

Figure 2 Comparison of GFR measured by DTPA clearance with eGFR assessed by various formulas and endogenous creatinine clearance measured by 24-h urine collection. Bland-Altman plot is showing bias and the 95% limit of agreement.

DTPA-clearance ($r = 0.67$; $P < 0.001$) followed by eGFR (CG) ($r = 0.64$; $P < 0.001$) (Table 2). Based on these results we decided to include DTPA-clearance, TCV and eGFR (CG) into further analyses.

Pre-transplant evaluation of split cortex volume and split renal function

According to MAG3-scintigraphy the percentage distribution between left and right kidney function was 51.2% (range 40.4–62.0%) vs. 48.8% (range 38.0–59.3%), respectively. According to CT-based cortex volume measurement the percentage distribution between left and right kidney volume was 49.8% (range 37.8–63.3%) vs. 50.2% (range 36.6–62.1%), respectively. A strong correlation ($r = 0.93$; $P < 0.001$) was observed between MAG3-based split renal function and CT-based split renal volume. Comparison between split renal function assessed by DTPA clearance combined with MAG3-scintigraphy (DTPA × MAG3%) and split cortex volume assessed by CT-investigation (TCV × Vol%) revealed a strong correlation (right kidney: $r = 0.66$; $P < 0.001$; left kidney: $r = 0.62$; $P < 0.001$).

Relationship of pre-transplant split cortex volume/GFR with post-transplant GFR

At 6 months after donation, the mean eGFR(CG) among all living kidney donors investigated was 75 ± 20 ml/min/1.73 m^2. By far, pre-donation eGFR(CG) in combination with MAG3-scintigraphy [eGFR(CG) × MAG%] or CT-based cortex volume measurement [eGFR(CG) × Vol%] showed the strongest correlation with post-donation eGFR (CG) of the preserved kidney (Table 3, Fig. 3).

Mean recipient age was 40 ± 15 years (range 16–71 years), 41% of the recipients were female. At 6 months after transplantation, the mean eGFR(CG) among all recipients was 66 ± 20 ml/min/1.73 m^2. The mean of the best eGFR of each recipient after transplantation was 80 ± 25 ml/min/1.73 m^2. Again, pre-transplant eGFR(CG) in combination with MAG3

Table 3. Correlation of pre-donation split cortex volume/GFR of the preserved kidney with eGFR(CG) at 6 months post-donation.

	Pre-donation split renal function/cortex volume	Correlation with eGFR(CG) at 6 months post-donation
eGFR(CG) × MAG3%	55 ± 14 ml/min/1.73 m^2	$r = 0.85$; $P < 0.001$
eGFR(CG) × Vol%	54 ± 15 ml/min/1.73 m^2	$r = 0.83$; $P < 0.001$
TCV × MAG3%	148 ± 62 cm^3	$r = 0.42$; $P < 0.001$
TCV × Vol%	124 ± 24 cm^3	$r = 0.50$; $P < 0.001$
DTPA clearance × MAG3%	69 ± 19 ml/min/1.73 m^2	$r = 0.43$; $P < 0.001$
DTPA clearance × Vol%	67 ± 18 ml/min/1.73 m^2	$r = 0.39$; $P < 0.001$

The mean eGFR(CG) of all living donors at 6 months after donation was 75 ± 20 ml/min/1.73 m^2. Split renal function/cortex volume of the preserved kidney before donation and its correlation with eGFR(CG) of the donor at 6 months after donation are shown.
CG, Cockroft-Gault; DTPA, diethylenetriamine-pentaacetate; eGFR, estimated glomerular filtration rate; MAG3%, percentage of MAG3-measured split renal function; TCV, total cortex volume; Vol%, percentage of CT-measured split cortex volume.

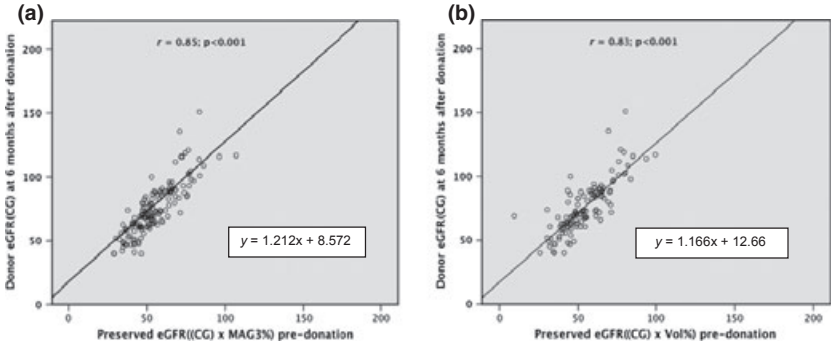

Figure 3 Correlation of pre-donation split GFR of the preserved kidney with eGFR(CG) at 6 months after donation. Split eGFR of the preserved kidney before donation was calculated via multiplying the percentage of either MAG3-measured split renal function (MAG3%) (Panel a) or CT-measured split cortex volume (Vol%) (Panel b) by eGFR(CG). Donor GFR at 6 months after transplantation was assessed by eGFR(CG). Abbreviations: CG, Cockroft-Gault; eGFR, estimated glomerular filtration rate; MAG3%, percentage of MAG3-measured split renal function; Vol%, percentage of CT-measured split cortex volume.

Table 4. Correlation of pre-transplant split cortex volume/GFR of the donated kidney with post-transplant eGFR(CG).

	Pre-transplant split renal function/cortex volume	Correlation with eGFR(CG) at 6 months post transplantation	Correlation with best eGFR(CG) post transplantation
eGFR(CG) × MAG3%	50 ± 20 ml/min/1.73 m^2	$r = 0.62$; $P < 0.001$	$r = 0.73$; $P < 0.001$
eGFR(CG) × Vol%	53 ± 24 ml/min/1.73 m^2	$r = 0.64$; $P < 0.001$	$r = 0.75$; $P < 0.001$
TCV × MAG3%	107 ± 36 cm^3	$r = 0.45$; $P < 0.001$	$r = 0.50$; $P < 0.001$
TCV × Vol%	111 ± 30 cm^3	$r = 0.43$; $P < 0.001$	$r = 0.50$; $P < 0.001$
DTPA clearance × MAG3%	58 ± 18 ml/min/1.73 m^2	$r = 0.36$; $P < 0.001$	$r = 0.48$; $P < 0.001$
DTPA clearance × Vol%	65 ± 24 ml/min/1.73 m^2	$r = 0.36$; $P < 0.001$	$r = 0.47$; $P < 0.001$

The mean eGFR(CG) in all recipients at 6 months after transplantation was 66 ± 20 ml/min/1.73 m^2. Best eGFR after transplantation was 80 ± 25 ml/min/1.73 m^2. Split renal function/cortex volume of the donated kidney before donation and its correlation with eGFR(CG) of the recipient at 6 months and with the best eGFR(CG) after transplantation are shown.
CG, Cockroft-Gault; DTPA, diethylenetriamine-pentaacetate; eGFR, estimated glomerular filtration rate; MAG3%, percentage of MAG3-measured split renal function; TCV, total cortex volume; Vol%, percentage of CT-measured split cortex volume.

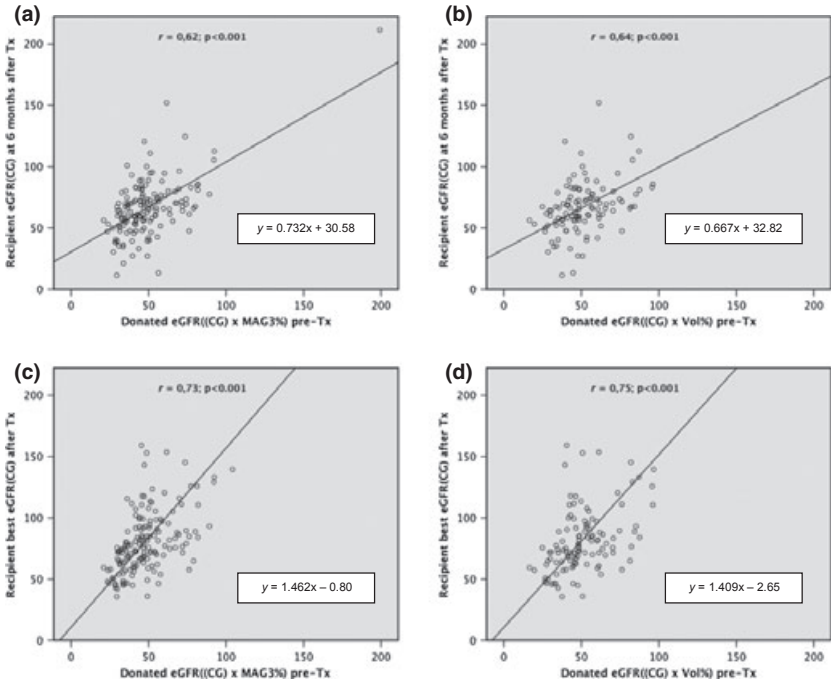

Figure 4 Correlation of pre-transplant split GFR of the donated kidney with post-transplant eGFR(CG). Split eGFR of the donated kidney before transplantation was calculated via multiplying the percentage of either MAG3-measured split renal function (MAG3%) (Panels a and c) or CT-measured split cortex volume (Vol%) (Panels b and d) by eGFR(CG). Recipient GFR at 6 months after transplantation (Panels a and b) as well as the best GFR of each recipient after transplantation (Panels c and d) was assessed by eGFR(CG). Abbreviations: CG, Cockroft-Gault; eGFR, estimated glomerular filtration rate; MAG3%, percentage of MAG3-measured split renal function; Vol%, percentage of CT-measured split cortex volume; Tx, transplantation.

scintigraphy [eGFR(CG) × MAG%] or CT-based cortex volume measurement [eGFR(CG) × Vol%] showed the strongest correlation with post-transplant eGFR(CG) of the recipient (Table 4, Fig. 4). In general, the correlation between best eGFR post-transplant and pre-transplant assessment of split GFR or cortex volume was superior to the correlation between eGFR at 6 months post-transplant and pre-transplant assessment of split GFR or cortex volume (Table 4).

Discussion

Accurate assessment of pre-transplant renal function in candidates for LKD is indispensable to ensure sufficient

long-term residual renal function for both, the donor and the recipient after transplantation. Undoubtedly, the use of exogenous filtration markers is the gold standard of GFR measurement. Because these reference methods are inconvenient and expensive in everyday clinical practice measurement of endogenous CrCl by 24-h urine collection and the use of creatinine-based eGFR prediction formulas are widely employed [19,20]. As there is no current and internationally recommended standard for determining renal function in potential LKDs, we conducted a survey among all ET transplant centers on their current practice of pre-transplant evaluation of living donor renal function using a standardized questionnaire. Our survey revealed that most centers use CrCl measured by 24-h urine collection to assess total renal function and radioisotopic methods to analyze split renal function. None of the centers uses creatinine-based formulas to estimate GFR. Split renal function is measured by radioisotopic methods in all German transplant centers, whereas all centers in the Netherlands use CT-based assessments of the kidney size.

Concerning pre-transplant evaluation of donor renal function, our results clearly show that the correlation of DTPA-clearance with CT-measured TCV was superior to the correlation of DTPA-clearance with eGFR assessments by different formulas or CrCl measurement by 24-h urine collection. Among the latter methods, the strongest correlation in healthy individuals with normal renal function was found between DTPA-clearance and eGFR(CG). In agreement with our results, Rule *et al.* [21] found that the correlation between eGFR(CG) and iothalamate GFR ($r = 0.35$) was superior to the correlation between eGFR (MDRD) and iothalamate GFR ($r = 0.26$) in potential kidney donors. However, both correlations are not really satisfactory. In our study, the correlation between DTPA-clearance and CrCl measurement by 24-h urine collection was disappointing, most probably due to the well-known problems with accurate urine collection in an outpatient setting, although all patients received intense advice on accurate 24-h urine sampling and the mean from 2 to 3 measurements was used in our study. These results confirm data by Issa *et al.*, who observed a poor correlation between CrCl and 125I-iothalamate GFR in 423 living kidney donors [22]. Based on these results even repeated measurements of CrCl can not be recommended for the precise evaluation of pre-transplant donor renal function, and physicians should be aware of those limitations. Surprisingly, eGFR(MDRD) and eGFR(CKD-EPI) had a poor correlation with DTPA-clearance, which might be explained by the fact that all our donors had an excellent GFR >80 ml/min, whereas both formulas were validated in patient cohorts with renal insufficiency [23]. Despite the widespread use of the MDRD formula there is little evidence on the accuracy in persons with normal kidney function. Consequently, we excluded these methods from further analyses.

Concerning the evaluation of split renal function before donation, a very strong correlation between MAG3-scintigraphy and CT-measured split cortex volume was observed, indicating that CT-measured split cortex volume is equivalent to MAG3-scintigraphy. A strong correlation was also observed between our current standard [DTPA-clearance in combination with MAG3-scintigraphy (DTPA × MAG3)] and CT-based measurement of split renal volume (TCV × Vol%). These results indicate that CT-based measurement of split cortex volume is a potentially useful tool to evaluate split renal function before donation. In 27 donors the difference between both kidneys assessed by MAG3-scintigraphy exceeded 10%. In all of these cases we decided to use the inferior kidney according to MAG3-scintigraphy for donation. If we had used the CT-based renal cortex volume measurement the decision would have differed in six cases, clearly indicating that more research is needed in this field.

Finally, the relationship between pre-transplant split cortex volume/GFR and post-transplant GFR was assessed. Post-transplant GFR was routinely assessed by eGFR(CG). For both, donors and recipients, the best correlation of post-transplant eGFR(CG) was found with pre-transplant eGFR(CG) in combination with the percentage of either MAG3-measured split renal function (MAG3%) or CT-measured split cortex volume (Vol%). The fact that the correlation between pre- and post-transplant GFR was generally better in donors than in recipients may reflect the obvious vagaries of the post-transplant situation in the recipient. The fact that the correlation between pre- and post-transplant GFR in recipients was generally better when using best eGFR(CG) than using eGFR at 6 months after transplantation underlines that renal function at a defined time-point after transplantation is influenced by many variables, which are not donor dependent. Our results also confirm previous studies indicating that a compensatory hypertrophy in both, donor and recipient may occur [24]. The different and heterogeneous degrees of post-donation hypertrophy may also be one reason for the suboptimal correlations between pre- and post-transplant GFRs.

Over the past years, several studies aiming to predict donor and recipient renal function based on kidney volume and weight have been published. Hugen *et al.* [25] found that a larger kidney volume calculated by 3-dimensional CT-examination was associated with lower recipient serum creatinine levels. Lee *et al.* [26] reported that the donated kidney volume to recipient BSA ratio is a predictor of recipient GFR. Amante *et al.* [27] observed that the ratio of renal allograft weight to recipient body weight was useful to predict recipient GFR. In contrast, Tent *et al.* [28] reported that transplanted kidneys adapt to the recipient's body size

without detrimental effects on renal function and outcome based on detailed renal function measurements pre-donation and post-transplantation in donors and recipients. In our study we took into consideration the fact that donor and recipient weight/BSA may differ significantly by adjusting all GFR values to BSA as normalizing these values is crucial when analyzing or comparing these parameters.

In conclusion, the ideal method for pre-transplant evaluation of the living donor renal function must (i) be applicable to all kinds of patients concerned, (ii) be practicable in everyday clinical practice, (iii) have a strong correlation with reference GFR measurements, and (iv) should have a strong correlation with post-transplant GFR of both, the donor and the recipient. Routine pre-transplant investigation of living kidney donors encloses many different investigations including abdominal CT-examination to reveal the exact donor anatomy. Our results show that eGFR(CG) in combination with CT-based cortex volume measurement provides a promising tool to predict renal function in donors and in recipients with the potential to substitute radioisotopic assessment of split renal function in future. As shown by our ET questionnaire, several transplant centers, especially in the Netherlands, have already stopped to perform radioisotopic GFR measurements. Bearing in mind that not every transplant center provides radioisotopic diagnostics and that some centers have already started to challenge the informational benefit given by radioisotopic diagnostics, our study may further advocate a radioisotope spearing approach, especially for those centers who already perform multislice CT-evaluations of the vascular anatomy. Approximately 10 min of additional time to perform the add-on CT-evaluation used in our study versus extra costs of about 260 € for MAG3 and 98 € for DTPA assessment (at our center) as well as evitable extra radiation exposure might tip the scales in favour of CT in future. Nevertheless, as decisions based on inaccurate GFR estimates do have severe consequences, GFR measurement using a reference procedure such as EDTA- or DTPA-clearance is indispensable [29] especially in cases where pre-transplant donor renal function is indeterminate.

Authorship

FH: acquired data, data analysis, wrote and drafted the manuscript, study design. GD, TK: acquired data, data analysis. TS: data analysis and critical revisions of the manuscript. FE, LL, FF, TFF, AM, H-HN, KB: made critical revisions of the manuscript. JW: research design, data analysis, drafted and wrote the manuscript, revisions of the manuscript.

Funding

No funding has been received for the presented study.

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