

Comparison of four different multi-detector computed tomography based split renal function (SRF) evaluation methods and their correlation with nuclear scintigraphy derived SRF for functional assessment of potential living renal donors

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Abstract

Background and Objectives: Preoperative anatomical and functional evaluation of donor kidneys is crucial for successful renal transplantation. While multi-detector computed tomography (MDCT) angiography is the standard imaging modality for anatomical assessment, nuclear scintigraphy using Technetium-99m Diethylenetriamine Pentaacetate (Tc-99m DTPA) remains the gold standard for evaluating split renal function (SRF). However, MDCT-based SRF estimation has recently emerged as a viable alternative.

The aim of this study is to compare four different MDCT-based SRF measurement techniques and assess their correlation with SRF obtained from nuclear scintigraphy.

Materials and Methods: This prospective study included 111 living kidney donors from 2019 to 2021 who underwent MDCT angiography. SRF was estimated using four CT-based methods: total renal volume, cortical renal volume, ellipsoid method (all using semi-automated ROI-Region of Interest), and differential attenuation of contrast. All measurements were performed using an Advantage Workstation (GE). The calculated SRFs were compared with Tc-99m DTPA-based SRF using the Pearson correlation coefficient.

Results: The mean age of donors was 44.32±10.25 years (range: 22–69). All four MDCT-based methods showed statistically significant correlation with nuclear scintigraphy SRF. For the right kidney, correlation coefficients (r) were 0.574 (total renal volume), 0.509 (cortical volume), 0.288 (ellipsoid method), and 0.323 (contrast attenuation); for the left kidney, r-values were 0.513, 0.473, 0.262, and 0.251, respectively (all p<0.001).

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Conclusion: MDCT-based SRF measurements demonstrate a significant correlation with nuclear scintigraphy. Given that MDCT angiography is routinely performed for anatomical evaluation, it can serve as a comprehensive, single-modality approach for both anatomical and functional assessment in living kidney donors.

Introduction

Renal transplantation has emerged as the treatment of choice for patients with end-stage renal disease (ESRD). It improves the quality of life and reduces the mortality risk of most patients as compared to the other available alternative treatments like maintenance hemodialysis (MHD) [1].

For successful renal transplantation, comprehensive preoperative anatomical and functional evaluation of the kidneys of potential living donors is of paramount importance, along with genetic workup [2].

Out of both kidneys from a living donor, the kidney to be harvested is decided by the principle of the nephron mass hypothesis, which suggests that the larger or more dominant kidney should remain with the donor. However, there are no universally recommended guidelines as to what difference in volume or functional asymmetry is acceptable when selecting an individual for living donor nephrectomy. Some centers have used a 60/40 split as a relative contraindication to donation [3].

Currently, multidetector computed tomography (MDCT) renal angiography is considered an investigation of choice for anatomical evaluation of kidneys and their vascular mapping, including anatomical variations, which are crucial for successful harvest and renal transplant. For functional assessments like glomerular filtration rate (GFR) and split renal function (SRF), nuclear scintigraphy is considered the gold standard.

In recent decades, several studies have shown that MDCT can also be used as an effective tool for measuring SRF in kidneys. MDCT can be used to measure kidney volume (total renal volume and cortical renal volume). And by volumes, we can calculate the SRF of kidneys, as volume reflects the split renal function.

There are various MDCT-based SRF estimation techniques that have been found to be as sensitive as nuclear scintigraphy [4,5]. CT volumetry methods

such as ellipsoid volumetry, total parenchymal volumetry, and renal cortex volumetry have been studied in detail and have been found effective methods for estimating SRF [6].

The purpose of this study is to compare MDCT-calculated SRF with nuclear scintigraphy-measured SRF.

Materials and Methods

This prospective analytical study was conducted at a tertiary care center in the department of radiology in collaboration with the Department of Nuclear Medicine, the Department of Urology, and the Department of Nephrology at the Sanjay Gandhi Postgraduate Institute of Medical Sciences, Lucknow, during the periods of 2019 and 2021.

Volunteer living kidney donors who were already scheduled for MDCT imaging for anatomical and vascular evaluation were recruited in the study after fulfilling the inclusion and exclusion criteria. There were 111 participants included in the study from 130 enrolled patients. The 19 patients were excluded from the study as they didn't meet inclusion criteria. After explaining the nature of the study and taking informed consent, CT angiography was performed as per the protocol in Table-1. CT renal volumetry (total renal volume and cortical renal volume) was done by the semi-automated ROI method and the ellipsoid method at Advantage Workstation of GE by two experienced radiologists with good training and experience of 3 years and 18 years, respectively. As per protocol in our institution for renal donor evaluation, all these prospective voluntary kidney donors underwent a Technetium-99m DTPA renal scan for SRF measurement preoperatively.

CT image acquisition: The MDCT was performed on a 128-channel scanner (brilliance CT, Philips Medical System, Netherlands) at the abovementioned institution.

Table-1: CT parameters for 128 channel Multi-detector Scanner

CT parameter	Unenhanced image	Corticomedullary Phase
Tube voltage	100kVp	120kVp
Reference mAs	150mAs	250mAs
Rotation time	0.75sec	0.75sec
Pitch	1.1725sec	1.172 sec
Field of view	350	350
Tube Matrix	512x512	512x512
Collimation	64x0.625	64x0.625
Slice Thickness/increment	3mm/1.5mm	0.9mm/0.45mm
Filter	Standard B	Standard B
Acquisition time	5-7 seconds	6-8 seconds

All donors were asked to drink 600 mL of plain water before CT examination, then asked to empty their bladders before taking a CT scan. First, a pre-contrast MDCT of the abdomen was obtained from the top of the left hemidiaphragm to the symphysis pubis during end-inspiration. Through consistent window settings, anatomical landmarks, and protocolized slice thickness, we have tried to minimize bias. A 100ml CM (Iohexol 350 mg/mL) at the rate of 4.0 mL/sec was administered through an 18G cannula placed in the right antecubital fossa by a power injector, followed by 20ml normal saline chaser. As per institutional protocol, images were acquired in late arterial (corticomedullary phase) from the top of the left hemidiaphragm to symphysis pubis after a delay of 15 seconds from the moment the HU (Hounsfield Units) of the subdiaphragmatic aorta reaches up to 150 HU by the bolus tracking method.

Split renal function calculation: Renal volume was calculated by the following methods:

The semiautomated region of interest (ROI) tool was applied in the corticomedullary phase, and the total volume of the kidney was calculated. The collecting system, fat in the renal sinus, and renal space and renal occupying lesions of water density were excluded by preset software thresholds. Using this volume, SRF was calculated as:

$$\text{SRF (R or L kidney)} = \text{R or L kidney volume} / \text{R+L kidney volume.}$$

Only renal cortex volume was calculated in the corticomedullary phase. Using this volume, SRF was

$$\text{calculated as SRF (R or L kidney)} = \text{R or L renal cortical volume (RCV)} / \text{R+L RCV.}$$

Renal volume was calculated by the modified ellipsoid method (height x width x depth x $\pi/6$). Depth and width were calculated in axial slices, and height was calculated in the plane of the kidney in the sagittal plane, in the corticomedullary phase of image acquisition and SRF was calculated as R or L kidney = R or L kidney volume by the ellipsoid method / R + L kidney total volume by the ellipsoid method.

The difference between the mean attenuation in the arterial series (Art Att) and the pre-contrast series (Pre Att) was multiplied by the mean of the respective parenchymal volumes (Art Vol and Pre Vol) to measure the accumulation (Art Acc) of contrast in each individual kidney during the arterial phase.

$$\text{Art Acc} = (\text{Art Att} - \text{Pre Att}) \times \{(\text{Art Vol} + \text{Pre Vol}) / 2\}$$

Once this procedure was completed for both the left and right kidneys in the arterial phase, the total arterial contrast accumulation (Art Acc) on the right was divided by the sum of the total arterial contrast accumulation in both kidneys to determine the relative clearance of the contrast media from the right kidney in the arterial phase (Rt Art Split).

$$\text{Rt Art Split} = \text{Rt Art Acc} / (\text{Lt Art Acc} + \text{Rt Art Acc}).$$

Estimation of SRF by renal scintigraphy: For differential renal function an angiographic perfusion study was performed using 1 mCi (millicurie) of ^{99m}Tc-diethylenetriamine

pentaacetic acid (DTPA) with donor in the supine position and the scintillation camera detector positioned so that the bifurcation of the aorta, iliac arteries, and urinary bladder in addition to the kidneys appeared in the camera field. Three second sequential exposures were obtained as long as the activity was clearly localized in the arterial system and kidney. This was followed by a 40-sec static image to evaluate renal size and shape. Subsequently, activity was quantified over the individual kidneys and bladder by the use of either the split crystal or region.

Statistical analysis: The normality of the continuous variable was assessed, and variables were considered normally distributed when the standard normal variate (Z) value of the skewness was ± 3.29 . The continuous variables were

presented in mean \pm standard deviation/median (interquartile range) and range (minimum-maximum). The categorical variables were presented in frequency (percentage). A paired samples t test was used to test the change in mean score between paired observations (pre-post). To compare the means between two unpaired groups, independent samples t-tests were used, while to compare the means among more than two groups, a one-way ANOVA test was used, followed by multiple comparisons using the Bonferroni method. To compare the proportions between the groups, a chi-square test was used. To assess the linear relationship between two continuous variables, the Pearson correlation coefficient was used. A p-value < 0.001 was taken as statistically significant. The data was analyzed by Statistical Package for Social Sciences, version 26 (SPSS-26, IBM, Chicago, USA).

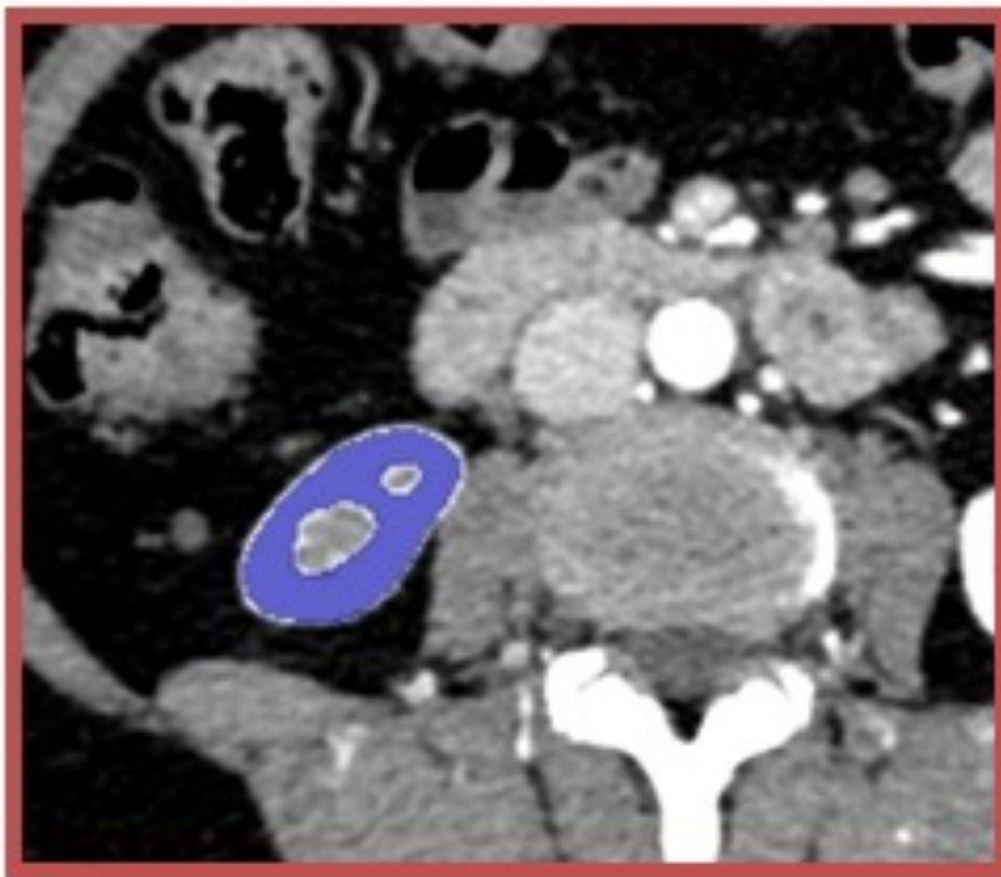


Figure-1a: Cortical volume by the semiautomatic region of interest tool

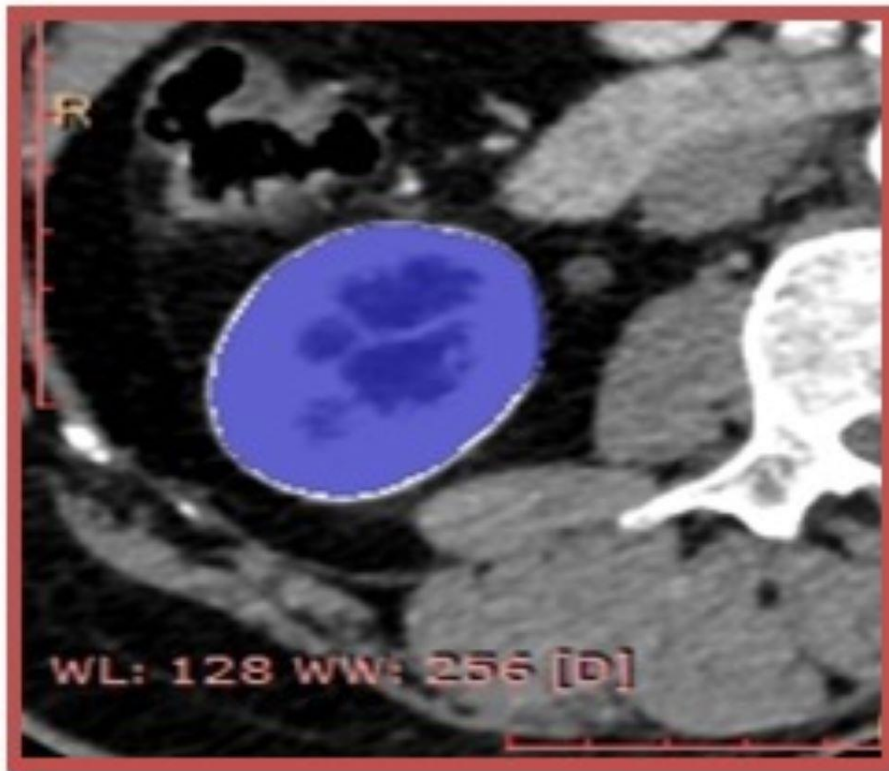


Figure-1b: Total volume by the semiautomatic region of interest tool

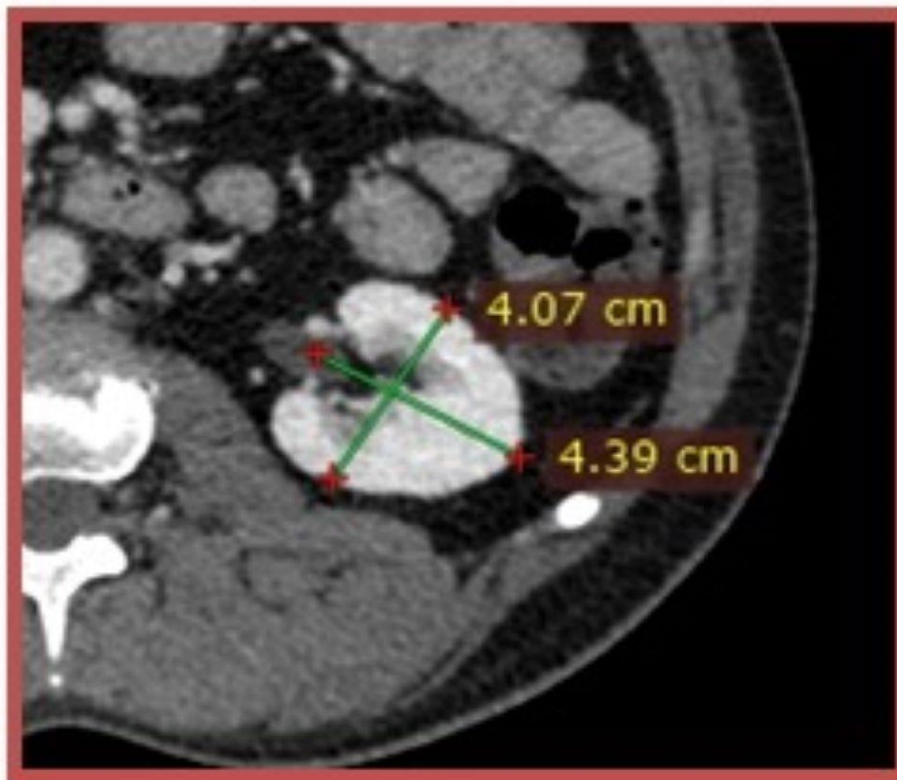


Figure-1c: Width and thickness by ellipsoid method



Figure-1c: Width and thickness by ellipsoid method

Figure-1 (a,b,c and d): The process of measuring of kidney volume, the semiautomatic region of interest (ROI) tool was applied slice by slice on axial corticomedullary phase images (a) for cortical volume and (b) for total volume. In ellipsoid method, width and thickness was taken in axial plane, length in sagittal plane, (c) and (d).



Figure-2: Estimation of total renal volume on coronal plane

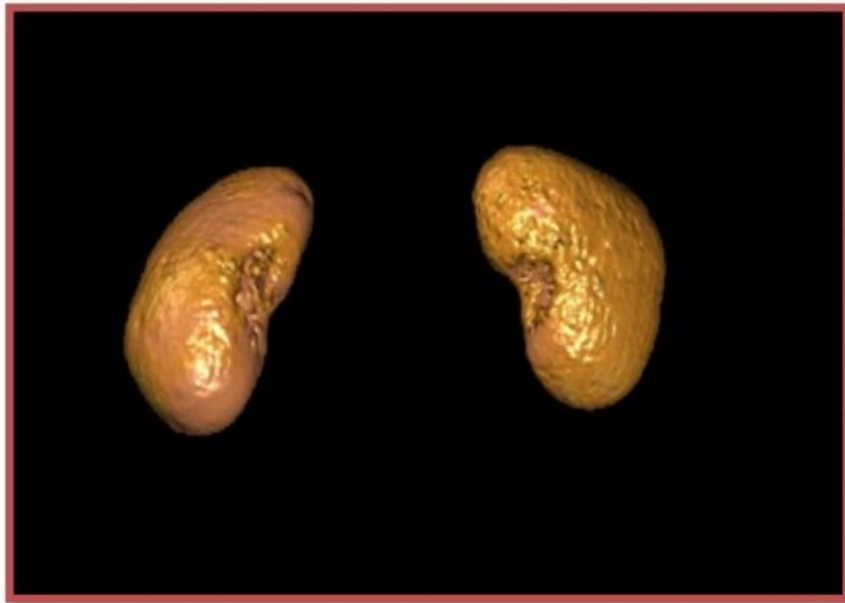


Figure-3: Volume rendered images for total volume calculation

Results

A total of 111 donors were finally evaluated. For the 111 donors, age was 44.32 ± 10.25 years (mean \pm SD), and the range was 22-69 years, while the median of the donors was 44 years. Most of the donors belonged to the age group 41-50 years (n = 39, 35.14%), followed by 31-40 years (n = 35,

31.53%), while the least were in the age group 61-70 years (n = 9, 8.04%). The majority of the participating donors were females (n = 91, 82.0%). The mean creatinine of donors was 0.8 mg/dL with a range of 0.7 to 1.4 mg/dL (Table-2, Figures- 4a and 4b).

Table-2: Demographic characteristics of kidney donors

Characteristics		Male (N)	Female (N)	Total (N)
Age	20-30	04	05	09
	31-40	05	30	35
	41-50	05	34	39
	51-60	04	15	19
	61-70	02	07	09
Total		20	91	111

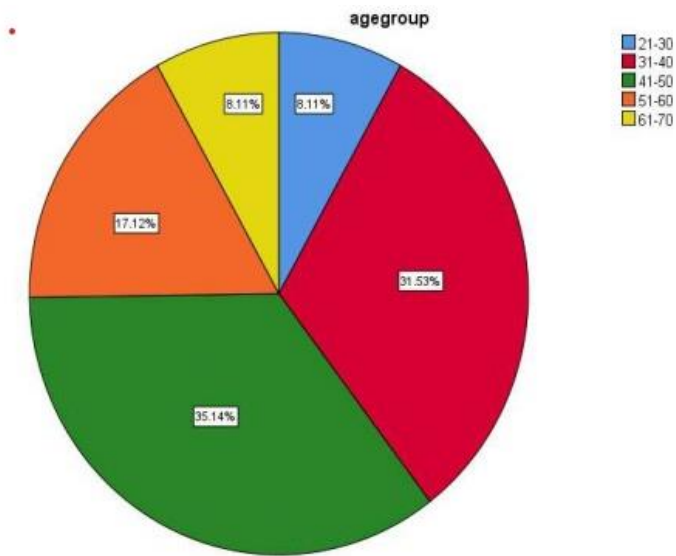


Figure- 4a: Pie chart showing age distribution and percentage of the study participants

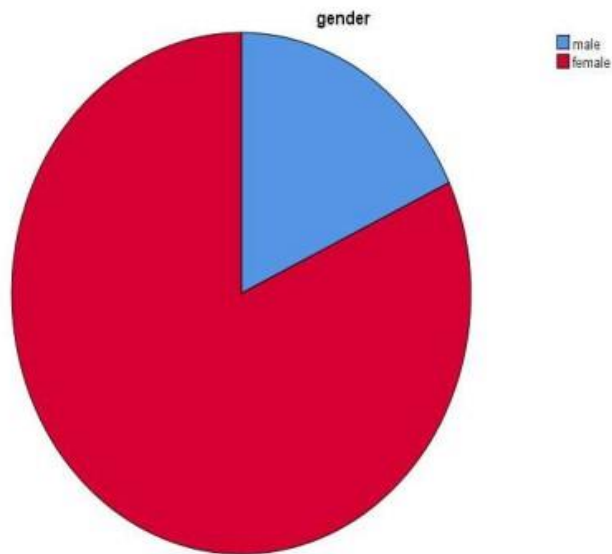


Figure-4b: Pie chart showing sex distribution and percentage of the study participants

SRF measurement using CT volumetry methods:

Total renal volume (semiautomated ROI method): The mean (\pm SD) CT derived left split renal function (SRF) for renal donors was $50.47 \pm 2.49\%$ and SRF ranged from 43.30% to 57%.

The mean (\pm SD) CT derived right split renal function (SRF) for renal donors was $49.51 \pm 2.49\%$ and SRF ranged from 43% to 56.70%.

Total renal volume (ellipsoid method): The mean (\pm SD) CT derived left split renal function (SRF) for

renal donors was 49.10±4.57% and SRF ranged from 35% to 59.80%.

The mean (±SD) CT derived right split renal function (SRF) for renal donors was 50.85±4.54% and SRF ranged from 40.20% to 65%.

Cortical renal volume method: The mean (±SD) CT derived left split renal function (SRF) for renal donors was 50.27±2.49% and SRF ranged from 43% to 57%.

The mean (±SD) CT derived right split renal function (SRF) for renal donors was 49.65±2.59% and SRF ranged from 42.70% to 57%.

Differential attenuation of contrast method: The mean (±SD) CT derived left split renal function (SRF) for renal donors was 50.71±3.69% and SRF ranged from 35.50% to 59%.

The mean (±SD) CT derived right split renal function (SRF) for renal donors was 49.30±3.67% and SRF ranged from 41% to 64.50%.

SRF measurement using DTPA: The mean (±SD) DTPA derived left split renal function for renal donors was 50.71±3.69% and SRF ranged from 35.5% to 59%.

The mean (±SD) CT derived right split renal function for renal donors was 50.19±3.49% and SRF ranged from 38% to 60%.

Comparison of SRF measured using CT volumetry methods and DTPA method: SRF measurement was done using MDCT as well as DTPA of the donors for the left and right kidneys. Pearson correlation coefficient was calculated for SRF measurements between MDCT methods and DTPA method. Results indicated that there was a significant correlation between the MDCT methods and DTPA method for the left kidney and right kidney at P value <.01 (Table 3a and 3b, Fig 5a, 5b, 5c and 5d).

Table-3a: SRF correlation between MDCT methods and DTPA method – Right kidney

MDCT methods	DTPA method		
	Correlation Coefficient(r)	p-value	Significance
Semiautomated total renal volume	0.574	p<0.01	significant
Ellipsoid method renal volume	0.288	p<0.01	significant
Cortical renal volume	0.509	p<0.01	significant
Differential attenuation of contrast	0.323	p<0.01	significant

Pearsons Correlation Coefficient used. p<0.01 is significant

Table-3b: SRF correlation between MDCT methods and DTPA method – Left kidney

MDCT methods	DTPA method		
	Correlation Coefficient(r)	p value	significance
Semiautomated total renal volume	0.513	p<0.01	significant
Ellipsoid method renal volume	0.262	p<0.01	significant
Cortical renal volume	0.473	p<0.01	significant
Differential attenuation of contrast	0.251	p<0.01	significant

Pearsons Correlation Coefficient used. p<0.01 is significant

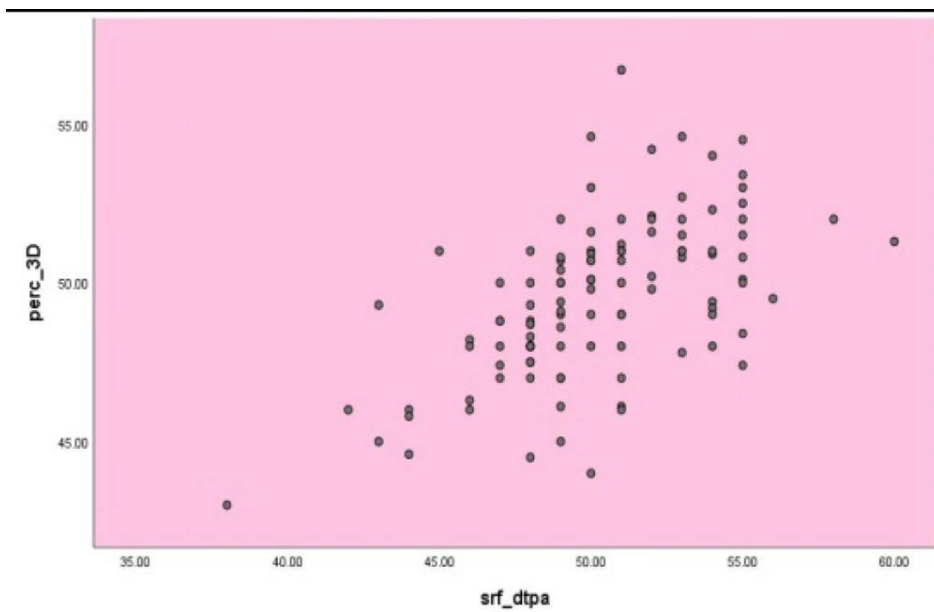


Figure-5a: Scattered diagram showing correlation between semi-automate ROI method SRF and DTPA method SRF.

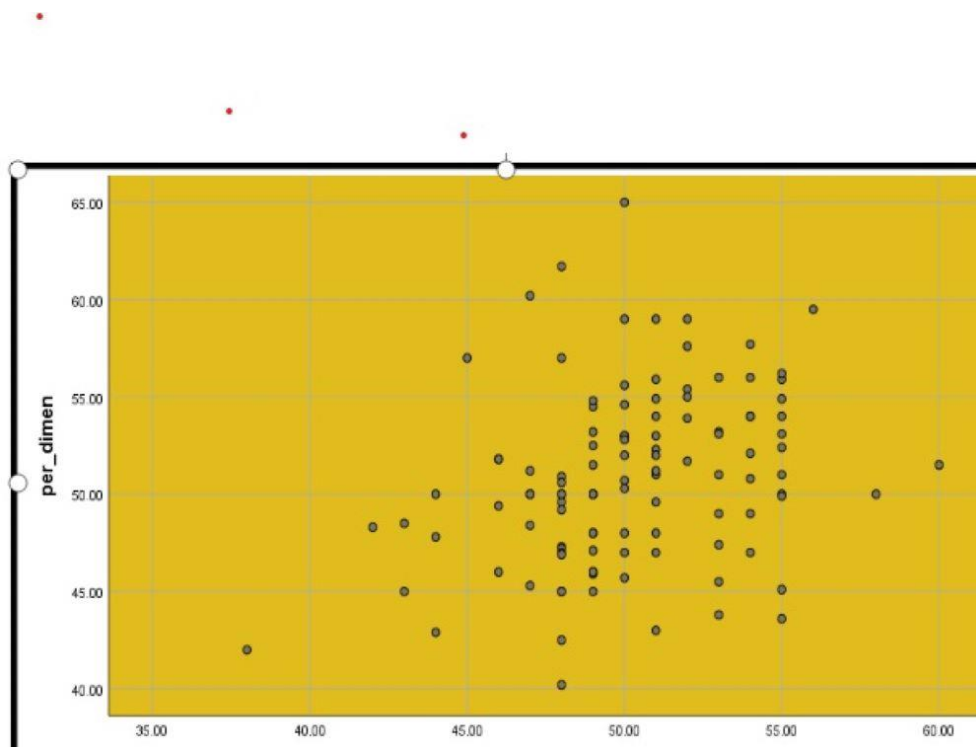


Figure-5b: Scatter diagram showing correlation between ellipsoid method SRF and DTPA method SRF

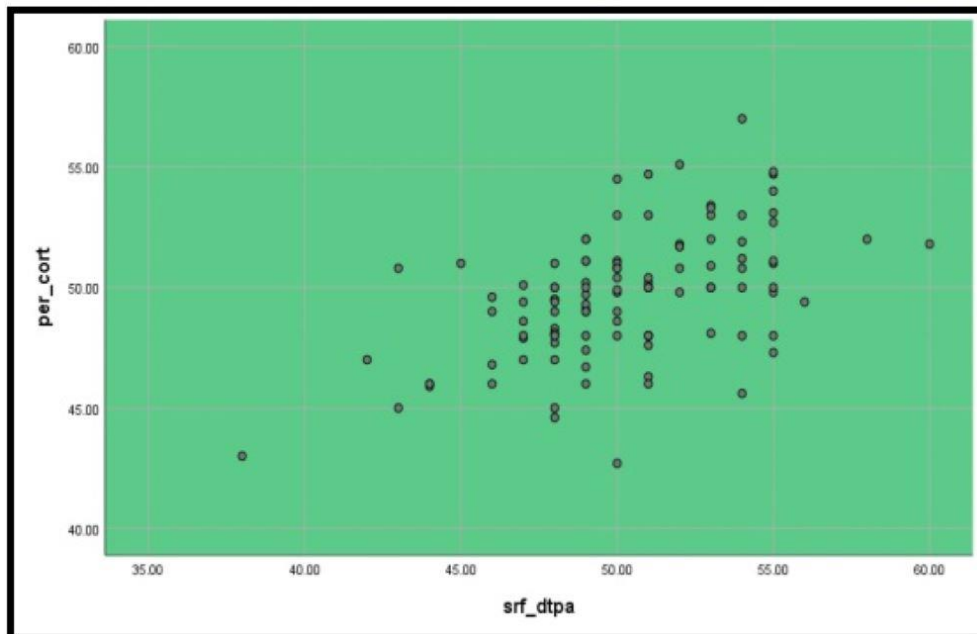


Figure-5c: Scatter diagram showing correlation between cortical renal volume method SRF and DTPA method SRF.

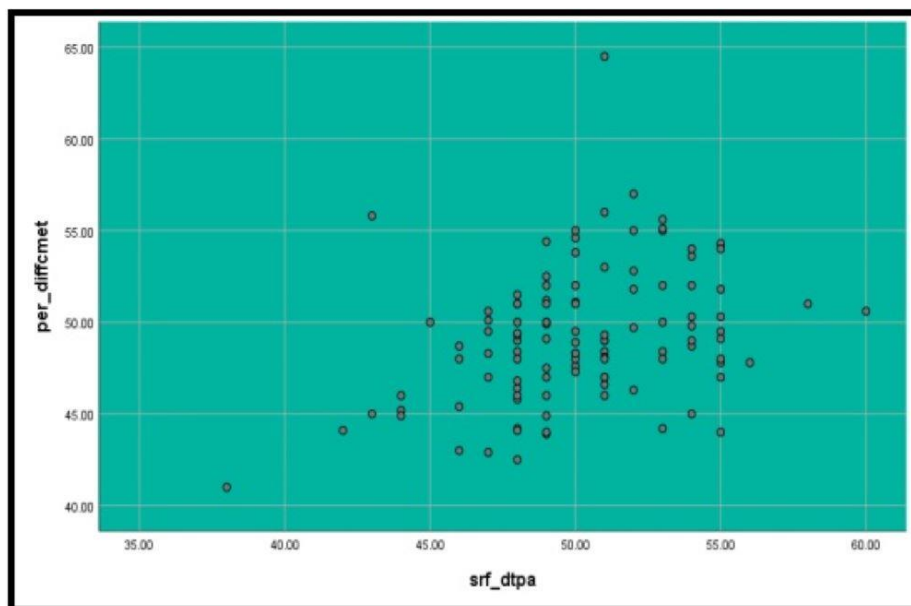


Figure-b5: Scatter diagram showing correlation between differential attenuation of contrast method SRF and DTPA method SRF

Discussion

At present, MDCT angiography is the gold standard for anatomical evaluation of living renal donors.

Namasivayam S et al. [7]. For functional evaluations like GFR and SRF, nuclear scintigraphy is considered the gold standard. Several studies have been

published regarding the use of MDCT to calculate SRF.

Several studies have also compared CT parenchymal volumetry methods (total renal volume by semiautomated ROI method, ellipsoid method, and cortical renal volume method) and the differential attenuation of contrast method with nuclear scintigraphy to estimate SRF and have shown moderate correlation between the two techniques (Table-4), suggesting that MDCT can be an alternative to nuclear medicine scintigraphy for determining SRF. The correlation coefficients for the best-performing method (3D ROI) are 0.574

(right) and 0.513 (left), which are moderate only, but for clinical decision-making, particularly regarding donor selection, higher accuracy may be warranted. While the correlation between MDCT-derived SRF and nuclear scintigraphy was moderate, this reflects real-world clinical variability and underscores the need for complementary evaluation in donor selection. This will result in a reduction in radiation exposure to the patients, optimum utilization of imaging resources, reduced preoperative workup cost, and a more convenient algorithm for the potential donor.

Table-4: Comparison between MDCT derived SRF and renal scintigraphy SRF of our study with previous studies

Studies	Number of donors/ Kidney donated (N)	Volumetric Methods	Correlation coefficient(r)
Summerlin et al (2008)	152	3D ROI method	r=0.36to 0.63
Knox et al(2010)	54	Area x thickness	r=0.61
Patankar et al (2014)	12	Attenuation method	r= 0.45
Diez et al (2014)	65	3D ROI method	r = 0.59
Yanishi et al. (2015)	35	Not reported	r=0.714
Wahba et al. (2016)	101	3D ROI and ellipsoid method	r=0.82-0.84, and 0.36
Barbas et al (2016)		Attenuation method	r = 0.51
Mitsui et al (2017)	34	3D ROI method	r=0.942
Edouard Gardan et al (2018)		Cortical volume method	r=0.60
Steven Habbous et al (2019)	115	Ellipsoid method	r = 0.28
Present study	Left kidney	3D ROI method	0.513
		Cortical volume method	0.473
		Ellipsoid method	0.262
		Attenuation method	0.251
	Right kidney	3D ROI method	0.574
		Corticalvolume method	0.509
		Ellipsoid method	0.288
		Attenuation method	0.322

In the present study, the correlation coefficient was calculated for SRF measurements by MDCT volumetry methods and the Tc99mDTPA method. The inter-observer variation was qualitatively minimal. Results indicated that there was a statistically significant correlation between two methods for the left and right kidneys. Future studies correlating MDCT-derived SRF with post-

donation renal function would further establish the method's clinical utility.

Limitations

There are a few limitations in this study, as the sample size is small and it is a single-center study. A large sample size and multicenter study should be

conducted in the future to further explore the feasibility of MDCT as an alternative to the nuclear scintigraphy method. Agreement between MDCT and nuclear SRF is not presented, which is critical to assess clinical interchangeability. Inter-observer variability with different levels of experience involved in volumetric measurements is not discussed.

Conclusion

The MDCT angiography is routinely done for the anatomical assessment of living renal donors. Different renal MDCT-based methods of SRF measurement have shown significant correlation as compared to SRF measured by Nuclear Scintigraphy Tc-99m DTPA methods. We propose that MDCT can be used as a one-stop solution for anatomical and functional evaluation of renal donors and become an important modality in the coming future.

Conflict of interest

Authors have no conflict of interest to declare.

Ethical statement

Ethical clearance was obtained from the Institutional Ethics Committee of Sanjay Gandhi Postgraduate Institute of Medical Sciences, Lucknow (IEC code: 2020-32-MD-114).

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Cite this article as:

Ahmad S, Prasad R, Lal H, Barai S, Srivastava A, Iqbaal SD. Comparison of four different multi-detector computed tomography based split renal function (SRF) evaluation methods and their correlation with nuclear scintigraphy derived SRF for functional assessment of potential living renal donors. *IMC J Med Sci.* 2026; **20**(1):002.

DOI: <https://doi.org/10.55010/imcims.20.002>.