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RESEARCH

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Comparison of Turbo Flash and dual-energy modes of third-generation dual-source CT in pre-transplant renal angiography: a prospective observational study

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Abstract

Background: The purpose of this study was to compare the Image Quality, Contrast Medium Volume, and Radiation dose in renal angiography performed using Turbo Flash mode and dual-energy (DE) mode in the third-generation dual-source dual-energy CT.

This prospective observational study was performed on renal donors who underwent CTA imaging as a pre-transplant workup. The study population was divided into two groups. Group A underwent DECT renal angiography. Group B underwent Turbo Flash Mode CT renal angiography. For group A, a contrast volume of 1 ml/kg and for group B at 0.5 ml/kg was administered. Image Quality was evaluated objectively by calculating CNR and SNR and subjectively by a 5-point scale. Radiation Dose analysis was done by noting CTDIvol and DLP on the scanner system and calculating effective radiation dose (ED).

Results: The subjective image quality scores for the Turbo Flash group were comparable with the DE group in qualitative image analysis. Additionally, in the Turbo Flash group, there was a reduction in contrast media and effective radiation dose by 47.5% and 32.7%, respectively. Nevertheless, mean attenuation of the abdominal arteries, CNR, SNR, and Noise (S.D) showed statistical significance between the two groups (*p* value < 0.01).

Conclusions: To our knowledge, no previous study compared Turboflash mode with DE protocol in CT renal angiography in a donor group of patients. Turbo Flash CT is an excellent modality that is faster and has an added advantage of decreased radiation dose and contrast media volume reduction, which can be recommended for screening of voluntary kidney donors but needs further clinical studies, validation, and standardization with tailored protocols.

Keywords: TurboFlash CT, Dual-energy CT, CT renal angiography

Background

Chronic kidney disease (CKD) is well known for its substantial health burden in terms of mortality and morbidity globally [1]. The treatment of choice for end-stage renal disease is renal transplantation, which significantly increases the patient's quality of life [2]. Since cadaveric transplantation fails to meet the ever-increasing demand for donor kidneys, more transplants from living donors occur, which can bridge the gap of deficit and offer long-term survival of graft with fewer complications. In such cases, careful preoperative assessment of the donor and assurance of donor safety becomes mandatory.

Among the various imaging modalities for evaluating prospective donors, C.T. angiography (CTA) can be

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considered the "one-stop-shop technique". This less invasive, safe, cost-effective, and more tolerable technique shows excellent delineation of renal anatomy, which plays a key role in the selection of donors [3]. Although the benefits of CTA outweigh its risk in renal donor evaluation, there has been a recent escalation of concerns regarding an increase in radiation and contrast-induced nephropathy. Though there is no direct evidence to link the radiation received from medical imaging with malignancies, some risks can be associated with even small doses of ionizing radiation. Hence, the ALARA principle becomes essential [4]. A meta-analysis study showed a close relationship between the volume of contrast medium (CM) with glomerular filtration rate and the occurrence of contrast-induced nephropathy (CIN) [5]. Bearing these potential adverse effects of radiation dose and CM usage in mind, it is crucial to reduce CT radiation dose and CM volume while maintaining diagnostic range image quality (IQ) during CTA. This warrants the search for additional novel techniques in CTA.

In this study, we compared a potential novel protocol using Turbo Flash to dual-energy CT in the evaluation of CTA of renal donors in an attempt to decrease radiation dose and contrast media volume while preserving diagnostic image quality.

Methods

This study was a prospective observational study for one year, approved by the ethical and scientific committee and with informed consent obtained from all participants. The study population included 60 prospective renal donors referred to the radiology department for CTA imaging as a part of pretransplant workup. Patients with renal tumours, abnormal RFT and small renal arteries (in whom ROI covering at least 11–40 mm^2 could not be placed) were excluded from this study.

Participants were randomly divided into two groups of 30 each: Group A scanned by Dual-energy CT (DECT) and group B scanned by Turbo Flash mode CT renal angiography. The scans were performed on Somatom Force, Siemens, a 3rd-generation dual-energy CT scanner.

The common parameters for both the modes of renal CTA are described in Table 1.

Table 2 details the different CT parameters used in two groups.

Images were reconstructed from raw data using offline reconstruction software with field-of-view sizes of 260 × 260 mm^2, as it is implemented in the commercially available scanner software. Post-processing was performed on dedicated workstations using 1-mm-thick images with an overlap of 0.5 mm. Images were processed on Siemens Somatom Force workstation and multiplanar reformatting (MPR), curved MPR (cMPR), maximum intensity projection (MIP), and 3D volume rendered images (VR) were reconstructed. The evaluation of images was done on Syngo via. Siemens.

Table 1 The common parameters for renal CTA

CT scanner parameter	Protocol
Voltage	120 kVp
Effective current	Auto Modulation
Slice thickness	1 mm
Slice increment	0.5 mm
Injection rate	4 ml/s
Reconstruction	50% overlap
Kernel	Bv 36—smooth
Image viewing (PACS)	Axial, coronal and sagittal (3 mm)
Anatomic coverage	Dome of diaphragm to iliac crest covering iliac arteries

Table 2 CT parameters used in two groups

Parameters	Group A	Group B
Tube current (Kvp)	90/Sn 150	120
Tube current time product (mAs)	Care dose	Care dose
Pitch	0.9	2.0
Rotation time in secs	0.5	0.25
Collimation	128 × 0.6	192 × 0.6

Group A underwent renal CTA in a dual-energy mode scanner with a conventional pitch (pitch = 0.9) and 1.0 mL/kg CM injection, with parameters from the standard protocol used in our institution

Group B underwent renal CTA on the same scanner via a Turbo Flash mode (pitch = 2.0) with 0.5 mL/kg CM injection

Contrast medium administration

Ultravist-370 (Iopromide) warmed to body temperature (37 °C) was administered with a dual-head power injector followed by a 30 mL saline chaser at a rate of 4 mL/s through an 18-gauge cannula placed in the antecubital vein of the right arm in both groups. An automatic bolus-tracking program was used for initiating arterial phase scanning after CM injection in both groups. A region of interest (ROI) was placed in the abdominal aorta at the level of diaphragm. A threshold of 150 Hounsfield unit (HU) for peak enhancement in the abdominal aorta was selected for triggering the arterial phase imaging.

Objective image quality evaluation

Image quality was evaluated by measuring the attenuation in the main abdominal artery (AA) and both renal arteries 1 cm from their origin. The ROIs were drawn as large as vessel lumen, whereas wall calcifications that might cause artefacts were avoided (range of ROI sizes, 11.0–40.0 mm^2). The measurements were performed and tabulated. The SD, which serves as a quantitative marker of image noise, and the attenuation of the right psoas muscle were measured at the level of the lower pole of the right kidney using an ROI with area 200 mm^2. To minimize bias from the use of a single measurement, we obtained three measurements for each of the following: the attenuation of the renal artery, image noise, and the attenuation of the psoas muscle. The mean of these values was used for further statistical analysis. The signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) of the renal arteries were calculated using the following formulas

$$\mathrm{SNR} = \text{Mean attenuation value of renal arteries/image noise}$$

$$\mathrm{CNR} = (\text{mean attenuation value of renal arteries} - \text{psoas muscle attenuation value})/\text{image noise}.$$

Subjective image analysis

Qualitative image evaluation was performed using the volume rendering images, 3 (axial, coronal, sagittal) orthogonal MIP and cMPR of the renal arteriography. The window level and width settings were adjusted for best viewing of anatomy during evaluation. The arteries were evaluated on a 5-point scale for arterial enhancement and the sharpness of the artery boundary (Table 3).

Radiation dose analysis

Volume CT dose index (CTDIvol) and dose length product (DLP) provided by the scanner system after each case were recorded. To account for variations in scan acquisition length between patients, DLP was normalized for a typical abdominal acquisition covering 32 cm for arterial phase was taken in all patients to avoid confusion. The effective radiation dose (ED) estimate was calculated for each patient by multiplying the DLP with an abdomen-specific conversion coefficient k of 0.015 mSv/(mGy cm) [6].

The donors' number of renal arteries and veins were compared with the intraoperative findings.

Statistical analysis

The collected data were analysed with IBM.SPSS statistics software 23.0 Version. To describe the data descriptive statistics frequency analysis, percentage analysis was used for categorical variables and the mean and S.D were used for continuous variables. To find the significant difference between the bivariate samples in independent groups, the unpaired sample t test was used. In the above statistical tool, the probability value 0.05 is considered as a significant level.

Results

Patient characteristics

The male-to-female ratio in group A was 18:12 in comparison to 15:15 for group B. There were no significant differences between the two groups regarding age ($p=0.303$), height ($p=0.720$), weight ($p=0.655$), and BMI ($p=0.975$). The patient baseline characteristics are given in Table 4.

Objective image quality analysis

The difference in mean attenuation of renal arteries was statistically significant between two groups (p value between 0.01 and 0.05). The difference in mean attenuation of abdominal aorta (AA), CNR, SNR, and noise (S.D) showed high statistical significance between the two groups (p value < 0.01).

Subjective image quality analysis

The mean subjective score of group A was 4.95 ± 0.224 and that of group B was 4.85 ± 0.305, thus showing comparable image quality in both groups (Figs. 1, 2) with statistical insignificance in qualitative image analysis ($p=0.15$).

Radiation dose and contrast media volume

There was significant reduction in CTDIvol, DLP, ERD in group B patients with high pitch protocol. The mean CTDIvol of group A and B are 8.3 ± 0.8 and 6.0 ± 1.8, respectively (p value of 0.0005). The mean DLP of group A and B are 266.4 ± 25.9 mGycm and192.5 ± 58.7 mGycm, respectively (p value of 0.0005). The mean ERD

Table 3 Subjective image quality evaluation

Score 1	Bad, non-diagnostic
Score 2	Poor, substandard
Score 3	Moderate, standard
Score 4	Good, better than standard
Score 5	Excellent

Table 4 Patient baseline characteristics of two groups

Patients' characteristics	Dual-energy CT	Turbo Flash CT	p value
Age (years)	44.0 ± 13.1	48.0 ± 11.3	0.303
Height (cm)	157.8 ± 7.6	156.9 ± 8.1	0.720
Weight (kg)	62.9 ± 10.3	61.4 ± 11.3	0.655
BMI (kg/m^2)	25.2 ± 3.4	25.2 ± 3.8	0.975

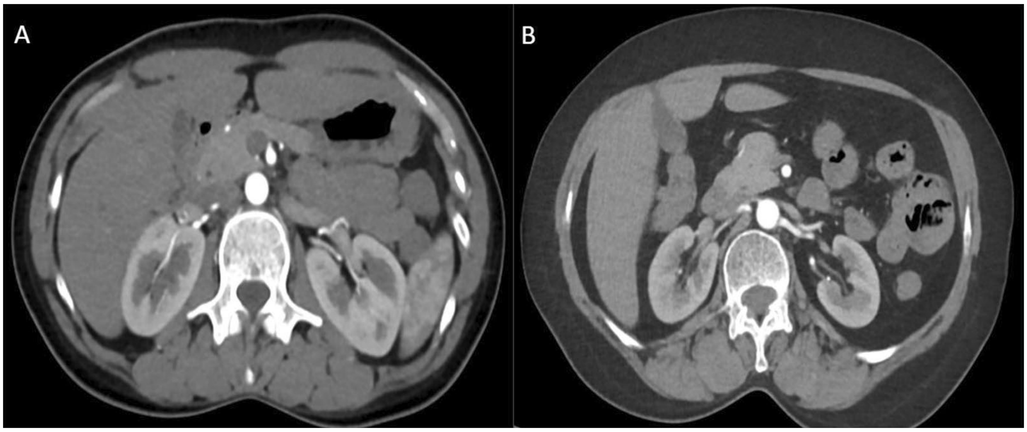

Fig. 1 Contrast CT Axial images of DECT (**A**) and Turbo Flash (**B**) at the renal artery level shows comparable image quality between both

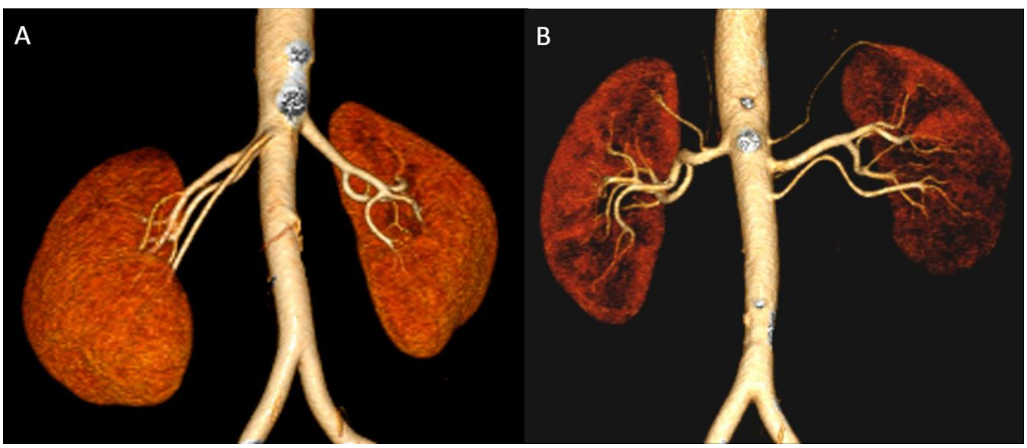

Fig. 2 Contrast CT VRT images of DECT (**A**) and Turbo Flash (**B**) of the aorta and renal arteries shows comparable image quality between both

of group A and B are 4 ± 0.4 mSv and 2.9 ± 0.9 mSv, respectively (p value of 0.0005) which represents a dose reduction of 32.7% (Table 5).

The mean CM volume in group B was 31.5 ± 7.0 mL compared with 60.00 ± 0.0 mL in group A ($p < 0.001$), which saved 48.33% of CM.

Among 60 patients evaluated, two from group A and one from group B did not undergo donor nephrectomy surgery for personal reasons. There is no difference between intraoperative and CT findings in the number of renal arteries and veins in the rest of the patients.

Discussion

Chronic kidney disease (CKD) continues to cause substantial health burden in terms of mortality and morbidity in India [7], and renal transplantation is the treatment of choice for CKD that offers several advantages [2]. All living renal donors should have a detailed medical evaluation to ensure donor safety, and CT Angiography is the imaging workhorse for their evaluation. CTA shows excellent delineation of renal anatomy, variations and other findings which play a key role in the selection of donors [3]. MDCT can detect accessory arteries, early branching of renal arteries, and renal vein anomalies, with an accuracy of 89–97%, 93–97% and 96–100%, respectively [8].

With the robust use of CTA, the knowledge regarding the risk of radiation and contrast induced nephropathy (CIN) is of prime importance. Though there is no direct evidence to link the radiation received from medical imaging with malignancies, some risk can be associated with even small doses of ionizing radiation. Hence, minimizing dose according to the ALARA principle becomes essential. And with the increased usage of iodinated CM in CTA, the apprehension of the risk of CIN is also

Table 5 Comparison of two CTA protocols (significant *p* value less than 0.05)

Groups		*N*	Mean	SD	*t* value	*p* value
Contrast volume	Group A	30	60.0	0.0	18.310	0.0005
	Group B	30	31.5	7.0		
Aorta HU	Group A	30	386.4	64.8	4.005	0.0005
	Group B	30	313.2	49.9		
RR mean	Group A	30	315.9	43.3	2.051	0.047
	Group B	30	287.1	45.4		
LR mean	Group A	30	320.9	49.2	2.413	0.021
	Group B	30	284.4	46.5		
Psoas mean	Group A	30	53.4	3.5	0.528	0.600
	Group B	30	54.4	7.2		
SD mean	Group A	30	8.0	2.0	3.819	0.0005
	Group B	30	13.6	6.3		
CTDIvol	Group A	30	8.3	0.8	5.155	0.0005
	Group B	30	6.0	1.8		
DLP	Group A	30	266.4	25.9	5.155	0.0005
	Group B	30	192.5	58.7		
ERD	Group A	30	4.0	0.4	5.155	0.0005
	Group B	30	2.9	0.9		
RR + LR mean	Group A	30	318.4	45.0	2.281	0.028
	Group B	30	285.7	45.5		
SNR	Group A	30	42.8	13.7	4.456	0.0005
	Group B	30	25.1	11.3		
CNR	Group A	30	35.6	12.0	4.531	0.0005
	Group B	30	20.2	9.3		

increased [9]. The incidence of CIN is dependent on the volume of CM used in CECT examinations as shown by literature [9–11]. Therefore, while maintaining the diagnostic image quality, it is also essential to reduce the radiation dose and CM amount during the CTA evaluation of prospective donors.

Dual-energy and turbo flash modes were used in this study to acquire the images. In Third-generation dual-source CT (DSCT) scanners, two tubes operate at different kVp in dual-energy mode. The DECT images have been increasingly used in renal imaging for preoperative workups, evaluation of vascular pathology, and oncological evaluation [12].

Turbo flash mode is a high pitch mode in dual-source scanners, in which ultrafast acquisition of images is possible. In this, both sources operate at the same kVp, and the table accelerates up to 737 mm/s depending on the selected pitch (1.5–3). The gantry rotation time of 0.25 s is the additional factor that helps acquire the images faster in third-generation Dual-source CT.

Image quality analysis

The objective analysis of image quality in this study was based on the attenuation of AA and both renal arteries. The difference in mean attenuation of both renal arteries and AA among the two groups, as well as the differences in CNR and SNR was statistically significant, with higher values in group A. But the subjective analysis showed that there was no statistical significance between two groups, suggesting comparable imaging quality between two groups. Though a comparable CNR, SNR could not be achieved in group B, possibly due to increased noise in TurboFlash mode [13]. MIP, cMPR and VR images demonstrated a fairly good diagnostic assessment and helped in risk stratification of donors (Figs. 3, 4). Also, known drawbacks of high pitch CT scanners like helical artefacts were not seen in any of the cases.

Radiation dose analysis

Third-generation dual-source CT (DSCT) scanners have different tools for radiation dose reduction [14]. An important technique is automated tube current modulation (Care dose 4D in Siemens) which utilizes scout image taken before the actual scan to estimate which region requires greater/lesser radiation doses; and based on the attenuation values acquired, the tube current can be modulated to deliver the appropriate doses to that particular region [15].

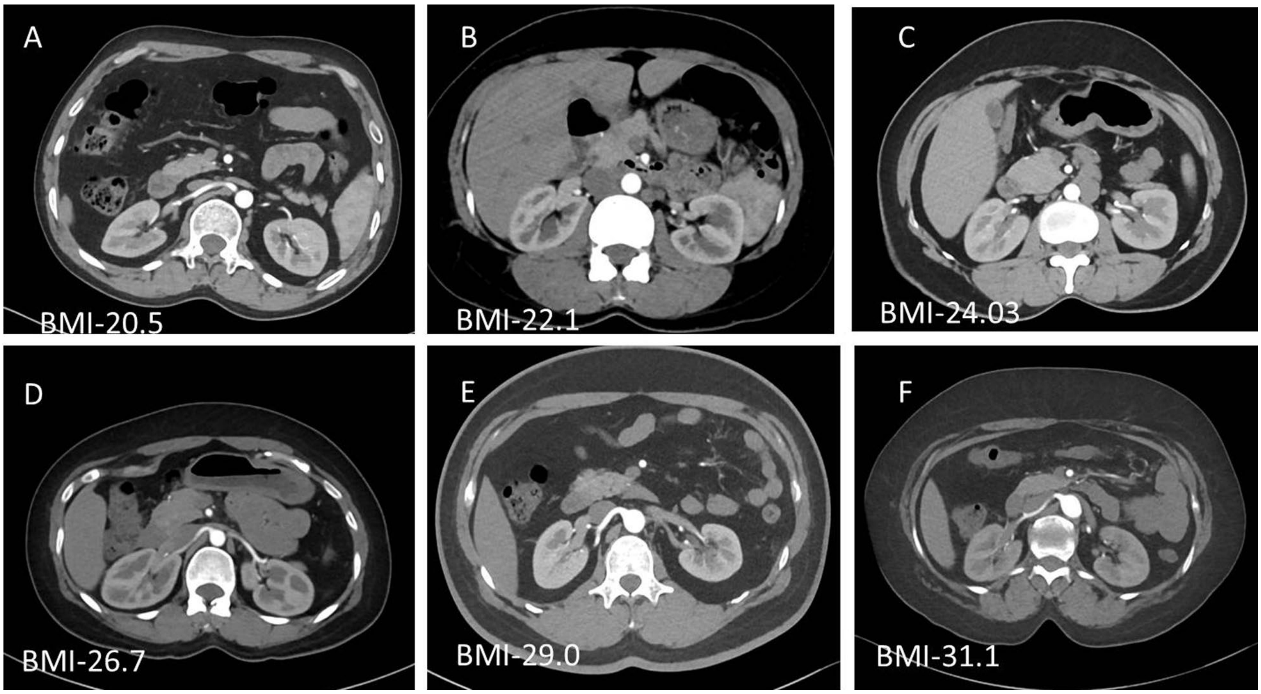

Fig. 3 Axial images of contrast enhanced CT renal angiography performed in Turbo Flash mode at renal level in patients with varying body mass index (BMI) show good image quality

Few other methods include reduction in the tube voltage (kVp), tube current (mA), use of different noise filters to process the images during reconstruction, modifying the reconstruction algorithms, and shielding the patient. The ability to create virtual non-enhanced data sets and to minimize image acquisition in the classic triple phase protocol renders DECT a helpful tool in further decreasing the radiation dose [16]. Davarpanah et al. have shown by reducing tube voltage current from 120 to 80 kV there is a significant reduction in radiation that also improved the SNR and CNR [17]. We had also replaced excretory phase acquisition by conventional radiography to further reduce the dose to the patient.

Another important technique is using high pitch, which can be performed by Turbo Flash mode in a third-generation DSCT, which can also perform extremely fast scans.

Because of its improved temporal resolution and faster overall acquisition times, Turbo Flash can decrease cardiac and respiratory motion related artefacts [18, 19]. It can also result in lower radiation dose to patients, according to Sommer et al. [20].

Similar results were obtained in our study, with lower mean CTDIvol, DLP and ERD in Turbo Flash mode, and an overall radiation dose reduction of approx. 32%. These results are in accordance with the previous similar study by Pang et al. [21] where there was a dose reduction of 38%.

Contrast media volume analysis

The incidence of CIN is dependent on the volume of CM, hence the reduction in CM is vital to reduce CIN risk. Adjusting CM volume to the patient's weight is a simple, robust, and widely used method for individually tailoring CM injection protocols [22].

According to Sodagari et al., 30 ml of iodinated contrast was effective in producing diagnostic quality images in 20 patients with chronic renal insufficiency who underwent high-pitch abdominopelvic (AP) CTA on a third-generation dual-source CT scanner [23]. In our study, with administration of 0.5 ml/kg of contrast media in the high pitch group, there was a reduction in contrast media by 47.5% when compared with conventional protocol using 1 mL/kg.

Limitations

- The contrast opacification was enough for diagnostic information but failed to give supportive objective evidence in our study.

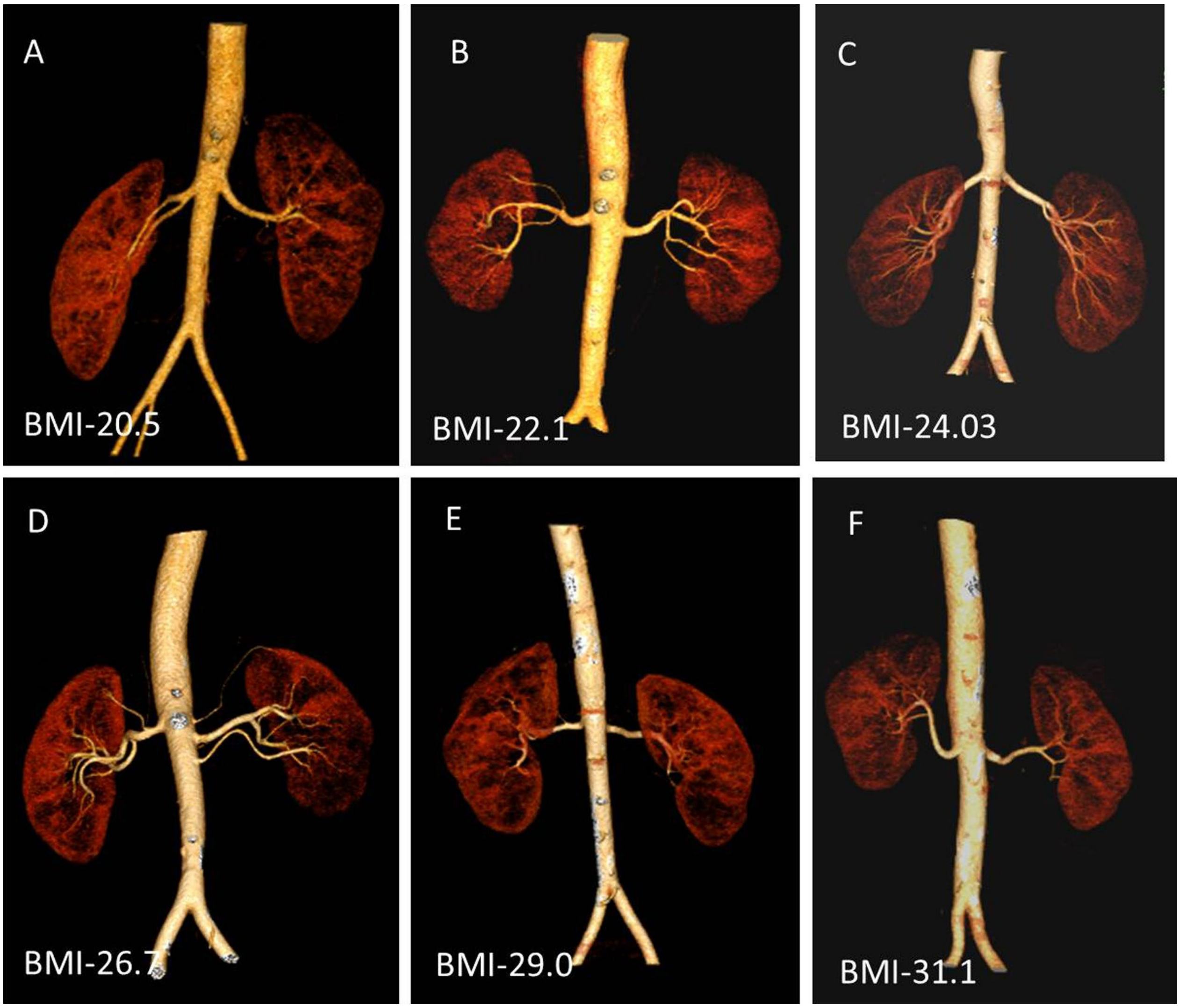

Fig. 4 VRT images of contrast enhanced CT renal angiography performed in Turbo Flash mode in patients with varying body mass index (BMI) show acceptable image quality

- Although promising, this study requires further standardization and future research before application into daily routine practice for solid results.
- Larger sample studies are required to validate the results in this study and to evaluate the smaller renal and accessory arteries.
- Being a novel technique, this lacks standardization with appropriate scanning parameters with respect to the patient's body habitus and CTA methodology. In patients with BMI > 27, increased image noise and less clarity of the small vessels in 3D VR images were noticed.

Conclusions

To the best of our knowledge, this is the first study where CT renal angiography was done using Turbo Flash mode on a third-generation scanner. In our study, the images from Turbo Flash mode demonstrated diagnostic information with delineation of vascular anatomy and their variants. Decreased radiation dose and contrast media volume reduction was also observed, which can be recommended for screening of voluntary kidney donors, but needs further larger clinical studies with tailored protocols. Due to an increase in apprehension regarding side effects of contrast media, new techniques that favour less contrast dose with preservation of diagnostic information should be encouraged. Though there are some limitations to Turbo Flash protocol, with proper standardization and further validation of this technique, this technology would have far reaching applications in medical imaging in near future.

Abbreviations
CKD: Chronic kidney disease; CTA: Computed tomographic angiography; MDCT: Multidetector CT; CTDI: Computed tomography dose index; DLP: Dose length product; CNR: Contrast to noise ratio; SNR: Signal to noise ratio; ROI: Region of interest; CM: Contrast media; MIP: Maximum intensity projection; MPR: Multiplanar reconstruction; VR: Volume rendered; S.D: Standard deviation, noise; ERD: Effective radiation dose; RR: Right renal; LR: Left renal.

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Author contributions
NC, GP, VKA, VP contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. RR, SR, PM, MC helped in reviewing the manuscript. All authors read and approved the final manuscript.

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Availability of data and material
The datasets generated and/or analysed during the current study are not publicly available for maintain the anonymity but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Have got Ethics committee approval (EC/AP/753/09/2019) from KMCH Ethics committee, Kovai Medical Centre and Hospital limited. Written consent was obtained from the participants during the study.

Consent for publication
We have put images that maintain the anonymity of the participants involved. Written consent to publish this information was obtained from study participants.

Competing interests
The authors declare that they have no competing interests.

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