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Ray sum image: its efficacy in renal tract calculus detection

S. Deb [a,*], Z. Lu [b,c], A. Kuganesan [a], K.K. Lau [a,c]

[a] *Department of Diagnostic Imaging, Monash Health, Victoria, Australia*
[b] *Monash Pathology, Monash Health, Victoria, Australia*
[c] *Faculty of Medicine, Nursing and Health Sciences, Monash University, Victoria, Australia*

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AIM: To determine the efficacy of a ray sum image derived from computed tomography of the kidneys, ureters and bladder (CT KUB) in detecting renal tract calculi and whether this can replace the baseline abdominal radiograph (AXR).

MATERIALS AND METHODS: This is a retrospective study performed at a tertiary referral centre examining adult patients referred for urolithiasis who had undergone AXR within 24 hours of the diagnostic CT KUB. AXR and ray sum image for calculus visibility were reviewed blindly by two readers. Anteroposterior thickness of the patient, presence of excess gas/faecal material, calculus size, location, and mean attenuation were analysed to determine effect on the AXR and ray sum sensitivity.

RESULTS: One hundred and fifty-two calculi were examined with ray sum image sensitivity of 44% (95% confidence interval [CI]: 36–52) and AXR 30% (95% CI: 22–38). Calculus size and mean attenuation significantly affected sensitivities of both ray sum and AXR. There was substantial agreement between the two techniques with κ(Kappa)=0.70 (95% CI: 0.58–0.81, $p<0.001$).

CONCLUSION: Ray sum image as a post-processed image derived from CT KUB dataset may be a viable alternative to the baseline AXR in patients with CT proven urolithiasis. This would reduce patient radiation dose and streamline workflow in busy radiology and emergency departments.

Introduction

Urolithiasis is a common emergency department presentation with an incidence of 10–15%.[1–3] The reference standard for investigation of renal colic is unenhanced computed tomography (CT) of the kidneys, ureters, and bladder (KUB)[2,4]; however, once urolithiasis is confirmed on CT, a baseline abdominal radiograph (AXR) is often requested by the urologist or emergency physician.[2,4–8] The role of this baseline AXR is twofold: firstly, to establish whether the calculus seen on CT is opaque on plain film, and secondly, if opaque, to serve as a guide for treatment planning and comparison for future AXRs which may be performed in order to monitor the progress of calculi.[2,6,7,9] The timing and whether a baseline AXR is performed at all differs amongst institutions. It has been stated in one guideline that the baseline AXR should be performed on the

* Guarantor and correspondent: S. Deb, 246 Clayton Road, Clayton, VIC, 3168, Australia. Tel.: +61 4 31040801.
E-mail address: Smita.Deb@monashhealth.org (S. Deb).

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same day as the CT once a diagnosis of renal calculi has been established; however, other guidelines state the AXR may be helpful for comparison without providing a definitive guide on timing.[7,8] Although, low-dose CT KUB has become commonplace in investigating renal colic, it is still a higher cost technique with increased radiation dose when compared to plain radiography; the CT dose ranges from 1.9–3.5 mSv whereas that of AXR is 0.7–1 mSv.[3,10] Thus, repeat imaging with CT leads to increased radiation burden in patients for whom this is often a recurrent disease process requiring repeat imaging for investigation.[1,7,10] Reducing the number of redundant ionising radiation studies performed on this group of patients is cost-effective and reduces the overall radiation burden.

The calculus detection sensitivity of AXR varies and is quoted in the literature as 40–70%.[4,5,9,11,12] Up to 15% of calculi are not plain-film opaque due to stone composition, and visibility is also affected by interposition of stool, bowel gas, presence of other calcifications and bony structures.[4,5,9,11,12] The performance of a baseline AXR after CT KUB requires an extra dose of radiation for patients and previous studies have sought to establish alternatives to the baseline AXR, such as the CT KUB planning image; however, the sensitivity of the CT planning image (17–52%) in detecting urolithiasis is much lower compared to the AXR and is felt to be an unsuitable direct alternative to the baseline AXR.[1–5,9,11] A recent study also examined whether maximum and average intensity projection images derived from thick-section CT KUB data set could replace the baseline AXR; however, these techniques did not show strong agreement with the AXR in detecting calculi.[13]

The present study investigated another possible replacement for the baseline AXR using the ray sum technique. A ray sum image derived from CT is created by casting “rays” through a dataset and adding voxel attenuation coefficients along the paths of the rays, combining to form the resultant image.[14,15] It is a CT post-processing technique and images created using this method appear comparable to a digital radiograph;[14,16,17] however, there is very limited literature regarding this technique. A recent laboratory study compared digital radiography (DR) with ray sum imaging reconstructed from CT with mixed results, indicating that ray sum and DR images were comparable for head and pelvic imaging, but ray sum image being of lower quality for extremity imaging.[18] Clinically, the image processing using the ray sum technique has been studied in the context of thoracic CT angiographic imaging and as a fluoroscopic technique aiding the location of pulmonary nodules during bronchoscopic biopsy in place of conventional X-ray fluoroscopy, with positive results.[16,17] To the authors’ knowledge, utilising an image formed from CT using the ray sum technique has not previously been reported as a possible replacement for the baseline AXR in patients with urolithiasis.

A virtual ray sum image from the CT KUB dataset can be created in a coronal plane with a similar appearance to that of a plain radiograph. The aim of this retrospective study was to determine the efficacy of a ray sum image derived from CT KUB in detecting renal tract calculi. It was hypothesised that this ray sum image will have at least equal sensitivity to that of the baseline AXR as well as good concordance with the AXR, meaning that calculi seen on the AXR will also be visible on the ray sum image.

Materials and methods

This was a retrospective study conducted at a tertiary referral centre with data collected from December 2016 to April 2017. Local ethics approval was obtained. Patients were identified using the hospital‘s picture archiving and communication system (PACS) by using the search term “CT urography”, which at Monash Health is used exclusively for investigating renal tract calculi. All consecutive adult patients with a non-contrast CT KUB, which showed at least one urinary tract calculus, and an AXR within 24 hours of the CT were included in the study. Patients who had the baseline AXR >24 hours after the initial CT or patients whose CT images were significantly degraded by motion or metallic artefacts were excluded. An equivalent number of consecutive adult patients who had a CT KUB in the same period that did not demonstrate renal tract calculi were also included for comparison.

Information regarding patient demographics, anteroposterior (AP) thickness of the patient, presence of excess bowel gas or faecal material, number of renal tract calculi in each patient as well as their location, maximum axial diameter, and mean attenuation were collected. This information was obtained from the CT KUB. The presence of excess bowel gas or faecal material was noted subjectively by the readers involved and was recorded as a binary value (“yes” or “no”).

CT KUB was performed as a low-dose unenhanced study with the patient in the prone position utilising a 256-section multidetector CT system (iPatientiCT, Phillips Healthcare, Cleveland, OH, USA). The CT parameters were similar for all patients: tube voltage of 100 kVp for patients weighing <80 kg and 120 kVp for those >80 kg, modulated automatic exposure control with 91 mAs (100 kVp) and 64 mAs (120 kVp) for a patient of average size, detector collimation of 0.625×128 mm, rotation time of 0.4 ms and pitch of 0.585. The AXR was performed using digital radiography (DR).

A single, coronal ray sum image with section thickness equal to the AP dimension of the patient was created from the fine section CT KUB dataset using a visualisation workstation (IntellispacePortal, ISP6, Philips Healthcare, Cleveland, OH, USA). The ray sum image was not vender specific and a similar resultant image could be produced on all imaging systems and applications as this is a CT post-processing technique which can be incorporated into the routine image post-processing protocol for CT KUB. An edge enhancement filter was applied to sharpen the image, thus creating an image with a similar appearance to a plain radiograph (Fig 1). The total processing time was <1 minute per patient.

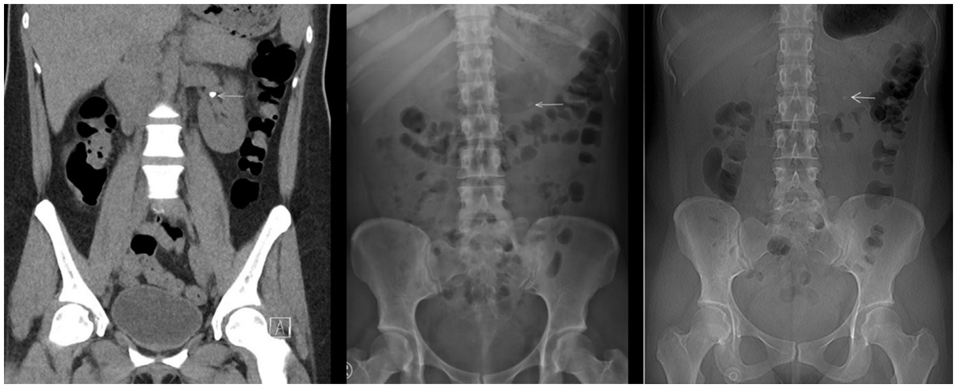

Figure 1 From left to right: CT KUB, AXR, and ray sum image derived from the CT. The ray sum image is comparable to the AXR. This patient has an intra-renal calculus that was visible on all three techniques.

Coronal ray sum and AXR images from patients were de-identified. They were reviewed randomly and independently on PACS by two readers (a senior radiologist with 28 years of abdominal CT and radiography experience and a radiology trainee with 3 years of CT and radiography experience). Adjustments in window width and centre levels were permitted during the image reviewing process.

When the readers were reviewing these ray sum images, they could use direct cross-referencing using the CT KUB to aid in the detection of renal tract calculi. An example of this cross-referencing is demonstrated in Fig 2. The final calculus visibility on the ray sum image was recorded based on the cross-reference finding, as this is the way the ray sum image would be utilised if incorporated into daily reporting. If there was disagreement about calculus visibility, this was re-reviewed jointly by the two readers and a consensus was reached.

Statistical analyses were performed using Microsoft Excel 2007 (enterprise edition) and IBM SPSS Statistics version 23. The sensitivity of the ray sum image in the detection of CT KUB demonstrated renal tract calculus was compared to that of the AXR using one sample test of proportions with a $p<0.05$ as a significant value. The concordance of these two imaging techniques was tested using Cohen's kappa. The kappa scores were interpreted as follows: ≤ 0 = no agreement, 0.01–0.20 = slight, 0.21–0.40 = fair, 0.41–0.60 = moderate, 0.61–0.80 = substantial agreement and 0.81–1.00 = near perfect.[19] Logistic regression analyses were performed to identify whether any patient (age, gender, AP thickness, or presence of excess faecal material/gas) or calculi factors (size, location or mean attenuation) affected the visibility of calculi on either AXR or the ray sum image with cross-referencing.

Results

In the control group of 50 adult patients who did not have renal tract calculi on CT KUB, no false-positive calculi

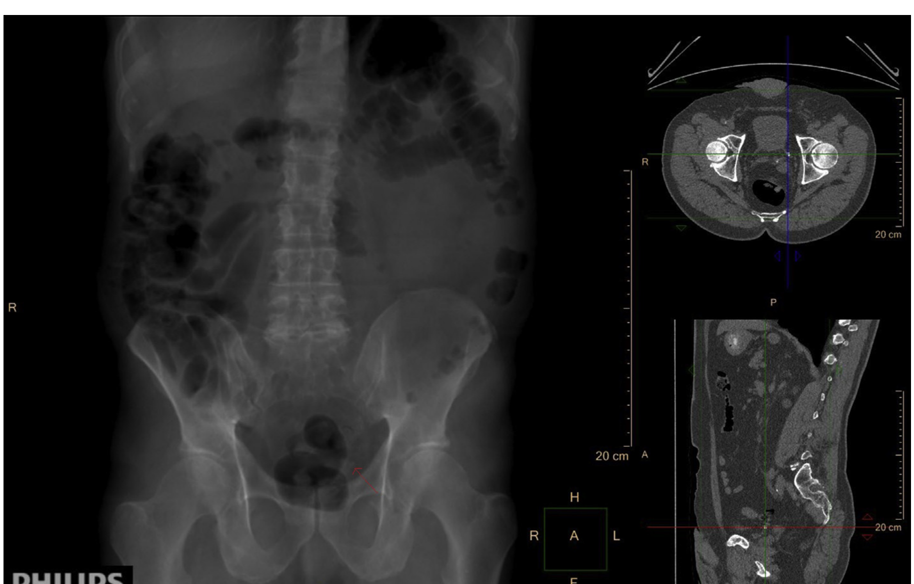

Figure 2 Direct CT cross-referencing allows confident detection of this left distal ureteric calculus on the ray sum image.

were reported on the ray sum images created for this group (100% specificity). A total of 50 out of 353 consecutive adult patients (14%) had renal tract calculi on the CT KUB during the study period who also had AXR performed within 24 hours of the CT. One patient was excluded due to motion artefact and 302 patients excluded as the baseline AXR was performed >24 hours after the CT KUB or a baseline AXR was not performed at all in these patients.

One hundred and fifty-two (n=152) CT KUB demonstrated renal tract calculi from 50 patients were examined in the study. The patient demographic information is shown in Table 1. The majority of calculi were located in the kidneys (68.4%), distal ureter (9.9%) or the vesico-ureteric junction (9.9%; Table 1). Forty-eight calculi (31.6%) were ≥5 mm in size.

Of the 152 CT KUB demonstrated calculi, the sensitivity of the AXR in detecting calculi was 30% (95% CI: 22–38; Fig 3). The sensitivity of the ray sum image with the aid of direct CT cross-referencing was 44% (95% CI: 36–52; $p<0.001$). Concordance between the ray sum image with cross referencing and AXR were found with 130 calculi: 45 visible on both and 85 invisible on both techniques (Table 2). Cohen's kappa score showed that the ray sum image and AXR had substantial agreement ($\kappa=0.70$; 95% CI: 0.58–0.81; $p<0.001$). Twenty-two (14%) calculi were detected on the ray sum images, but not on the AXR (Table 2). Importantly, there were no calculi visible on the AXR and invisible on the ray sum image.

Logistic regression analyses demonstrated that patient factors such as age, sex, AP thickness, and presence of excess gas/faecal material did not significantly affect the sensitivity of either the AXR or ray sum image in detecting renal tract calculi (Model 1, Table 3); however, calculus visibility on both techniques were positively associated with increasing size and mean attenuation of the calculi (Model 2, Table 3).

Discussion

A ray sum image can be easily created from the CT KUB dataset on the modern CT workstation, which requires no more than an extra minute of processing time. Furthermore, this technique does not require an extra dose of radiation and the ray sum image has a similar appearance to a plain radiograph.

In the current study, the sensitivity of the ray sum image in detecting renal tract calculi with direct CT cross-referencing was demonstrated to be higher than the AXR (44% versus 30%), with the same factors impacting the sensitivity of each technique, namely calculus size and mean attenuation (Table 3). Substantial agreement in the detection of renal tract calculi was seen between the two techniques, as demonstrated by the kappa score of 0.70. When a calculus was visible on the AXR in this study, visibility was also confirmed on the ray sum 100% of the time, and if a calculus was invisible on the AXR it was also invisible on the ray sum image 79% of the time (85/107), as displayed in Table 2. Only 22 discordant results (14%) were found where the calculus was detected on the ray sum image but not on the AXR (Table 2). This may be explained by the timing difference between the AXR and CT (and therefore, the resultant ray sum image) as the plain radiograph is normally requested by the clinician after urolithiasis has been confirmed on the CT. Thus, the calculus may have migrated or passed completely after the CT was performed. Additionally, the patient's posture, degree of inspiration, and bowel position are likely to be different between CT and AXR due to the timing difference and patient positioning; the AXR was routinely performed supine, whereas the ray sum image was derived from the CT, which was often performed prone.

Use of the ray sum technique has significant advantages. As the ray sum image is a post-processed image created

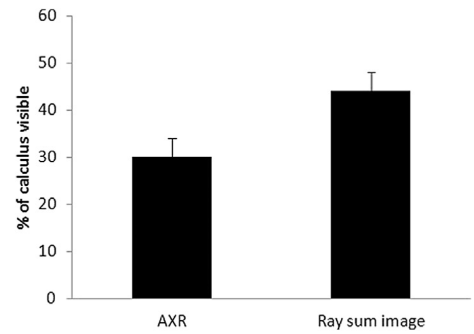

Figure 3 Data represents mean (bars) and standard deviation (lines) of the sensitivity of the AXR (30%) and ray sum image (44%) in the detection of renal tract calculi. The values for the sensitivity of ray sum image were obtained with the aid of direct CT cross-referencing.

Table 1
Data for patient demographics in both calculus positive and calculus negative groups as well as calculi characteristics are as displayed.

Patient demographics		Positive		Negative
Mean age (years)		49		52
Male sex		43 (86%)		26 (52%)
Mean patient thickness (cm)		24.0		–
Presence of multiple calculi		30 (60%)		–
Renal tract calculi characteristics	**Mean**	**Median**	**Min**	**Max**
Largest axial diameter (mm)	3.8	3.0	0.5	26
Mean attenuation (HU)	552	478.5	99	1657
Location				
Proximal ureter	11 (7.2%)			
Mid ureter	5 (3.3%)			
Distal ureter	15 (9.9%)			
Pelvi-ureteric junction	1 (0.7%)			
Vesico-ureteric junction	15 (9.9%)			
Intra-renal	104 (68.4%)			
Bladder	1 (0.7%)			

Table 2
Comparison of calculus visibility on ray sum image to abdominal X-ray (AXR).

	Ray sum visible	Ray sum invisible	Total
AXR visible	45	0	45
AXR invisible	22	85	107
Total	67	85	152

Cross tabulation comparison of calculus visibility on both AXR and the ray sum image with cross referencing. Total number of calculi included in the study was 152.

Table 3
Variables affecting sensitivity of renal tract calculus detection on ray sum image and AXR.

	Ray sum image			AXR		
	OR	95% CI	*p*-Value	OR	95% CI	*p*-Value
Model 1: patient factors						
Age	0.99	0.97–1.02	NS	0.99	0.96–1.02	NS
Sex	0.60	0.17–2.06	NS	0.62	0.18–2.14	NS
AP thickness	1.00	0.91–1.10	NS	1.04	0.94–1.14	NS
Excess gas/faecal material	0.51	0.21–1.21	NS	0.48	0.17–1.32	NS
Model 2: Model 1 + calculi factors (location, size and mean attenuation)						
Age	0.98	0.94–1.02	NS	0.97	0.94–1.01	NS
Gender	0.40	0.05–3.15	NS	1.19	0.22–6.45	NS
AP thickness	1.03	0.88–1.20	NS	1.14	1.00–1.31	NS
Excess gas/faecal material	0.52	0.11–2.45	NS	0.55	0.14–2.26	NS
Calculus location (categorical)	–	–	NS	–	–	NS
Size	2.36	1.54–3.61	<0.001	1.25	1.05–1.50	0.015
Mean attenuation	1.002	1–1.004	<0.001	1.003	1.001–1.005	<0.001

Odds ratios, confidence intervals, and *p*-values regarding calculus visibility on ray sum image with cross referencing and AXR for patient factors (age, gender, AP thickness, presence of excess gas/faecal material) and calculi factors (location, largest axial diameter and mean attenuation).
Model 1: patient factors only; Model 2: Model 1 with addition of calculi factors.
NS, not significant.

from the original CT dataset, there is no additional radiation dose to the patient. Without the requirement of a dedicated base-line plain AXR, this helps streamline workflow in busy radiology and emergency departments with a simultaneous reduction in the patient radiation burden. This also eliminates the difference in timing between initial CT and baseline AXR, allowing both CT and ray sum image to be reported concurrently. Furthermore, direct CT cross-referencing can also be employed with the ray sum image to increase calculus visibility, which would be another factor that improves its calculus detection over the AXR. Cross-referencing is also particularly helpful in differentiating renal tract calculi from other intra-abdominal or pelvic calcifications, thus providing a guide for interpretation on any follow-up AXR and resulting in more confident calculus detection by the readers.

Limitations of this study include the relatively small patient number and the inclusion of a large number of smaller intra-renal calculi, which are felt to have decreased the overall sensitivity rate for both AXR and the ray sum image. As previously mentioned, there has been no consensus amongst physicians and urologists on the timing of the baseline AXR. This was also felt to have contributed to the relatively low number of patients included in the study, despite a large number of "positive" CT KUB identified during the study period. The timing difference between the AXR and CT examinations affects the true comparability of the AXR and ray sum image, as previously described.

In conclusion, the post-processed ray sum image created from the CT KUB dataset has been shown to have good concordance with the AXR in detecting renal tract calculi, with similar factors affecting their sensitivity. The ray sum technique, which can be easily performed on modern CT workstations, may replace the routinely performed baseline AXR in patients with CT KUB proven urolithiasis. This reduces patient radiation burden and aids in streamlining imaging protocol and workflow.

Conflicts of interest

The authors declare no conflict of interest.

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