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A prospective, matched comparison of ultra-low and standard-dose computed tomography for assessment of renal colic

Matthew J. Roberts*,†,‡, Julia Williams§, Sam Khadra*, Sunny Nalavenkata*, Jonathan Kam*, Steve P. McCombie*, Mohan Arianayagam*, Bertram Canagasingham*, Richard Ferguson*, Mohamed Khadra*,†, Celi Varol*, Matthew Winter*, Fardin Sanaei§, Han Loh†,§, Yogesh Thakkar§, Piers Dugdale§ and Raymond Ko*,†

*Nepean Urology Research Group, Kingswood, †Discipline of Surgery, Nepean Clinical School, Faculty of Medicine and Health, University of Sydney, Sydney, NSW, ‡Faculty of Medicine, The University of Queensland, Brisbane, Qld, and §Department of Medical Imaging, Nepean Hospital, Kingswood, NSW, Australia

Objective

To determine the diagnostic accuracy of ultra-low-dose computed tomography (ULDCT) compared with standard-dose CT (SDCT) in the evaluation of patients with clinically suspected renal colic, in addition to secondary features (hydroureteronephrosis, perinephric stranding) and additional pathological entities (renal masses).

Patients and methods

A prospective, comparative cohort study was conducted amongst patients presenting to the emergency department with signs and symptoms suggestive of renal or ureteric colic. Patients underwent both SDCT and ULDCT. Single-blinded review of the image sets was performed independently by three board-certified radiologists.

Results

Among 21 patients, the effective radiation dose was lower for ULDCT [mean (SD) 1.02 (0.16) mSv] than SDCT [mean (SD) 4.97 (2.02) mSv]. Renal and/or ureteric calculi were detected in 57.1% (12/21) of patients. There were no significant differences in calculus detection and size estimation between ULDCT and SDCT. A higher concordance was observed for ureteric calculi (75%) than renal calculi (38%), mostly due to greater detection of calculi of <3 mm by SDCT. Clinically significant calculi (≥3 mm) were detected by ULDCT with high specificity (97.6%) and sensitivity (100%) compared to overall detection (specificity 91.2%, sensitivity 58.8%). ULDCT and SDCT were highly concordant for detection of secondary features, while ULDCT detected less renal cysts of <2 cm. Inter-observer agreement for the ureteric calculi detection was 93.9% for SDCT and 87.8% for ULDCT.

Conclusion

ULDCT performed similarly to SDCT for calculus detection and size estimation with reduced radiation exposure. Based on this and other studies, ULDCT should be considered as the first-line modality for evaluation of renal colic in routine practice.

Keywords

computed tomography, renal colic, urolithiasis, ultra-low-dose CT

Introduction

Renal colic is a common presentation to emergency departments and a significant source of morbidity worldwide [1]. Diagnosis is often suggested on clinical grounds requiring confirmation using imaging, most commonly with non-contrast CT [2]. For ureteric calculus detection, CT has high specificity (97%) and sensitivity (95%), and is more accurate than ultrasound (specificity 84–100%, sensitivity 19–93%) [3]. Non-contrast CT has become the standard imaging modality used [2], despite variability in recommendations by international guidelines [4].

CT is associated with radiation exposure, with standard-dose non-contrast CT (SDCT) estimated to be 4.5–5 mSV [2]. Associated deterministic and stochastic effects may result in adverse consequences, including development of fetal anomalies or loss during pregnancy, as well as malignancy later in life [5]. Much effort has been expended to reduce radiation exposure, including use of ultrasound in randomised trials [1]. Another approach is use of low-dose

CT (<3–3.5 mSv) or ultra-low-dose CT (ULDCT, <1–1.9 mSv), which affords lower dose radiation equivalent to plain film (0.5–1 mSv) with the accuracy and localisation of cross-sectional imaging [6–8]. While the European Association of Urology (EAU) guidelines stipulate low-dose CT to be the first choice for detection of ureteric calculi [2], the performance and benefit from routine adoption in clinical practice are unclear.

The aim of the present study was to determine the diagnostic accuracy of ULDCT compared with SDCT in the evaluation of patients with clinically suspected renal colic, in addition to secondary features and additional pathological processes.

Patients and methods

Design

A prospective, comparative cohort study was conducted at the Nepean Hospital, New South Wales, Australia, over a 3-month period. Consecutive patients were considered for inclusion following presentation to the emergency department with signs and symptoms suggestive of renal or ureteric colic. Exclusion criteria included age <18 years and positive pregnancy test. Informed consent to proceed with both SDCT and ULDCT was obtained prior to proceeding with imaging. Body mass index (BMI) was not prospectively collected and not retrospectively available, so BMI was estimated using the method described by O'Neill et al. [9], who reported good correlation between BMI and imaging measurements (r = 0.88).

The study received ethical approval from the Nepean Blue Mountains Local Health District Human Research Ethics Committee (Approval no. 13/48 – HREC/13/NEPEAN/97).

Imaging

Patients underwent both SDCT and ULDCT using a SOMATOM Definition AS (Siemens Healthcare GmbH, Erlangen, Germany) scanner, using a slice thickness of 2.5 mm. The radiation exposure from the ULDCT was deemed to be similar to a plain abdominal radiograph, which is routinely performed to characterise calculus radiolucency, and thus not have an added radiation exposure risk.

The acquisition parameters and typical values for each approach are outlined in Table 1. The effective dose was calculated according to adjustment described by Christner et al. [10].

Image interpretation and data collection

Single-blinded review of the image sets was performed independently by three board-certified radiologists (F.S., H.L., Y.T.). Each radiologist received two folders, with one folder containing all the SDCT studies and the other containing all the ULDCT studies; all studies were anonymised and ordered at random within the folders. CT image studies were subsequently independently reviewed and reports were issued following a standardised reporting template. This included the assessment of any renal or ureteric calculi (calculus presence, location, size, and number), presence of other features of obstruction including presence of hydronephrosis and perinephric stranding, and presence of any renal parenchymal lesions and alternate pathology. Median values for measurements between radiologist reports were used.

Statistical analysis

Statistical analysis was performed using MedCalc for Windows, version 18 (MedCalc Software, Ostend, Belgium). Categorical variables were compared using Fisher's test and continuous variables using Student's t-test. Inter-observer agreement for ureteric and renal calculus detection between the three radiologists was analysed for both groups using Cohen κ statistics.

Results

Demographics

A total of 21 patients were included in the study; 11 were male and 10 were female, with a mean (SD) age of 53.5 (16.2) years (Table 2). The radiation dose was lower for ULDCT [mean (SD) 68.5 (10.4) mGy·cm] than SDCT [mean (SD) 331.6 (135) mGy·cm], which resulted in estimated mean (SD) effective doses of 1.02 (0.16) mSv and 4.97 (2.02) mSv, respectively (Table 1).

Overall detection

Amongst the 21 included patients, renal and/or ureteric calculi were detected in 12, hydronephrosis without calculus detected in three, diffuse bladder wall thickening in one, and no abnormality detected in five. Three patients had hydronephrosis, specifically including one with hydronephrosis with a 4-mm bladder calculus presumed to be a spontaneously passed ureteric calculus, one with bilateral hydroureteronephrosis with cortical thinning (one), and one with unilateral hydronephrosis with cortical thinning without hydroureter suspicious for PUJ obstruction.

Detection according to diagnostic modality

As outlined in Table 2, patients who underwent SDCT had more calculi (n = 17) detected than those undergoing ULDCT (n = 13). Calculus sizes were similar according to position and imaging modality (P > 0.05), while most ureteric calculi were distal (six of eight SDCT and four of six

Table 1 Comparison of imaging protocols for SDCT and ULDCT scans, including acquisition parameters and radiation dose within the cohort.

	SDCT	ULDCT
Acquisition parameters		
kV	120	120
Tube current, mA, average and max	165	20
Rotation time, s	0.5	0.5
Pitch	0.6	1.4
Collimation (slice width and configuration)	5 mm (64 × 0.6)	5 mm (64 × 0.6)
Radiation dose (DLP), mGy.cm, mean (SD)	331.6 (135.0)	68.5 (10.4)
Estimated effective dose, mSv, mean (SD)	1.02 (0.16)	4.97 (2.02)

Effective dose calculated from the dose–length product (DLP) × 0.015, as described by Christner et al. [10].

Table 2 Comparison of SDCT and ULDCT with respect to calculus detection and size estimates.

Variable	Overall	SDCT	LDCT	P
Gender, M:F, *n* (%)	12:9 (57.1)			
Age, years, mean (SD)	53.5 (16.2)			
Patients	*n*	12	8	0.27
Overall	*n*	17	13	
	Size, mm, median (IQR)	3 (2–6)	4.5 (2.5–6.5)	0.22
Renal	*n*	9	7	
	Size, mm, median (IQR)	2.5 (2–3)	3 (2.5–5.5)	0.26
Ureter	*n*	8	6	
	Size, mm, median (IQR)	4 (2.9–6.5)	5.5 (3–7.25)	0.34

IQR, interquartile range. Hypothesis testing performed using one-sided Student's t-test.

ULDCT) without being significantly different in size ($P > 0.05$).

Concordance in calculus detection

A total of 12 patients (57.1%) within the cohort had renal or ureteric calculi detected. Renal calculi ($n = 9$) were detected in eight patients according to SDCT. Three of the eight patients showed concordant calculus detection without significant differences detected in size between SDCT and ULDCT.

Ureteric calculi ($n = 8$) were detected in eight patients according to SDCT with six patients demonstrating concordant calculus detection with ULDCT (Figs 1,2A,B). Minor discrepancies in calculus size of 0.5 mm between modalities were observed.

Discordance in calculus detection

When renal calculus detection was considered, four renal calculi were missed by ULDCT in four of the eight patients (median calculus size 2 mm, all calculi <3 mm). One patient had two calculi, with the 6-mm calculus being concordant between SDCT and ULDCT, but ULDCT missed a 2.5 mm calculus. The ULDCT detected three calculi (two of 2.5 mm, one of 5 mm) incorrectly, due to vascular calcification misclassification. There was no significant difference in the effective radiation dose between SDCT ($P = 0.92$) and

Fig. 1 Comparison of standard-dose CT (Panels **A**, **C**, **E**) and low-dose CT (Panels **B**, **D**, **F**) imaging for ureteric calculus detection at sizes >3 mm (**A**, **B**) and <3 mm (**C**, **D**); secondary features (hydroureteronephrosis) were detected with both modalities (**E**, **F**).

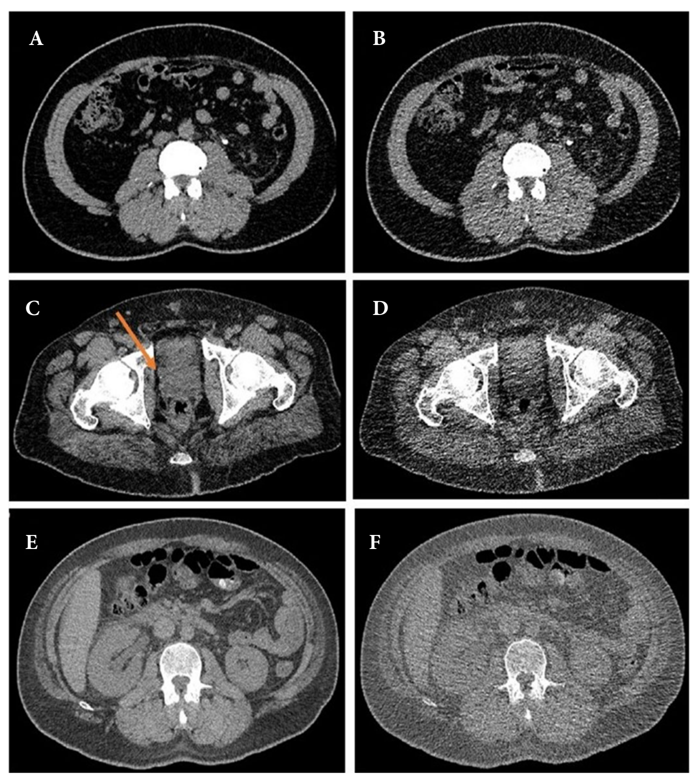
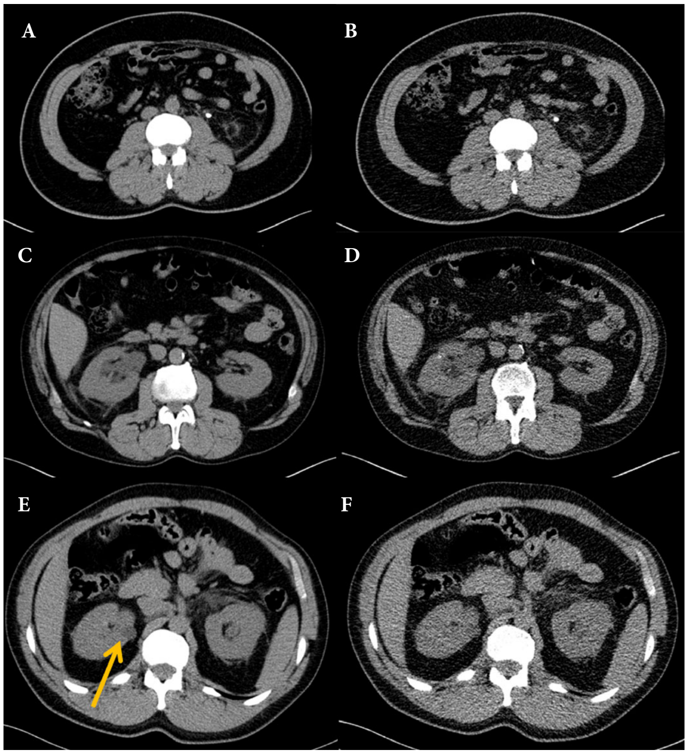


Fig. 2 Comparison of standard-dose CT (Panels **A**, **C**, **E**) and ultra-low-dose CT (Panels **B**, **D**, **F**) imaging to demonstrate difference in imaging quality when assessing for ureteric calculus (**A**, **B**), hydroureteronephrosis (**C**, **D**), and parenchymal lesions (hypodense structure on posteromedial lip of right kidney, arrow; **E**, **F**).



ULDCT (P = 0.46), as well as estimated BMI (P = 0.18) between patients with discordant renal calculus detection and the remaining patients.

For ureteric calculus detection, two of the eight patients showed discordant findings on ULDCT due to failure to detect calculi of <3 mm on ULDCT (median size 2.25 mm; Fig. 1C,D). However, both of these patients had hydronephrosis, as well as an associated higher effective radiation dose for SDCT (P < 0.001) and ULDCT (P < 0.005), but similar calculated BMI (P = 0.29). No differences in discordance between renal and ureteric calculi were identified (P = 0.1).

The overall diagnostic performance for ULDCT compared to SDCT is presented in Table 3.

Secondary features

A high concordance rate was seen for hydronephrosis (100%) and stranding (83%). Hydroureter was concordant in nine of 12 patients (five positive, four negative; Fig. 2C,D), with three patients having hydronephrosis and stranding without hydroureter (two patients with ureteric calculi, one patient without calculus). When combined with secondary features, diagnostic accuracy of overall calculus detection was high (sensitivity 87.5%, specificity 100%, negative predictive value 94.1%, positive predictive value 95.6%) for ureteric calculi.

Parenchymal lesions

The SDCT detected nine parenchymal lesions in seven patients, of which all were described as cysts. Lesion concordance was achieved for four lesions (size range 1–2.5 cm), while five lesions (size range 1–1.5 cm; Fig. 2E,F) and a case of diffuse bladder thickening were missed on ULDCT. Among patients with lesions detected on SDCT (n = 7), SDCT detected significantly more lesions than ULDCT (P = 0.015); however, among all 21 patients no significant difference was observed (P = 0.36).

Inter-observer agreement

Inter-observer agreement for the detection of ureteric calculi was noted between the three senior radiologists of 93.9% for SDCT and 87.8% for ULDCT.

Clinical outcomes

Among the eight patients with ureteric calculi, four underwent cystoscopic placement of ureteric stent [mean (SD) size 6.75 (1.5) mm, position: two distal, two proximal] during the index admission. Another patient whose 2-mm calculus was reported to be in the bladder or vesicoureteric junction on both ULDCT and SDCT with associated hydroureteronephrosis and perinephric stranding, presented to the emergency department 2 days after the index presentation and was managed conservatively. Excluding patients who had stents placed during their index admission, no other related presentations or re-operations were required within 6 months following index presentation.

Discussion

In the present study, the diagnostic performance of ULDCT was evaluated relative to SDCT for ureteric and renal calculus detection, as well as secondary features (hydroureteronephrosis and perinephric stranding) and pathologies (renal masses). There were no significant differences overall between ULDCT and SDCT for the calculus detection rate or size estimation. A significantly greater concordance was seen for detection of ureteric compared to renal calculi due to the failure of ULDCT to detect calculi of <3 mm. Detection of secondary features was similar between modalities and highly accurate overall, while SDCT detected more parenchymal lesions due to improved detection of lesions of <2 cm.

Overall, we found that ULDCT resulted in equivalent diagnostic accuracy as SDCT for clinically significant calculi,

Table 3 Diagnostic test evaluation of LDCT compared to SDCT for calculus detection ('per calculus').

	Overall		Renal		Ureteric	
	Overall	Size ≥3 mm	Overall	Size ≥3 mm	Overall	Size ≥3 mm
Sensitivity, %	58.8	100	44.4	100	75	100
Specificity, %	91.2	97.6	83.3	95.8	100	100
PPV, %	76.9	85.7	57.1	75	100	100
NPV, %	81.6	100	75	100	88.9	100

NPV, negative predictive value; PPV, positive predictive value.

being >3 mm, with 100% sensitivity and 100% specificity. This performance is in keeping with the EAU guidelines and other studies [8,11]. We estimated a considerable difference in radiation exposure between ULDCT (1.02 mSv) and SDCT (4.97 mSv). Both diagnostic accuracy and difference in effective radiation doses were similar to meta-analytical data, which reported a pooled sensitivity of 95.2% ((95% CI 93.7–96.4%) and specificity of 96.9% (95% CI 05.5–98%), as well as mean effective radiation doses of 2.1–4.5 mSv for SDCT and 0.48–1.9 mSv for ULDCT [8]. Our present findings are similar to a contemporary study using ULDCT from California, USA [mean (SD) effective radiation dose 1.04 (0.41) mSv, 42% calculus detection rate], where ULDCT was used as the 'gold standard' [12]. Cumulative radiation exposure is an important consideration in diagnostic imaging for renal colic, particularly for recurrent-calculus formers [2]. Thus, we support the routine use of low-dose CT or ULDCT in patients with clinical features consistent with renal colic, as supported by the EAU guidelines and other studies [2,4].

Furthermore, we found that detection of secondary features of ureteric calculi with obstruction (hydronephrosis, hydroureter, perinephric fat stranding) afforded 100% accuracy. The ureteric calculi not detected by ULDCT ($n = 2$) were 2-mm distal ureteric calculi with a high likelihood of spontaneous passage (Fig. 1) and required more radiation on each modality without a significant difference in BMI to the remaining patients. Thus, where features are present without a calculus identified, routine management on the basis of a small (<3 mm) calculus may be appropriate in the absence of contraindications. This is supported by the clinical outcomes observed in the present study, with ureteric stenting required for large calculi [mean (SD) size 6.75 (1.5) mm], with only one further re-presentation that was conservatively managed. If further imaging was desired, selective use of ultrasonography, which can be highly accurate in characterising distal calculi without additional radiation, or SDCT could be considered according to clinician discretion. In a high-risk clinical scenario (e.g. fever/sepsis, renal failure, solitary kidney etc.), clinicians should preferentially use SDCT for optimal clinical decision-making and to limit treatment delay.

Limitations in missing additional parenchymal lesions demonstrated by ULDCT (18.1%) vs SDCT (45.4%) are unlikely to be clinically significant [13], as those lesions that were missed were described as cysts of <2 cm (Fig. 2E,F). This is in keeping with common descriptions that CT detects more incidental findings than ultrasound, with rates as high as 14% [13]. Other potentially missed pathology with ULDCT includes urothelial neoplasms; however, these can be characterised with dedicated CT urography after appropriate risk stratification [14]. With further multidisciplinary studies on this topic [15], ultimately radiomics and artificial intelligence may improve diagnosis rates and accuracy of ULDCT, as has been observed for distinguishing ureteric calculi from phleboliths [16].

The limitations of the present study include the sample size, which was the result of the 3-month study duration, limited statistical power in assessing outcome comparisons between the SDCT and ULDCT groups, as well as prevalence estimates of additional pathology, such as parenchymal lesions. As the diagnostic accuracy estimates for ureteric calculi are similar to that reported in the EAU guidelines based on other studies, no significant changes in characterisation of calculus detection would be expected with a greater sample size. Furthermore, the high proportion of scans negative for urolithiasis (41%) limits detailed analysis of those with confirmed urolithiasis; however, this proportion is lower than that observed in large, randomised studies (65.5–68.8%) [1]. The absence of prospective BMI calculation and requirement for BMI estimation based on imaging and radiation dose variables limits the accuracy and applicability of this as a consideration; however, does provide an indication for the reader as to the influence of BMI in the present study. Additional limitations include calculus density estimation with ULDCT vs SDCT, with paradoxical increase in Houndsfield unit overall with variation in density estimates reported previously [17].

Conclusion

ULDCT performs similarly to SDCT for calculus detection and size estimation with reduced radiation exposure. Detection of secondary features was similar between modalities and highly accurate overall, while SDCT detected more parenchymal lesions due to improved detection of lesions of <2 cm. It is relatively straightforward for most CT scanners to be used for ULDCT [7] and, based on the present and other studies, ULDCT should therefore be considered as the first-line modality for evaluation of renal colic in routine practice.

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Conflicts of interest

None to declare.

References

1 **Smith-Bindman R**, **Aubin C**, **Bailitz J et al.** Ultrasonography versus computed tomography for suspected nephrolithiasis. *N Engl J Med* 2014; 371: 1100–10

2 **Turk C**, **Petrik A**, **Sarica K et al.** EAU guidelines on diagnosis and conservative management of urolithiasis. *Eur Urol* 2016; 69: 468–74

3 **Niemann T**, **Kollmann T**, **Bongartz G**. Diagnostic performance of low-dose CT for the detection of urolithiasis: a meta-analysis. *AJR Am J Roentgenol* 2008; 191: 396–401

4 **Brisbane W**, **Bailey MR**, **Sorensen MD**. An overview of kidney stone imaging techniques. *Nat Rev Urol* 2016; 13: 654–62

5 **Valovska M-TI**, **Pais VM Jr**. Contemporary best practice urolithiasis in pregnancy. *Ther Adv Urol* 2018; 10: 127–38

6 **Rob S**, **Bryant T**, **Wilson I**, **Somani BK**. Ultra-low-dose, low-dose, and standard-dose CT of the kidney, ureters, and bladder: is there a difference? Results from a systematic review of the literature. *Clin Radiol* 2017; 72: 11–5

7 **Gervaise A**, **Gervaise-Henry C**, **Pernin M**, **Naulet P**, **Junca-Laplace C**, **Lapierre-Combes M**. How to perform low-dose computed tomography for renal colic in clinical practice. Diagnostic and Interventional. *Imaging* 2016; 97: 393–400

8 **Rodger F**, **Roditi G**, **Aboumarzouk OM**. Diagnostic accuracy of low and ultra-low dose CT for identification of urinary tract stones: a systematic review. *Urol Int* 2018; 100: 375–85

9 **O'Neill S**, **Kavanagh RG**, **Carey BW**, **Moore N**, **Maher M**, **O'Connor OJ**. Using body mass index to estimate individualised patient radiation dose in abdominal computed tomography. *Eur Radiol Exp* 2018; 2: 38

10 **Christner JA**, **Kofler JM**, **McCollough CH**. Estimating effective dose for CT using dose-length product compared with using organ doses: consequences of adopting International Commission on Radiological Protection publication 103 or dual-energy scanning. *AJR Am J Roentgenol* 2010; 194: 881–9

11 **Poletti PA**, **Platon A**, **Rutschmann OT**, **Schmidlin FR**, **Iselin CE**, **Becker CD**. Low-dose versus standard-dose CT protocol in patients with clinically suspected renal colic. *AJR Am J Roentgenol* 2007; 188: 927–33

12 **Cheng RZ**, **Shkolyar E**, **Chang TC et al.** Ultra-low-dose CT: an effective follow-up imaging modality for ureterolithiasis. *J Endourol* 2020; 34: 139–44

13 **Khan N**, **Ather MH**, **Ahmed F**, **Zafar AM**, **Khan A**. Has the significance of incidental findings on unenhanced computed tomography for urolithiasis been overestimated? A retrospective review of over 800 patients. *Arab J Urol* 2012; 10: 149–54

14 **Batura D**, **Hashemzehi T**, **Gayed W**. Should contrast CT urography replace non-contrast CT as an investigation for ureteric colic in the emergency department in those aged 65 and over? *Emerg Radiol* 2018; 25: 621–6

15 **Lawrentschuk N**. Urology trial success – get urologists involved early. *BJU Int* 2019; 124: 4

16 **De Perrot T**, **Hofmeister J**, **Burgermeister S et al.** Differentiating kidney stones from phleboliths in unenhanced low-dose computed tomography using radiomics and machine learning. *Eur Radiol* 2019; 29: 4776–82

17 **Pan S**, **Su JJ**, **Syed J**, **Moore C**, **Israel G**, **Singh D**. Reduced dose computed tomography: the effects of voltage reduction on density measurements of urolithiasis. *J Endourol* 2019; 33: 682–6

Correspondence: Matthew J. Roberts, Nepean Urology Research Group, Kingswood, NSW 2747, Australia.

e-mail: m.roberts2@uq.edu.au

Abbreviations: BMI, body mass index; EAU, European Association of Urology; SDCT, standard-dose CT; ULDCT, ultra-low-dose CT.