UROGENITAL

Increased urinary bladder volume improves the detectability of urinary stones at the ureterovesical junction in non-enhanced computed tomography (NECT)

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Abstract

Objectives To evaluate the influence of the urinary bladder volume on the detectability of urolithiasis at the ureterovesical junction (UVJ) using a low-dose CT (LD-CT) with iterative reconstruction (IR) and a standard-dose CT (SD-CT) without IR in a large cohort.

Methods Four hundred patients (278 males (69.5%), mean 44.6 ± 14.7 years) with urolithiasis at the UVJ were investigated either by an LD-CT with IR ($n = 289$, 72%) or an SD-CT without IR ($n = 111$, 28%) protocol. The detectability of distal urolithiasis was assessed by a dichotomous assessment (definite or questionable) by two radiologists in consensus and by a quantitative analysis of the signal density distribution across a line drawn parallel to the distal ureter. Based on the resulting graph, minimum/maximum density values and mean/maximum upslopes and downslopes were derived and calculated automatically. In all patients, the total bladder volume was calculated by a slice-by-slice approach on axial CT images.

Results Patients with definite stones showed significantly higher urinary bladder volumes compared to patients with questionable stones in both LD-CT and SD-CT ($p < 0.01$). These results were independent of stones' length and patients' BMI values. Using cutoffs of 92 ml for LD-CT and 69 ml for SD-CT, high positive predictive values/accuracy rates of 96%/85% (LD-CT) and 98%/86% (SD-CT) were observed to identify definite urinary stones.

Conclusions Urinary bladder volume has a significant impact on the detectability of distal urolithiasis. Moderate bladder filling by pre-CT hydration with subsequent CT scan at the time of high urge to void increases the detectability of urinary stones at the UVJ in clinical routine.

Key Points
• *Urinary bladder volume significantly affects the detectability of distal urolithiasis*
• *Higher bladder volumes are associated with improved detectability of distal urinary stones*
• *Oral pre-CT hydration for urolithiasis is easily applicable and cost-effective*

Keywords Urolithiasis · Radiation dosage · Image reconstruction · Spiral CT · Diagnostic imaging

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Abbreviations

BMI	Body mass index
CT	Computed tomography
DECT	Dual-source CT
DLP	Dose-length product
HU	Hounsfield units
IQR	Interquartile range
IR	Iterative reconstruction
LD-CT	Low-dose CT
NECT	Non-enhanced CT
NPV	Negative predictive value

PPV	Positive predictive value
ROC	Receiver operating curve analysis
SD-CT	Standard-dose CT
TCC	Transitional cell carcinoma
UVJ	Ureterovesical junction

Introduction

Urolithiasis is the most frequent cause of acute flank pain. It shows an increasing incidence and prevalence around the world [1] and is associated with rising healthcare costs [2, 3]. Among the variable locations where ureteral stones may lodge, the ureterovesical junction (UVJ) is one of the most common, ranging from 36 to 61% [4, 5]. Compared with ultrasound, non-enhanced CT (NECT) provides a higher diagnostic yield in the detection of urinary stones, particularly in the distal ureter [6, 7], and has become the modality of choice for evaluation of urolithiasis [8–10]. Moreover, in patients with a body mass index (BMI) < 30 kg/m^2, a low-dose CT (LD-CT) with a mean dose of < 3 mSv was proposed [11–13] and was implemented into current international guidelines to reduce the radiation risk [14, 15] with a reported pooled sensitivity of 0.93 and a specificity of 0.97 in a recent meta-analysis [16]. Additionally, a LD-CT with iterative reconstruction (IR) was shown to provide excellent diagnostic performance and interobserver agreement, while significantly reducing the radiation exposure compared to filtered back projection [17, 18].

Despite all the advantages of an LD-CT, large cross-sectional studies in the USA demonstrated only a small clinical implementation rate of LD-CT for evaluation of renal stones ranging from 2% between 2011 and 2013 [19] to 7.6% during 2015–2016, indicating a slight increase of 5.6% compared to CT examinations in 2011–2012 [20]. Moreover, the detection rate of small ureteral stones < 3 mm was considerably lower using LD-CT compared to a standard-dose CT (SD-CT) with a sensitivity of 86% versus 100% [11]. Recently, a lower interobserver agreement of emergency urology residents and radiologists was reported in interpreting CT studies of patients with renal colic with kappa values of 0.93 for SD-CT and only 0.73 for LD-CT [21]. In another prospective study, where emergency patients with renal colic received both an SD-CT and an LD-CT, all false-positive stones (8/27, 30%) were reported to be inside the ureter on LD-CT and turned out to be phleboliths on SD-CT [22].

As the stones' diameter gets smaller the closer to the UVJ they are located [5, 23], a precise detection of distal urolithiasis becomes increasingly difficult and the potential error rate increases [24]. Data about a routinely applicable and cost-effective method for increasing the detectability of

distal urolithiasis using different CT protocols are yet missing. In this study, we investigated the influence of the volumetric urinary bladder filling on the detectability of stones at the UVJ using LD-CT with IR and SD-CT without IR in a large cohort.

Materials and methods

Study population

This retrospective study was HIPAA compliant and was approved by our institutional review board (IRB). Written informed consent was waived by our local IRB. From 2098 consecutive adult patients with clinical symptoms of acute urolithiasis, who underwent NECT between January 2010 and December 2017, 400 patients (278 males (69.5%) and 122 females (30.5%); mean 44.6 ± 14.7 years; age range, 18–90 years) revealed urolithiasis at the ureterovesical junction (Fig. 1). The inclusion criterion was a single ureteral stone in the axial, coronal, and sagittal plane. Clinical and radiological data were taken from the electronic and radiologic database of our institution. The median body mass index (BMI) was 26 kg/m^2 (IQR 23–29 kg/m^2) and was documented in 214 out of 400 patients (54%). All patients underwent the diagnostic workup that is routinely applied to all patients with suspected urolithiasis at our institution. This includes a detailed medical history, a physical examination, a biochemical workup, and diagnostic imaging with ultrasound and unenhanced CT. All CT examinations were reviewed by one radiological resident/consultant (1–6 years of experience in CT imaging) and one senior consultant (7–16 years of experience in CT imaging) to agree on a final diagnosis in consensus.

CT acquisition

CT was performed in all patients in supine position using a 256-detector row CT scanner (Brilliance iCT; Philips Medical Systems). All patients received a non-enhanced CT (NECT), where the scan region covered the area from the diaphragm to the pubic symphysis. In 289 patients (72%), a low-dose CT in a supine position with advanced hybrid iterative reconstruction (iDose4, Philips Healthcare) was used. Technical parameters of the low-dose (LD) protocol included the following: tube voltage 120 kV, reference tube current time product 40 mAs, collimation 2 mm × 128 mm × 0.625 mm, pitch 0.922, and gantry rotation time 0.4 s. In the remaining 111 patients (28%), who were investigated before the introduction of iterative reconstruction techniques in August 2012 in our department, a standard-dose CT without iterative reconstruction was performed using the following protocol: tube voltage 120 kV, variable mAs settings determined by the automatic exposure control system (ACS and z-axis dose modulation (Z-
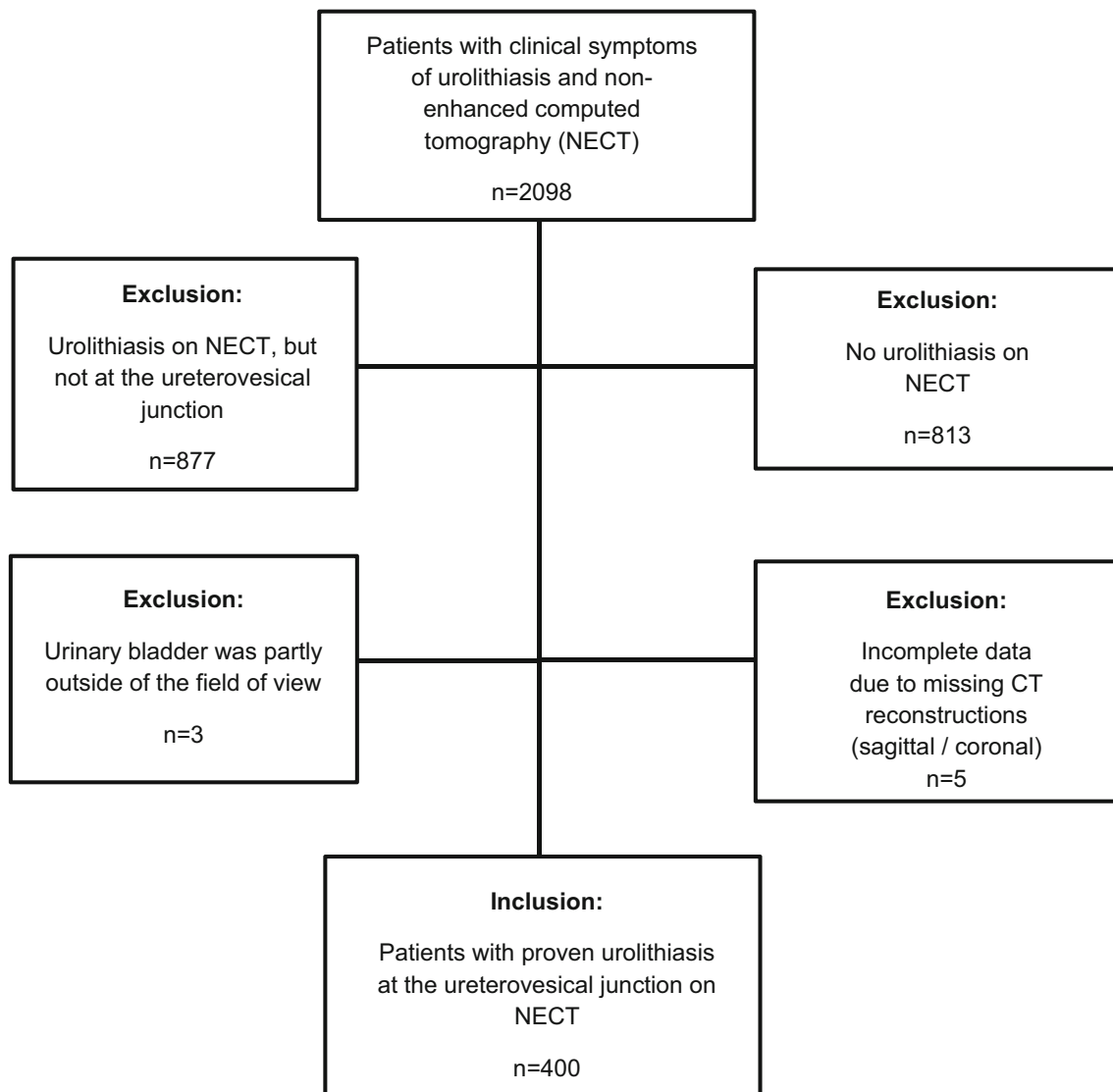
Fig. 1 Flowchart of the selected study group according to recommended standards for reporting diagnostic accuracy (STARD)

DOM)), with an average exposure of 93mAs (effective), collimation 2 mm × 128 mm × 0.625 mm, pitch 0.993, and gantry rotation time 0.5 s. All CT exams were reconstructed in axial, coronal, and sagittal orientations from isotropic voxels with a 3 mm slice thickness and 50% overlap, a soft-tissue kernel, and a 512 × 512 matrix from thin-sliced source images.

Radiation dose measurement

The dose-length product (DLP) was recorded from the automatically generated dose report for each CT. The effective dose was calculated by multiplying the dose-length product (mGy × cm) by a conversion factor (0.0155 mSv × mGy − 1 × cm − 1) [25]. In 289 patients, where low-dose CT was applied, a median effective dose of 1.9 mSv (IQR 1.5–2.7 mSv) was measured, whereas in

the remaining 111 patients with standard-dose CT, a median effective dose of 3.9 mSv (IQR 3.5–4.1 mSv) was noted.

Qualitative assessment of the reader confidence to diagnose distal urolithiasis

Based on the final CT reports, a dichotomization of the reader confidence regarding the diagnosis of urolithiasis at the UVJ was applied to all investigated CT scans:

1. Definite stone
2. Questionable stone

Questionable stones included "probable" or "uncertain" stones, according to the CT reports.

Quantitative assessment of the detectability of distal urolithiasis

The quantification of the urolithiasis detectability of at the UVJ was made using an in-house programmed Plug In of ImageJ, an open source imaging software [26, 27]. First, a line was manually drawn parallel to the course of the distal ureter, which contained the calculus. Second, the algorithm automatically measured all signal densities across the line in Hounsfield units (HU). Third, all signal densities across the drawn line were plotted on a graph obtaining a parabolic shape (Fig. 2). Finally, based on the graph, minimal and maximal density values, as well as mean and maximum slopes left to the

maximum density (upslope) and right to the maximum density (downslope), were derived and calculated automatically (Fig. 3).

Volumetry of the urinary bladder

In all CT data sets, the area of the urinary bladder was manually traced by an experienced radiologist slice-by-slice on every axial slice, where the bladder could be depicted using the integrated volumetry option of the RIS/PACS system (Centricity™ 5.1, GE Healthcare). The total bladder volume was automatically calculated in cubic centimeter according to the sum of all traced areas in axial CT slices (Fig. 4).
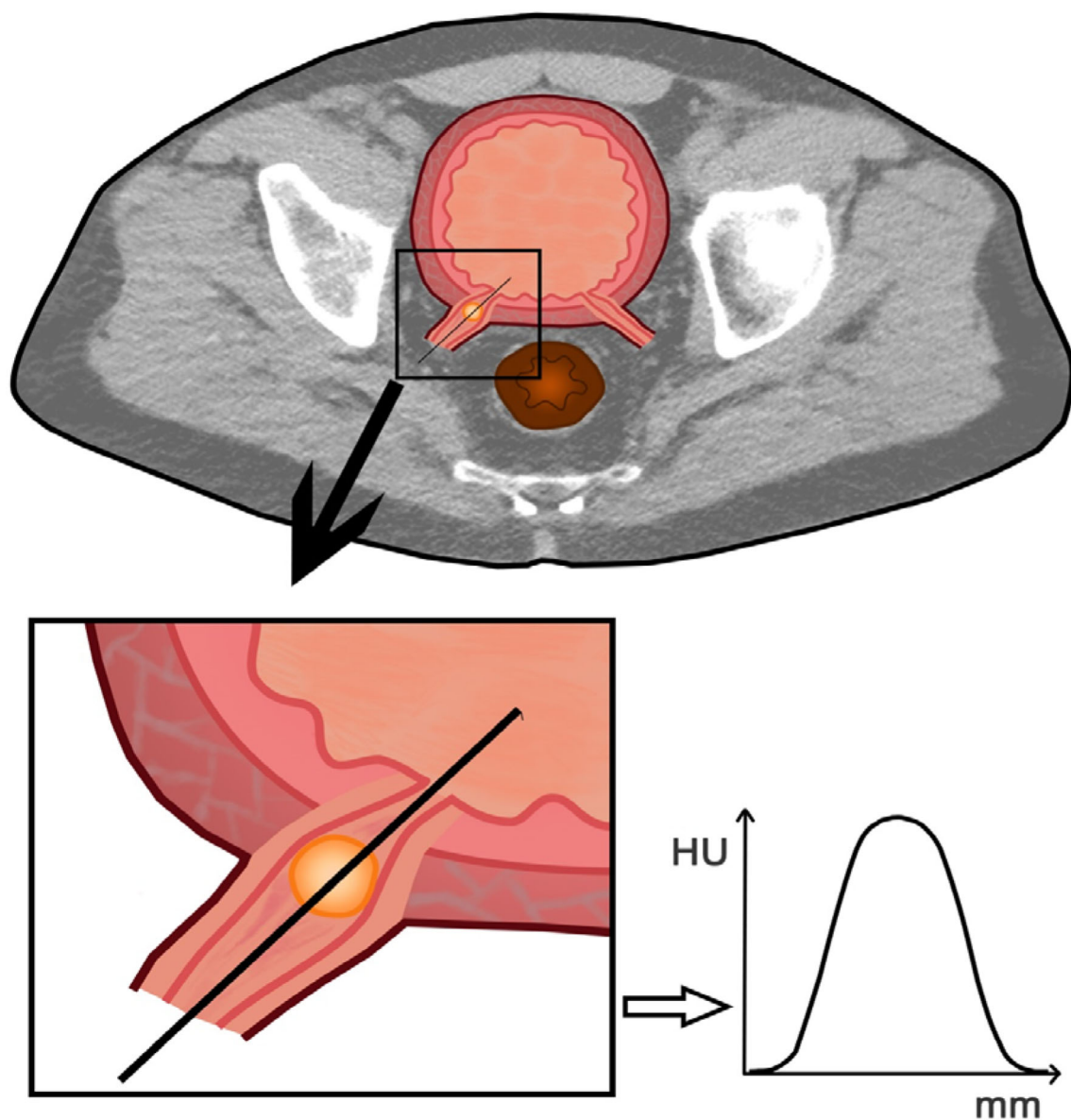

Fig. 2 Quantification of the signal density (Hounsfield units, HU) along a line, which was drawn parallel to the course of the distal ureter containing the stone
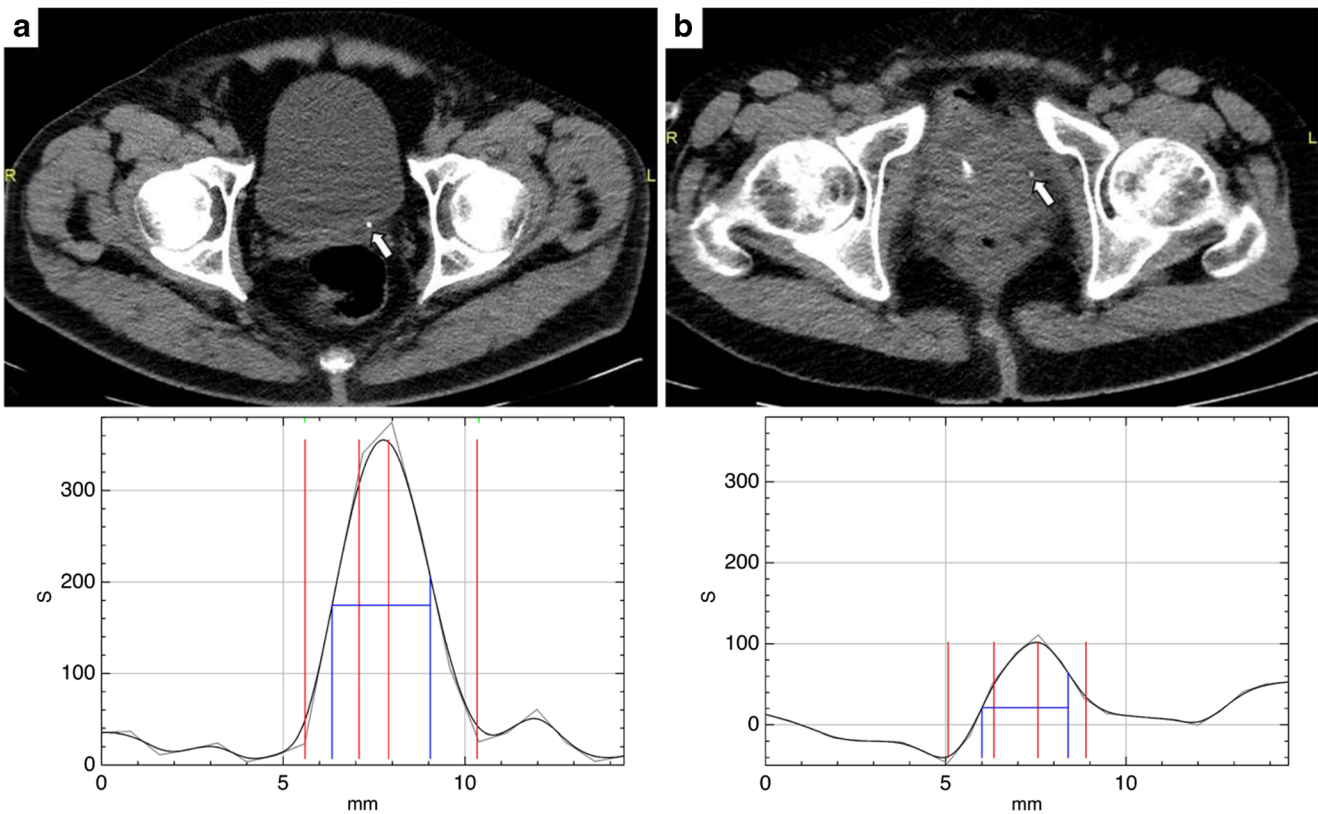
Fig. 3 Comparison of two patients with a definite stone (**a**) and a questionable stone (**b**) of 3 mm diameter in each case (upper row, white arrows) with corresponding quantitative analysis graphs (lower row), demonstrating the length of the drawn line in mm (x-axis) and the corresponding signal densities (HU) across the line (y-axis). Vertical blue lines of the graphs represent mean up- and downslopes within the automatically defined slope limits (vertical brown lines). Note the decrease of maximum signal densities between **a** (356HU) and **b** (101HU)

Statistics

Continuous variables are presented as mean ± standard deviation (SD) in normally distributed data or as median and interquartile range (IQR) otherwise. The Shapiro-Wilk test assessed normality of continuous data. Pairwise comparisons were performed using a t test for normally distributed data or Mann-Whitney U test otherwise. Proportions from two independent samples were compared by chi-squared test. Receiver operating characteristic (ROC) curve analysis was performed to analyze the diagnostic accuracy of the urinary bladder volume to discriminate between patients with definite and questionable stones. The diagnostic performance was expressed as the area under the curve (AUC), cutoff values, sensitivity, specificity, positive and negative predictive values (PPV and NPV), and accuracy with corresponding 95% confidence intervals (95% CI) using the modified Wald method. The Youden index obtained optimal cutoff values. Statistical significance was defined as $p < 0.05$. Data collection and statistical calculations were performed using MedCalc 15.8 (MedCalc Software) and SPSS Statistics 22 (IBM SPSS) software.

Results

Patient characteristics

The basic characteristics of the study population are presented in Table 1. The majority of the patients were males (69.5%, mean age 44.6 ± 14.7 years) without any significant difference among both CT protocols. Also, the stones' length in any orientation, the clinical confidence, the bladder volume, and the quantitative parameters like left and right mean and maximum slopes and the minimum and maximum density values were comparable for both CT protocols. Only the DLP and the effective doses were significantly lower in patients who received an LD-CT with IR compared to those who had an SD-CT without IR (DLP 125.4 mGy cm (LD-CT) vs. 250.5 mGy cm (SD-CT), $p < 0.001$; effective dose: 1.9 mSv (LD-CT) vs. 3.9 mSv (SD-CT), $p < 0.001$).

Qualitative and quantitative detectability of distal urinary stones

When comparing the qualitative clinical confidence assessment with the quantitative results, larger maximum/mean stones'

Fig. 4 Schematic overview of the slice-wise volumetry of the urinary bladder by a coronal CT view
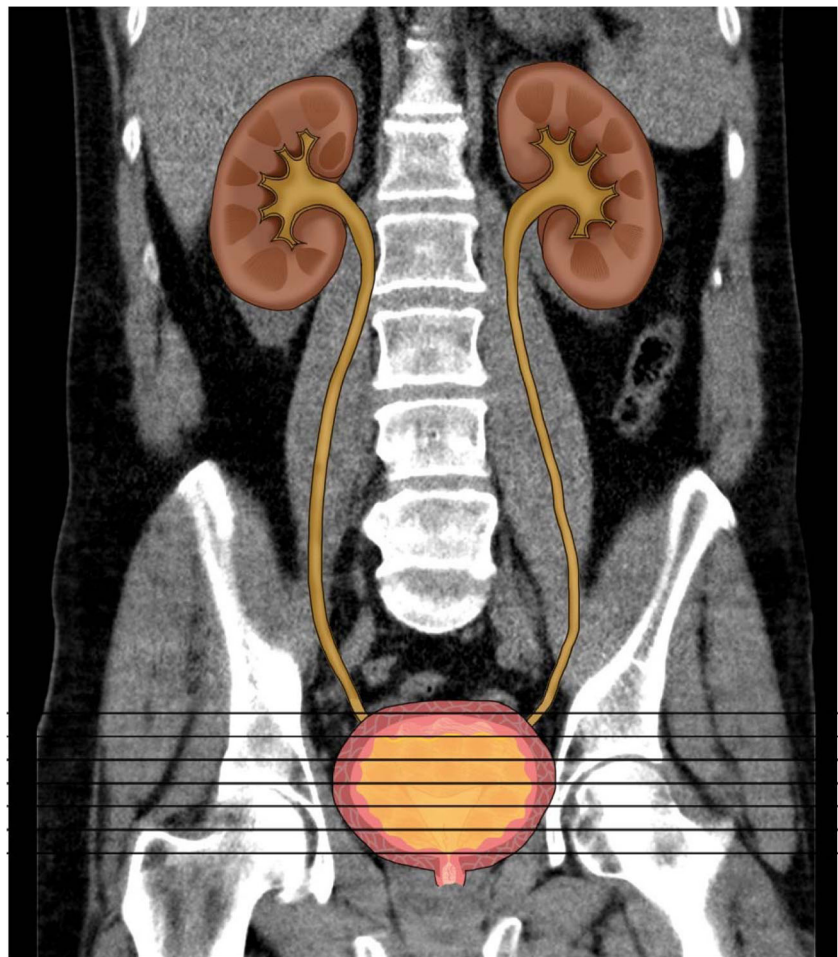
length, higher maximum density values, increased bladder volumes, and higher values of the corresponding left and right slopes of the density distribution curves were associated with a higher clinical confidence of a stone (e.g., definite stone, $p < 0.001$ for all, Table 2). Only minimum density values of the stones were not significantly altered between both groups using both CT protocols ($p > 0.05$ for both). Moreover, all quantitative results and comparisons were comparable among patients with LD-CT with IR and those with SD-CT without IR.

Urinary bladder volume and detectability of urinary stones

After dichotomization of all stones into "definite stone" or "questionable stone," the corresponding bladder volumes of patients with different stone lengths ranging from ≤ 3 up to ≥ 6 mm were compared with each other using both a LD-CT with IR and a SD-CT without IR. Using LD-CT with IR, the median bladder volumes in patients with definite stones ranged from 95 to 126 cm^3 and were significantly higher than the median bladder volumes of patients with questionable stones, which ranged between 51 and 65 cm^3 ($p < 0.01$ for all comparisons, Table 3).

Comparable results were observed in patients, who received an SD-CT without IR, where median bladder volumes of patients with definite stones (84 to 174 cm^3) differed significantly from median bladder volumes in patients with questionable stones (31 to 51 cm^3, $p < 0.01$). These results were for both CT protocols independent of stones' length (Table 3, Fig. 5).

Diagnostic performance of urinary bladder volume to discriminate patients with definite and questionable stones

In patients who received an LD-CT, a urinary bladder volume of 92 cm^3 led to an AUC of 0.877, a sensitivity of 84%, a specificity of 89%, a PPV and NPV of 96% and 65%, and an accuracy of 85% to discriminate patients with definite and questionable stones. A slightly better diagnostic performance was observed in patients with an SD-CT and a lower cutoff of the urinary bladder volume of 69 cm^3. Using this threshold, an AUC of 0.886, a sensitivity of 86%, a specificity of 90%, a PPV of 98%, a NPV of 57%, and an accuracy of 86% could be achieved (Table 4, Fig. 6).

Table 1 Basic characteristics of the study population with distal urinary stones

	Total number ($n = 400$)	LD-CT with IR ($n = 289$ (72%))	SD-CT without IR ($n = 111$ (28%))	p value
Male/female, n (%)	278 (69.5)/122 (30.5)	202 (70)/87 (30)	76 (68)/35 (32)	0.88
Age (years)	44.6 ± 14.7	45.2 ± 14.7	43.5 ± 14.4	0.35
Stone length axial (mm)	3.6 ± 1.7	3.7 ± 1.7	3.5 ± 1.5	0.44
Stone length coronal (mm)	3.7 ± 2.3	3.8 ± 2.2	3.7 ± 2.5	0.36
Stone length sagittal (mm)	3.9 ± 2.2	3.9 ± 2.2	3.7 ± 2.2	0.33
Max. stone length (mm)	4.3 ± 2.4	4.4 ± 2.3	4.1 ± 2.6	0.14
Min. stone length (mm)	3.2 ± 1.7	3.2 ± 1.8	3.1 ± 1.4	0.73
Mean stone length (mm)	3.7 ± 2.0	3.7 ± 2.1	3.6 ± 2.0	0.52
Mean stone ≤ 3 mm	223 (56)	160 (55)	63 (57)	0.80
Mean stone 4–5 mm	131 (33)	94 (33)	37 (33)	0.91
Mean stone ≥ 6 mm	46 (11)	35 (12)	11 (10)	0.70
Clinical confidence				
Definite stone	309 (77)	217 (75)	92 (83)	0.12
Questionable stone	91 (23)	72 (25)	19 (17)	0.12
Bladder volume (cm³)	94 (IQR 58–170)	92 (IQR 58–158)	106 (IQR 56–182)	0.65
Left max slope (HU/mm)	117 (IQR 84–159)	116 (IQR 82–166)	122 (IQR 85–153)	0.91
Left mean slope (HU/mm)	115 (IQR 82–157)	114 (IQR 81–164)	119 (IQR 84–151)	0.92
Right max slope (HU/mm)	113 (IQR 81–151)	110 (IQR 80–151)	118 (IQR 83–152)	0.58
Right mean slope (HU/mm)	112 (IQR 80–149)	108 (IQR 79–149)	117 (IQR 82–150)	0.57
Maximum density (HU/mm)	282 (IQR 190–408)	288 (IQR 189–408)	278 (IQR 192–423)	0.70
Minimal density (HU/mm)	36 (IQR 15–60)	38 (IQR 14–61)	33 (IQR 15–56)	0.61
DLP (mGy cm)	161.2 (IQR 105.9–244.2)	125.4 (IQR 96.0–176.2)	250.5 (IQR 228.0–263.7)	< 0.001*
Effective dose (mSv)	2.5 (IQR 1.6–3.8)	1.9 (IQR 1.5–2.7)	3.9 (IQR 3.5–4.1)	< 0.001*
BMI (kg/m²)	$n = 214$ (54%)	$n = 159$ (55%)	$n = 55$ (50%)	–
	26 (IQR 23–29)	26 (IQR 23–29)	25 (IQR 23–28)	0.22

LD, low-dose; *SD*, standard-dose; *IR*, iterative reconstruction; *IQR*, interquartile range; *$p < 0.05$ (significant difference)

Urinary bladder volumes in patients with different BMI and CT protocol

In a subgroup of 214 patients with documented BMI, urinary bladder volumes were compared between patients with a BMI < 30 kg/m² and those with a BMI ≥ 30 kg/m², who received either an LD-CT or an SD-CT. Using any of the two CT protocols, obese patients (BMI ≥ 30 kg/m²) with definite stones had significantly higher urinary bladder volumes compared to patients with questionable stones (LD-CT 106 cm³ vs. 65 cm³, $p = 0.004$; SD-CT 144 cm³ vs. 50 cm³, $p = 0.03$, Table 5). Patients with a BMI ≥ 30 kg/m² and < 30 kg/m² and definite or questionable stones failed to show a significant difference in urinary bladder volumes ($p > 0.05$ for all comparisons, respectively, Table 5).

Discussion

The present study examined the effect of volumetric filling of the urinary bladder concerning the detectability of distal ureteral stones at the UVJ in 400 patients who received either a non-enhanced LD-CT with IR or an SD-CT without IR. Our results demonstrated significantly higher urinary bladder volumes in patients with definite stones compared to patients with questionable stones. The automatic quantitative stone assessment also supported this finding in terms of steeper density curve slopes and higher maximum and lower minimum stone density values in the "definite stone" group compared with the "questionable stone" group. Moreover, this result was irrespective of the stones' length or the applied CT protocol, as both CT protocols revealed comparable results. Furthermore, we calculated optimal cutoff values of urinary bladder volumes for a proper distinction of definite stones of 92 ml for patients receiving an LD-CT with IR and of 69 ml for patients receiving an SD-CT without IR. Thereby, we obtained high PPVs/accuracy rates of 96%/85% (LD-CT) and 98%/86% (SD-CT), respectively. These results are of high clinical importance, as they indicate the benefit of pre-CT oral hydration in patients with clinical suspicion of urolithiasis in order to achieve a better detectability of

Table 2 Clinical confidence of distal urinary stones using LD-CT with IR or SD-CT without IR depending on the clinical confidence

	Clinical confidence using LD-CT with IR		p value
	Definite stone (n = 217)	Questionable stone (n = 72)	
Max. stone length (mm)	4.8 ± 2.5	3.3 ± 1.1	< 0.001*
Mean stone length (mm)	4.1 ± 2.2	2.5 ± 1.0	< 0.001*
Bladder volume (cm³)	108 (IQR 68–180)	64 (IQR 47–90)	< 0.001*
Left max slope (HU/mm)	133 (IQR 103–179)	69 (IQR 55–90)	< 0.001*
Left mean slope (HU/mm)	131 (IQR 101–177)	67 (IQR 54–89)	< 0.001*
Right max slope (HU/mm)	127 (IQR 97–161)	65 (IQR 47–83)	< 0.001*
Right mean slope (HU/mm)	124 (IQR 95–158)	64 (IQR 46–81)	< 0.001*
Maximum density (HU)	319 (IQR 226–443)	157 (IQR 119–233)	< 0.001*
Minimal density (HU)	35 (IQR 13–58)	45 (IQR 19–64)	0.09
	Clinical confidence using SD-CT without IR		p value
	Definite stone (n = 92)	Questionable stone (n = 19)	
Max. stone length (mm)	4.4 ± 2.7	2.6 ± 1.3	< 0.001*
Mean stone length (mm)	3.8 ± 2.0	2.0 ± 1.1	< 0.001*
Bladder volume (cm³)	118 (IQR 67–206)	48 (IQR 32–52)	< 0.001*
Left max slope (HU/mm)	130 (IQR 105–156)	54 (IQR 32–81)	< 0.001*
Left mean slope (HU/mm)	127 (IQR 104–154)	53 (IQR 31–80)	< 0.001*
Right max slope (HU/mm)	125 (IQR 96–157)	55 (IQR 45–86)	< 0.001*
Right mean slope (HU/mm)	123 (IQR 95–155)	54 (IQR 44–85)	< 0.001*
Maximum density (HU)	321 (IQR 211–444)	159 (IQR 97–246)	< 0.001*
Minimal density (HU)	30 (IQR 12–56)	44 (IQR 23–59)	0.32

LD, low-dose; SD, standard-dose; IR, iterative reconstruction; IQR, interquartile range; *p < 0.05 (significant difference)

distal urinary stones. This is yet to be mentioned in the current recommendations and workup guidelines for urolithiasis [10, 14, 15].

Current international guidelines recommend the use of LD-CT as the method of choice for patients with suspected urolithiasis [10, 14, 15]. However, in obese patients with a BMI > 30 kg/m², an SD-CT is preferred due to the lower sensitivity and specificity of LD-CT for detecting ureteral stones [10, 14,

15]. In contrast, our results showed a significant difference of urinary bladder volumes in obese patients (BMI ≥ 30 kg/m²) between definite and questionable stones using either LD-CT with IR or SD-CT without IR with a lower p value for LD-CT (p = 0.008 vs. p = 0.03). These interesting findings may be caused by the IR algorithm, which allows to significantly reduce the noise compared with the filtered back projection (FBP) while maintaining the same image quality [28]. This

Table 3 Comparison of the bladder volume between definite and questionable urinary stones and different maximum lengths of the stones

	Clinical confidence using LD-CT with IR		
	Definite stone (n = 217 (75%))	Questionable stone (n = 72 (25%))	
Max. length	Bladder volume (cm³)		p value
≤ 3 mm	126 (IQR 69–226)	65 (IQR 48–91)	< 0.001#
4–5 mm	95 (IQR 62–151)	51 (IQR 42–78)	0.001#
≥ 6 mm	113 (IQR 82–183)	56 (IQR 51–60)	0.007#
Any length	108 (IQR 68–180)	64 (IQR 47–90)	< 0.001#
	Clinical confidence using SD-CT without IR		
	Definite stone (n = 92 (83%))	Questionable stone (n = 19 (17%))	
Max. length	Bladder volume (cm³)		p value
≤ 3 mm	174 (IQR 102–244)	51 (IQR 45–85)	< 0.001#
4–5 mm	84 (IQR 58–147)	31 (IQR 28–51)	0.003#
≥ 6 mm	109 (IQR 57–148)	48*	–
Any length	118 (IQR 67–206)	50 (IQR 39–56)	< 0.001#

LD, low-dose; SD, standard-dose; IR, iterative reconstruction; IQR, interquartile range

*Due to a single case, the IQR could not be calculated; #p < 0.05 (significant difference)

Fig. 5 Comparison of definite and questionable urinary stones at the UVJ (white arrow) using a LD-CT with IR (upper row) or a SD-CT without IR (lower row). Note: All stones had the same maximum diameter of 3 mm

finding is also supported by a recent study, which demonstrated significantly better image quality and diagnostic confidence in overweight and obese patients (BMI ≥ 25 kg/m^2) compared to those with a BMI < 25 kg/m^2 using an LD-CT protocol with statistic IR technique [29]. Hence, our findings support a possible universal pre-CT patient hydration with consecutive increased bladder volume in clinical routine independent of the applied CT protocol and the BMI values of the patients. Recent publications demonstrated an additional value of dual-source CT (DECT) to conventional CT for determining stone composition, especially for differentiating uric acid stones from non-uric acid stones, as the former may be treated pharmacologically rather than invasively [30, 31]. A recent study demonstrated that stone detection and characterization by DECT was also feasible in patients with large body habitus of > 90 kg of weight [32]. The drawbacks of DECT (inconsistent characterization of small stones < 3 mm and stone mimics [33]) might be reduced by a simple and cost-effective oral hydration, especially in case of small stones ≤ 3 mm at the UVJ [5, 23]. Pre-CT oral hydration may help discriminate among different stone mimics such as pelvic phleboliths or incidental transitional cell carcinomas (TCC) of the bladder [34] or of the distal ureter, which are found in up to 75% of cases of ureteral TCC [35]. Previous studies suggested different CT-based signs for this purpose like the rim sign, indicating a ureteral wall edema [36, 37] and the comet tail sign as a hallmark of a dilated vein leading to the phlebolith [37, 38] as well as prone CT scanning [39]. However, they either turned to be not clinically helpful [40] or required an additional radiation exposure for prone

Table 4 Diagnostic performance of the urinary bladder volume to discriminate between patients with definite and questionable urinary stones at the ureterovesical junction using a LD-CT or a SD-CT protocol

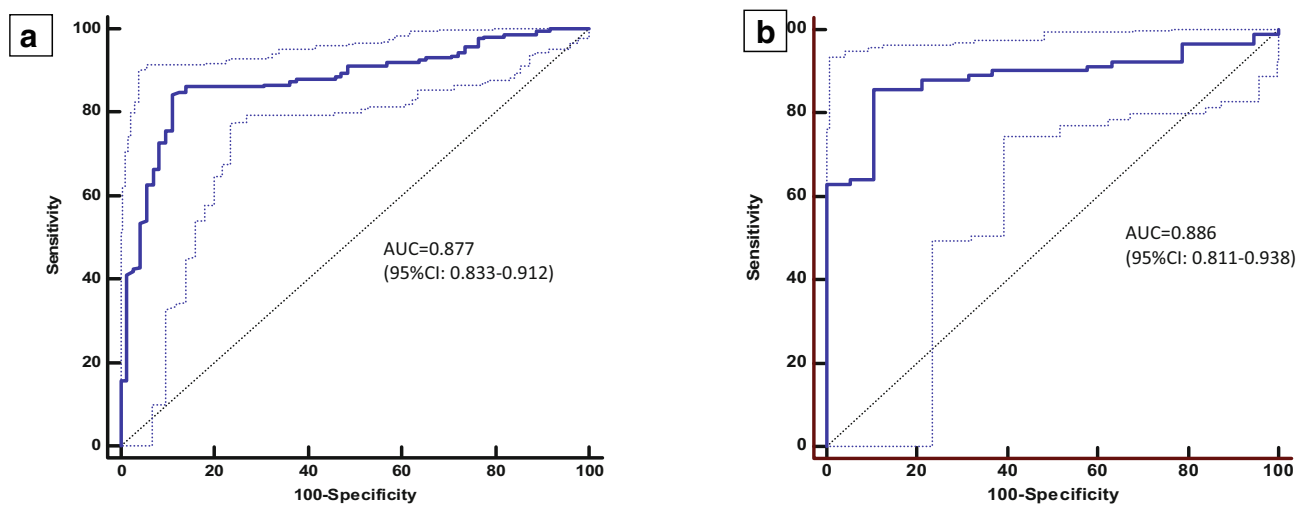|	AUC (95%CI)	*p* value	Cutoff (ml)	Sensitivity (95%CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)	Accuracy (95%CI)
LD-CT	0.877 (0.833–0.912)	< 0.001	≥ 92	84 (79–89)	89 (79–95)	96 (92–98)	65 (55–74)	85 (81–89)
SD-CT	0.886 (0.811–0.938)	< 0.001	≥ 69	86 (77–92)	90 (67–99)	98 (91–99)	57 (39–73)	86 (79–92)

Fig. 6 ROC analysis with 95% confidence intervals (CI) of the urinary bladder volume to discriminate between definite and questionable stones at the ureterovesical junction in patients receiving a LD-CT with IR (**a**) or a SD-CT without IR (**b**) protocol

scanning after an initial supine position [39]. A recent study discriminated urinary stones from phleboliths on LD-CT using radiomics and machine learning, which resulted in an overall accuracy of 85%, an AUC of 0.902, and positive and negative predictive values of 81.5% and 90%, respectively [41]. The combination of these promising techniques and an appropriate bladder filling might further increase the diagnostic yield of distal urolithiasis in the future and requires further investigation.

Our calculated volume cutoffs represent only small amounts of a healthy functional bladder capacity in adults of nearly 350 ml [42, 43], ranging from 20% (69/350 ml) in SD-CT to 26% (92/350 ml) in LD-CT. Thus, a pre-CT hydration with at least 250 ml of water, which represents a commonly used saline solution volume for intravenous hydration and slightly more than one plastic cup for oral hydration, should generally lead to the desired increase in bladder volume. Thereafter, the CT scan should only be initiated when an urge to void becomes noticeable. This approach probably would not affect the patients' compliance, as micturition is normally

prompted near complete bladder volume capacity [44]. Moreover, moderate bladder filling was already implemented for ultrasound investigations in distal urolithiasis [45]. Additionally, intravenous hydration is commonly applied routinely to patients with uncomplicated renal colic and low urine volume, due to reduced intake or increased loss of water, which leads to an increased production of concentrated solutes and to recurrent stone formation [46, 47].

Our study had several limitations. Firstly, it was limited by the retrospective study design. It requires further external prospective validation with different CT protocols before clinical application. Secondly, despite the observed difference of bladder volumes in obese patients with definite and questionable stones, the sample size in both CT protocols was rather small, so that we were unable to provide a discrete cutoff value of the bladder filling for these patients to prevent a sampling bias with resulting low accuracy of the results [48, 49]. Especially, these findings require further verification. Thirdly, the implemented dichotomization for qualitative assessment of the detectability of distal urolithiasis into "definite stone" and "questionable

Table 5 Comparison of urinary bladder volumes in patients with definite and questionable urinary stones depending on the BMI and the CT protocol

LD-CT with IR (n = 159) Bladder volume (cm³)	BMI < 30 kg/m² (n = 126)	BMI ≥ 30 kg/m² (n = 33)	p value
Definite stone	106 (IQR 70–174)	120 (IQR 72–209)	0.51
Questionable stone	65 (IQR 49–91)	56 (IQR 40–80)	0.38
p value	< 0.001*	0.004*	–
SD-CT without IR (n = 55) Bladder volume (cm³)	BMI < 30 kg/m² (n = 47)	BMI ≥ 30 kg/m² (n = 8)	p value
Definite stone	144 (IQR 75–209)	136 (IQR 118–207)	0.67
Questionable stone	50 (IQR 38–111)	50 (IQR 36–52)	1.00
p value	0.03*	0.03*	–

BMI, body mass index; *LD*, low-dose; *SD*, standard-dose; *IR*, iterative reconstruction; *p < 0.05 (significant difference)

stone" is subjective and may be debatable. However, this assessment was performed by two radiologists (including one senior consultant) in consensus and was adapted from other publications dealing with urolithiasis [50, 51]. Moreover, our subjective arrangement of the reader detectability was also supported by the presented objective automatic quantitative stone assessment.

Conclusions

Urinary bladder volume has a significant impact on the detectability of distal urolithiasis, indicating that moderate oral or intravenous pre-CT hydration and subsequent CT scan at the time of high urge to void allows for an easily applicable and cost-effective method to increase the detectability of stones at the UVJ in clinical routine.

Compliance with ethical standards

Guarantor The scientific guarantor of this publication is Dr. Maxim Avanesov.

Conflict of interest The authors of this manuscript declare no relationships with any companies whose products or services may be related to the subject matter of the article.

Statistics and biometry One of the authors has significant statistical expertise.

Informed consent Written informed consent was waived by the Institutional Review Board.

Ethical approval Institutional Review Board approval was obtained.

Methodology
• Retrospective
• Observational
• Performed at one institution

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