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ORIGINAL ARTICLE

Very low-dose computerized tomography for confirmation of urinary stone presence

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Abstract

Purpose To determine whether a modified non-contrast very low-dose computed tomography (VLD-CT) protocol is applicable for confirmation of known urolithiasis.

Methods and materials Consecutive adult patients with a CT scan showing urinary tract stone(s) between 6/2017–12/2018 were included. They were referred to a modified VLD-CT protocol if stone presence was equivocal or if stone location needed reassessment before an endourological interventional procedure. The scanned area was limited to the level of initial stone location caudally. Data on patients' demographics andbody mass index, were collected. The scanned length and radiation dose were calculated. Images were reviewed by two radiologists who assessed stone size and location. Follow-up reference standard included stone passage, surgical removal, and other imaging and clinical information.

Results Sixty-three patients [63 stones, mean BMI 28.7 (range 19–41.9)] were included. VLD-CTs revealed 31 stones in 31 patients, with a mean stone length of 5.5 mm. Fifteen stones remained at the same location, and 16 had migrated, of which two appeared in the bladder. Thirty-two stones were not observed on VLD-CT. The mean span scanned on the VLD-CT was 274 mm (± 80). The average radiation exposure was 1.47 mGy (range 1.09–3.3), and the absorbed dose was 0.77 mSv (range 0.39–1.43), compared to 10.24 mGy (range 1.75–28.9) and 7.87 mSv (range 1.44–18.5) in the previous scan. The mean radiation dose reduction between scans was 89%. On follow-up, all VLD-CT findings were confirmed.

Conclusion A modified imaging protocol is applicable for confirmation of stone presence and location by utilizing very low-dose radiation exposure.

Keywords Radiation dosage · Computed tomography · Urolithiasis · Modified protocol

Abbreviations

BMI	Body mass index
CT	Computed tomography
VLD	Very low dose
NCCT	Non-contrast computed tomography
DLP	Dose length product

Introduction

Since it was initially described in 1995 [1], non-contrast adnominal computed tomography (NCCT) has become the gold standard modality for initial diagnosis and follow-up of nephro- and urolithiasis [2]. Confirmation of retained stones has a high clinical significance before interventional

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treatment, since often the time of stone passage, if happened at all, is unknown. A conventional non-contrast abdomen/pelvis CT is estimated to expose a patient to 3–11 mSv of radiation [3, 4]. Technological advancements in the scanners, including those in hardware and software, has enabled a significant decrease in the radiation dose exposure [5] while maintaining high diagnostic imaging quality [6]. Low-dose CT protocols apply a lower tube current in order to decrease radiation exposure with good results [7, 8]. Several ultra-low-dose CT protocols for the diagnosis of urinary tract calculi have been published, and some have succeeded in achieving a mean dose of 0.91 mSv [9] and even doses as low as 0.68 mSv [10].

Reduction of the radiation dose is especially relevant to patients undergoing repeat scans for follow-up and management of known urolithiasis. Although CT is not routinely used for urinary stone follow-up, a very low-dose protocol has been recommended with the aim of decreasing total radiation exposure for such patients [11]. Dose reduction can be accomplished by applying several techniques, including iterative model reconstruction. Unfortunately, the achievement of reduction of tube current leads to a decrease in image quality and accuracy [12]. When choosing to implement a low-dose protocol, the clinical probability of stone presence, and stone size, as well as patient age and body mass index (BMI) should be taken into consideration [6, 13–15]. A limited scanned field has also been suggested for following patients with ureteral stones [16] in an attempt to decrease radiation by limiting the exposed area.

In this study, we tested an individually tailored very low-dose CT protocol (VLD-CT) limited to the relevant body area for the confirmation of known urolithiasis.

Materials and methods

This study was performed at an urban, tertiary care academic center. It was a retrospective review of a prospectively maintained database of patients who underwent a VLD-CT for confirmation of renal stone presence as demonstrated on an earlier CT. The study was approved by the institutional review board that waived informed consent.

Participant selection

The study was conducted between June 2017 and December 2018. The study population included adults who were referred for stone confirmation on CT studies in order to guide clinical management. All enrolled patients had a previous CT scan that demonstrated a clinically significant urinary stone. These patients were either treated during hospitalization or discharged and followed up in the outpatient clinic, depending upon stone size, location, and symptoms. Patient referral to VLD-CT was a part of follow-up to either confirm the presence of a stone in case of uncertain clinical presentation, or to determine the location of the stone prior to an endourological procedure. Exclusion criteria were the absence of earlier CT imaging studies, urolithiasis symptom resolution following conservative treatment, and having undergone any endourologic procedures following the initial CT scans. Patient data comprised demographics and body mass index (BMI) values. The location and size of the urinary stone were assessed on both the previous scan and the VLD-CT study. CT parameters on all scans included body scan length and calculated effective radiation dose. Clinical reference included clinical passage, post-imaging surgical removal, and other imaging and clinical information.

VLD-CT protocol

All studies were performed on a 256-slice multidetector Revolution CT scanner (GE Healthcare, Waukesha, WI, USA). All patients were examined in the prone position. No intravenous or oral contrast materials were given. The scan area was individually tailored prior to imaging according to the various stone locations derived from previous CT data. The scan area covered parts of the abdomen and pelvis, from slightly above the initial stone location (in relation to the spine) and caudally to the symphysis pubis. Planning was performed by one of two radiologists (OP and DR). An anteroposterior and a lateral 60-cm scout image were obtained prior to the helical acquisition. The scan parameters were as follows: a helical scan with a 0.992:1 pitch, a tube voltage of 100 kV, a Smart MA in the range of 50–300 Ma, a 0.5-s rotation time, a detector coverage 80 mm per rotation, a coverage speed of 158.75. Standard Kernel and a noise index of 13.9. All examinations were performed with an Iterative Reconstruction Asir-V 80%. Thickness axial images of 3.75 mm and 1.25 mm slices were reconstructed. Coronal and sagittal reformations were added for each scan.

Radiation dosage

Relevant radiation dose data, including volume CT dose index and dose length product (DLP), were obtained using dose-monitoring software. The mean effective dose depends on patient size and the region of the body being scanned. The organ dose-based calculations using tissue-weighting factors were estimated when converting DLPs into effective doses, depending upon the body region [17].

Image analysis

Two reviewers, one a dedicated uroradiologist (OP) with more than 20 years of experience and the other a radiology resident (DR), assessed all images separately on a

PACS system (Carestream health Rochester, NY). In case of disagreement, a consensus was reached with the aid of other senior radiologists (RSB, LG). The patients' previous CT scans, which depicted a urinary stone, were also reviewed. Clinical data, including patient demographics, BMI, and clinical and procedural history were available for all participants. The reviewers were asked to report on the VLD-CT and on the presence or absence of urinary stones in comparison to those that were present on the previous CT scan. The reviewers were also asked to note the number, location, and size of any detected stones on the new scans. Segmental descriptions along the urinary tract included the intra-renal collecting system, renal pelvis, ureter (proximal, mid-, distal and uretero-vesical junction), and bladder. Stone size was measured in three dimensions on both scans (if present). Indirect signs of urinary obstruction were also noted, including hydronephrosis, dilatation of the ureter that had been included in the scanned area, and perinephric and retroperitoneal fat stranding.

Final clinical diagnosis

The patient's diagnosis was determined by review of the electronic medical data. Reports of surgical procedures, subsequent additional radiologic examinations (ultrasound or CT), and relief of symptoms were reviewed for follow-up analyses. When any follow-up information was not available in the medical records, the patients were contacted directly and asked to fill in a questionnaire for the missing data (according to IRB approval).

Results

A total of 66 patients with urinary stone disease underwent a VLD-CT for stone confirmation during the study period. Three patients were excluded from the study, one because the earlier CT scan images demonstrating his initial diagnosis of urolithiasis were not available, one because the previous scan radiation dose information was not available, and the third because she underwent an interventional procedure in the affected ureter in the interval between the original CT scan and the VLD-CT. Thus, the final study cohort included 63 patients who had all the required VLD-CT information for confirmation of stone presence. The patients' demographics are summarized in Table 1. The locations of the stones on the original CT included the renal collecting system ($n=2$, 3%), renal pelvis ($n=1$, 2%), proximal ureter ($n=21$, 33%), middle ureter ($n=8$, 13%), distal ureter ($n=22$, 35%), uretero-vesical junction ($n=4$, 6%), and urinary bladder ($n=5$, 8%). The mean stone diameter was 5.5 mm (range 1–11 mm). Thirty-seven (59%) of the stones were in the left urinary system, 21 (33%) in the right urinary system, and 5 (8%) in the urinary bladder (Table 2). The patients' average BMI was 28.7 (range 19–41.9). More artifacts were seen in the VLD-CT of those with higher BMIs, although even small stones were depicted (Fig. 1).

The median interval between the original CT and the VLD-CT was 32 days)range 3–358). The mean patient length scanned in the VLD-CT was 274 mm (range 86–510 mm). A total of 32 (51%) stones were no longer present, 15 stones had remained in the same location (24%), and 16 (25%) stones had migrated from their original location distally in the urinary tract (Fig. 2). The specifics of the

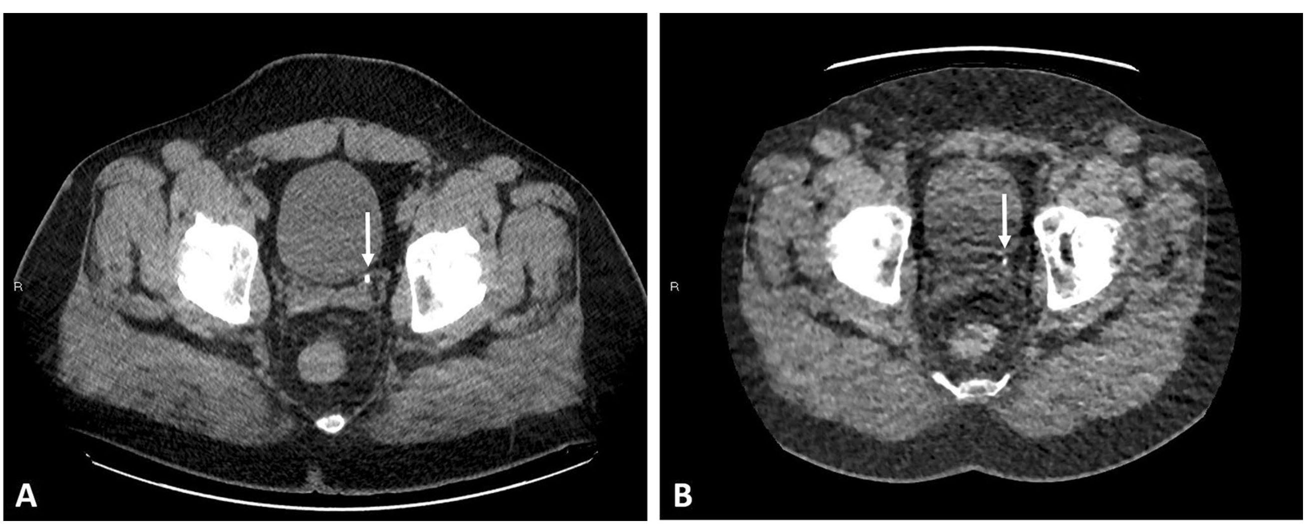

Fig. 1 A 38-year-old patient with a BMI of 39. **a** A 5-mm stone in the left distal ureter on an axial NCCT (arrow), and **b** an axial prone VLD-CT image showing the stone in the same location despite artifacts

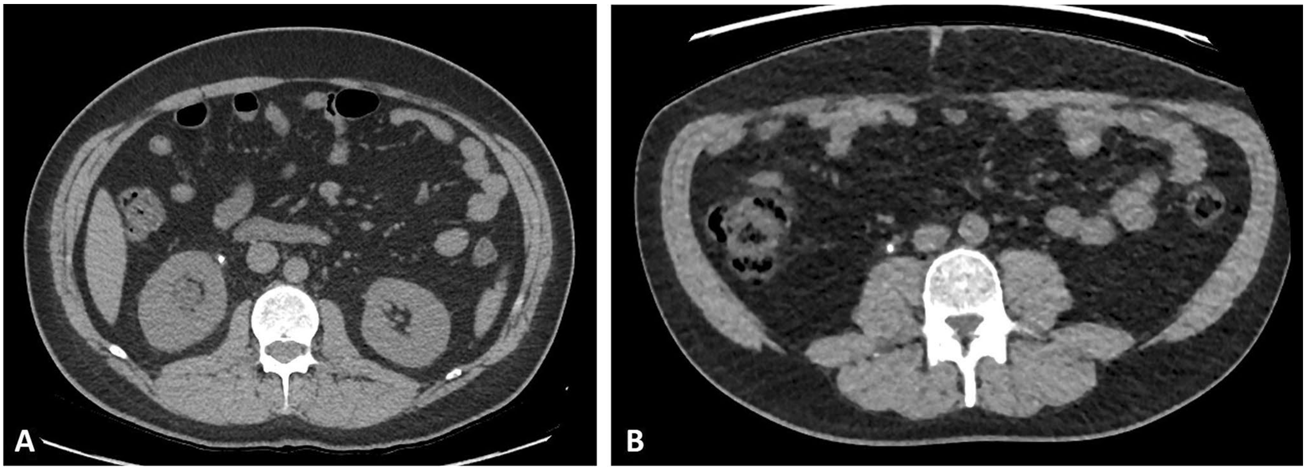

Fig. 2 A 40-year-old patient with a suspected retained stone. **a** A 5-mm stone in the proximal right ureter on the original axial NCCT and **b** an axial prone VLD-CT 1 month later showing slight stone migration caudally in the ureter. He underwent endoscopic treatment

stone dynamics are summarized in Table 3. Four patients with a negative VLD-CT were lost to follow-up.

The average emitted radiation was 10.24 mGy (range 1.75–28.9) and the calculated mean absorbed radiation was 7.87 mSv (range 1.44–18.5) on the original scans. On the VLD-CT scans, the average radiation exposure was 1.47 mGy (range 1.09–3.3) and the absorbed dose was 0.77 mSv (range 0.39–1.43). The mean dose reduction between the scans was 89%. Data on the radiation dose are provided in Table 4, and Fig. 3 depicts an example of similar images of a very small ureteral stone following a significant dose reduction.

A full clinical follow-up was available for 59 of the patients (93%). Thirty-six of them (61%) reported having undergone clinical resolution of symptoms and stone passage prior to the VLD-CT. 23 patients (39%) with a remaining stone on the VLD-CT had undergone endourological procedures for stone removal. All follow-up findings on the VLD-CTs were confirmed clinically. Nine patients (15%) had additional imaging studies after the VLD-CT, including 8/59 (13%) who had an ultrasound and 1/59 (2%) who had a regular protocol NCCT. The additional imaging findings confirmed the VLD-CT findings.

Fig. 3 A 65-year-old patient with unrelenting left abdominal pain. **a** A coronal view from the original abdominal-pelvic CT showing a 3-mm stone in the left mid-ureter (arrow). The effective radiation dose was 11.8 mSv. **b** A coronal VLD-CT image showing the stone in the same location 1 week later. The effective radiation dose dropped to 0.7 mSv (a reduction of 94%)

Discussion

While NCCT is the preferred modality for the initial diagnosis of nephrolithiasis and urolithiasis, the optimal imaging modality for the follow-up of patients with known stones is still unclear. For these latter cases, imaging is highly important for patient management, including treatment planning that depends upon stone location and size. Subsequent management can be tailored according to EAU and AUA guidelines [2, 18]. Radiation exposure remains an issue, especially when taking into consideration additive radiation exposure in the operating room during treatment [19]. This is particularly important as part of preprocedural evaluation for patients in whom the presence of urolithiasis is equivocal or the exact stone location needs to be reassessed. Therefore, plain abdominal X-ray films of the kidneys, ureters, and bladder—with or without ultrasound or any imaging at all—comprise the current management of patients with suspected retained stones [20–22].

The implementation of ultra-low- and low-dose scans has been reviewed in the setting of total radiation exposure. Pooler et al. [9] described using ultra-low-dose scans with an effective dose of 0.91 ± 0.72 mSv with high specificity and sensitivity for a stone threshold > 4 mm in diameter. Those authors also suggested using ultra- low-dose CT for surveillance. In their study, the radiation dose for patients with a BMI > 30 kg/m^2 was significantly higher than the dose administered to patients with a BMI < 30 kg/m^2 (1.3 vs. 0.67 mSv, respectively, $p < 0.01$ for ultra-low dose and 6.3 vs. 3.5 mSv, respectively, $p < 0.06$ for regular dose).

In a systematic review, Rob et al. [13] assessed ultra-low-dose, low-dose, and standard-dose CT protocols. The effective radiation dose was < 1.9 mSv for the ultra-low-dose and < 3.5 mSv for the low-dose. Those levels were less effective in diagnosing stones < 3 mm in size and in patients with a BMI > 30 kg/m^2.

A recently published systematic review and meta-analysis [24] evaluated protocols with an average radiation dose between 1 and 1.5 mSv, while maintaining 90–100% sensitivity and 86–100% specificity for diagnosing urinary tract stones. Those authors recommended applying this method in patients with high probability of stone disease or in the follow-up of patients with known calculi. The issue of radiation was not addressed for patients with a BMI > 30 kg/m^2. The ability to correctly identify ureteric calculi varied in the reviewed literature [24].

With our VLD-CT protocol, we could identify very small urinary stones (even those that were 1 mm in size) despite artifacts caused by a high BMI. The ability to identify stones < 3 mm in obese patients with a very low dose CT protocol was appreciated in the study by Glazer et al. [15], but they found lack of diagnostic certainty for these small stones.

Freifeld et al. [16] followed patients with known urinary stones by applying a limited-field CT scan. Those authors prospectively divided patients into two groups according to the location of the stone, i.e., proximal and distal, and tailored the scans to administer a mean radiation dose of 6.1 mSv and 4.1 mSv, respectively. The average batch length was 46.5 cm. The patients' BMI levels were not discussed.

Our study was designed to decrease the amount of ionizing radiation on follow-up VLD-CT by both technically decreasing the radiation exposure and by limiting the total exposed body field. The field limitation was based on the premise that stones migrate distally in the urinary tract [25]. Using the combination of a decrease in radiation and limitation of the field, we succeeded in reducing the radiation exposure dose from 10.2 to 1.47 mGy (± 0.32) and the absorbed dose from 7.87 to 0.77 mSv (± 0.26), resulting in a mean reduction of 89% in radiation dose. As expected, a lower BMI and a distal location of the clinically significant stone resulted in lower radiation exposure on the VLD-CT and greater radiation reduction between the initial scan and the follow-up, but other technical changes in the protocol enabled the considerable difference in the amount of radiation.

As mentioned by Freifeld et al. [16], limitation of the scanned field may result in loss of information. In our current study design, the follow-up focus was on the clinically significant stone in question, while the initial stone burden assessment was made on the original NCCT.

Our impression, from the results of the study, is that the images in VLD-CT were sufficient for the differentiation of ureteral stones from phleboliths in most cases.

This study has limitations that bear mention. The protocol was implemented on a single CT scanner, and we recommend that it should be tested on other scanners as well. Radiation was compared between the full-length abdominal and pelvic CTs with or without contrast material injection (the previous scan) and a non-contrast scan with limited body area (the index scan). This resulted in a greater reduction of radiation than if the comparison would have been made between the same limited scanned areas. Nevertheless, we found that the other parameters included in our protocol contributed to achieving remarkable reduction of radiation exposure levels. The assessment of stone presence was conducted in consensus and, therefore, correlation or discrepancies between radiologists were not calculated. Finally, the availability of a previous CT scan was a prerequisite for the limited area VLD-CT, and no other imaging modalities were used for scan planning. This excluded patients who could potentially benefit from this follow-up examination such as those whose previous imaging had been by ultrasound.

Conclusions

Despite the potential of some additional radiation exposure from a follow-up imaging study, the application of a VLD-CT scan can be used to confirm the presence of urinary stones. It offers a significant reduction in radiation exposure and may substantially alter patient management. We. Therefore. recommend a modified VLD-CT protocol that utilizes very low-dose radiation exposure for the confirmation of stone presence and location.

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