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Original Research

Minimizing radiation exposure in pediatric nephrolithiasis: The effectiveness of a low-dose computed tomography protocol

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Summary

Purpose

Ultrasonography is the recommended first-line investigation for the diagnosis of pediatric nephrolithiasis. Despite higher sensitivity and specificity for this condition, computed tomography is reserved for more complex cases due to its radiation exposure. Despite increasing stone prevalence in the pediatric population, there is a lack of low-dose computed tomography pediatric urolithiasis protocols and descriptions of low-dose protocols are sparse. Herein we report the development and implementation of a low-dose protocol to reduce radiation exposure to this vulnerable population.

Materials and methods

A novel low-dose computed tomography protocol was designed through multidisciplinary collaboration, literature review, and phantom trials. Patients undergoing computed tomography for urolithiasis assessment were evaluated using the novel low-dose protocol and were compared to a retrospective cohort. Radiation reduction was characterized using descriptive statistics and comparative analysis.

Results

Mean (± standard deviation) age for the low-dose group was 12.6 ± 4.2 years ($n = 26$) compared to 12.4 ± 3.7 years for the standard-dose group ($n = 15$). The low-dose protocol reduced radiation dose when compared to the standard-dose group by 55.5 % (≥45 kg) ($p = 0.02$) and 27.8 % (<45 kg) ($p = 0.03$). The low-dose protocol visualized stones seen on ultrasound with 100 % accuracy ($n = 6$), and in 61.5 % ($n = 16/26$) of patients. There was no difference in stone sizes between groups.

Conclusions

Reduced-dose computed tomography protocols are effective for assessing urolithiasis while reducing radiation exposure. Implementation of reduced-dose computed tomography protocols in cases of suspected urolithiasis is advised to limit radiation exposure while maintaining diagnostic imaging detail.

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Introduction

The incidence of pediatric urolithiasis is rising with increased patient medical complexity, dietary trends, and environmental risks which presents evolving challenges in the diagnosis and monitoring of stone disease [1,2]. For the evaluation of pediatric urolithiasis, ultrasound is the standard first-line investigation due to the acceptable sensitivity and specificity and the avoidance of radiation exposure [3]. As the pediatric population is particularly radiosensitive, the use of computed tomography (CT) is often reserved for suspected occult stones not identified on ultrasound, for pre-operative planning, or for more complex cases where increased diagnostic accuracy outweighs potential harms associated with radiation exposure [3,4]. This is especially important as pediatric patients with urolithiasis have recurrence rates of approximately 50 % within 3 years which may predispose patients to a high cumulative radiation burden over the course of life if CT is utilized for detection [5]. To minimize radiation exposure, reduced-dose CT protocols for urolithiasis detection have been implemented in the adult urological population but adoption to pediatric urology is limited [6]. This aligns with the *as low as reasonably achievable* (ALARA) principle to limit exposure to excessive radiation that does not provide direct patient benefit. Reduced-dose CT protocols, characterized as "low-dose" ($\leq$3.0 millisieverts (mSv)) or "ultra-low-dose" ($\leq$1.9 mSv), based on radiation exposure thresholds, have been found to detect stone presence with maintained sensitivity and resolution, while substantially minimizing radiation exposure [7]. Based on expert consultation and literature review, a low-dose CT (LDCT) protocol for urolithiasis detection was developed and implemented in January 2024 at our tertiary pediatric center.

This study evaluates the reduction in radiation exposure achieved through the implementation of a LDCT protocol for urolithiasis detection in a pediatric population. Radiation exposure and stone detection accuracy was retrospectively compared to a cohort who underwent a standard-dose CT (SDCT) protocol for the assessment of stone disease.

Materials and methods

Low-dose CT protocol creation

A LDCT protocol was developed based on literature review and expert consultation including pediatric urologists, pediatric radiologists, medical physicists, medical imaging technologists and CT application specialists. To achieve dose-reduction, two protocols were developed based on body mass $<$45 kg (kg) and $\geq$45 kg. These body mass cutoffs were chosen based on expert review to align with current Canadian CT protocols. Original parameters for the SDCT protocol included a 100 kV (kV) voltage and a tube current range from 60 mA (mA) to 320 mA (maximum). The LDCT protocol reduced operating voltage to 80 kV for $<$45 kg and utilized a tube current range of 60–270 mA. For patients $\geq$45 kg, 80 kV were used with a tube current ranging from 60 to 320 mA. A phantom study was performed to analyze and optimize parameters before clinical implementation and demonstrated approximate dose reduction of 25 %. Spatial resolution was not affected, albeit at the expense of higher noise and lower contrast detectability. The same CT scanner (Canon Aquilion Prime) was utilized in this study for both the SDCT and LDCT protocols. The LDCT protocol was available to be ordered by both pediatric emergency medicine physicians and pediatric urologists.

Study population and data collection

Using a retrospective approach, a low-dose patient group, defined as those who underwent CT imaging for urolithiasis detection after low-dose protocol implementation (January 1, 2024–May 1, 2025) were identified and compared to a patient cohort who underwent SDCT based on available records (January 1, 2020–December 31, 2023). Only patients who underwent CT investigation specifically for urolithiasis (non-contrast) were included, with indications including accurate assessment of known stone burden, suspected nephrolithiasis in a patient with known stone disease not identified on ultrasound, or new flank pain and/or gross/microscopic hematuria in a patient with/without prior stone disease history. Patients younger older than 18 years of age, and patients undergoing non-contrast CT scans for other indications, or patients undergoing combined CT studies with contrast were excluded. To ensure the LDCT protocol was used exclusively for the aforementioned indications, all CT scan requests at our institution require discussion with the on-call pediatric radiologist before being approved to ensure that the SDCT protocol was not incorrectly utilized.

Data was collected on patient age at time of CT, body mass in kilograms, history of stone disease, prior ultrasound, stone presence on ultrasound and/or CT, laterality, stone location, and presence of hydronephrosis/hydroureteronephrosis. Additionally, radiation effective dose, expressed in millisieverts (mSv), was collected. Furthermore, clinical actions based on CT imaging findings were collected by chart review [i.e., observation, treatment with medical expulsive therapy (MET), ureteroscopic management (URS), or percutaneous nephrolithotomy (PCNL)]. Patients were not required to have prior ultrasound imaging performed, but if present, ultrasound data was collected and analyzed. Seven pediatric radiologists provided reports on the CT scans included in this study. Institutional ethics approval was obtained (Nova Scotia Health/IWK Health Centre Research Ethics File: 1029894).

Statistical analysis

Patient demographics and stone factors were collected and expressed using descriptive statistics and presented as mean $\pm$ standard deviation for parametric data, median [interquartile range] for non-parametric data, and frequency (percentage) for categorical data. Assessment of normality was performed graphically and by analysis of skewness and kurtosis. Chi-square, student's T-test, and Mann–Whitney U tests were used for comparative analysis. When comparing non-parametric and parametric groups, non-parametric statistical tests were used. Statistical significance was set at $p < 0.05$. Patients were stratified based on body mass into two groups: <45 kg, and ≥45 kg. Statistical analysis was performed using IBM SPSS Version 30.

To quantify performance of the LDCT protocol, direct comparison with SDCT was not able to be done as this would needlessly expose patients to excess radiation in a patient group in which excessive radiation is a concern. Additionally, after the LDCT protocol was implemented, SDCT was not performed at our institution. Therefore, detection accuracy was analyzed by comparing the ability of the LDCT protocol to identify stones seen on ultrasound at a non-inferior rate compared to the standard-dose population.

Results

After review of patient records, 15 patients were identified that underwent SDCT and 26 patients underwent LDCT for urolithiasis assessment. The mean ± standard deviation age was 12.4 ± 3.7 years in the SDCT group and 12.6 ± 4.2 years in the LDCT group (p = 0.4). Prior history of stone disease was more common in the SDCT group compared to the LDCT group (53.3 %, n = 8/15, vs 38.5 %, n = 10/26, p = 0.03) (Table 1). LDCT scans were ordered more frequently for ambiguous cases in which there was hydronephrosis/hydroureter on ultrasound but no visualized stone when compared to standard-dose patients (61.5 %, n = 16/26, vs 26.7 %, n = 4/15, p = 0.03) (Fig. 1). There were no differences in management approach based on CT findings between the SDCT and LDCT protocol groups, with most patients being treated with observation (60.0 %, n = 9/15, vs 61.5 %, n = 16/26, p = 0.92). Of patients who underwent ureteroscopic management, stones were visualized and treated 100 % of the time in both the SDCT and LDCT populations.

There were no statistical differences between maximal CT stone dimensions between standard-dose and low-dose protocols for the <45 kg and ≥45 kg patient groups (<45 kg length: 5.90 [9.6] mm vs 6.68 ± 3.4 mm, p = 0.379, width: 5.00 [15.6] mm vs 5.50 ± 2.7 mm, p = 0.126, ≥45 kg length: 7.10 ± 1.9 mm vs 8.04 ± 4.1 mm, p = 0.06, width: 6.30 ± 1.8 mm vs 4.02 ± 1.4 mm, p = 0.448) (Table 2). This relationship was further seen between the corresponding maximal dimensions on ultrasound compared to the SDCT and LDCT groups (<45 kg length (ultrasound prior to SDCT vs ultrasound prior to LDCT): 9.40 ± 3.2 mm vs 13.3 ± 2.9 mm, p = 0.95, width: 5.25 ± 1.1 mm vs 7.50 ± 0.7 mm, p = 0.86, ≥45 kg length: 7.15 ± 3.8 mm vs 7.70 ± 4.2 mm, p = 0.83, width: 6.65 ± 0.49 mm vs 8.00 ± 1.3 mm, p = 0.654). The

Table 1 Patient demographic and stone burden factors.

Demographic Factor	Standard-Dose (n = 15)		Low-Dose (n = 26)	
	Frequency: n (%)		Frequency: n (%)	
	BMI <45 kg (n = 7)	BMI >45 kg (n = 8)	BMI <45 kg (n = 16)	BMI >45 kg (n = 10)
History of stone disease				
Yes	4 (57.1)	4 (50.0)	6 (40.0)	4 (40.0)
No	3 (42.9)	4 (50.0)	9 (60.0)	6 (60.)
Scan indication				
Complex history	2 (28.5)	2 (25.0)	2 (12.5)	1 (10.0)
Stone on ultrasound	3 (42.9)	4 (50.0)	3 (18.8)	4 (40.0)
No stone on ultrasound (ambiguous)	2 (28.5)	2 (25.0)	11 (68.7)	5 (50.0)
Treatment based on CT				
Ureteroscopy	2 (28.5)	3 (37.5)	4 (25.0)	3 (30.0)
MET	1 (14.4)	0 (0)	2 (12.5)	1 (10.0)
Observation	4 (57.1)	5 (62.5)	10 (62.5)	6 (60.0)
Presence of HN/HUN				
HUN	0 (0)	0 (0)	2 (12.5)	1 (10.0)
HN	3 (42.9)	3 (37.5)	3 (18.8)	1 (10.0)
None	4 (57.1)	5 (62.5)	11 (68.7)	8 (80.0)
Side				
Bilateral	2 (33.3)	3 (50.0)	1 (14.4)	1 (20.0)
Right	0 (0)	1 (16.7)	2 (28.5)	0 (0)
Left	4 (66.6)	2 (33.3)	4 (57.1)	4 (80.0)
Stone location				
Upper pole	0 (0)	0 (0)	1 (20.0)	0 (0)
Interpolar	2 (40.0	3 (50.0)	0 (0)	0 (0)
Lower pole	1 (20.0)	0 (0)	0 (0)	2 (40.0)
Renal pelvis	0 (0)	1 (16.7)	1 (20.0)	0 (0)
Proximal ureter	1 (20.0)	1 (16.7)	3 (60.0)	2 (40.0)
Distal ureter	1 (20.0)	1 (16.7)	0 (0)	1 (20.0)
Stone seen on CT (not on US)				
Yes	1 (20.0)	0 (0)	3 (50.0)	3 (60.0)
No	4 (80.0)	6 (100.0)	3 (50.0)	2 (40.0)

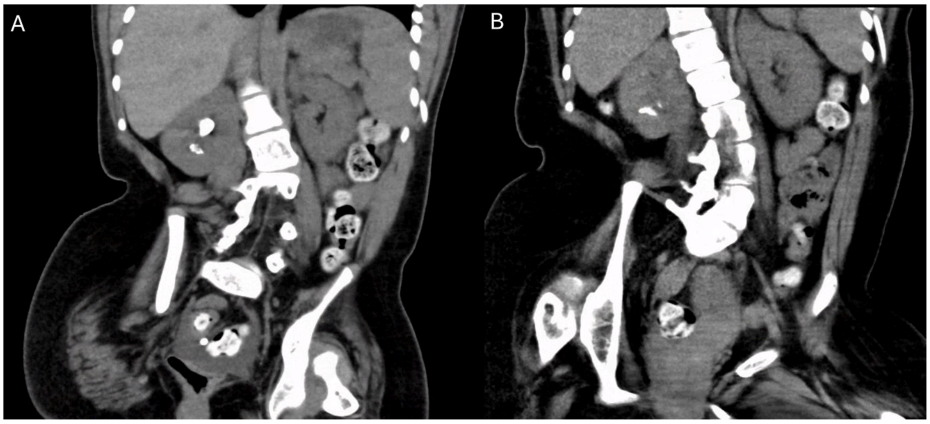

Fig. 1 Visual comparison of scan quality between (A) standard-dose CT protocol (3.20 mSv), and (B) low-dose protocol (2.03 mSv). CT scan comparison is made between the same patient who underwent both CT scan protocols approximately 4 years between scans.

range of stone dimensions detected by the LDCT protocol ranged from 1.8 to 12.5 mm, with the smallest dimension being 1.8 mm detected in the ≥45 kg group, and 3 mm in the <45 kg group. The majority (60 %) of stones visualized in the LDCT group were ureteric stones (n = 6/10, <45 kg: n = 3, >45 kg: n = 3), whereas intrarenal stones (63.6 %, n = 7/11, <45 kg: n = 3, >45 kg: n = 4) were the most common location in the SDCT population.

Stones were visualized on SDCT 80.0 % (n = 12/15) of the time, compared to 46.1 % (n = 12/26) in the LDCT group. When examining if CT identified stones not seen on ultrasound, only 1 stone was visualized on the SDCT protocol for patients <45 kg (9.1 %, n = 1/11), compared to the LDCT group where a stone was visualized on CT that was not seen on ultrasound 54.5 % of the time (n = 6/11). In cases where a stone was visualized on ultrasound, the stone was seen on LDCT 100 % of the time (n = 6).

Radiation exposure was significantly reduced for both the <45 kg and ≥45 kg groups when comparing LDCT with SDCT (Fig. 2). Patients <45 kg had a 27.8 % reduction in effective dose with the LDCT protocol compared to the SDCT group (2.03 [2.16] mSv vs 2.81 [1.31] mSv, p = 0.03), while patients ≥45 kg had a 55.5 % reduction in radiation exposure (2.29 ± 1.04 mSv vs 5.15 ± 2.02 mSv, p = 0.02).

Discussion

The use of CT is crucial for detecting stone disease with studies showing diagnostic accuracy >85 % for detecting uric acid, cystine, calcium oxalate monohydrate, and brushite calculi [8]. Therefore, the development and implementation of low-dose CT protocols for pediatric urolithiasis is crucial for providing higher detection accuracy while minimizing radiation exposure in this vulnerable population [9–11]. This is especially true with the increasing incidence and recurrence rates of pediatric stone disease [12]. Nonetheless, the use of LDCT for pediatric stone evaluation remains limited and is - if at all - primarily utilized at pediatric specialty centers [6,13]. Furthermore, Pittman et al. reported that in pediatric centres in the United States, LDCT was only utilized 18 % of the time due to established practice patterns [13]. With a mean patient age of approximately 12.5 years and a

Table 2 Radiation dose and CT and US stone characteristics.

	Standard-Dose (n = 15)		Low-Dose (n = 26)	
	Mean ± Standard Deviation Median [Interquartile Range]		Mean ± Standard Deviation Median [Interquartile Range]	
	<45 kg (n = 7)	>45 kg (n = 8)	<45 kg (n = 16)	>45 kg (n = 10)
Days between US and CT	13.0 [36]	164.5 [317.3]	8.0 [35.5]	32.0 [250]
Radiation dose (mSv)	5.98 ± 6.38	5.15 ± 2.02	2.40 ± 1.10	2.29 ± 1.04
	2.81 [1.31]	5.07 [4.68]	2.03 [2.16]	3.23 [1.8]
Stone number	4.2 ± 3.6	4.5 ± 4.0	1.3 ± 0.5	2.6 ± 1.5
CT scan measurements (mm)				
Maximal length	5.90 [9.6]	7.10 ± 1.9	6.68 ± 3.4	8.04 ± 4.1
Maximal width	5.00 [15.6]	6.30 ± 1.8	5.50 ± 2.7	4.02 ± 1.4
Ultrasound scan measurements (mm)				
Maximal length	9.40 ± 3.2	7.15 ± 3.8	13.3 ± 2.9	7.7 ± 4.2
Maximal width	5.25 ± 1.1	6.65 ± 0.49	7.5 ± 0.7	8.0 ± 1.3

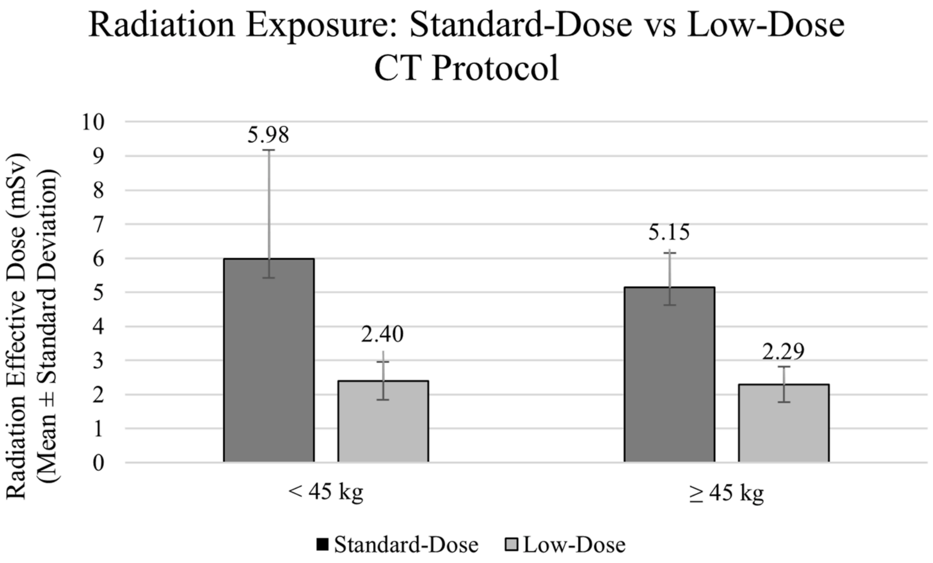

Fig. 2 Reduction in radiation exposure with low-dose CT imaging protocol for urolithiasis detection.

documented 50 % recurrence rate within three years for pediatric first-time stone formers, a considerable subset of our cohort is likely to experience recurrent stone events before adulthood [5,12]. This may subject pediatric patients to multiple CT scans and increase their cumulative radiation exposure and associated potential radiation-induced malignancy [9,11]. Thus, even modest reductions in radiation per scan can cumulatively lead to a substantial overall decrease in radiation exposure. This is exemplified by our study showing that 43.9 % of patients who underwent CT investigation had a prior history of stone disease and associated radiographical investigations.

Compared to the existing literature, radiation dose in our SDCT cohort was within the range for reported standard-dose protocols for pediatric population (literature: 4.13 ± 0.84 mSv) and CT parameters aligned with established standards [6,14—19]. When analyzing the radiation-dosage delivered using the LDCT protocol, our low-dose of 2.29—2.40 mSv aligned with the standard definition of a "low-dose" protocol, $\leq$3.0 mSv, but did not meet the threshold for "ultra-low-dose" categorization with effective dose $\leq$1.9 mSv [20—22]. With our low-dose protocol, patients $\geq$45 kg demonstrated the greatest radiation reduction of 55.5 %, whereas patients $<$45 kg demonstrated reductions of 27.8 %. This is likely due to limitations of the CT scanner and parameter range as designed in the protocol. As parameters are decreased towards the lower-limit within the protocol, the radiation delivered will trend towards the lowest possible radiation dose. For patients $\geq$45 kg, there exists more potential for radiation reduction within the protocol's parameters based on the ability to modulate the tube current across a larger range based on the patient's weight. Although 27.8 % radiation reduction with preserved accuracy is a substantial reduction for patients $<$45 kg, further radiation reduction may be possible with refinement of the protocol and changes to the parameters [14]. Furthermore, subsequent protocols can be developed using additional body mass cutoffs to better fine—tune parameter ranges (i.e. $<$ 15 kg, 15—30 kg, 30—45 kg, etc.). At our institution, further work is being done to design reduced-dose protocols for these body mass cut-off ranges to better serve this patient group.

The LDCT protocol was able to detect stones found on ultrasound at the same rate as the SDCT protocol with 100 % detection accuracy. Thus, the reduction in spatial resolution and reduced signal-to-noise inherent to the LDCT protocol did not negatively impact detection accuracy [23,24]. Direct comparison between the standard-dose and low-dose protocols were unable to be performed as to limit the radiation exposure delivered to the patients in the study. This direct comparison has been done in the adult literature with favourable results [19]. When analyzing stone and patient characteristics between groups, patients in the LDCT group had less stone burden than the SDCT group, albeit there were no differences in maximal stone dimensions on CT or corresponding ultrasound image [24]. This difference in stone burden between groups is likely attributed to lower thresholds for performing CT imaging on patients in the LDCT group compared to the SDCT group due to more limited radiation exposure. Additionally, at our institution during the time-period that the LDCT protocol was implemented, there was substantially reduced access to ultrasound imaging due to an issue with ultrasonographer hiring practices. Therefore, CT for stone assessment was more commonly performed due to the availability of CT. Increased ordering of LDCT compared to SDCT may also be due to ordering bias once a reduced-dose CT option became available, reducing the threshold for ordering physicians to advocate for CT imaging. The SDCT and LDCT protocols were able to detect both intrarenal and ureteric stones with the smallest stone dimensions measured by the LDCT protocol being 3 mm ($<$45 kg) and 1.8 mm ($\geq$45 kg). This supports the utility of the LDCT protocol for detecting both ureteric and intra-renal stones including small size stones. Additionally, there were no stones seen on ultrasound that were not visualized on LDCT highlighting the sensitivity of the low-dose protocol when compared to ultrasound imaging use [24]. When comparing the increased utilization of

LDCT for stone assessment compared to the SDCT group, this difference in patient numbers may also highlight that patients were sent for LDCT scans earlier in their clinical course and perhaps with less symptoms or less ambiguity in ultrasound findings when compared to the SDCT group. Alternatively, this may represent the increase in patients seen at our centre and/or increased complexity of the patients seen in the pediatric urology clinic in the more recent cohort. Additionally, this may reflect a lower threshold for ordering a LDCT by pediatric urologists and pediatric emergency physicians due to the lower presumed radiation risk, where historically these patients in the SDCT era may have been followed with interval ultrasound imaging. Despite this, treatment based on CT scan findings were the same between LDCT and SDCT patient groups, with the majority being recommended observation 61 % of the time. Therefore, the low-dose protocol did not result in any changes in management or intervention when compared to the standard-dose patient group.

This study provides support for low-dose CT protocols for pediatric urolithiasis assessments and serves as one of few studies that provides a direct comparison to a standard-dose protocol - with radiation reductions of 55.5 % and 27.8 % [6,14,18]. As this study only included CT scans done for urolithiasis assessment, the benefit of this low-dose protocol may also be expanded to other pediatric populations undergoing non-abdominal scans or abdominal scans for other indications — further perpetuating patient benefit and reduced oncological risk [9].

Limitations in this study exist. Firstly, a direct comparison between SDCT and LDCT protocols was unable to be done using the same patients, as to minimize patient radiation exposure, therefore comparisons were made between two similar independent cohorts. Additionally, detection accuracy was unable to be directly compared between groups and a surrogate measure utilizing stone detection based on ultrasound findings had to be made. Evaluation of the adult literature on LDCT protocols have demonstrated radiation dose reductions of up to 73 % without any reduction in detection accuracy, further supporting the accuracy of our LDCT protocol which features a more modest dose reduction [24—26]. We were unable to distinguish differences in detection accuracy between intrarenal and ureteric stones due to the low number of stone events in our study, and furthermore, detection of stones $<$1.8 mm was not performed in our study due to the nature of the observed stone burden in our patient group. Further studies examining smaller stones need to be done to fully assess the detection accuracy of this LDCT protocol. Future work involves the implementation of this LDCT protocol to other pediatric institutions for further validation and to reduce radiation exposure in the pediatric urolithiasis population. Challenges may also include implementing this LDCT protocol at centres that utilize a different CT scanner which may have different limits on the voltage and amperage parameters. This may limit the ability to implement this protocol on a larger scale. Additionally, as reduced-dose protocols evolve and become more common, the target radiation dose which defines "low" and "ultra-low" may continue to change which is an important consideration when contextualizing this study within the field.

Conclusion

Establishing and utilizing low-dose CT protocols is critical in optimizing care for pediatric patients at risk for (recurrent) nephrolithiasis. This study presents a successfully implemented protocol that achieved substantial radiation dose reduction without compromising the sensitivity of stone detection.

Ethics approval

Institutional ethics approval was obtained for this study (Nova Scotia Health/IWK Health Centre Research Ethics File: 1029894).

Data availability statement

The data sets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Funding source

No funding was obtained for this study.

Conflicts of interest

The authors of this manuscript have no conflicts of interest related to this work to declare.

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