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The efficacy of tin-filtration for computed tomography in diagnosing urolithiasis

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ABSTRACT

Introduction: The purpose of this study was to evaluate the radiation dose and image quality of computed tomography urograms (CTU) using tin-filtration compared to conventional CTU (without tin-filtration) examinations in patients with suspected urolithiasis.

Methods: Group 1 consisted of 100 patients who were examined using the tin-filtered CTU protocols (Sn100kVp or Sn150kVp); Group 2 consisted of 100 patients who were examined using the same protocols but without tin-filtration (GE-NI41 or GE-NI43). The scanning protocol was based on the patients' body weight (< 80 kg and ≥ 80 kg). The effective doses of all scans were compared between the two groups. Subjective image quality was evaluated by two blinded radiologists. The objective image quality was assessed for noise, signal-to-noise ratio (SNR), contrast-to-noise ratio (CNR) and figure-of-merit (FOM) using the CTU scans acquired from both the tin-filtered and non-tin-filtered protocols.

Results: Tin-filtration resulted in the reduction of effective radiation dose ranging between 72% to 88% for the ≥ 80 kg and < 80 kg patient groups respectively. For both groups, tin-filtration resulted in no significant differences in SNR and a significant increase in FOM. For the < 80 kg group, tin-filtration resulted in significantly noisier images but with no significant difference in CNR. For the ≥ 80 kg group, tin-filtration resulted in significantly higher CNR. There was no significant difference in subjective image quality when assessed by the radiologists in terms of diagnostic confidence for urolithiasis.

Conclusion: Tin-filtration significantly reduces patient dose while maintaining diagnostic image quality of CTUs for patients with suspected urolithiasis.

1. Introduction

The number of patients diagnosed with urolithiasis is progressively increasing [1]. This is believed to be due to lifestyle and nutritional changes in recent years. In Australia, the incidence of urolithiasis is approximately 150 per 100,000 people [2]. Diagnostic imaging examinations, either in the form of an abdominal X-ray (AXR) examination or a non-contrast enhanced computed tomography urogram (CTU), are required to detect and characterise urinary stones so that appropriate patient management can be promptly initiated [3]. With the exception of pregnant women, the gold standard imaging modality for patients with known or suspected urolithiasis is CTU [3–6]. When performed using conventional CTU scanning protocols, the sensitivity and specificity of CTU in the diagnosis and characterisation of the calculi range from 95% to 97% and 96% to 100% respectively [7–10]. The high sensitivity and specificity of CTU in the diagnosis and characterisation of the urinary calculi can be credited to the fact that CT scans, unlike plain-film X-ray examinations, are not affected by the presence of overlying bowel gas or bony structures [9]. Furthermore, CTUs are useful because of their speed and ability to provide differential diagnoses in patients suffering from abdominal or flank pain [8,10].

Despites its advantages, one of the significant drawbacks of CTUs is the exposure of the patients to a relatively high amount of ionising radiation [11]. Hence, some physicians still request abdominal plain-film X-ray examinations for patients presenting with renal colic or acute abdominal pain. The typical effective dose of an AXR is 0.6 mSv while the effective dose of a conventional CTU ranges between 9 mSv to 16 mSv [11]. The radiation dose is a major area of concern especially for younger patients who may require multiple CTU examinations for

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follow-up imaging due to the high recurrence rates of the urolithiasis [8,10,12].

CTU scans performed with the use of radiation dose reduction techniques can be referred to as either low-dose CTUs (LDCTUs) or ultra-low-dose CTUs (ULDCTUs). LDCTUs are defined as CTUs which have radiation doses of < 3.5 mSv while ULDCTUs are defined as CTUs which have radiation doses of ≤1.9 mSv [13].

Spectral shaping of the X-ray beam and the removal of lower energy photons using tin filtration in CT scanners has been shown to lower the radiation dose to patients, reaching doses of ULDCTUs [14–18]. Two prior studies performed on patients with suspected urolithiasis demonstrated substantial dose reduction of 56% and improved subjective image quality of 15% in CTUs using the tin-filtration technology with 150kVp tube voltage (Sn150kVp) [14,16]. However, both of the studies used the Sn150kVp protocol for all the patients regardless of their body weight. The use of 100kVp tube voltage, accompanied by the use of the additional tin filter (Sn100kVp), may be possible for patients with smaller body habitus, allowing for further reductions in effective dose and improvements to image quality.

To the best of our knowledge, the studies available in current literature have only explored using the Sn150kVp scanning protocol with positive results suggesting that the use of tin-filtration can significantly reduce radiation dose. The purpose of our study was to explore the use of both the Sn100kVp or Sn150kVp protocols for patients of different body habitus by stratifying the patients based on their body weight. We aim to assess the radiation dose and image quality of ULDCTUs performed with the novel tin-filtration technique in comparison to conventional LDCTUs performed without tin-filtration for patients with suspected urolithiasis, according to their body habitus.

2. Materials and methods

2.1. Diagnostic imaging examinations

All the patients included in this study were aged 18 years or older, and pregnant patients were excluded from this study. Between November 2017 and March 2018, 100 consecutive patients with suspected urolithiasis who underwent ULDCTUs using either the Sn100kVp or Sn150kVp protocol on the Siemens SOMATOM Force (Siemens Healthcare, Germany) were selected into the study. These examinations were compared to a second group of 100 consecutive patients who underwent conventional LDCTUs for the same clinical indication on the GE Lightspeed VCT (General Electric, United States), using either the GE NI41 or GE NI43 protocol during the same time period. The scanning protocol for each examination was chosen based on patient body weight. Table 1 describes the technical parameters for the scanning protocols which were used for each CT scanner. In all patients, the scan range covered from above the kidneys to below the lesser trochanter of the femur.

Table 1
CT urogram scanning protocols for SOMATOM Force and Lightspeed VCT.

Protocol number[a]	Siemens SOMATOM Force	GE Lightspeed VCT
1	< 80 kg scanned at SN100kVp Quality Reference mAs (QRef.) = 80 mAs Rotation time = 0.5 s	< 80 kg scanned at 100kVp Noise Index (NI) = 41 Rotation time = 0.8 s
2	≥80 kg scanned at Sn150kVp Quality Reference mAs (QRef.) = 230 mAs Rotation time = 0.5 s	≥80 kg scanned at 120kVp Noise Index (NI) = 43 Rotation time = 0.8 s

[a] The automatic dose modulation was selected for all the five scanning protocols. The tube-current modulation strength was set to “average”, as per manufacturers' default setting on both CT scanners (CARE Dose4D, Siemens Healthcare; Smart MA, General Electric).

2.2. Evaluation of image quality and patient dose

Subjective image quality of the CTUs was independently evaluated by two radiology consultants. Twenty CTU scans were randomly selected from each scanning protocol within each patient group (< 80 kg and ≥80 kg). The anonymised sets of data were presented to the readers in random order. These scans were read under conditions which were compliant with the guidelines set by The Royal Australian and New Zealand College of Radiologists (RANZCR). The brightness of the monitor screens were set to at least 350 cd/m^2 and there was minimal extraneous room light [19]. On a 5-point Likert scale (1 = not confident/unacceptable quality, 2 = slightly confident/fair quality, 3 = somewhat confident/moderate quality, 4 = confident/good quality, 5 = very confident/excellent quality), confidence in diagnosing urolithiasis, confidence in diagnosing other abdominal pathology and overall image quality, were individually rated.

Objective image quality was analysed by evaluating image noise, signal-to-noise ratio (SNR), contrast-to-noise ratio (CNR) and figure-of-merit (FOM) between the two acquisition protocols used for both the < 80 kg and ≥80 kg patient groups. Regions-of-interest (ROIs), with a standardised size of 15 mm^2, were manually placed on an axial slice in the kidneys and soft tissue surrounding the kidneys (Fig. 1). The mean and standard deviation of CT attenuation Hounsfield Unit (HU) values in the ROIs were recorded. Image noise was represented by the standard deviation HU values within the ROIs placed in the soft tissue surrounding the kidneys. The SNR, CNR and FOM were calculated using Eqs. (A.1), (A.2) and (A.3) respectively. The FOM is a metric used to compare the dose efficiency of the two scanning protocols [15].

$$SNR = \frac{Mean\ HU\ within\ Soft\ Tissue}{Standard\ Deviation\ HU\ within\ Soft\ Tissue} \tag{A.1}$$

$$CNR = \frac{Mean\ HU\ within\ Kidney - Mean\ HU\ within\ Soft\ Tissue}{Mean\ HU\ within\ Soft\ Tissue} \tag{A.2}$$

$$FOM = \frac{CNR^2}{Effective\ Dose} \tag{A.3}$$

The effective dose of each CTU examination was calculated using CT-Expo v2.5(E) (SASCRAD, Germany).

Measurements of the anterior-posterior (AP) and lateral dimensions of each patient's pelvis, at the level of the iliac crest, was conducted using the calliper tool on the Syngo.via imaging software (Siemens

Fig. 1. Location of ROIs placed within the CTU scan for the analysis of objective image quality. The red circles represent the ROIs positioned in the kidney and the green circles represent the ROIs positioned in the soft tissue surrounding the kidneys. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

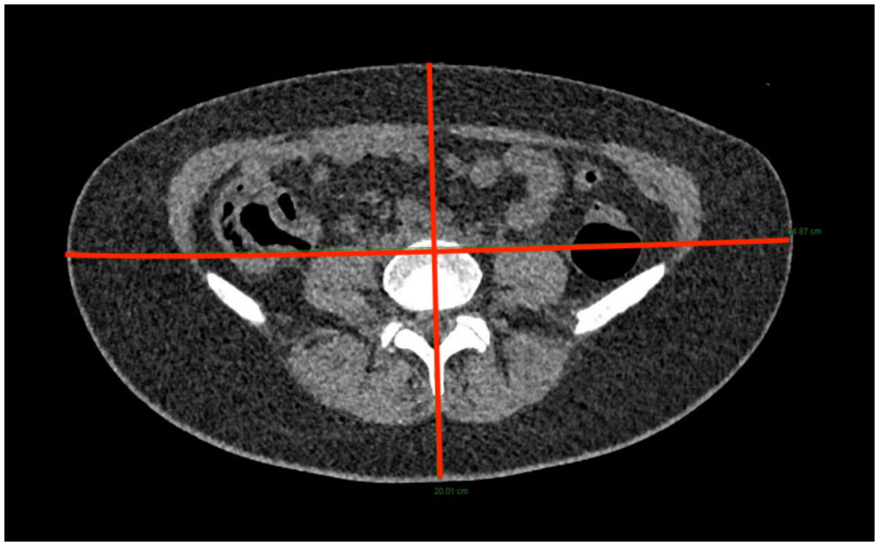

Fig. 2. Measurement of AP and lateral dimensions to calculate the effective abdominal diameter (at the level of the iliac crest) of each patient.

Healthcare, Germany) (Fig. 2). The abdominal effective diameter was then calculated using Eq. (B.1). The effective diameter was used to estimate the abdominal cross-sectional area to allow for more accurate comparison of patient body habitus between the two CT scanners within both patient groups (< 80 kg and ≥80 kg). This was done to reduce the probability of falsely detecting radiation dose reduction that was attributable to patient body habitus.

$$\text{Effective Diameter} = \sqrt{AP\ Measurement * Lateral\ Measurement} \qquad \text{(B.1)}$$

2.3. Statistical analysis

Statistical analysis was performed using IBM® SPSS® Statistics Version 25 for Macintosh (Chicago, USA). A p-value of < 0.05 was afforded significance. Subjective image quality of CTUs obtained using tin-filtration and CTUs obtained without tin-filtration was evaluated by calculating the inter-observer agreement using Cohen's Kappa values. Chi-squared tests were performed to compare the proportion of cases according to gender, presence of urolithiasis and presence of other abdominal pathology, between the two CT scanners used in this study, within each patient group (< 80 kg and ≥80 kg). The chi-squared test was also performed to compare the radiation doses between the CTU scans and published typical effective dose for AXRs, within each patient group (< 80 kg and ≥80 kg). Independent-samples two-tailed *t*-tests were used to detect statistically significant differences in terms of abdominal effective diameter, $CTDI_{vol}$, DLP and effective doses between the two CT scanners used in the study, for each patient group (< 80 kg and ≥80 kg), The *t*-test was also used to compare the measurements of objective image quality (SNR, CNR and FOM) between the tin-filtration and non-tin-filtration protocols.

2.4. Ethics approval

Ethics approval was given by Monash Health Human Research Ethics Committee Low Risk Panel (HREC/18/MonH/17).

3. Results

3.1. Patient demographic characteristics

The patient demographic characteristics for the CTU study group are summarised in Table 2. Within both patient groups (< 80 kg and ≥80 kg), there were no statistically significant differences in terms of patient gender, age or effective diameter between the tin-filtration and non-tin-filtration group (all $p > 0.05$).

3.2. Radiation dose

Figs. 3 and 4 show the graphical comparison of the published typical effective dose for AXRs and both CTU scanning protocols for each patient group (< 80 kg and ≥80 kg). For both patient groups, the mean effective dose for non-tin-filtered protocols was significantly higher than the mean effective dose for tin-filtered protocols ($p < 0.001$). The mean effective dose for Sn100kVp protocol was not significantly different from the published typical effective dose for AXRs ($p = 0.999$).

3.3. Objective image quality

The objective image quality results are summarised in Table 3. For the < 80 kg patient group, the CTU images acquired using the Sn100kVp protocol had a significantly higher FOM than those acquired using the GE NI41 protocol ($p < 0.001$). However, there were no significant differences in terms of SNR ($p = 0.18$) and CNR ($p = 0.34$) between the tin-filtration and non-tin-filtration protocols. For the ≥80 kg patient group, there were no significant differences in terms of SNR, regardless of whether tin-filtration was used ($p = 0.23$). However, the Sn150kVp protocol had significantly higher CNR ($p < 0.001$) and FOM ($p < 0.001$) than the GE NI43.

3.4. Subjective image quality

For both patient groups (< 80 kg and ≥80 kg), there were no significant differences in the radiologists' confidence in diagnosing urolithiasis (both $p > 0.05$). However, the radiologists' confidence in diagnosing other abdominal pathology and overall image quality were significantly lower for the Sn100kVp protocol compared to the GE NI41 protocol (all $p < 0.001$). There was almost-perfect inter-rater agreement for the GE NI43 protocol in terms of the radiologists' confidence in diagnosing urolithiasis and for the overall image quality. There was substantial inter-rater agreement for the all the other categories of ratings for the scanning protocols. The inter-rater agreement for all four protocols are summarised in Table 4.

4. Discussion

Our study demonstrates that CTUs performed with tin-filtration

Table 2
Patient characteristics for CTU examinations.

	< 80 kg			≥80 kg		
	Siemens	GE	p-Value	Siemens	GE	p-Value
N	50	57	–	50	43	–
Age, years	49.8 (± 14.9)	50.1 (± 17.2)	0.946	52.1 (± 16.4)	50.7 (± 16.2)	0.677
Male, n (%)	21 (42%)	27 (47%)	0.577	35 (70%)	35 (81%)	0.204
Effective diameter, cm	25.8 (± 2.59)	26.3 (± 3.0)	0.353	32.2 (± 4.35)	31.4 (± 3.80)	0.323
CT evidence of urolithiasis, n (%)	30 (60%)	41 (72%)	0.193	29 (58%)	23 (47%)	0.059
CT evidence of other abdominal pathology, n (%)	19 (38%)	23 (40%)	0.804	22 (44%)	20 (47%)	0.808
$CTDI_{vol}$, mGy	0.733 (± 0.15)	6.01 (± 4.52)	< 0.001	2.59 (± 1.13)	10.55 (± 6.02)	< 0.001
DLP, mGy·cm	31.17 (± 7.39)	252.44 (± 152.95)	< 0.001	116.96 (± 55.32)	502.12 (± 318.88)	< 0.001
Effective dose, mSv	0.60 (± 0.14)	5.00 (± 3.03)	< 0.001	2.40 (± 1.14)	8.50 (± 5.40)	< 0.001

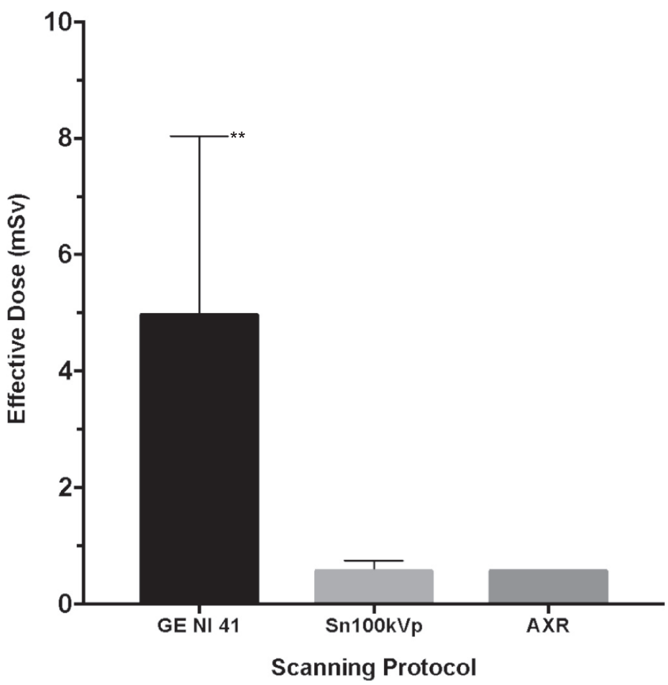

Fig. 3. Mean and standard deviation of the effective dose for the GE NI41 and Sn100kVp protocols, in comparison to published typical effective dose for AXRs.

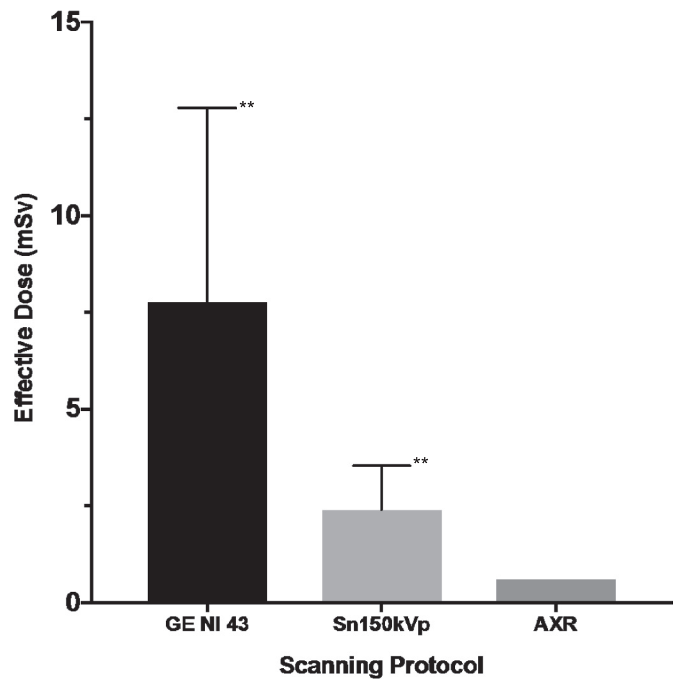

Fig. 4. Mean and standard deviation of the effective dose for the GE NI43 and Sn150kVp protocols, in comparison to published typical effective dose for AXRs.

result in significantly lower effective dose for patients than standard CTUs performed without tin-filtration. This reduction in effective dose is achieved while maintaining diagnostic image quality for confident assessment of urolithiasis. However, the confidence in diagnosing other abdominal pathologies is compromised.

The data from our study is consistent with the results of the literature which suggest that CTUs performed using tin-filtration results in significantly lower radiation dose and increased FOM while maintaining diagnostic confidence [14–18,20,21]. Previous studies have mainly applied the tin-filtration scanning technique to evaluate its effects on the characterisation of urinary stones [22–24]. To date, there have only been two studies investigating the effect of tin-filtration on radiation dose and image quality of CTUs for patients with suspected urolithiasis [14,16]. Both of these studies only evaluated the effect of the Sn150kVp protocol on radiation dose and image quality. In our study, we compared the radiation dose and image quality of the CTUs performed with tin-filtration (Sn100kVp protocol for patients weighing < 80 kg and Sn150kVp protocol for patients weighing ≥80 kg) to that of the protocols without tin-filtration (GE NI41 protocol for patients weighing < 80 kg and GE NI43 protocol for patients weighing ≥80 kg).

The results achieved in our study demonstrate that in comparison to conventional scanning protocols without tin-filtration, the use of tin-filtration results in significant radiation dose reduction ranging from 72% to 88% depending on the patient's body habitus. Additionally, our study has shown that the effective radiation dose from a CTU using the Sn100kVp protocol is not statistically different to the published typical effective dose for AXRs. This reduction in radiation dose was also observed in the two previous studies [14,16]. Table 5 compares the radiation dose reduction between our study and the two previous studies. Although there were differences in the pitch settings selected for the tin-filtration protocols used in these studies, the results from both studies were unanimous in showing that there was a significant reduction in radiation dose of 36% to 56% when the tin-filtration technique was used [14,16]. The mean (± SD) DLP measurements for the Sn150kVp in our study (117 (± 55.3) mGy·cm) was higher than the DLP measured in the regular-pitch Sn150kVp protocol used in the study performed by Dewes et al. (93 (± 30) mGy·cm). This could be due to the fact that the patients who were included in our study were stratified based on their body weight. In contrast to the study protocol by Dewes et al. [16], only the patients who weighed ≥80 kg were scanned using the Sn150kVp protocol in our study. The inherent differences in patient body weight would have likely affected the measured DLP since the automated tube-current modulation is dependent on patient body size and the resultant

Table 3
Objective image quality results.

	Sn100kVp	GE NI41	p-Value	Sn150kVp	GE NI43	p-Value
Image noise	22.55 (± 2.71)	19.52 (± 5.60)	0.036	15.50 (± 2.43)	14.77 (± 2.84)	0.39
Signal-to-noise ratio	5.32 (± 0.84)	5.64 (± 1.40)	0.18	7.14 (± 1.38)	7.51 (± 2.08)	0.23
Contrast-to-noise ratio	1.31 (± 0.05)	1.29 (± 0.06)	0.34	1.33 (± 0.05)	1.25 (± 0.06)	< 0.001
Figure-of-merit	2.88 (± 0.2)	0.30 (± 0.03)	< 0.001	0.75 (± 0.05)	0.19 (± 0.02)	< 0.001

Table 4
Inter-rater agreement (Kappa) for radiologists' ratings for the (1) confidence in diagnosing urolithiasis, (2) confidence in diagnosing other abdominal pathology and (3) overall image quality.[1]

	Confidence in diagnosing urolithiasis	Confidence in diagnosing other abdominal pathology	Overall image quality
Sn100kVp	0.67	0.63	0.72
GE NI41	0.71	0.74	0.78
Sn150kVp	0.69	0.62	0.78
GE NI43	0.72	0.73	0.98

[1] Inter-observer agreement was evaluated using Cohen's Kappa values, which were interpreted as poor (< 0), slight (0.0 – 0.20), fair (0.21 – 0.40), moderate (0.41 – 0.60), substantial (0.61 – 0.80) and almost perfect (0.81 – 1.0) respectively.

Table 5
Comparison of mean (SD) radiation dose between our study and literature.

	Sn100kVp	Sn150kVp	Dewes et al.	Shi et al.
$CTDI_{vol}$, mGy	0.7 (± 0.2)	2.6 (± 1.1)	2.1 (± 0.5)	3.1 (± 1.0)
DLP, mGycm	31.2 (± 7.4)	117.0 (± 55.3)	93.0 (± 30.0)	155.5 (± 54.5)
Effective Dose, mSv	0.6 (± 0.1)	2.4 (± 1.1)	Not Provided	2.3 (± 0.8)

attenuation profile. Nevertheless, our results show that by determining the scanning protocol based on patient size, even further dose optimisation is possible.

For the comparison of objective image quality in terms of image noise, SNR, CNR and FOM between the tin-filtration and non-filtration protocols, our results have shown that CTUs performed using tin-filtration showed a significantly higher dose efficiency, in terms of FOM. For the < 80 kg patient group, image noise was significantly increased when tin-filtration was used but there were no significant differences in SNR and CNR between the tin-filtered and non-tin-filtered protocols. For the ≥80 kg patient group, the use of tin-filtration resulted in significantly higher CNR. However, there were no significant differences in terms of SNR and image noise. In terms of objective image quality, previous studies have shown that with the use of tin-filtration, there were generally no significant differences in terms of SNR. However, it was inconclusive whether there was an increase or reduction in CNR with the use of tin-filtration since two previous studies had conflicting outcomes [14,16].

Since acute abdominal pain can arise from a plethora of pathologies, consideration must be given to the required CNR to accurately assess the soft tissue structures. Hence, the increased mean energy of the resultant X-ray beam due to the use of tin-filtration may not be suited for all clinical indications. The overall image quality and the radiologists' confidence in diagnosing other abdominal pathology was significantly lower for the CTUs acquired using the tin-filtration protocol. However, there was no significant difference in the radiologists' confidence in diagnosing urolithiasis regardless of whether tin-filtration was used. Generally, CTUs can tolerate noisier images since there is high inherent contrast from the urinary stones which are usually composed of calcium. Thus, if the patient was referred for a CTU examination for suspected urolithiasis, the radiation dose given to the patient need to only be sufficient to either rule out or confirm the presence of urolithiasis. Therefore the use of the tin-filtration protocol is appropriate. However, before consideration is given to change of clinical practice for all CTUs, further studies are needed to assess the efficacy of the tin-filtration protocol in diagnosing other abdominal pathologies.

4.1. Limitations

Two different CT systems were used for our measurements. Consequently, there could be other technical factors, such as the detector quantum efficiency, detector material and focal spot size, which could have influenced the reduction in radiation dose. Nevertheless, these differences in technical factors between the two CT scanners would not account for the drastic increase in dose efficiency as a result of using tin-filtration.

5. Conclusion

CTU examinations performed using the tin-filtration technique result in significantly reduced effective radiation dose, which is similar to that of AXR, while maintaining diagnostic image quality when urolithiasis is indicated. However, further studies are required to assess the efficacy of using the tin-filtration protocol for other abdominal pathologies. Our study also suggests that in order to achieve optimum diagnostic image quality and maximum radiation dose reduction when using tin filtration, it is essential to select the scanning protocol based on the patient's body weight.

References

[1] Raheem OA, Khandwala YS, Sur RL, Ghani KR, Denstedt JD. Burden of urolithiasis: trends in prevalence, treatments, and costs. Eur Urol Focus 2017;3(1):18–26.
[2] Sewell J, Katz DJ, Shoshany O, Love C. Urolithiasis - ten things every general practitioner should know. Aust Fam Physician 2017;46(9):648–52.
[3] Shaaban MS, Kotb AF. Value of non-contrast CT examination of the urinary tract (stone protocol) in the detection of incidental findings and its impact upon the management. Alex J Med 2016;52(3):209–17.
[4] Fulgham PF, Assimos DG, Pearle MS, Preminger GM. Clinical effectiveness protocols for imaging in the management of ureteral calculous disease: AUA technology assessment. J Urol 2013;189(4):1203–13.
[5] Türk C, Petřík A, Sarica K, Seitz C, Skolarikos A, Straub M, et al. EAU guidelines on interventional treatment for urolithiasis. Eur Urol 2016;69(3):475–82.
[6] Coursey CA, Casalino DD, Remer EM, Arellano RS, Bishoff JT, Dighe M, et al. ACR appropriateness criteria® acute onset flank pain - suspicion of stone disease. Ultrasound Q 2012;28(3):227–33.
[7] McLaughlin P, Murphy K, Hayes S, Carey K, Sammon J, Crush L, et al. Non-contrast CT at comparable dose to an abdominal radiograph in patients with acute renal colic; impact of iterative reconstruction on image quality and diagnostic performance. Insights Imaging 2014;5(2):217–30.
[8] Andrabi Y, Patino M, Das CJ, Eisner B, Sahani DV, Kambadakone A. Advances in CT imaging for urolithiasis. Indian J Urol 2015;31(3):185–93.
[9] Kennish SJ, Wah TM, Irving HC. Unenhanced CT for the evaluation of acute ureteric colic: the essential pictorial guide. Postgrad Med J 2010;86(1017):428–36.
[10] Brisbane W, Bailey MR, Sorensen MD. An overview of kidney stone imaging techniques. Nat Rev Urol 2016;13(11):654–62.
[11] Lipkin M, Ackerman A. Imaging for urolithiasis: standards, trends, and radiation exposure. Curr Opin Urol 2016;26(1):56–62.
[12] Soenen O, Balliauw C, Oyen R, Zanca F. Dose and image quality in low-dose CT for urinary stone disease: added value of automatic tube current modulation and iterative reconstruction techniques. Radiat Prot Dosimetry 2016;174(2):242–9.
[13] Imran F, Zaman Z, Iqbal MJ. Diagnostic accuracy of IVU compared to unenhanced CT KUB for detection of urinary tract calculi. J Islamabad Med Dent Coll 2017;6(4):234–9.

[14] Shi B, Sun H, Xue H-D, Wang Y, Liang J-X, Xu K, et al. High-pitch low-dose abdominopelvic CT with tin-filtration technique for detecting urinary stones. Abdom Radiol 2017;42(8):2127–34.
[15] Braun FM, Johnson TR, Sommer WH, Thierfelder KM, Meinel FG. Chest CT using spectral filtration: radiation dose, image quality, and spectrum of clinical utility. Eur Radiol 2015;25(6):1598–606.
[16] Dewes P, Frellesen C, Scholtz J-E, Fischer S, Vogl TJ, Bauer RW, et al. Low-dose abdominal computed tomography for detection of urinary stone disease – impact of additional spectral shaping of the X-ray beam on image quality and dose parameters. Eur J Radiol 2016;85(6):1058–62.
[17] Messerli M, Kluckert T, Knitel M, Wälti S, Desbiolles L, Rengier F, et al. Ultralow dose CT for pulmonary nodule detection with chest X-ray equivalent dose–a prospective intra-individual comparative study. Eur Radiol 2017;27(8):3290–9.
[18] Haubenreisser H, Meyer M, Sudarski S, Allmendinger T, Schoenberg SO, Henzler T. Unenhanced third-generation dual-source chest CT using a tin filter for spectral shaping at 100 kVp. Eur J Radiol 2015;84(8):1608–13.
[19] T.R.A.a.N.Z.C.o.R. RANZCR. Standards of Practice for Diagnostic and Interventional Radiology Version 10.2. 2017.
[20] Primak AN, Giraldo JCR, Eusemann CD, Schmidt B, Kantor B, Fletcher JG, et al. Dual-source dual-energy CT with additional tin filtration: dose and image quality evaluation in phantoms and in vivo. Am J Roentgenol 2010;195(5):1164–74.
[21] Gordic S, Morsbach F, Schmidt B, Allmendinger T, Flohr T, Husarik D, et al. Ultralow-dose chest computed tomography for pulmonary nodule detection: first performance evaluation of single energy scanning with spectral shaping. Invest Radiol 2014;49(7):465–73.
[22] Stolzmann P, Leschka S, Scheffel H, Rentsch K, Baumüller S, Desbiolles L, et al. Characterization of urinary stones with dual-energy CT: improved differentiation using a tin filter. Invest Radiol 2010;45(1):1–6.
[23] Fung GS, Kawamoto S, Matlaga BR, Taguchi K, Zhou X, Fishman EK, et al. Differentiation of kidney stones using dual-energy CT with and without a tin filter. Am J Roentgenol 2012;198(6):1380–6.
[24] Thomas C, Krauss B, Ketelsen D, Tsiflikas I, Reimann A, Werner M, et al. Differentiation of urinary calculi with dual energy CT: effect of spectral shaping by high energy tin filtration. Invest Radiol 2010;45(7):393–8.