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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

Patricia Dewes, Claudia Frellesen, Jan-Erik Scholtz, Sebastian Fischer, Thomas J. Vogl, Ralf W. Bauer*, Boris Schulz

University Hospital Frankfurt, Department of Diagnostic and Interventional Radiology, Frankfurt, Germany

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ABSTRACT

Objectives: To evaluate a novel tin filter-based abdominal CT protocol for urolithiasis in terms of image quality and CT dose parameters.
Methods: 130 consecutive patients with suspected urolithiasis underwent *non-enhanced* CT with three different protocols: 48 patients (group 1) were examined at tin-filtered 150 kV (150 kV Sn) on a third-generation dual-source-CT, 33 patients were examined with automated kV-selection (110–140 kV) based on the scout view on the same CT-device (group 2), and 49 patients were examined on a second-generation dual-source-CT (group 3) with automated kV-selection (100–140 kV). Automated exposure control was active in all groups. Image quality was subjectively evaluated on a 5-point-likert-scale by two radiologists and interobserver agreement as well as signal-to-noise-ratio (SNR) was calculated. Dose-length-product (DLP) and volume CT dose index (CTDIvol) were compared.
Results: Image quality was rated in favour for the tin filter protocol with excellent interobserver agreement (ICC = 0.86–0.91) and the difference reached statistical significance ($p < 0.001$). SNR was significantly higher in group 1 and 2 compared to second-generation DSCT ($p < 0.001$). On third-generation dual-source CT, there was no significant difference in SNR between the 150 kV Sn and the automated kV selection protocol ($p = 0.5$). The DLP of group 1 was 23% and 21% ($p < 0.002$) lower in comparison to group 2 and 3, respectively. So was the CTDIvol of group 1 compared to group 2 (−36%) and 3 (−32%) ($p < 0.001$).
Conclusion: Additional shaping of a 150 kV source spectrum by a tin filter substantially lowers patient exposure while improving image quality on un-enhanced abdominal computed tomography for urinary stone disease.

1. Introduction

Unenhanced computed tomography (CT) of the abdomen is a well-established imaging modality in suspected urolithiasis: Identifying even small calculi and determining their anatomical localization as well as their morphology is critical for defining the therapeutic strategy. For various reasons low-dose unenhanced CT has become the standard tool to rule out urolithiasis and has replaced radiographic urography in most of the cases for over a decade now [1].

Since CT is known to be the imaging modality contributing the most to cumulative annual radiation exposure of people in Western societies, radiologists and CT vendors constantly make efforts to keep patient exposure as low as possible to still guarantee adequate diagnosis. In a high-contrast environment, as this is the case in detecting highly dense urinary calculi in a soft tissue surrounding, substantial dose reduction can be achieved mainly by reducing the tube voltage and current or advanced noise-reducing iterative reconstruction algorithms which have recently become standard in CT imaging [2–5].

With the recent advent of the third generation of dual-source CT, new X-ray tubes are available that can optionally be operated with

Abbreviations: ADMIRE, advanced modeled iterative reconstruction; ALARA, as low as reasonably achievable; BMI, body mass index; CT, computed tomography; CTDIvol, CT dose index; DLP, dose-length-product; DSCT, dual-source CT; FBP, filtered back projection; GFR, glomerular filtration rate; HU, hounsfield units; ICC, intraclass correlation coefficient; Sn, tin filter; SNR, signal-to-noise ratio.

* Corresponding author at: University Hospital Frankfurt, Department of Diagnostic and Interventional Radiology Theodor-Stern-Kai 7, 60590 Frankfurt, Germany. Tel.:+ 49 69 6301 87200.

E-mail address: ralfwbauer@aol.com (R.W. Bauer).

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Table 1
Examination details of the three low-dose CT protocols. Br40 3 in Group1 and 2 is the description of the medium soft kernel with ADMIRE grade 3 in the 3rd generation DSCT and B30f in Group 3 characterizes the equivalent medium soft kernel in the older CT device.

	Group 1	Group 2	Group 3
CT device	Force	Force	Flash
Tube potential, kV	150 Sn	110, 120 or 140 auto selected	100, 120 or 140 auto selected
Reference Tube current-time-product, mAs	64	64/50/34	84/50/35
Slices per rotation	192	192	128
Collimation, mm	0.6	0.6	0.6
Kernel	Br40 3	Br40 3	B 30 f
Reconstructed slices	3 mm axial and coronal	3 mm axial and coronal	3 mm axial and coronal

Table 2
Patient characteristics.

	All patients	Group 1	Group 2	Group 3	P value
Patients, n	130	48	33	49	–
Age, years	45.2 ± 13.9	46.7 ± 14	45.6 ± 14.8	43.6 ± 13.4	>0.05
Male, n (%)	83; (63.8%)	35; (72.9%)	21; (63.6%)	37; (75.5%)	>0.05
Abdominal patient volume, dm^3	25.1 ± 8.5	24.8 ± 8.7	24.5 ± 9.2	25.7 ± 8.1	>0.05
CT evidence of calculi, n (%)	92; (70.1%)	31; (64.7%)	24; (72.7%)	37; (75.5%)	>0.05

an additional tin photon filter applied at a tube voltage of 150 kV. This filter will result in an additional spectral shaping of the polychromatic X-ray beam, moving the mean energy close to 100 keV. Prior studies have shown a superior image quality and dose efficiency with spectral shaping in CT of the chest [6–8]. However the effect of tin-filter based CT when looking for urinary stone disease is unknown so far. The purpose of this study is therefore to analyze radiation exposure and image quality of the novel tin filtered technique in comparison to standard low-dose abdominal CT.

2. Materials and methods

2.1. CT examinations

Between September and December 2014, 48 consecutive patients with suspected urolithiasis underwent unenhanced abdominal CT at 150 kV and additional hardening of the spectrum with a tin filter (Sn) (Somatom Force, Siemens Healthcare, Forchheim, Germany). The examinations were compared to a patient group of 33 individuals who underwent standard low-dose CT for the same indication on the same CT device earlier in September and August 2014 (Group 2), but with attenuation-based automated selection of the tube potential (between 110 and 140 kV). The third study group consisted of 49 consecutive patients whore were examined on a CT device of a prior generation (Somatom Definition Flash, Siemens Healthcare, Erlangen, Germany) in June 2014, also with attenuation-based automated selection of the tube potential (between 100 and 140 kV). Automated exposure control (CAREDose4D) was activated in every case. A pitch factor of 0.6 and a rotation time of 0.5 s was used in all groups. Technical details regarding the different examination protocols can be found in Table 1. Images were reconstructed with iterative reconstruction (ADMIRE, strength 3 of 5) in group 1 and 2 and with filtered back projection in group 3.

2.2. Evaluation of image quality and patient dose

Subjective image quality was independently evaluated by two radiologists who were blinded to the examination type. On a 5-point likert scale (1 = excellent, 2 = good, 3 = moderate, 4 = fair, 5 = unacceptable), depiction of concrements and abdominal soft tissue were individually rated. Objective image quality was analyzed by evaluating the signal-to-noise ratio (SNR) of muscle and fat tissue. Therefore the quotient of the CT density in Hounsfield Units (HU) of the left psoas muscle respectively the surrounding fat tissue and the standard deviation of air outside the patient (i.e. background noise) was calculated.

Radiation exposure was estimated by using the volume CT dose index (CTDIvol) and dose-length-product (DLP). Since automated tube current modulation was activated the total patient volume of each examination was assessed to take individual patient anatomy in account. The individual anatomic evaluation was performed by using HU based thresholds which cut off the surrounding air and examination table on a multimodality workstation (Advantage Workstation-Suite, GE Healthcare, Barrington, USA) and the given result of mm^3 was noted (Fig. 1).

2.3. Statistics

Subjective image quality was evaluated by calculating the interobserver agreement (intra-class correlation coefficient) of both raters. Descriptive and analytical calculations were made using the statistical software BiAS 9.07 for windows (Epsilon Verlag, Frankfurt Germany). The Kolmogorov-Smirnov test was applied to assess the normality of data distribution. Normally distributed data was analyzed by means of the student's *t*-test. In case of unequal variances, the Wilcoxon signed-rank test was used. A *P*-value < 0.05 was considered statistically significant.

3. Results

Patient characteristics for the three study groups are shown in Table 2. There were no statistically significant differences between the three groups in patient gender, age, or effective patient volume ($p > 0.05$, Table 2). A total of 92 patients (70.1%) were diagnosed with at least one calculus (group 1: n = 31; 64.7%; group 2: n = 24; 72.7%; group 3: n = 37; 75.5%). The average calculus diameter was 3.6 mm (standard deviation: 1.8 mm) with no significant difference between the three study groups.

Subjective image quality was rated in favor for the group examined with the new tin filter technique with an average score of 1.18 compared to 1.4 (group 2) and 1.6 (group 3) for definability of concrements (ICC = 0.86; $p < 0.001$) and with an average score of 1.6 compared to 2.1 (group 2) and 2.4 (group 3) for quality of abdominal soft tissue (ICC = 0.91; $p < 0.001$). The differences reached statistical significance with a p-value of $p < 0.001$.