Low-dose CT for renal colic with Automatic Tube Current Modulation, Adaptive Statistical Iterative Reconstruction and low kV: impact of body mass index.

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Aims and objectives

Our study aims at assessing the impact of patients' morphology on dose, image quality and diagnostic performance of our low-dose unenhanced CT, performed with low kV, automatic mA modulation and ASiR on patients with suspicion of renal colic.
Methods and materials

**Studied population:**

This retrospective single-center study included all patients referred to our imaging department for the suspicion of renal colic and who underwent an unenhanced abdominopelvic CT with our low dose protocol between the 1\textsuperscript{st} of January 2012 and the 31\textsuperscript{st} of December 2012.

For all patients, following parameters were systematically recorded previous to the examination: sex, age (years), weight (kg), size (m). The Body Mass Index (BMI) was calculated according to the following formula: weight / size\(^2\) (kg/m\(^2\)). Patients were divided according to their BMI: thin patients with BMI < 18.5 kg/m\(^2\), patients with a normal corpulence with BMI \# 18.5 kg/m\(^2\) and < 25 kg/m\(^2\), overweight patients with BMI \# 25 kg/m\(^2\) and < 30 kg/m\(^2\) and obese patients BMI \# 30 kg/m\(^2\). Then patients were divided in two groups according to their BMI: patients with BMI < 25 kg/m\(^2\) and patients with BMI \# 25 kg/m\(^2\).

**CT acquisition and reconstruction techniques:**

All examinations were performed in supine position with a 64-slice multidetector CT (OPTIMA CT660, General Electric Healthcare, USA). Every examination started with an acquisition of two scout views, a lateral view and an antero-posterior (AP) view, using 120 kV and 10 mA. The low-dose CT consisted of a unenhanced helical craniocaudal acquisition that was centered on the urinary tract from the kidneys upper pole (spotted on the AP scout view) to the symphysis pubis. Tube voltage were set at 100 kV but it remained possible to perform an acquisition with 120 kV for patients weighing more than 80 kg and with 80 kV for people weighing less than 60 kg. Other acquisition settings were constant for all patients: automatic tube current modulation in the x,y,z-axis (SmartmA, General Electric Healthcare, USA) with a noise index set at 50 for a slice thickness of 1.25 mm and a soft tissue window, with mA minimum and maximum set at 10 mA and 300 mA respectively, a rotation time of 0.7 s and a pitch of 1.375.

Noise index was set at 50 in consensus with all the radiologists of our department. After a two-month experience (from November to December 2011) with different noise index levels, we chose the level that seemed to lead to the best trade-off between dose reduction and sufficient image quality for the diagnosis of renal colic.

Images were reconstructed with iterative reconstruction ASiR with a percentage of 50, SOFT kernel, a slice thickness of 1.25 mm and a slice interval of 1.25 mm. ASiR percentage was the proportion of ASiR imaged within a mix of standard FBP images.
and ASiR images. This percentage was set according to the recommendations of the manufacturer.

When the radiologist had any doubt about the presence of a stone after the low-dose unenhanced acquisition, he could perform another unenhanced acquisition with a standard dose (automatic tube current modulation, noise index set at 21.5, 120 kV and the same other acquisition and reconstruction settings).

Similarly, if no renal colic was visible on the first acquisition and a diagnostic differential was suspected, radiologist could perform an additional abdominopelvic acquisition during the portal venous phase, with a standard dose (noise index set at 21.5, 120 kV and the same other acquisition settings), to complete the examination.

All images from the examination, as well as the report including dosimetric data were sent directly and archived in the database of our PACS.

**Images analysis:**

Low dose unenhanced CT images were analyzed by 2 senior radiologists (M.L.C. and P.N.), who respectively have 8 and 5 years of experience in abdominopelvic CT reading (readers 1 and 2) and by a third-year resident in radiology (F.C.) (reader 3). All the readers were not involved in patients' selection and had no information about clinical data and final diagnosis.

Neither had they access to the potential additional acquisitions with or without contrast performed at standard dose. CT reading was carried out independently by the three readers on randomized and anonymized examinations, after a common training session of ten low-dose unenhanced abdominopelvic CT scans performed between November and December 2011, that were not included in the study. Images were visualized on a post-processing workstation ADW4.6 (GE Healthcare, USA). The readers were allowed to use all available visualization tools. They could increase slice thickness, display multiplanar reformat or Maximum Intensity Projections (MIP) and zoom. During the reading session, they had to assess the presence or absence of renal colic. In the event of a positive diagnosis for renal colic, they had to record the size and localization of the responsible stone. For all examinations, they graded their diagnostic confidence on a 3-point Likert scale (1 = no diagnostic confidence; 2 = confidence with reservations; 3 = total diagnostic confidence) and graded the subjective image quality for the diagnosis of renal colic on a 5-point Likert scale (1 = unacceptable image quality; 2 = suboptimal image quality; 3 = acceptable image quality; 4 = good image quality; 5 = excellent image quality).

**Final diagnosis:**

For each examination, final diagnosis was established by the study investigator (A.G.), with 7 years of experience in abdominopelvic CT reading, who had access to the
entire patient database including the low-dose unenhanced CT as well as the potential additional acquisition with or without contrast, performed at standard dose. He had also access to clinical, biological and follow-up information available in our medical database at our institution (Follow-up CT, complementary ultrasound or MRI, reports of medical appointments and surgery reports).

**Objective evaluation of image noise:**

Image noise in low-dose unenhanced CT was objectively evaluated by measuring standard deviation (HU) in a region of interest (ROI) with an area of 100 mm$^2$ placed in a standardized way by the investigator (A.G.) on a 1.25 mm-thick slice in soft tissue window, in the left psoas muscle, at the level of the fifth lumbar vertebrae, on a post-processing workstation ADW 4.6 (GE Healthcare, USA).

**Evaluation of radiation dose:**

Radiation doses were directly provided by the exam report that was accessible from the PACS. They consisted in the volume Computed Tomography Dose Index (CTDI), in mGy and the Dose Length Product (DLP), in mGy.cm, of the low dose unenhanced CT. The effective dose (ED), in mSv, was calculated by using a tissue conversion coefficient (k) for the abdomen of 0.015 according to the following formula: $ED = k \times DLP$.

In order to compare average dose our low-dose CT versus standard-dose CT, the average DLP of the additional contrast acquisition was compared to the average DLP of the low-dose unenhanced acquisition for the patients who had underwent an additional contrast examination at standard dose.

**Statistical analysis:**

Data were analyzed with the software R for windows (R Foundation for Statistical Computing, Vienna, Austria). The sensitivity, the specificity and the diagnostic accuracy of the three readers were calculated on the basis of the presence or the absence of renal colic, with the final diagnosis given by the study investigator as a reference. An inter-observer variability was calculated using a Kappa-Cohen test. This variability was considered as excellent for a value of k higher than 0.80. For the patients who had had an additional standard-dose contrast acquisition, the average DLP of the low-dose CT and the average DLP of the standard-dose CT were compared thanks to a Wilcoxon-signed rank test. A correlation coefficient was calculated between the patients’ CTDI and their BMI by using a linear correlation Pearson test. Between the two patient groups with a BMI < 25 kg/m$^2$ and with a BMI > 25 kg/m$^2$, CTDIs, averages of objective image noise measurements, image quality and diagnostic confidence scores (average of the three readers scores) were compared using a Mann-Whitney U-test. The average diagnostic accuracy, the number of false positives and false negatives were compared using an
accurate Fischer test. A p-value below 0.05 was considered as significant statistical difference.
Results

Patient and acquisitions characteristics:

Eigthy-six CTs of eighty-six patients were included in this study. There were 49 men and 37 women. The average age was 43.8 ± 14.7 years old (from 21 to 82 years old) and the average BMI was 25.3 ± 4.2 kg/m$^2$ (from 15.6 to 42.9 kg/m$^2$ with a median of 25.3 kg/m$^2$). Based on the BMI, 4 patients (5 %) were thin, 35 (41 %) had a normal corpulence, 39 (45 %) were overweight and 8 (9 %) were obese. 39 patients (45 %) had a BMI < 25 kg/m$^2$ and 47 (55 %) had a BMI ≥ 25 kg/m$^2$.

Among the 86 low-dose CT performed, 5 had their kV modified: 1 CT with kV set at 80 kV (patient of 58 kg, with a BMI of 22.7 kg/m$^2$) and 5 CT with kV set at 120 kV (2 patients of 81 kg with BMI of 27.7 and 28 kg/m$^2$ and 3 patients of 84, 100 and 107 kg with a BMI of 29.5, 31.6 et 42.8 kg/m$^2$ respectively).

Thirty-three patients (38.4 %) had a complementary contrast acquisition during the portal venous phase and with standard dose protocol. There were 13 men and 20 women with an average BMI of 24.1 ± 3.1 kg/m$^2$ (from 17.6 to 31.9 kg/m$^2$). Two (2.3 %) of the 86 patients received an additional unenhanced acquisition at standard dose.

Final diagnosis:

Among the 86 patients, 40 (46.5 %) had a final diagnosis of renal colic. The average size of the stones was 4.4 ± 2 mm (from 2 to 10 mm). Eight stones were located in the lumbar ureter, 2 at the cross with the iliac vessels, 4 in the pelvic ureter and 26 at the ureterovesical meatus. Among the 46 patients who had no renal colic, 28 (32.5 %) differential diagnosis were made: ten disco-radicula pathologies, seven urinary tract infections, two gynceological infections, one pyeloureteral junction syndrom, one renal infarction, one renal colic cured at the CT time, two acute appendicitis, one ileitis, one diverticulitis, one colitis and one stomach ulcer. Finally, for 18 patients (21 %), the causes of the painful symptomatology couldn't be explained.

Diagnostic performance:

Sensitivity, specificity and diagnostic accuracy for each of the three readers, as well as the average of these values are displayed in the figure 1. The inter-observer variability for the diagnosis of renal colic between the readers was excellent: $k = 0.88$ between the readers 1 and 3 and the readers 2 and 3 and $k = 0.95$ between the readers 1 and 2.
The most experimented reader (reader 1) had a high sensitivity and a high specificity, 97.5 % and 100 % respectively, and a diagnostic accuracy of 98.8 %. This reader made one single mistake corresponding to a false-negative. Reader 2 made three mistakes (three false-negatives) and reader 3 made six mistakes (4 false-negatives and 2 false-positives). In total, the three readers made 10 mistakes for seven patients. There was one false-negative made by the three readers for the same patient (figure 2) and for another patient, the readers 2 and 3 both made a false-negative (figure 3). Among the five patients who had had at least one false-negative by one of the readers, three had a stone enclosed in the uretero-vesical meatus and two had a stone in the pelvic ureter, located just upstream from the uretero-vesical meatus. These 5 stones had a diameter below 3 mm.

In terms of diagnostic accuracy, false-negatives and false-positives, there was no significant difference between the two groups of patients with a BMI < 25 kg/m² and ≥ 25 kg/m² (Table 1). Among the 10 mistakes, 5 (3 false-negatives and 2 false-positives) were made for patients with a BMI < 25 kg/m² and 5 (five false-negatives) for patients with a BMI ≥ 25 kg/m². No mistake was done for the 8 patients with a BMI ≥ 30 kg/m².

### Table 1. Comparison of dose, objective image noise measurement, image quality and diagnostic confidence scores, diagnostic accuracy and false positive and negative cases for all patients and between patients with a BMI < 25 kg/m² and ≥ 25 kg/m².

<table>
<thead>
<tr>
<th></th>
<th>All patients</th>
<th>BMI &lt; 25 kg/m²</th>
<th>BMI ≥ 25 kg/m²</th>
<th>P values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective</td>
<td>86 (100 %)</td>
<td>39 (45 %)</td>
<td>47 (55 %)</td>
<td></td>
</tr>
<tr>
<td>CTDI (mGy)</td>
<td>3.1 ± 1.2 (1.4 - 8.1)</td>
<td>2.4 ± 0.8 (1.4 - 4.3)</td>
<td>3.7 ± 1.2 (2.0 - 8.1)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Objective image noise (UH)</td>
<td>33.6 ± 7.2</td>
<td>34.1 ± 6.2</td>
<td>33.1 ± 6.2</td>
<td>0.56</td>
</tr>
<tr>
<td>Image quality scores</td>
<td>3.6 ± 0.7</td>
<td>3.4 ± 0.6</td>
<td>3.8 ± 0.6</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Diagnostic confidence scores</td>
<td>2.6 ± 0.6</td>
<td>2.5 ± 0.6</td>
<td>2.8 ± 0.4</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Diagnostic accuracy (%)</td>
<td>96.0</td>
<td>95.7</td>
<td>96.4</td>
<td>0.83</td>
</tr>
</tbody>
</table>
False-negative (no.)
8 3 5 0.48

False-positive (no.)
2 2 0 0.14

\textsuperscript{a} values are means ± standard deviations and range values are in parentheses.

\textsuperscript{b} scores are means ± standard deviations.

\textsuperscript{c} for all readers.

\textbf{Image quality and diagnostic confidence scores:}

The diagnostic confidence and image quality scores for all patients were recorded in figure 4. These scores were also sorted according to patients' BMI. The higher was the BMI, the higher were the scores. The scores of diagnostic confidence and of image quality were significantly better for patients with a BMI \# 25 kg/m\(^2\) than for patients with a BMI < 25 kg/m\(^2\) (Table 1).

\textbf{Objective evaluation of image noise:}

The average of objective image noise measurements for all patients was 33.6 ± 7.2 HU. The distribution of noise values according to patient's BMI is given in Table 2. Concerning image noise measurements, there were no significant difference between the patients with a BMI < 25 kg/m\(^2\) and the patients with a BMI \# 25 kg/m\(^2\) (Table 1).

\textbf{Table 2.} Comparison of dose and objective image noise measurement for different categories of BMI (kg/m\(^2\)).

<table>
<thead>
<tr>
<th>BMI &lt; 18.5</th>
<th>18.5 # BMI &lt; 25</th>
<th>25 # BMI &lt; 30</th>
<th>BMI # 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 (5 %)</td>
<td>35 (41 %)</td>
<td>39 (45 %)</td>
<td>8 (9 %)</td>
</tr>
<tr>
<td>CTDI (mGy)\textsuperscript{a}</td>
<td>2.0 ± 0.6 (1.4 - 2.7)</td>
<td>2.4 ± 0.8 (1.5 - 4.3)</td>
<td>3.4 ± 0.8 (2.1 - 5.1)</td>
</tr>
<tr>
<td>DLP (mGy.cm)\textsuperscript{a}</td>
<td>79.2 ± 22.8 (52.4 - 106.6)</td>
<td>109.7 ± 35.3 (58.6 - 209.3)</td>
<td>155.0 ± 41.3 (92.5 - 263.1)</td>
</tr>
<tr>
<td>Effective dose (mSv)</td>
<td>1.2 ± 0.3 (0.8 - 1.6)</td>
<td>1.6 ± 0.5 (0.9 - 3.1)</td>
<td>2.3 ± 0.6 (1.4 - 3.9)</td>
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<tr>
<td>----------------------</td>
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</tr>
<tr>
<td>Objective image noise (UH)</td>
<td>34.1 ± 7.2</td>
<td>34.1 ± 6.2</td>
<td>33.3 ± 4.7</td>
</tr>
</tbody>
</table>

*a* values are means ± standard deviations and range values are in parentheses.

*b* values are means ± standard deviations.

**Dose evaluation:**

Average CTDIs, DLPs and effective doses for all patients were respectively 3.1 ± 1.2 mGy (from 1.4 to 8.1 mGy), 140.6 ± 59.4 mGy.cm (from 52.4 to 383.2 mGy.cm) and 2.1 ± 0.9 mSv (from 0.8 to 5.7 mSv). The distribution of CTDI according to patients' BMI is given in Table 2. There was an excellent correlation between patients' BMI and CTDIs of their low-dose CT: the Pearson linear correlation coefficient was 0.81 (figure 5). There was a significant difference between the radiation dose of patients with a BMI < 25 kg/m² and ≥ 25 kg/m² (respectively 2.4 vs 3.7 mGy with p < 0.001) (Table 1).

Concerning the 33 examinations with an additional standard-dose contrast CT during the venous portal phase, the average DLP of the contrast acquisitions was 583 ± 215 mGy.cm (from 324 mGy.cm to 899 mGy.cm). There was a significant difference between the dose of the unenhanced low-dose CTs and the dose of the contrast-enhanced standard-dose CTs (140 vs. 583 mGy.cm, p < 0.001) with 76 % of dose reduction for the low-dose CT.
Fig. 1: Chart depicts the values (in percentages, shown as numbers at tops of bars) of sensibility (black bars), specificity (white bars) and diagnostic accuracy (grey bars) for each reader and averaged over three readers for the diagnosis of renal colic with our low-dose CT.

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Fig. 2: 41-years-old man (height, 1.78 m; weight, 78 kg; BMI, 25.5 kg/m²) with acute left-sided lumbar pain. Unenhanced low-dose CT (100 kV; noise index of 50) with DLP of 105 mGy.cm and effective dose of 1.6 mSv. a- Axial 1.25-mm slice shows 2.5-mm urinary stone in the pelvic ureter (arrow head) that led to false-negative finding of small phlebolith by the three readers. b- Axial 1.25 mm slice shows a small obstructive dilatation (arrow) without perirenal fat stranding.

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**Fig. 3:** 22-years-old woman (height, 1.72 m; weight, 62 kg; BMI, 21 kg/m²) with acute right-sided flank pain. A and B, Axial 1.25 mm unenhanced low-dose CT slices (100 kV, noise index of 50, DLP of 72 mGy.cm and effective dose of 1.1 mSv) show 2-mm stone at the junction of ureter with bladder (arrow head) misinterpreted as small phlebolith by two of the three readers, with minimal obstructive dilatation (arrow). C and D, Axial 1.25 mm portal enhanced standard-dose CT slices (120 kV, noise index of 21.5, DLP of 333 mGy.cm and effective dose of 5 mSv) show stone (arrow head) depicted in A and allow a better visualization of the obstructive dilatation (arrow) in comparison with the unenhanced low-dose CT in B.

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**Fig. 4:** Chart depicts the mean scores of image quality (grading scale 1 - 5, black bars) and diagnostic confidence (grading scale 1 - 3, white bars) of low-dose CT for the diagnosis of renal colic for all patients and for different categories of patient's BMI.

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Fig. 5: Graph shows an excellent correlation between BMI (kg/m²) and CTDI (mGy) of the low-dose CT with a Pearson linear correlation coefficient of 0.81.

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Conclusion

Our low-dose unenhanced CT protocol performed with the automatic tube current modulation, low kV and the ASiR iterative reconstructions for patients with suspicion of renal colic has an excellent diagnostic performance for all patients. However we obtained a better image quality, as well as a better diagnostic confidence for patients with a BMI $\geq 25\, \text{kg/m}^2$, despite a greater dose, compared to patients with a BMI $< 25\, \text{kg/m}^2$. A reduction of the maximal mA threshold of the automatic tube current modulation could reduce the doses for overweight and obese patients, while keeping a good diagnostic performance.
References


