REVIEW / Genito-urinary imaging

How to perform low-dose computed tomography for renal colic in clinical practice

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Abstract Computed tomography (CT) has become the reference technique in medical imaging for renal colic, to diagnose, plan treatment and explore differential diagnosis. Its main limitation is the radiation dose, especially as urinary stone disease tends to relapse and mainly affects young people. It is therefore essential to reduce the CT radiation dose when renal colic is suspected. The goal of this review was twofold. First, we wanted to show how to use low-dose CT in patients with suspected renal colic in current clinical practice. Second, we wished to discuss the different ways of reducing CT radiation dose by considering both behavioral and technological factors. Among the behavioral factors, limiting the scan coverage area is a straightforward and effective way to reduce the dose. Improvement of technological factors relies mainly on using automatic tube current modulation, lowering the tube voltage and current as well using iterative reconstruction.

Since unenhanced (or plain) computed tomography (CT) was introduced in the 1990s, it has become the reference tool for the diagnosis of renal colic [1–3]. This is because CT has many advantages. It is fast, does not require intravenous administration of iodinated contrast material, has high diagnostic capabilities [2,4], helps exclude other conditions that are clinically similar to renal colic [5–8], provides direct information relative to the size and attenuation value of urinary stones [9] and helps predict spontaneous stone passage [10].

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Its main limitation, however, is the radiation dose given to the patient, especially because urinary stone disease tends to relapse and mainly to affect young people. Katz et al. report that 4% of the patients that undergo CT for suspected renal colic have had at least three CT examinations for the same indication, with cumulated doses ranging from 20 to 154 mSv [11]. Considering the ALARA principle (As Low As Reasonably Achievable) and the potential risks of radiation-induced cancer caused even using low doses of X-rays [12,13], dose reduction in CT for suspected renal colic is hence essential. In this context, many studies have shown that it is possible to detect renal colic with low-dose CT. Doses may be reduced by 75 to 90% compared to standard acquisition doses, without modifying the diagnostic performance [4,14–18]. However, a recent study showed that in most imaging centers low-dose CT protocols were not used to diagnose renal colic [19].

The goal of this review was twofold. First, we wanted to show how to use low-dose CT in patient with suspected renal colic in current clinical practice. Second we wished to discuss the different ways of reducing the CT radiation dose by considering both behavioral and technological factors.

What is low-dose CT?

The definition of low dose is controversial. The term refers to CT scans where, compared to a “normal” or “standard” dose scan, the image quality has been deliberately modified to reduce the exposure dose while preserving the diagnostic performance [20]. Renal colic is particularly appropriate for low-dose CT because of the excellent spontaneous contrast between most urinary stones that are spontaneously hyperattenuating (between 200 and 2800 HU) [2] and the soft tissues that surround them. Thus, even if the dose reduction is substantial, the naturally high contrast between urinary stones and the surrounding soft tissues prevents too much deterioration of the contrast-to-noise ratio while preserving good diagnostic performance [9].

Data from the literature reveal that the effective “low dose” to detect renal colic, is between 1 and 3 mSv [4,19]. The threshold of 3 mSv (i.e. a dose length product [DLP] of 200 mGy.cm) is arbitrary but has become the standard threshold for low-dose CT when investigating renal colic [19] because it corresponds more or less to the average radiation of intravenous urography that used to be the reference modality in the past [21]. If we consider that the average dose of a standard abdomen and pelvic CT is between 10 and 12 mSv [22,23], a low-dose scan of less than 3 mSv corresponds to a dose reduction of more than 75%.

Despite this significant dose reduction, various studies have shown that the diagnostic performance of low-dose CT remains excellent compared to normal-dose CT. A meta-analysis published in 2008 showed an average sensitivity of 96.6% and an average specificity of 94.9% [4]. At the same time, it was shown that low-dose CT could explore differential diagnosis, just like normal-dose unenhanced CT [24] (Fig. 1) and also that there was no significant difference when determining the size and density of the stones [17,25].

Recently, experts have suggested using “ultra-low-dose” CT, below the level of 1 mSv and close to the dose used to perform a plain abdominal radiography, i.e. 0.7 mSv [21]. Despite the recent technological advances and the use of new very powerful iterative algorithms for reconstructions, these ultra-low-dose protocols perform less well than low-dose protocols for detecting small urinary stones below 3 mm [18,21].

How to perform low-dose CT to detect renal colic?

The modalities to reduce dose in CT are based on the radioprotection principles of CT dose justification and optimization [26]. These modalities have already been extensively described [27–33]. In this review, we discuss them and concentrate on how to reduce the dose of abdominal and pelvic CT when looking for renal colic. The different modalities depend both on behavioral factors, independent of the CT equipment, and technological factors, some of which depend on how recent the CT equipment is. The behavioral factors are the level of awareness of the medical and paramedical teams, the principles of substitution and justification, as well as limiting the scan coverage area. The technological factors include reduction of the tube current and voltage, automatic tube current modulation and iterative reconstructions, as well as optimization of the pitch and slice thickness.

Compliance with the indications and substitution with a non-radiating imaging technique

Due to its excellent diagnostic performance, CT has become the reference investigation to diagnose renal colic. In 2014 the European Association of Urology has recommended low-dose CT as the first-line imaging modality in case of suspected renal colic (grade A recommendation) [34]. In 2008, the French-speaking Society of Medical Emergencies (Société Francophone d’Urgences Médicales) [35] recommended radiologists to perform plain abdomen radiography together with an ultrasound or an unenhanced CT as a first-line examination for suspected non-complicated renal colic. However, CT should be favored if a complicated case is suspected or in special situations (pregnancy, single kidney, transplanted kidney, known uropathy or renal failure) or if there are signs of complications (signs of infection; oliguria, anuria or oliguria) and in case of doubtful diagnosis. In pregnant women, ultrasound must be used as first-line modality and, in case of doubtful ultrasound, magnetic resonance imaging should be used as a second-line imaging modality before CT [36].

Raising the awareness and training the medical teams

Raising the awareness and training the radiologists and clinicians is also essential [37]. Clinicians must be able to detect renal colic and ask explicitly the radiologist to look for it. The radiologist must use a low-dose CT protocol with pre-adjusted parameters. It is also essential that clinicians and radiologists agree to seek, not the best possible image quality, but one that is sufficient for diagnosis. For radiologists
How have tely to gists but available. In Figure 1: A 28-year-old woman was admitted to the emergency department for pelvic pain irradiating towards the left lumbar fossa. Unenhanced abdominal and pelvic CT (100 kVp, noise index at 50, DLP of 74 mGy cm and effective dose of 1.1 mSv). Axial views, 1.25 mm centered on the kidneys (a) and the pelvis (b). Low-dose unenhanced CT does not show any dilatation of the pelvicalyceal system (arrows) and no wedged urinary stone, thereby excluding the presence of renal colic. However, even if the dose reduction has been significant, it is possible to evidence intraperitoneal peritoneal effusion (asterisk) as well as a hyperattenuating spontaneous effusion in the Douglas pouch (arrowhead) suggesting hemoperitoneum. Further enhanced CT confirmed hemoperitoneum caused by left ovarian cyst rupture.

and operators to be properly aware of low-dose CT, they must know the delivered doses. Therefore, it is essential that the dose (DLP) be displayed on the CT workstation before any acquisition. Currently all manufacturers systematically provide this display. Awareness is also raised by the software’s dose-recording system that allows radiologists to monitor the doses absorbed by the patients and to detect cumulated doses, sometimes substantial [38,39]. More generally, national and international dose registers are available. For instance, the CT Dose Index Registry [40] in the United States has made it possible to evidence that low-dose CT protocols were not sufficiently used to detect renal colic [19].

**Limiting the scan coverage area**

A straightforward and effective way to reduce doses is to reduce the acquisition length. Unenhanced image acquisition must be restricted to the urinary tract, from the upper pole of the kidneys to the base of the urinary bladder. Besides reducing the CT overall dose by limiting the scan coverage area, this centering prevents radiosensitive organs such as gonads in men and breasts in women to be exposed to X-rays (Fig. 2) [41].

**Reducing the tube current (mA) and tube voltage (kV)**

**Effects of mA and kV**

Lowering the tube current lowers the dose proportionally but also causes an increase in image noise proportionally to the reciprocal value of the square root of the mA [42]. In practice, reducing the tube current by half reduces the dose by 50% but increases the image noise by 41%.

Lowering the kV may also reduce the dose. However, this will also increase the image noise [42].

**Effect of patient’s body mass**

Because of the high natural contrast between most urinary stones and surrounding soft tissues, several experts have recommended low-dose CT protocols with significantly lowered tube current, by 10 to 100 milliamperes per second (Fig. 3) [5,24,43–46]. Many studies have shown excellent diagnostic performance for low-dose CT, equivalent to the one of a standard-dose CT [4]. Hamm et al. [44] and Poletti et al. [24] have, however, observed that low-dose CT performed less well in obese patients who had a Body Mass Index (BMI) > 30 kg/m². This was associated to the constant mA used for all the patients, resulting in a significant loss of image quality in obese patients. Based on this, some experts have suggested not using low-dose CT for obese patients (> 30 kg/m²) [24,44,45] while others have recommended tailoring the mA to these patients [5]. After these studies were published, automatic tube current modulation during acquisition was introduced. This has allowed radiologists to adapt the mA and the image quality to the patient’s body mass while reducing the dose by about 43 to 66% [47,48]. Mulkens et al. confirmed that low-dose CT with automatic tube current modulation provides excellent diagnostic performance in all patients with suspected renal colic, including overweight and obese patients [49]. However, in order to preserve an acceptable image quality in overweight patients, the automatic tube current modulation increases the CT dose. Moreover, it has been shown that automatic tube current modulation provides better scores of image quality and diagnostic performance for overweight patients with a BMI > 25 kg/m² than for patients with a BMI < 25 kg/m² [16]. These results may seem inconsistent, but they can be explained by the fact that, with an equivalent level of image noise, it is easier to diagnose renal colic in a patient who has a lot of intra-abdominal and intra-pelvic fat [50]. Indeed, fat may help delineate the ureters from surrounding structures, even if the image noise is high. It also seems easier to detect secondary signs of renal colic such as perirenal stranding and the “rim sign” in overweight patients. This is why diagnosis errors are more often observed in thin patients who have a BMI < 25 kg/m², in whom it is difficult to distinguish small stones in the lower ureter from pelvic phleboliths, even with normal-dose CT [16,49].

As far as the kV is concerned, beam-hardening artifacts have been observed in overweight patients if the kV has been too much reduced. So, while it is possible to reduce the tube voltage to 80 kVp in a patient with standard morphotype, it...
Figure 2. 41-year-old woman with suspected left renal colic. Low-dose unenhanced CT followed by standard-dose abdominal and pelvic enhanced CT (since renal colic was excluded). Scout view (a) shows the borders of the unenhanced (red lines) and enhanced (blue lines) acquisitions and first and last images in axial view without (b and c) and after injection (d and e). Note the low-dose CT centered from the upper pole of the kidneys to the mid pubic symphysis making it possible to reduce by 20% the scan coverage area compared to the standard acquisition, absent in the low-dose series of images.

Figure 3. 30-year-old man monitored for a 4-mm urinary stone in the left kidney (arrow). Normal-dose unenhanced abdominal and pelvic CT (120 kVp, noise index at 21.4, DLP at 1189 mGy.cm and effective dose of 17.8 mSv) and (b) follow-up CT with our low-dose protocol (100 kVp, noise index of 50, DLP of 80 mGy.cm and effective dose of 1.2 mSv). Even with a 93.5% reduction of the dose, low-dose CT perfectly shows the left renal stone (arrow).

must be kept to 100 kVp in overweight patients (Figs. 4 and 5) [14,16].

Iterative reconstructions

Reducing mA and kV is limited by the use of conventional Filtered Back Projection (FBP) reconstructions because of the significant increase in image noise when doses have been too reduced [51]. The recent introduction of iterative reconstruction algorithms has significantly reduced image noise compared to standard FBP reconstructions [14–18,52–56]. So, when doses are lowered by mA and kV reductions, iterative reconstructions compensate for the decreased image quality. On standard abdominal and pelvic CT, iterative reconstructions have allowed radiologists to reduce doses by at least 50% [57]. Kulkarni et al. have shown that, for suspected renal colic, it was possible to maintain excellent diagnostic performance equivalent to the one of standard-dose CT by using automatic mA modulation, adaptive statistical iterative reconstruction (ASIR) and a kV fixed at 80 kVp for patients weighing less than 90 kg [14]. Iterative reconstruction also maintains adequate quality of image in
overweight patients [16] while using low kV (Fig. 5) and, in addition, has the advantage of reducing beam-hardening artifacts, including at the pelvis [57].

**Pitch effect**

Some experts have recommended increasing the pitch in low-dose CT protocols for patients with suspected renal colic [58]. Nowadays, pitch does not affect dose anymore, since most CT have automatic tube current modulation software [59]. However, a high pitch, about 1 to 1.5, is better, because it reduces acquisition time and, thereby, movement artifacts by the patient.

**Adapting the slice thickness**

To obtain high spatial resolution, images should always be acquired using thin sections (1 to 1.25 mm). Thin sections with isotropic voxels enhance the quality of three-dimensional multiplanar reformations and volume rendering [60]. However, thin sections also cause significant increase in image noise, especially if the mA and kV have been considerably reduced, as happens in low-dose CT. So, after using thin sections for image acquisition, it is possible to reconstruct thicker sections during image review at the CT workstation [61]. With thickened 3-mm sections it is possible to reduce image noise while preserving good detectability and characterization of all radiodense urinary stones, including those below 3 mm [62,63]. Other abdominal structures are also better visualized. However, 5-mm thickened sections may cause partial-volume artifacts and reduce the detectability of small stones below 3 mm [64]. Small stones and spontaneously dense stones are also more readily detected with thickened sections in maximum intensity projection (MIP) and lower image noise. In their study, Corwin et al. have confirmed that urinary stones and their density are more accurately measured on 5-mm coronal MIP images (Fig. 5) [65].

**In routine practice**

Acquisition must be centered from the upper pole of the kidneys to the middle of the pubic symphysis. The kV may be reduced to 100 kVp, even 80 kVp in patients that are not overweight, and the level of noise of the automatic tube current modulation may be increased in order to obtain a 75% reduction of dose compared to a standard abdominal and pelvic scan protocol. Iterative reconstructions should be used whenever possible (Table 1). Finally, CT images are visualized on millimetric native axial sections, thick sections (average 3 mm) and 5-mm coronal MIP reformations.
Table 1  Example of a low-dose CT protocol, used in our institution in routine practice to diagnose renal colic with a 64-slice MDCT (OPTIMA CT660, General Electric Healthcare, USA) and iterative reconstructions (Adaptive Statistical Iterative Reconstruction [ASIR]). Comparison between acquisition and reconstruction parameters of this low-dose protocol and those of a standard abdominal and pelvic CT. The differences between the two protocols lie with the limited acquisition duration, the lowering of the tube voltage and the increase of the noise level of the automatic tube current modulation.

<table>
<thead>
<tr>
<th>Acquisition and reconstruction parameters</th>
<th>Low-dose CT Protocol to detect renal colic</th>
<th>Standard abdominal and pelvic CT Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquisition mode/detectors</td>
<td>Helical/64 × 0.5 mm</td>
<td>Helical/64 × 0.5 mm</td>
</tr>
<tr>
<td>Start of acquisition</td>
<td>Upper pole of the kidneys</td>
<td>Upper border of the diaphragmatic domes</td>
</tr>
<tr>
<td>End of acquisition</td>
<td>Middle of the pubic symphysis</td>
<td>Lower border of the pubic symphysis</td>
</tr>
<tr>
<td>Tube voltage</td>
<td>80 kVp for a patient with average BMI</td>
<td>120 kVp</td>
</tr>
<tr>
<td></td>
<td>100 kVp for an overweight patient</td>
<td></td>
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<tr>
<td>Tube current (mA)</td>
<td>Automatic tube current modulation</td>
<td>Automatic tube current modulation</td>
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<tr>
<td>Noise index</td>
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<td>21.5</td>
</tr>
<tr>
<td>Min (mA)/Max (mA)</td>
<td></td>
<td>120/500</td>
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<tr>
<td>Pitch</td>
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<tr>
<td>Rotation time</td>
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<tr>
<td>Reconstruction algorithm</td>
<td>ASIR 50%</td>
<td>ASIR 50%</td>
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<tr>
<td>Slice thickness (mm)/interval (mm)</td>
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<td>1.25/1.25</td>
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Conclusion

CT has become the reference technique to diagnose renal colic. Because of its ionizing radiation, it is necessary to reduce doses. In order to perform low-dose CT in patients with suspected renal colic, the most important measures to implement are: to increase the awareness of the medical and paramedical teams, to limit the scan coverage area, to use automatic tube current modulation and to reduce mA and kV. Iterative reconstruction algorithms have also made it possible to significantly reduce doses (Boxed text 1). Technological advances and the introduction of new algorithms for even better iterative reconstructions allow us to expect ultra-low CT with excellent diagnostic performance.

Boxed text 1: The 5 golden rules of low-dose CT for suspected renal colic are:
1. Comply with the indications.
2. Center and restrict the acquisition coverage area.
3. Use automatic tube current modulation.
4. Lower tube current and tube voltage.
5. Use iterative reconstructions.

Disclosure of interest

The authors declare that they have no competing interest.

References


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