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FULL PAPER

Optimizing z-axis coverage of abdominal CT scans of the urinary tract: a proposed alternative proximal landmark for acquisition planning

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E-mail: alban.gervaise@hotmail.fr**Objective:** To evaluate an alternative method to reduce the acquisition coverage of urinary tract CT.**Methods:** This retrospective study included 365 abdominopelvic CT studies. Three radiographers simulated shortened acquisition coverages using three methods to determine the upper limit of the acquisition: Method 1 used the renal contours; Method 2 used the inferior margin of the 10th thoracic vertebra; and Method 3 used the point of intersection of the left diaphragmatic dome and the anterior margin of the vertebral bodies. Reductions in acquisition coverage and number of CT scans with a portion of the kidney excluded from the simulated reduced acquisition were compared between the three methods.**Results:** The mean \pm standard deviation reduction of acquisition coverage for the three readers with Methods 1, 2 and 3 were 20.5 ± 4.8 , 15.1 ± 6.5 and $18.2 \pm 5.3\%$, respectively. Compared with Method 2, Method 3 allowed a mean scan length reduction of 3.6%. The proportions of CT scans with a portion of the kidney excluded from the simulated reduced acquisition with Methods 1, 2 and 3

and averaged over the three readers were 6.7, 0.7 and 1.4%, respectively, with no significant difference between Methods 2 and 3. Interreader and intrareader agreements were excellent with all methods, but interclass correlation coefficients were higher with Method 3.

Conclusion: The method using the renal contours should not be used owing to its high proportion of kidneys with a portion excluded from the acquisition. Using the intersection of the left diaphragmatic dome and the anterior margin of the vertebral bodies for proximal landmark for urinary tract CT represents a new alternative method with a better reduction of scan length compared with the method using the inferior margin of T10 and with no significant increase in the number of kidneys with a portion excluded from the reduced acquisition.**Advances in knowledge:** A new method using the point of intersection of the left diaphragmatic dome and the anterior border of the vertebral bodies on the lateral scout radiograph is introduced to reduce the z-axis coverage of urinary tract CT scans.

INTRODUCTION

Since its introduction in the 1990s, unenhanced CT has become the gold standard for urinary tract imaging in patients with renal colic.^{1,2} It offers many advantages: availability, no injection of the iodinated contrast medium and excellent diagnostic performance.³ Its main limitation is related to radiation, especially as urinary stone disease mainly affects patients who are young, with a tendency to relapse.^{4,5} In accordance with the cautionary principle of as low as reasonably achievable and given the potential risk of

radiation-induced cancers associated with low X-ray doses,^{6,7} reducing the dose in urinary tract CT is paramount.

Many studies have shown that it is possible to use low-dose CT to investigate renal colic with excellent diagnostic performance.^{3–20} The researchers primarily evaluated the possibility of reducing the dose by increasing the pitch,⁸ lowering the tube current,^{9–11} using automatic tube current modulation,¹² reducing the tube voltage^{13,14} and using iterative reconstruction algorithms.^{13–19}

Another simple and effective way to reduce the dose is to limit acquisition coverage from the top of the kidneys to the lower edge of the bladder. For the lower acquisition limit, the lower edge of the symphysis pubis bone is an accurate landmark.^{21,22} Identifying the upper limit of the acquisition is more complicated. In our institution, we reduce the acquisition coverage by trying to locate the top of the kidneys on the frontal scout image. However, the renal contours are frequently hard to identify and to our knowledge, the effectiveness of this method has not yet been evaluated.

In order to find a more reliable method of reducing acquisition coverage without excluding the upper pole of the kidneys, two recent studies have evaluated the possibility of using a vertebral bony landmark to define the upper acquisition limit. For de Leon et al,²¹ use of the superior margin of the 11th thoracic vertebral body (T11) reduced the acquisition coverage by 18%, compared with standard abdominopelvic acquisition, without excluding the upper pole of the kidneys from the reduced acquisition. For Corwin et al,²² placing the upper limit of the acquisition at the inferior margin of the 10th thoracic vertebral body (T10) led to a 17.7% coverage reduction without excluding the upper pole of the kidneys from the reduced acquisition. Although these two studies showed that the use of T10 or T11 bony landmark excluded no kidneys during the acquisition, we believe that with these two methods the reduction of the scan coverage is not so important that it could be in many patients. In addition, the relatively high frequency of anatomical variants in the thoracolumbar spine and the fact that it is not applicable in patients with scoliosis adds to the difficulty in applying these methods in clinical practice.

We propose an alternative method for placement of the upper acquisition limit of urinary tract CT scans. This method is based on the lateral scout image and uses the point of intersection between the left diaphragmatic dome and the anterior margin of the vertebral bodies. We believe that this may allow optimal coverage reduction while using a simple anatomical landmark, which could represent an advantage over conventional methods. The aim of our study was to compare three coverage-reducing methods with an evaluation of scan coverage reduction percentage and number of CT scans with a portion of the kidney excluded from the simulated reduced acquisition.

METHODS AND MATERIALS

This study was approved by our local ethics committee. Taking into account its retrospective nature, written consent of patients was not necessary.

Study population

This retrospective single-centre study included all patients over 18 years referred to our imaging department between November 2014 and February 2015 for a standard abdominopelvic CT scan with injection of iodinated contrast medium. Four patients were excluded because the frontal or lateral scout image did not cover the entire abdomen, one patient because of severe scoliosis and three patients because of left pulmonary effusion that precluded visualization of the left diaphragmatic dome on the lateral scout

image. Overall, 365 CT scans involving 343 patients were included in the study.

For all patients, the following parameters were systematically collected at the time of the scan: sex, age (years), weight (kilogram) and height (metres). The body mass index (BMI) was calculated using the formula: $BMI = \text{weight}/\text{height}^2$ (kg m^{-2}).

CT acquisition and reconstruction parameters

All examinations were performed in supine position using a 64-slice multidetector CT scanner (OPTIMA CT660; General Electric Healthcare, Chicago, IL). Examinations began with a frontal and lateral scout radiograph with 120 kV and 10 mA during a deep in-breath. Acquisition of both frontal and lateral scout radiographs was necessary to enable automatic exposure control. The examinations included at least one abdominopelvic acquisition at the portal phase from the top of the diaphragm through the ischial tuberosities. In some cases, additional series were performed (unenhanced, arterial or delayed phases). These series were not evaluated in this study. Acquisition parameters included tube voltage from 100 to 140 kV according to weight, automatic tube current modulation (GE SmartmA) with a noise index of between 18 and 25 and adaptive statistical iterative reconstruction. Images were reconstructed in thin slices of 1.25 mm every 1.25 mm with a soft-tissue kernel. All examination images as well as the scout images and the review report with location data for the first and last slices were archived in our picture archiving and communication system database.

Z-axis scan coverage evaluation

For each CT scan, the coverage of the standard abdominopelvic acquisition was calculated as the difference in centimetres between the location of the first and last slices of the acquisition.

The location of the lower limit of the simulated reduced acquisition was standardized for all three methods and was identical to that used by de Leon et al²¹ and Corwin et al.²² It corresponded to the section passing through the inferior aspect of the bony symphysis and was placed on each standard abdominopelvic CT scan by the study investigator (AG), a radiologist with 9 years' clinical experience, using a post-processing workstation ADW v. 4.6 (GE Healthcare, Chicago, IL).

The location of the upper limit of the simulated reduced acquisition was different for each of the three methods. Method 1 corresponded to the placement of the upper limit of the acquisition from the frontal scout image by locating the top of the kidneys. Method 2 was that described by Corwin et al²² and corresponded to the placement of the upper limit of the acquisition from the frontal scout image at the level of the inferior margin of T10. The lowest rib-bearing vertebral body was considered to represent the 12th thoracic vertebral body. Method 3 was the alternative method we propose. With this method, the upper limit of the acquisition was placed on the lateral scout image at the point of intersection between the anterior margin of the vertebral body and the left diaphragmatic dome (Figure 1). The left dome was identified by the lowest position of the right dome. It could also be identified because it was not fully seen owing to the heart and because the stomach

bubble lay under the left diaphragmatic dome. In case of doubt, the frontal scout image was used to confirm the laterality of the dome.

For each scan, the upper limits of the acquisition for all three methods were determined by three general radiographers with at least 4 years' experience in CT scanning for renal colic in our institution using Method 1. The three radiographers were not involved in patient selection and did not know the aim of the study. With regard to the upper limit selection, radiographers had access to frontal and lateral scout images, which had been anonymized and randomized. The upper limit was placed on ADW v. 4.6 workstation (GE Healthcare) using the "localizer" function, which allowed the determination of the slice location on the z-axis on the scout images. Readers were able to zoom and change the window settings of scout images. A second reading session was conducted by Readers 2 and 3, 2 months after the first reading on 30 CT scans randomly selected and placed in a different random order to the first session. This second reading was used to calculate intraobserver agreement.

Having determined the upper limits, the lengths of simulated reduced acquisition were calculated for each scan and each method as the difference in centimetres between the location of the upper and lower limits.

The study investigator (AG) noted, for each standard abdominopelvic CT, the z-axis location of the superiormost aspect of the highest kidney. By comparing the location data of the upper limit of the simulated reduced acquisition and the top of the uppermost kidney, it was possible to determine how many CT scans had a portion of the kidney excluded from the simulated

reduced acquisition. The number and the length of the kidney portions that were excluded from the simulated reduced acquisitions were evaluated for each method and for each reader.

Statistical analysis

Data were analyzed using R software for Windows v. 3.2.0 (R Foundation for Statistical Computing, Vienna, Austria). The values were given as the mean \pm standard deviation with the extreme values in parentheses. For each of the three radiographers, the Tukey's test and Fisher's exact test were used to compare, respectively, reduced acquisition coverage and proportion of CT scans with a portion of the kidney excluded from the simulated reduced acquisition among the three methods. A p -value <0.05 was considered to represent a statistically significant difference. An interclass correlation coefficient (ICC) was used to assess the interreader agreement and intrareader agreement for Radiographers 2 and 3. The ICC was considered as excellent for a value between 0.75 and 1.²³

RESULTS

Study population

Of the 343 patients enrolled, 178 patients were females and 165 patients were males, with an average age of 54.7 ± 17.9 years (range 18–92 years), a mean weight of 77.2 ± 19.9 kg (35–170 kg), an average height of 167.9 ± 9.7 cm (143–199 cm) and a mean BMI of 27.2 ± 6.3 kg m⁻² (14.9–60 kg m⁻²).

Reduced simulated acquisitions

The average coverage of standard abdominopelvic acquisition was 43.93 ± 3.81 cm (33.87–54.75 cm). The scan coverage of the reduced simulated acquisitions for each of the three methods and all three radiographers are shown in Table 1 and Figure 2.

Figure 1. The frontal (a, b) and lateral (c) scout images are showing how to place the upper limit of the reduced acquisition with the three methods evaluated. For Method 1 (a), the upper limit of the acquisition was placed by locating the top of the kidneys using the renal contours as reference (arrowheads). Method 2 (b) has used the inferior margin of T10 as reference. Method 3 (c) has used the lateral scout image and the point of intersection (arrow) between the anterior margin of the vertebral bodies (solid line) and the left diaphragmatic dome (dashed line).

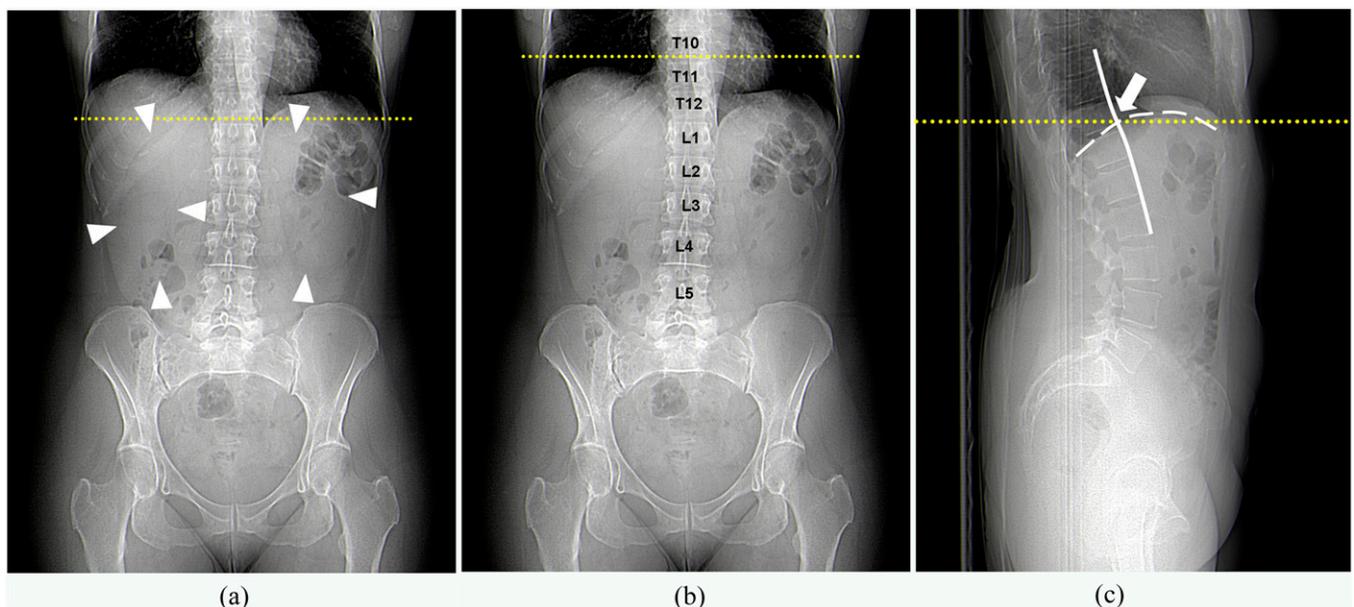


Table 1. Simulated acquisition coverage according to each reader and each of the three methods

Readers	Simulated acquisition coverage (cm)			<i>p</i> -value		
	M1	M2	M3	M2/M1	M3/M1	M3/M2
Reader 1	35.77 ± 2.94	37.25 ± 2.03	36.01 ± 3.10	<0.001	0.483	<0.001
Reader 2	34.10 ± 2.89	37.45 ± 2.08	35.91 ± 3.04	<0.001	<0.001	<0.001
Reader 3	34.96 ± 2.82	37.15 ± 2.12	35.87 ± 3.04	<0.001	<0.001	<0.001

M1, Method 1; M2, Method 2; M3, Method 3.
Results are given as mean ± standard deviation.

For all radiographers, Method 1 permitted a greater reduction in acquisition coverage over standard abdominopelvic acquisition, and Method 2 produced the smallest reduction in acquisition coverage. For Readers 2 and 3, the differences between the three methods were statistically significant ($p < 0.001$). For Reader 1, only the difference between Methods 1 and 3 was not statistically significant ($p = 0.483$).

Compared with standard abdominopelvic acquisition, the percentage of reduction in acquisition coverage with Methods 1, 2 and 3, averaged over the three readers, were 20.5, 15.1 and 18.2%, respectively. Compared with Method 2, Methods 1 and 3 allowed a mean reduction in acquisition coverage of 6.3 and 3.6%, respectively.

The average distance between the lower limit of standard abdominopelvic acquisition and the inferior aspect of the symphysis pubis was 2.3 ± 1.4 cm, which corresponded to a 5.2% reduction of the length of acquisition. Reduction of the acquisition coverage linked to the upper limit alone was 15.2, 9.9 and 13% for Methods 1, 2 and 3, respectively.

Number of CT scans with a portion of kidney excluded from the simulated reduced acquisition
The numbers of simulated reduced CT scans with a portion of the kidney which was excluded from the scan coverage for each method coverage optimization are shown in Table 2. The percentage of CT scans with a portion of the kidney excluded from the simulated reduced acquisition with Methods 1, 2 and 3,

Figure 2. A chart showing the distribution of simulated reduced acquisition coverages according to the three methods for each of the three readers: it can be noted that with Method 2 (M2) and Method 3 (M3), the acquisition coverages are very consistent between the three readers in comparison with Method 1 (M1). Also, the greater reduction in the acquisition coverage with Method 3 (M3) compared with Method 2 (M2) can be noted.

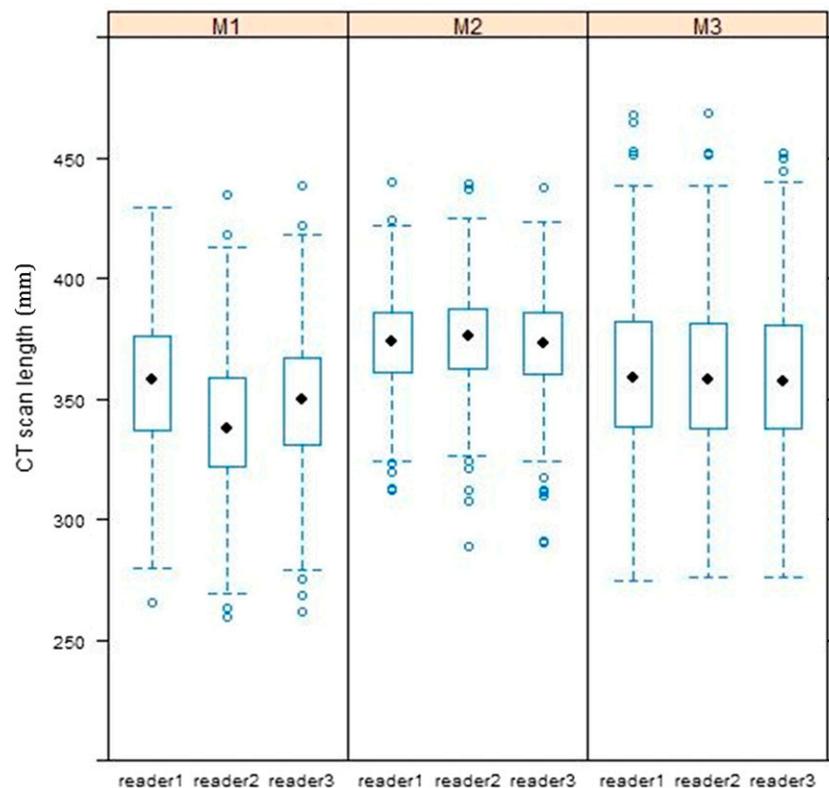


Table 2. Number of CT scans with a portion of the kidney excluded from the simulated reduced acquisition based on each reader and each of the three methods

Readers	Number of CT scans with a portion of the kidney excluded from the simulated reduced acquisition			p-value		
	M1	M2	M3	M2/M1	M3/M1	M3/M2
Reader 1	7 (1.9%)	3 (0.8%)	5 (1.4%)	0.772	0.882	0.772
Reader 2	46 (12.6%)	2 (0.5%)	5 (1.4%)	<0.001	<0.001	0.451
Reader 3	20 (5.5%)	3 (0.8%)	5 (1.4%)	0.001	0.005	0.725

M1, Method 1; M2, Method 2; M3, Method 3.

Results are given as number and percentage in parentheses.

averaged over the three readers, were 6.7, 0.7 and 1.4%, respectively. Method 1 resulted in most number of kidneys with a portion excluded from the simulated reduced acquisition with a significant variation between the three readers (from 7 for Reader 1 to 46 for Reader 2). There was no significant difference between Method 2 with respect to Method 3, regardless of the reader ($p > 0.451$). For Method 2, three same studies had a kidney with a portion excluded from the simulated reduced acquisition with Readers 1 and 3 and two of these three studies had a kidney with a portion excluded from the simulated reduced acquisition with Reader 2.

The maximum lengths of the portion of the kidney excluded from the simulated reduced acquisition with Methods 1, 2 and 3 were 4.2, 0.6 and 1 cm, respectively, for the three readers (2.1, 0.5 and 1 cm for Reader 1; 4.2, 0.5 and 1 cm for Reader 2; and 2.8, 0.6 and 0.8 cm for Reader 3, respectively).

In order not to have kidneys with a portion excluded from the simulated reduced acquisition, the bony landmark should be the middle of the vertebral body of T10.

Intrareader and interreader agreements

The interreader agreement was excellent regardless of the method (Table 3). There was a progressive increase in ICC values from Methods 1 to 3, with Method 3 having the overall best interreader agreement. The intrareader agreements of Readers 2 and 3 were excellent, regardless of the method and the reader (Table 4). For Reader 3, the intrareader agreement was significantly better for Methods 2 and 3 than that for Method 1.

DISCUSSION

Our study confirms that a 15–20% reduction in the coverage of urinary tract CT scans can be obtained by optimizing the

acquisition protocol. As it has been shown for other CT applications,^{24,25} reducing the acquisition coverage is a simple and effective way of limiting the dose in patients and is recommended in clinical practice. Because of the close relation between scan length and effective dose, when the acquisition length is reduced, a similar reduction in effective dose can be expected. In a recent study assessing the possibility to reduce the CT scan coverage for acute appendicitis which was also based on T10 anatomical landmark, Corwin et al²⁴ found that a reduction of the scan coverage of 24% corresponded to a dose reduction of 23%. In addition, by optimizing coverage, it is also possible to reduce the exposure of radiosensitive organs, such as the gonads in males and the breasts in females.²⁶ In practice, like other dose reduction techniques such as iterative reconstruction algorithms,^{13–19,27} optimization of the acquisition coverage could have a significant impact on the dose delivered to patients undergoing a urinary tract CT.

One of the major findings of our study is that the use of the kidney contours as reference on the frontal scout image is difficult in practice (Method 1). Even if it reduces the acquisition coverage by up to 20.5% compared with a standard abdominopelvic acquisition and 6.3% in comparison with Method 2, it was the least reproducible and the most likely method to exclude a portion of the upper pole of the kidney from the reduced acquisition. For Reader 2, in 12% of cases, the kidneys had a portion excluded from the simulated reduced acquisition with a maximal distance of excluded portion of 4.2 cm, which is not acceptable in clinical practice. This limitation is related to the difficulty of visualizing the kidney on the frontal scout image. These findings underscore the importance of identifying a more suitable anatomical landmark for the determination of the upper limit of urinary tract CT acquisitions.^{21,22}

In our study, we used the bony landmark of Corwin et al,²² which corresponded to the inferior margin of T10 (Method 2) and not the superior margin of T11 as in the study by de Leon et al.²¹ Although the difference between these two landmarks is minimal, we chose to study the uppermost landmark in order to favour the method that excluded the least kidneys. While for Corwin et al, 100% of kidneys were included in the reduced acquisition, in our study, Readers 1 and 3 excluded the upper pole of the left kidney in three patients using Method 2. In contrast to de Leon et al²¹ and Corwin et al,²² our study shows that the inferior margin of T10 is not infallible and that

Table 3. Interreader agreement between the three methods

Methods	ICC	95% CI
M1	0.926	0.814 < ICC < 0.962
M2	0.979	0.974 < ICC < 0.983
M3	0.992	0.991 < ICC < 0.994

CI, confidence interval; ICC, interclass correlation coefficient; M1, Method 1; M2, Method 2; M3, Method 3.

Table 4. Intrareader agreement for Readers 2 and 3 based on 30 CT scans randomly selected

Readers	Methods	ICC	95% CI
Reader 2	M1	0.937	0.073 < ICC < 0.985
	M2	0.986	0.972 < ICC < 0.994
	M3	0.982	0.962 < ICC < 0.991
Reader 3	M1	0.984	0.962 < ICC < 0.993
	M2	0.999	0.998 < ICC < 1
	M3	1	1 < ICC < 1

CI, confidence interval; ICC, interclass correlation coefficient; M1, Method 1; M2, Method 2; M3, Method 3.

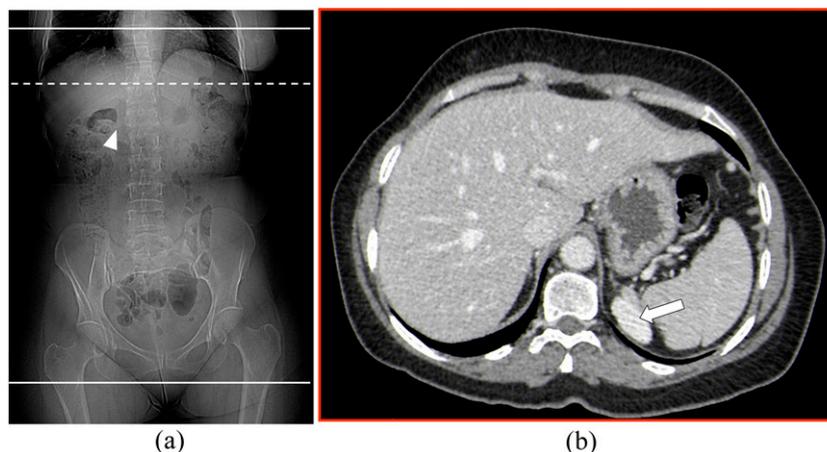
in order not to have a portion of the kidney excluded from the reduced acquisition, the bony landmark should be the middle of the vertebral body of T10. However, with such a landmark, reduced acquisition coverage would be increased for roughly 1 cm. In one particular patient with small 12th ribs hardly visible on the scout image, Reader 2 did not exclude the upper pole of the kidney from the simulated reduced acquisition, because the inferior margin of the 9th thoracic vertebral body was mistakenly used as the landmark (Figure 3). This shows that the vertebral bony landmark method can also have pitfalls.

The proposed Method 3, based on the lateral scout image and taking as a reference point the intersection of the anterior margin of the vertebral bodies and the left diaphragmatic dome, may be of interest to optimize the coverage of urinary tract CT scans and thereby reduce the delivered dose. It was the most reproducible method of the three, both between readers and for an individual reader. It is not hampered by anatomical variants and uses landmarks that are quick and easy to find, which is supported by excellent interreader and intrareader agreements.

In particular, the distinction between the left and right diaphragmatic domes on the lateral scout image poses no problem because the left diaphragmatic dome is often lower than the right diaphragmatic dome. It is also possible to detect its position relative to the right diaphragmatic dome on the frontal scout image. This method allows a significant reduction of the acquisition coverage over Method 2 (18.2 against 15.1% $p < 0.001$). Although the proportion of CT scans with a portion of the kidney excluded from the simulated reduced acquisition using Method 3 was greater than that with Method 2 (1.4 vs 0.7%), this difference was not statistically significant. In addition, with Method 3, in the CT scans with a portion of the kidney excluded from the simulated reduced acquisition, <1 cm of the kidney was out of the field of view, which seems acceptable in patients evaluated for renal colic. This method strikes as a good compromise between Method 1, which has too many kidneys with a portion excluded from the acquisition but with a greater reduction in coverage, and Method 2, which rarely has a portion of the kidney excluded from the acquisition but gives a smaller coverage and dose reduction.

Our study has several limitations. First, it is retrospective study. A prospective study with a larger patient population would be interesting to confirm our results, especially given the low number of CT scans with a portion of the kidney excluded from the simulated reduced acquisition using our new method. Second, we included all patients who had a standard abdominopelvic CT, without selecting those referred for suspected renal colic. This allowed us to include more patients and compare reductions in acquisition length with the length of standard abdominopelvic acquisition in the same patient. However, three patients had to be excluded from our study because they had left pulmonary effusion that masked the left diaphragmatic dome on the scout image and prevented us from using the proposed method. In clinical practice, this has little impact, since the association of left-sided pleural effusion and renal colic is relatively

Figure 3. A female aged 65 years with a body mass index of 26.4 kg m^{-2} : in the frontal scout image (a), the solid lines are corresponding to the limits of the standard abdominopelvic acquisition and the dashed line is corresponding to the upper limit of the reduced acquisition coverage using Method 2. The axial CT slice (b) passing through the lower margin of T10 is showing that the top of the left kidney is excluded from the reduced acquisition (arrow). The presence of small T12 ribs [arrowhead in (a)] can be noted, which were not seen by Reader 2, who mistakenly used the inferior margin of T9 as the landmark and did not excluded the upper pole of the left kidney from the reduced acquisition.



rare. Third, we did not try to assess the frequency of lesions (e.g. pulmonary nodule, adrenal mass) that might be missed on acquisitions with reduced coverage, as it was not among the objectives of this study. Moreover, according to current clinical practice, a patient whose scan was negative would probably undergo an additional standard enhanced CT to search for possible differential diagnoses.¹⁴ Fourth, the detail and clarity of scout images may vary across different CT vendors. The results of our study should be confirmed on CT scanners from other manufacturers. Finally, we used a CT protocol with automatic tube current modulation, which implies that the dose reduction is not strictly proportional to the reduction in acquisition

coverage. Therefore, we did not directly estimate the percentage reduction in the dose.

In conclusion, using the intersection of the left diaphragmatic dome and the anterior margin of the vertebral bodies on the lateral scout image to set the upper limit of the acquisitions of CT scans in patients with suspected renal colic appears to be a good compromise. This method allows for a greater reduction of acquisition coverage in comparison with the inferior margin T10 landmark and excludes fewer kidneys than the method using kidney contours on frontal scout image. It is also the most reproducible method evaluated that we now use in clinical practice.

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