Renal Cyst Pseudoenhancement at Multidetector CT: What Are the Effects of Number of Detectors and Peak Tube Voltage?¹

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Purpose:

To determine the effect of the number of detectors and peak tube voltage on renal cyst pseudoenhancement in a phantom model.

Materials and Methods:

This study on computed tomographic (CT) phantoms did not require institutional review board approval. The renal compartments of a CT phantom were filled with iodinated contrast material diluted to attain attenuations of 40, 140, and 240 HU. Saline-filled cylinders simulating cysts of varying diameters (range, 0.7–3.0 cm) were serially suspended in the renal compartments and scanned at 80, 90, 100, 120, and 140 kVp in 16-detector ($n = 3$) and 64-detector ($n = 2$) CT scanners. Generalized estimating equations were used to determine predictors of cyst pseudoenhancement (defined as a >10 HU increase in cyst attenuation when the background renal attenuation increased from 40 to 140 or 240 HU).

Results:

Pseudoenhancement was seen with higher frequency (59 [61%] of 96 cysts vs 52 [39%] of 132 cysts, $P < .05$) and magnitude (17 vs 13 HU, $P < .005$) with 64- rather than with 16-detector scanners. Pseudoenhancement was also seen with higher frequency (25 [42%] of 60 cysts vs 11 [18%] of 60 cysts, $P < .005$) and magnitude (18 vs 13 HU, $P < .05$) at 140 kVp than at 80 or 90 kVp. Cyst pseudoenhancement increased with higher background renal enhancement ($P < .005$) and smaller cyst diameter ($P < .05$). The number of detectors, peak tube voltage, renal parenchymal enhancement level, and cyst diameter were independent predictors of cyst pseudoenhancement.

Conclusion:

Lower tube voltage settings may be useful when accurate differentiation between small renal cysts and solid masses is critical, particularly for 64-detector CT scanners.

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The distinction between solid and cystic masses seen at computed tomography (CT), which is a particularly common and important issue in evaluating focal renal lesions, is determined primarily on the evaluation of whether the lesion enhances after the intravenous administration of iodinated contrast material. While this approach is generally robust, the assessment of enhancement in small renal cystic lesions may be unreliable. Attenuation measurements for such small lesions may erroneously suggest enhancement even though the lesion is truly cystic because of partial volume averaging and pseudoenhancement. Renal cyst pseudoenhancement refers to the artifactual increase in the attenuation of a simple renal cyst following contrast material administration, even when the effects of partial volume averaging have been removed (1–4). Pseudoenhancement is most problematic for small cysts and at high levels of renal parenchymal enhancement (1–3,5–7). This problem is magnified by the fact that renal cysts are present in 20%–40% of the population (8) and that certain renal cell carcinomas, such as the papillary subtype, typically enhance in a weak and homogeneous manner (9). Pseudoenhancement may therefore lead to mischaracterization of a small renal cyst as an enhancing neoplasm and unnecessary intervention.

Pseudoenhancement is believed to be a consequence of beam-hardening effects of the enhanced renal parenchyma combined with artifact introduced by the CT image reconstruction algorithm (1). A recent report suggests that pseudoenhancement is worse with newer-generation multidetector CT scanners than with earlier scanners (10). Given the increasing prevalence of 16- and 64-detector scanners in clinical practice, confirmation of these findings, as well as improved understanding of the means to reduce pseudoenhancement, are

clearly needed. While it is known that peak tube voltage settings affect CT image contrast and attenuation measurement (11), the influence of peak tube voltage on pseudoenhancement is not well studied. Therefore, we undertook this study to determine the effect of the number of detectors and peak tube voltage on renal cyst pseudoenhancement in a phantom model.

Materials and Methods

CT Phantom

A water-filled abdominal CT phantom, measuring approximately 32×27 cm in cross section and 20 cm in length, was cast from the abdomen of a male volunteer of average size (12). Two compartments, each measuring 6 cm in diameter, were placed bilaterally to simulate the kidneys (Fig 1). The walls of the phantom and the renal compartments were made of polyethylene, which has an attenuation approximating that of fat. The renal compartments were sequentially filled with iohexol (Omnipaque 350; Nycomed-Amersham, Princeton, NJ) of three different dilutions, selected to reflect the established range of renal attenuation (unenhanced, 40 HU; moderately enhanced, 140 HU; and maximally enhanced, 240 HU). Since iodine is known to have higher attenuation at low peak tube voltage settings (11), the dilution was adjusted for each peak tube voltage used in the study (80, 90, 100, 120, and 140 kVp) to maintain the same renal background attenuation (40, 140, and 240 HU) for the different tube voltages (Table 1). To simulate renal cysts, saline-filled polyethylene cylinders of six diameters (0.7, 1.0, 1.3, 1.5, 2.1, and 3.0 cm) were constructed. The cylinders measured 8 cm in length. The cylindrical shape of the cysts eliminated

the effect of partial volume averaging for our study. The saline-filled simulated renal cysts had an attenuation of approximately 5 HU when immersed in saline baths.

Imaging Techniques

The six simulated renal cysts were sequentially suspended in the renal compartments of the phantom (Fig 2), and scanned in five multidetector CT scanners (16 detector, $n = 3$; 64 detector, $n = 2$) at different peak tube voltage settings (80, 90, 100, 120, and 140 kVp) and constantly at 200 mA tube current. The scanning parameters are shown in Table 2. Three 16-detector scanners (Lightspeed, GE Healthcare, Madison, Wis [$n = 1$]; Somatom Sensation, Siemens Medical Solutions, Forchheim, Germany [$n = 1$]; and Mx8000, Philips Medical Systems, Best, the Netherlands [$n = 1$]) and two 64-detector scanners (Lightspeed VCT, GE Healthcare) were used. For the GE and Siemens scanners, the cysts were scanned at 80, 100, 120, and 140 kVp. For the Philips scanner, the cysts were scanned at 90, 120, and 140 kVp (80- and 100-kVp settings were not available on this scanner). For quality control, each scanner was calibrated immediately prior to the experiments according to manufacturer's specifications. The renal cyst phantoms were scanned in saline baths immediately before and after each experiment, documenting absence of iodine contamination. The criterion used for absence of

Advance in Knowledge

- Renal cyst pseudoenhancement can be reduced by using lower peak tube voltage settings.

Implication for Patient Care

- Lower tube voltage settings may prove useful when accurate differentiation between small renal cysts and solid masses is critical, particularly for 64-detector CT scanners.

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Abbreviation:

ROI = region of interest

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iodine contamination was a change in cyst attenuation of 5 HU or less; no iodine contamination occurred in any of the renal cyst phantoms in our study.

Image Analysis

The primary investigator (Z.J.W.) reviewed all CT images on a picture archiving and communication system workstation (Impax; Agfa, Mortsels, Belgium). The images from the same CT scanner were reviewed generally in the order in which they were acquired (ie, with increasing renal background attenuation and increasing tube voltage settings). The images were reviewed over a period of 2 months. The attenuation of each simulated cyst was the mean of three manually placed circular regions of interest (ROIs) on contiguous images in the mid portion of the cylindrical cyst, with care to exclude the cyst walls. The ROIs were approximately 0.17, 0.35, 0.59, 0.79, 1.53, and 3.14 cm² for the 0.7-, 1.0-, 1.3-, 1.5-, 2.1-, and 3.0-cm diameter cylindrical cysts, respectively. The ROIs were placed at approximately the same location for each cyst. A total of 1026 ROI measurements (three for each mean cyst attenuation measurement) were acquired for this study, resulting in 342 mean cyst attenuation measurements, which sampled a combination of peak tube voltages, scanner types, cyst diameters, and background renal attenuation levels. There were six simulated cysts of different diameters, scanned at four peak tube voltages (80, 100, 120, and 140 kVp) in four scanners (the GE and Siemens scanners), at three peak tube voltages (90, 120, and 140 kVp) in one scanner (the Philips scanner), and at three renal background attenuation levels, resulting in 342 mean cyst attenuation measurements ([6 cysts × 4 peak tube voltages × 3 renal background attenuation levels × 4 scanners] + [6 cysts × 3 peak tube voltages × 3 renal background attenuation levels × 1 scanner] = 342) (Fig 3). Cyst enhancement was determined by measuring the difference in cyst attenuation values between the 140- and 40-HU renal background attenuation levels and between the 240- and 40-HU renal background attenua-

tion levels. Therefore, a total of 228 measurements of cyst enhancement were obtained ([6 cysts × 4 peak tube voltages × 2 changes in renal background enhancement × 4 scanners] + [6 cysts × 3 peak tube voltages × 2 changes in renal background enhancement × 1 scanner] = 228) (Fig 4). Pseudoenhancement was considered to be present when the cyst attenuation level increased by more than 10 HU (13,14).

Statistical Analysis

Statistical analysis was performed with software (Stata, version 8.0; Stata, College Station, Tex). The χ^2 test was used to compare the frequency of cyst pseudoenhancement, and the two-tailed Student *t* test was used to compare the magnitude of cyst pseudoenhancement between 16- and 64-detector scanners, tube voltage settings (high [140 kVp] vs low [80 and 90 kVp]), two renal background enhancement levels (140 and 240 HU), and cyst size (small [≤ 1.0 cm] vs large [> 1.0 cm]). To assess for independent predictors of renal cyst pseudoenhancement, generalized estimating equations determined by using a binary logistic regression model (to assess likelihood of finding pseudoenhancement) or a linear regression model (to assess magnitude of pseudoenhancement) were used. Each model included scanner type (16 vs 64 detector), tube voltage settings (80, 90, 100, 120, and 140 kVp), renal background enhancement levels (140 and 240 HU), and cyst diameters (0.7, 1.0, 1.3, 1.5, 2.1, and 3.0 cm). The covariance structure was modeled by assuming data to be correlated or independent when derived

from the same or from different imaging sessions, respectively. Results were considered significant for *P* values of less than .05.

Results

The frequency and magnitude of cyst pseudoenhancement were significantly greater with 64- than with 16-detector scanners across all peak tube voltages, background renal enhancement levels, and cyst diameters (frequency, *P* < .05; magnitude, *P* < .005) (Fig 5). Fifty-nine (61%) of 96 cyst measurements demonstrated a mean pseudoenhancement of 17 HU $\pm$ 5 (standard deviation) on the 64-detector scanners, compared with 52 (39%) of 132 cyst measurements with a mean pseudoenhancement of 13

Figure 1

Figure 1: Photograph of CT phantom used to study renal cyst pseudoenhancement. Bilateral renal compartments (K) were filled with diluted iodinated contrast material during experiment. Rest of phantom is filled with water through opening at superior aspect of phantom; opening covered with rubber stopper (black round structure).

Table 1

Concentration of Iodinated Contrast Material Required to Attain Renal Background Attenuation for Each Tube Voltage Setting

Renal Background Attenuation (HU)	Peak Tube Voltage Setting (kVp)				
	80	90	100	120	140
40	0.9	1.0	1.1	1.3	1.4
140	3.0	3.4	3.9	4.7	5.7
240	5.1	5.8	6.7	8.0	10.0

Note.—Data are doses of iodinated contrast material measured as milligrams of iodine per milliliter.

HU $\pm$ 3 on the 16-detector scanners. When pseudoenhancement was compared between different generation multidetector CT scanners from the same manufacturer (GE Healthcare), the frequency of pseudoenhancement increased from 14 (29%) of 48 cyst measurements on the GE Healthcare 16-detector scanner to 54 (56%, $P < .005$) of 96 measurements on the GE 64-detector scanners; the magnitude of mean pseudoenhancement increased from 13 HU $\pm$ 2 on the GE Healthcare 16-detector scanner to 17 HU $\pm$ 5 ($P < .05$) on the GE Healthcare 64-detector scanners.

Figure 2

Figure 2: CT scan of phantom shows simulated renal cysts within bilateral renal compartments. Renal compartments were serially filled with dilutions of iodinated contrast material to simulate established range of renal parenchymal attenuation. Saline-filled cylinders were placed in renal compartments (R = right, L = left) to simulate 1.0-cm (arrow) and 0.7-cm (arrowhead) intrarenal cysts.

Higher tube voltage settings resulted in higher frequency and greater magnitude of cyst pseudoenhancement across all scanners, background renal enhancement levels, and cyst diameters (Fig 6). At a tube voltage of 80 kVp (90 kVp for the Philips scanner), pseudoenhancement occurred in only 11 (18%) of 60 of cyst measurements with a mean magnitude of 13 HU $\pm$ 4; however, at 140 kVp, pseudoenhancement was seen in a higher proportion of cyst measurements (25 of 60, 42%, $P < .005$) with a higher mean magnitude of 18 HU $\pm$ 5 ($P < .05$).

Higher renal background attenuation levels and smaller cyst diameters were each significantly associated with increased cyst pseudoenhancement. At 140 HU renal background attenuation, 16 (14%) of 114 cyst measurements showed a mean magnitude of 12 HU $\pm$ 2. In comparison, at 240 HU renal background attenuation, pseudoenhancement was seen in a higher proportion of cyst measurements (62 of 114, 54%, $P < .001$) with a higher mean magnitude of 17 HU $\pm$ 5 ($P < .005$). Larger cysts (>1.0 cm in diameter) showed pseudoenhancement in 40 (26%) of 152 cyst measurements, with a mean magnitude of 12 HU $\pm$ 6. In comparison, small cysts (≤ 1.0 cm) showed a significantly higher frequency of pseudoenhancement (30 of 76 measurements, 39%, $P < .05$), and a higher mean magnitude of 20 HU $\pm$ 3 ($P < .001$).

Generalized estimating equation models showed that the use of 64- rather than 16-detector scanners, higher peak

tube voltage settings, higher renal background attenuation levels, and smaller cyst diameters were each independent predictors of both the likelihood of finding pseudoenhancement ($P < .001$, $P < .001$, $P < .001$, and $P < .05$ respectively), and the magnitude of the pseudoenhancement ($P < .001$ for each).

Discussion

We found that the frequency and magnitude of renal cyst pseudoenhancement were significantly higher for 64-detector scanners, as compared with 16-detector scanners. Our findings are in agreement with a recent study showing increasing incidence of renal cyst pseudoenhancement with newer-generation CT scanners (10) and support the concern for a worsening trend in the reliability of attenuation measurements as the numbers of detectors per scanner increase. While 10 HU was the traditional threshold level for determining renal lesion enhancement (15), higher threshold levels are likely required for multidetector scanners (1,2,5,10), even for different CT reconstruction algorithms from the same multidetector scanner (10). Regarding CT scanners with higher numbers of detectors, equivocal cases of enhancement will likely occur more commonly and referral to magnetic resonance or ultrasonographic imaging for confirmation should be strongly considered. The increased pseudoenhancement with higher numbers of detectors may result from higher

Table 2

Parameters for Multidetector CT Scanners

Scan Parameter	No. and Type of CT Scanner			
	GE Lightspeed ($n = 1$)	GE Lightspeed VCT ($n = 2$)	Philips Mx8000 ($n = 1$)	Siemens Somatom Sensation ($n = 1$)
No. of detectors	16	64	16	16
Peak voltage settings (kVp)	80, 100, 120, 140	80, 100, 120, 140	90, 120, 140	80, 100, 120, 140
Tube current (mA)	200	200	200	200
Section thickness (mm)	2.5	2.5	3	3
Reconstruction kernel	Standard	Standard	C	B31S
Beam pitch	1.375:1	1.375:1	1.238:1	1.375:1
Table speed (mm per rotation)	27.5	55	29.7	32.4
Gantry rotation time (sec)	0.8	0.5	0.75	0.75
Field of view (cm ²)	400	400	400	400

intersection scatter radiation and crosstalk owing to the higher number of simultaneously acquired sections (16). CT image reconstruction algorithms may only partially compensate for the scatter radiation, resulting in a varying degree of pseudoenhancement that depends on the reconstruction algorithms.

More importantly, we found that lower peak tube voltage settings were associated with significantly lower frequency and magnitude of cyst pseudoenhancement in our phantom model. This observation may result from two factors. First, the contrast material solutions we used for lower tube voltage settings contained lower concentrations of iodine because less iodine is needed to achieve the same renal background attenuation level at low tube voltage compared with high tube voltage (11). A reduced amount of required iodine results in less beam hardening of the x-ray by the iodine. Although the concomitant lower x-ray beam energy at lower tube voltage may increase beam hardening, the reduction in the amount of required iodine may result in an overall decrease in x-ray beam hardening at lower peak tube voltage and therefore less cyst pseudoenhancement. Second, lower tube voltage settings produce x-rays with energies closer to the k edge of iodine (33 keV), hence, a greater proportion of x-rays is completely absorbed (photoelectric effect) rather than scattered (Compton interactions) by the iodinated contrast material. The decreased scattered radiation at lower tube voltages may result in fewer non-linearity errors at CT (16) and therefore less cyst pseudoenhancement. Our results differ slightly from those of Coulam et al (2) who reported increased cyst pseudoenhancement at lower tube voltages. However, this discrepancy is readily explained by that study's use of fixed iodine concentrations across the range of tube voltage settings rather than compensatory reductions in iodine concentrations at lower tube voltages, resulting in an unnecessarily high enhancement of renal parenchyma and higher cyst pseudoenhancement at lower peak tube voltage.

Figure 3

Figure 3: Flowchart of study design to obtain total number of cyst attenuation measurements.

Figure 4

Figure 4: Flowchart of study design to obtain total number of cyst enhancement measurements. * = Enhancement between 140- and 40-HU renal background attenuation levels and between 240- and 40-HU renal background attenuation levels.

At lower peak voltage settings, reduced doses of iodinated contrast material can be used owing to the increased sensitivity of CT for iodine detection, with the added benefit that reductions in contrast levels can reduce the risk of contrast-induced nephropathy (17). In our study, the amount of contrast material required to achieve 140 HU renal background attenuation at 80 kVp was about 50% of what was required at 140 kVp (Table 1). An even more compelling benefit of reduced tube voltages for

clinical CT scanning is the substantial reduction in radiation dose, which has been shown to be reduced as much as 56% in abdominal CT (11). These two benefits of lower tube voltage settings, combined with the reduction in pseudoenhancement artifact, suggest that reduced tube voltage settings may prove useful when imaging patients for renal mass characterization at CT. Scanning at lower tube voltage settings, however, results in higher image noise levels, which degrade image quality.

Therefore, lowering tube voltage may not be possible in the setting of large patient body weight. The higher image noise at lower tube voltage settings may be partially compensated for by increasing tube current. Additional studies are needed to determine the optimal tube current when a lower tube voltage setting is used to optimize image quality and to decrease radiation dose.

Our study had several limitations. Ours was an in vitro study and the ob-

served frequency and magnitude of cyst pseudoenhancement may be different among patients. Nevertheless, our phantom study allowed for cyst pseudoenhancement assessment in the absence of motion and partial volume averaging, and in a setting of repeated imaging at different tube voltages, which is not feasible in patients. Second, both 64-detector scanners used in our experiment were manufactured by GE Healthcare; we did not have access

to 64-detector scanners from other manufacturers to make direct comparisons of the degree of cyst pseudoenhancement between the 16- and 64-detector scanners from other manufacturers. However, our results agree with those from the previous report comparing renal cyst pseudoenhancement between the different generations of multidetector Siemens scanners (10). Third, we did not investigate the effect of reconstruction algorithms on pseudoenhancement in our phantom study. As noted by Birnbaum et al (10), cyst pseudoenhancement was significantly affected by using different reconstruction algorithms, even within the same manufacturer. However, reconstruction algorithms alone did not account for the differences in cyst pseudoenhancement between the 64- and 16-detector scanners in our study, as we also showed significantly higher frequency and magnitude of cyst pseudoenhancement with the 64- and 16-detector GE Healthcare scanners compared by using the same reconstruction algorithms. Furthermore, the reconstruction algorithms selected for our phantom experiments were the ones optimized for our clinical abdominal imaging protocols. Fourth, the investigator who reviewed the CT images could not be completely blinded to the knowledge of the tube voltage settings because the images obtained at lower peak tube voltage tended to have greater visible image noise. Although the knowledge of the tube voltage settings may introduce bias, the use of objective attenuation measurement should minimize that potential bias.

In conclusion, renal cyst pseudoenhancement is more pronounced on 64- than on 16-detector CT scanners but can be decreased by using a lower tube voltage setting. Lower tube voltage settings may prove useful when accurate differentiation between small renal cysts and solid masses is critical.

Renal cyst pseudoenhancement worsens with 64-detector rather than with 16-detector CT scanners, higher peak tube voltage setting, higher renal parenchymal enhancement, and smaller cyst size. While radiologists are not readily able to change their CT scanners, low-

Figure 5

Figure 5: Bar graphs of (a) frequency and (b) magnitude of pseudoenhancement for 16- and 64-detector CT scanners, averaged across all tube voltages, cyst diameters, and background renal enhancement. Frequency and magnitude of cyst pseudoenhancement were significantly higher for 64-detector scanner compared with 16-detector scanners (frequency, $P < .05$; magnitude, $P < .005$). T-whiskers demarcate 1 standard deviation from the mean.

Figure 6

Figure 6: Bar graphs of (a) frequency and (b) magnitude of cyst pseudoenhancement at different peak tube voltages, averaged across all scanners, cyst sizes, and renal background attenuation levels. Lower peak tube voltages of 80 or 90 kVp were associated with significantly lower frequency and magnitude of cyst pseudoenhancement (frequency, $P < .005$; magnitude, $P < .05$). * = includes pseudoenhancement measurements at 90 kVp on Philips Mx8000 scanner. T-whiskers demarcate 1 standard deviation from mean.

ering the tube voltage setting with a compensatory decrease in intravenous contrast agent dose may prove useful to reduce the pseudoenhancement effect, particularly for the 64-detector CT scanners.

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1-4	\$223	\$239	\$352	\$473	\$597	\$719
5-8	\$349	\$401	\$601	\$849	\$1,099	\$1,349
9-12	\$486	\$517	\$852	\$1,232	\$1,609	\$1,992
13-16	\$615	\$651	\$1,105	\$1,609	\$2,117	\$2,624
17-20	\$759	\$787	\$1,357	\$1,997	\$2,626	\$3,260
21-24	\$897	\$924	\$1,611	\$2,376	\$3,135	\$3,905
25-28	\$1,033	\$1,071	\$1,873	\$2,757	\$3,650	\$4,536
29-32	\$1,175	\$1,208	\$2,122	\$3,138	\$4,162	\$5,180
Covers	\$97	\$118	\$215	\$323	\$442	\$555

International (includes Canada and Mexico))						
# of Pages	50	100	200	300	400	500
1-4	\$278	\$290	\$424	\$586	\$741	\$904
5-8	\$429	\$472	\$746	\$1,058	\$1,374	\$1,690
9-12	\$604	\$629	\$1,061	\$1,545	\$2,011	\$2,494
13-16	\$766	\$797	\$1,378	\$2,013	\$2,647	\$3,280
17-20	\$945	\$972	\$1,698	\$2,499	\$3,282	\$4,069
21-24	\$1,110	\$1,139	\$2,015	\$2,970	\$3,921	\$4,873
25-28	\$1,290	\$1,321	\$2,333	\$3,437	\$4,556	\$5,661
29-32	\$1,455	\$1,482	\$2,652	\$3,924	\$5,193	\$6,462
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