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FULL PAPER

Evaluation of hyperdense renal lesions incidentally detected on single-phase post-contrast CT using dual-energy CT

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Objective: To investigate the utility of dual-energy CT (DECT) for differentiating between solid and benign cystic lesions presenting as hyperdense renal lesions incidentally detected on single-phase post-contrast CT.

Methods: 90 hyperdense renal lesions incidentally detected on single-phase post-contrast CT were evaluated with follow-up DECT. DECT protocols included true non-contrast (TNC), DE corticomedullary and DE late nephrographic phase imaging. The CT numbers of hyperdense renal lesions were calculated on linearly blended and iodine overlay (IO) images, and the results were compared.

Results: In total, 47 benign cystic and 43 solid renal lesions were analyzed. For differentiating between solid and benign cystic lesions on the two phases, the specificity and accuracy of all lesions and lesions <1.5 cm were

statistically lower in IO images than in linearly blended images ($p < 0.05$), while those for lesions ≥ 1.5 cm were not statistically different between them ($p > 0.05$). For all types of lesions ≥ 1.5 cm, the CT numbers between linearly blended and IO images and between TNC and virtual non-contrast images were not statistically different ($p > 0.05$).

Conclusion: DECT may be useful for differentiating between solid and benign cystic lesions presenting as hyperdense renal lesions incidentally detected on single-phase post-contrast CT, particularly with the size ≥ 1.5 cm.

Advances in knowledge: DECT may be used to characterize hyperdense renal lesions ≥ 1.5 cm incidentally detected on single-phase post-contrast CT, without the use of TNC images.

INTRODUCTION

The incidence of renal lesions has increased during the past several decades largely due to increased use of non-invasive abdominal imaging modalities such as CT, mainly for non-urolurgical reasons.^{1–3} Most of these incidental renal lesions are benign cysts that can be diagnosed when the measured attenuation value of a non-enhancing mass is <20 Hounsfield units (HU) on CT.^{4–6} However, hyperdense renal lesions at least 30 HU on post-contrast CT can either be hyperdense benign cysts or solid masses, including renal cell carcinoma (RCC).^{7–9}

Generally, the radiologists do not have difficulty in interpreting a cystic renal lesion on routine single-phase post-contrast abdominal CT in daily practice. However, in cases of hyperdense renal lesions incidentally detected on routine single-phase post-contrast abdominal CT, a dilemma due to unavailable pre-contrast images occurs. Thus, repeated CT or MR examinations with pre- and post-contrast images are needed for further characterization of renal

lesions. However, in cases of CT examinations, additional radiation exposure to patients is inevitable, in addition to increased costs and greater patient anxiety. Although MRI is an alternative, its drawbacks include a long acquisition time, limited availability and high costs. Therefore, if CT examinations without pre-contrast images can characterize hyperdense renal lesions, it would save time and cost while reducing radiation exposure to patients.

Dual-energy CT (DECT), which simultaneously obtains CT data at two different X-ray spectra in a single acquisition, can detect differences in material composition based on variations in photon absorption at different photon energies.^{10,11} With post-processing algorithms based on three material decomposition principles, iodine can be subtracted from the images and virtual non-contrast (VNC) images can be developed. Furthermore, iodine images, which reveal the distribution of iodine in the scan field, can be created. These iodine images can be superimposed onto VNC images and create colour-coded iodine overlay (IO) images.

To date, several previous studies have reported that VNC images derived from DECT may allow accurate characterization of renal lesions.^{12–16} Furthermore, IO¹⁵ images can be useful for differentiating between solid and benign cystic renal lesions.^{13,17,18} To our knowledge, no studies have demonstrated the utility of DECT in evaluating hyperdense renal lesions incidentally detected on single-phase post-contrast CT. Therefore, the purpose of our study was to retrospectively investigate the utility of DECT for differentiating between solid and benign cystic lesion presenting as hyperdense renal lesions incidentally detected on single-phase post-contrast abdominal CT.

METHODS AND MATERIALS

Patients

This retrospective study was approved by our institutional review board, with a waiver of the requirement for informed consent. From October 2010 to September 2011, 79 patients (45 males, 34 females; mean age, 55.2 years; age range, 22–90 years) met all of the following inclusion criteria: (a) hyperdense (>30 HU) renal lesions (≥ 0.5 cm in the greatest transverse diameter) incidentally detected on single-phase post-contrast abdominal CT,⁹ (b) three-phase kidney CT protocol including true non-contrast (TNC) and post-contrast imaging of DE corticomedullary phase (CMP) and DE late nephrographic phase (LNP), (c) available CT data for reconstruction and (d) available pathological diagnoses or reports on follow-up examinations. Thus, 90 hyperdense renal lesions incidentally detected on single-phase post-contrast CT were further evaluated with DECT (Figure 1).

Data acquisition

All CT examinations were performed by a dual-source dual-energy scanner (SOMATOM® Definition Flash; Siemens Healthcare, Forchheim, Germany). This system is composed of 2 X-ray tubes arranged on 1 gantry with 2 corresponding 64-section detectors. The field of view is 33 cm which is enough to cover both kidneys.

Figure 1. Flowchart of the study design. DECT, dual-energy CT.

The CT examinations consisted of three-phase protocol that included TNC and DE-based post-contrast imaging of CMP and LNP. Imaging protocols and DE post-processing were introduced in a previous study.¹³ Tube voltages of DE mode were 100 and 140 kV.

The dose-length products from the patient protocol were recorded for each of the three phases. These values were used to measure effective radiation doses (millisieverts, mSvs) using normalized conversion factors.

Image analysis

A radiologist (CKK, with more than 13 years' of experience in abdominal CT imaging interpretation) who was blinded to the original radiological reports and patients' clinical information, measured CT attenuation of the renal lesions and of the normal renal cortex.

On colour-coded IO images derived from CMP and LNP, regions of interest (ROIs) were manually drawn by the radiologist. The CT numbers were calculated in the renal lesions and normal renal cortex. The overlay values on colour-coded IO images indicate the mean mass enhancement on the corresponding phase in HU. The CT numbers of the renal lesions and of the normal renal cortex were also measured on the TNC and linearly blended images of CMP and LNP. Furthermore, the radiologist assessed the presence or absence of macroscopic fatty tissue within the lesions on TNC and VNC images.

The enhancement values of the renal lesions and normal renal cortex were calculated by subtracting the CT numbers measured on post-contrast images by that measured on TNC images. Renal lesions were considered as solid when the CT attenuation difference between the post-contrast image and pre-contrast image was >20 HU.^{6,13} If the difference was <20 HU, the lesion was considered cystic. The ROIs were drawn along the inner contours of the whole lesion, with sizes of at least 10 mm^2 (mean, 37.9 mm^2). Two measurements per lesion were performed and an average was recorded. Any renal lesions with <0.5 cm in the greatest transverse diameter were excluded in our study to minimize or avoid measurement errors due to partial volume or beam-hardening artefacts. In patients with multiple renal lesions, the CT number was measured each on one kidney; therefore, up to two lesions per patient were measured. The CT number of normal renal cortex was measured in the contralateral renal cortex at the level of the hilum. Each ROI was at least 10 mm^2 (mean, 13.1 mm^2).

Reference standard

A radiologist (DC, with 1 year of experience in abdominal CT imaging interpretation) who assessed patients' records, including the pathologic report and the entire imaging history, established the reference standard. In patients who underwent surgical resection or biopsy, histopathological reports were used as the reference standard. If histopathology was not confirmed, follow-up imaging was used to make a final diagnosis: any renal lesions that showed no change in size for at least 12 months by follow-up imaging (ultrasound, CT or MRI) after undergoing DECT examination were classified as benign.

Enhancing solid lesions with macroscopic fatty tissue that had no change in size on follow-up imaging were considered as angiolipomas (AMLs). If an enhanced solid mass did not contain macroscopic fatty component, the mass was considered as a RCC. When the CT number of a non-enhancing mass without internal septa or calcification was <20 HU on TNC images, it was considered as a simple cyst. If the CT number within a non-enhancing mass was 20 HU or greater on TNC images, it was classified as a haemorrhagic cyst.

Statistical analysis

Statistical analyses were performed using PASW statistical software version 20.0 (SPSS®; IBM Corporation, Armonk, NY; formerly SPSS Inc. Chicago, IL). All renal lesions were divided into three categories: all, cystic and solid lesions. The three categories were subdivided into two groups according to their sizes resulting in 100% specificity for differentiating between solid and benign cystic lesions on both CMP and LNP of the IO images. For differentiating between solid and benign cystic lesions, the sensitivity, specificity, positive-predictive value, negative-predictive value and accuracy of IO images and of linearly blended images were calculated and a significant difference was compared using McNemar test.

On CMP and LNP, the overlay values of IO images were compared with enhancement values of linearly blended images. The CT numbers of VNC images from the CMP and LNP were compared with TNC images, respectively. A significant difference was compared with the Student paired *t*-test. A two-sided $p < 0.05$ was considered to suggest a significant difference.

RESULTS

Lesion characteristics

The mean size of 90 hyperdense renal lesions in 79 patients was 1.6 cm (range, 0.5–4.9 cm). In total, 47 cystic lesions (25 haemorrhagic cysts and 22 simple cysts) and 43 solid lesions (24 RCCs and 19 AMLs) were analyzed. All 24 RCCs were confirmed histopathologically after biopsy ($n = 14$), partial nephrectomy ($n = 7$) or radical nephrectomy ($n = 3$). The remaining 66 hyperdense renal lesions were diagnosed with imaging and clinical findings. The mean follow-up period was 14.2 months (range, 12–28 months). The mean size of each type of renal lesion was as follows: RCC, 2.3 cm (range, 0.8–4.4 cm); AML, 1.4 cm (range, 0.6–3.7 cm); haemorrhagic cyst, 1.2 cm (range, 0.5–3.6 cm); and simple cysts, 1.1 cm (range, 0.5–3.5 cm).

Differentiation between solid and benign cystic lesions

Table 1 summarizes the diagnostic performance of linearly blended and IO images in differentiating between solid and benign cystic renal lesions. On IO images of both CMP and LNP, the minimal size representing 100% specificity was 1.5 cm. Thus, 1.5 cm was used for subgroup divisions in each category: numbers of lesions <1.5 cm were 55, whereas those of lesions ≥ 1.5 cm were 35. For differentiating between solid and benign cystic renal lesions, the sensitivity of IO images was the same as those of linearly blended images on the two phases ($p > 0.05$). The specificity and accuracy of IO images in all lesions and lesions <1.5 cm were significantly lower than those of linearly blended images on the two phases ($p < 0.05$), whereas those in

Table 1. Diagnostic performance of linearly-blended and iodine overlay (IO) images for differentiating solid between benign cystic renal lesions

Variable	CMP			LNP		
	Linearly blended	IO	<i>p</i> -value	Linearly-blended	IO	<i>p</i> -value
Sensitivity (%)	97.7 (42/43)	97.7 (42/43)	1.000	100 (43/43)	100 (43/43)	1.000
<1.5 cm	100 (16/16)	100 (16/16)	1.000	100 (16/16)	100 (16/16)	1.000
≥ 1.5 cm	96.3 (26/27)	96.3 (26/27)	1.000	100 (27/27)	100 (27/27)	1.000
Specificity (%)	95.7 (45/47)	77.6 (36/47)	0.008	80.1 (38/47)	55.3 (26/47)	0.002
<1.5 cm	94.9 (37/39)	71.8 (28/39)	0.013	76.9 (30/39)	46.2 (18/39)	0.013
≥ 1.5 cm	100 (8/8)	100 (8/8)	1.000	100 (8/8)	100 (8/8)	1.000
PPV (%)	95.5 (42/44)	79.2 (42/53)	–	82.7 (43/52)	67.2 (43/64)	–
<1.5 cm	88.9 (16/18)	41.0 (16/39)	–	64 (16/25)	43.2 (16/37)	–
≥ 1.5 cm	100 (26/26)	100 (26/26)	–	100 (27/27)	100 (27/27)	–
NPV (%)	97.8 (45/46)	97.3 (36/37)	–	100 (38/38)	100 (26/26)	–
<1.5 cm	100 (37/37)	100 (28/28)	–	100 (30/30)	100 (16/16)	–
≥ 1.5 cm	88.9 (8/9)	88.9 (8/9)	–	100 (8/8)	100 (8/8)	–
Accuracy (%)	96.7 (87/90)	86.7 (78/90)	0.035	90 (81/90)	76.7 (69/90)	0.017
<1.5 cm	96.4 (53/55)	80 (44/55)	0.013	83.6 (46/55)	61.8 (34/55)	0.008
≥ 1.5 cm	97.1 (34/35)	97.1 (34/35)	1.000	100 (35/35)	100 (35/35)	1.000

CMP, corticomedullary phase; LNP, late nephrographic phase; NPV, negative-predictive value; PPV, positive-predictive value. The values in parentheses are raw data. *p*-value: comparisons between linearly blended and IO images on CMP and LNP.

lesions ≥ 1.5 cm were not significantly different between IO and linearly blended images ($p > 0.05$) (Figures 2 and 3).

On IO images, the CMP showed 11 false-positive lesions (*i.e.* pseudoenhancement) (3 haemorrhagic cysts and 8 simple cysts); the median overlay value and size were 26.2 HU (range, 20.6–40.8 HU) and 0.8 cm (range, 0.5–1.1 cm), respectively. The LNP revealed 21 false-positive lesions (6 haemorrhagic cysts and 15 simple cysts); the median overlay value and size were 39.4 HU (range, 21.4–54.7 HU) and 0.8 cm (range, 0.5–1.4 cm), respectively. Therefore, the minimum size of renal lesions necessary to accurately differentiate solid lesions from benign cystic lesions on both CMP and LNP was 1.5 cm.

On linearly blended images, two renal simple cysts showed false-positive findings on CMP; the CT number and size were 21.6 HU and 0.7 cm, and 41.0 HU and 0.8 cm, respectively. On LNP, 9 renal simple cysts had false-positive findings; the median CT number and size were 28.2 HU (range, 24.2–52.8 HU) and 0.7 cm (range, 0.5–1.1 cm), respectively.

Quantitative analysis

Comparison of linearly-blended and iodine overlay image

Table 2 shows the results of CT numbers of renal lesions and renal cortex on IO and linearly blended images. The CT numbers of IO images were not statistically different from those of

linearly blended images for all renal lesions including cystic and solid lesions on CMP and LNP, and solid lesions on LNP ($p > 0.05$). However, the CT numbers of IO images in cystic lesions were statistically different from those of linearly blended images on the two phases ($p < 0.05$).

In subanalysis according to the lesion size, the CT numbers of all types of lesions ≥ 1.5 cm, including all renal, cystic and solid lesions, were not statistically between IO and linearly blended images on the two phases ($p > 0.05$). However, the CT numbers of cystic lesions < 1.5 cm were statistically different between IO and linearly blended images on CMP ($p = 0.006$) and LNP ($p < 0.001$).

In the renal cortex, the CT numbers of IO images were not statistically different from those of linearly blended images on the two phases ($p > 0.05$).

Comparison between true non-contrast and virtual non-contrast

Table 3 shows comparison of the CT numbers between TNC and VNC images in the renal lesions and renal cortex. For the solid lesions, the CT numbers of VNC images from the CMP and LNP were not statistically different from those of TNC images, regardless of the lesion size. In all renal and cystic lesions, the CT numbers of VNC images from the CMP and LNP were not statistically different from those of the TNC images in the lesions ≥ 1.5 cm.

Figure 2. A-46-year-old female with a left renal simple cyst [(a) initial axial single-phase single-energy CT; (b–e) follow-up axial kidney dual-energy CT]. (a) Initial single-phase CT image shows a 5-mm hyperdense lesion (arrow) in the left kidney, measuring 76 Hounsfield units (HUs). The presence of enhancement cannot be determined on the basis of this CT image. (b, c) In a left renal lesion (arrows), the CT numbers of true non-contrast image (b) and linearly blended image of late nephrographic (c) phase are 12 and 71 HU, respectively. (d, e) On iodine overlay (d) and virtual non-contrast (e) image from late nephrographic phase, the overlay value and CT numbers in left renal lesions (arrows) are 41 and 4 HU, respectively. Enhancement values of this renal lesion are ≥ 20 HU on linearly blended image of late nephrographic phase and iodine overlay image, probably resulting from “pseudoenhancement”. This lesion was diagnosed as a simple renal cyst by follow-up MRI, which was confirmed by imaging follow-up over 17 months.

Figure 3. A-38-year-old female with a renal cell carcinoma in the right kidney [(a) initial axial single-phase single-energy CT; (b–e) follow-up axial kidney dual-energy CT]. (a) Initial single-phase CT image shows a 29-mm hyperdense lesion (arrow) in the right kidney, measuring 153 HUs. The presence of tiny fatty tissue cannot be determined on the basis of this CT image. (b, c) In a right renal lesion (arrows), the CT numbers of true non-contrast image (b) and linearly blended image (c) of late nephrographic phase are 24 and 113 HU, respectively. (d, e) On iodine overlay (d) and virtual non-contrast (e) images from late nephrographic phase, the overlay value and CT numbers in a right renal lesion (arrows) are 113 and 25 HU, respectively. No fatty tissue in a right renal lesion is seen. These findings most likely represent a renal cell carcinoma. This diagnosis was confirmed by surgery.

In the renal cortex, the CT numbers were not statistically different between TNC and VNC images from the CMP and LNP ($p > 0.05$).

Radiation doses

The mean effective radiation dose of standard three-phase protocol and of TNC were 12.0 ± 2.9 mSv (range, 2.9–19.9 mSv) and 2.2 ± 0.6 mSv (range, 0.6–3.8 mSv), respectively. The mean effective radiation dose for two-phase protocol, including DE-based CMP and LNP, was 9.8 ± 2.4 mSv (4.9–19.1 mSv). By omitting the TNC images, the two-phase DE-based CMP and LNP protocol could acquire a dose reduction of $19.4 \pm 3.2\%$ as compared with the three-phase protocol.

DISCUSSION

In this retrospective study, we investigated whether DECT can help differentiate between solid and benign cystic lesions presenting as hyperdense renal lesions incidentally detected on single-phase post-contrast CT that cause an uncertainty between true enhancement and pseudoenhancement due to unavailable pre-contrast images. Our results demonstrated that the overlay values of hyperdense renal lesions on IO images created from DECT post-processing techniques were comparable with the enhancement values on linearly blended images. Specifically, the minimum size of hyperdense renal lesions to accurately differentiate between solid and benign cystic lesions on CMP and LNP was 1.5 cm, with 100% specificity. Furthermore, the CT numbers of hyperdense renal lesions ≥ 1.5 cm on VNC images were not significantly different from those on TNC images, regardless of whether they were solid or

cystic lesions. These findings indicate that DECT using colour-coded IO and VNC images can accurately differentiate solid lesions from benign cystic lesions presenting as hyperdense renal lesions incidentally detected on single-phase post-contrast CT, especially in cases of lesions ≥ 1.5 cm. Therefore, if any hyperdense renal lesions ≥ 1.5 cm are seen on single-phase post-contrast DECT images, DECT may accurately distinguish solid lesions from benign cystic lesions without additional CT or MR examinations, which in turn may save time and additional costs while reducing radiation exposure to patients. However, a large further prospective study will be needed to validate it.

In our study, for differentiating between solid and benign cystic lesions on CMP and LNP, the specificity and accuracy of IO images were significantly lower than those of linearly blended images. However, in the subanalysis, the specificity (100% on CMP and 100% on LNP, respectively) and accuracy (97.1% on CMP and 100% on LNP, respectively) of IO images for lesions ≥ 1.5 cm were the same with those of linearly blended images. Interestingly, a recent study investigated DECT to classify phantom renal lesions as cysts or enhancing masses. Their results demonstrated that small lesions with low enhancement were more frequently misdiagnosed, but all renal lesions ≥ 1.5 cm were properly identified as cystic or solid and the specificity of IO images was approximately 83%.¹⁷

In this study, we compared the overlay and enhancement values between IO and linearly blended images in renal lesions and the renal cortex. In the renal cortex, the CT numbers of the IO

Table 2. CT numbers of renal lesions and renal cortex on iodine overlay (IO) and linearly blended images

		CT number		
Variable		Linearly blended	IO	<i>p</i> -value
All renal lesions	CMP	39.4 ± 38.0	38.9 ± 34.9	0.909
	LNP	36.4 ± 26.5	38.5 ± 24.2	0.064
<1.5 cm	CMP	23.1 ± 30.6	17.9 ± 24.3	0.397
	LNP	19.2 ± 23.5	16.9 ± 21.1	0.001
≥1.5 cm	CMP	31.2 ± 39.9	32.3 ± 41.5	0.217
	LNP	18.8 ± 25.8	19.3 ± 26.6	0.131
Cystic lesions	CMP	10.5 ± 7.0	14.4 ± 9.5	0.024
	LNP	13.7 ± 11.3	22.6 ± 16.1	<0.001
<1.5 cm	CMP	10.8 ± 7.4	16.0 ± 9.4	0.006
	LNP	14.6 ± 12.2	25.6 ± 15.9	<0.001
≥1.5 cm	CMP	8.8 ± 4.4	6.4 ± 5.5	0.141
	LNP	9.0 ± 3.0	7.8 ± 5.4	0.327
Solid lesions	CMP	71.0 ± 32.5	65.8 ± 32.7	0.028
	LNP	57.0 ± 18.6	54.9 ± 19.9	0.094
<1.5 cm	CMP	65.6 ± 31.2	56.7 ± 25.4	0.023
	LNP	55.6 ± 18.6	54.2 ± 18.7	0.623
≥1.5 cm	CMP	74.2 ± 33.4	71.2 ± 35.6	0.337
	LNP	57.8 ± 19.0	55.3 ± 20.9	0.064
Renal cortex	CMP	124.0 ± 38.7	122.1 ± 39.8	0.109
	LNP	137.4 ± 25.2	136.1 ± 24.7	0.101

CMP, corticomedullary phase; LNP, late nephrographic phase.

Data are presented as mean ± standard deviation. *p*-value: comparisons between linearly-blended and IO images on CMP and LNP.

images on CMP and LNP were similar with those of the linearly blended images. In cases of all types of lesions ≥1.5 cm, including all renal, cystic and solid lesions, the overlay values on IO images were similar to the CT numbers on linearly blended images for CMP and LNP. However, in cases of lesions <1.5 cm, all renal and solid lesions on CMP and cystic lesions on CMP and LNP demonstrated significant differences in CT numbers between IO and linearly blended images. These findings suggest that any hyperdense renal lesions ≥1.5 cm can be accurately characterized as benign cysts or solid lesions using DECT, but renal lesions <1.5 cm should be cautiously interpreted due to the false-positive or false-negative findings.

In the differentiation of solid lesions from cystic lesions, our study demonstrated that the specificity of the IO technique on DECT was lower than that of several previous studies.^{13,15} One possible reason might be because the smallest size of renal lesions in our study was 0.5 cm, whereas that of renal lesions in other previous studies was 1 cm.^{13,15} Our study demonstrated that IO images from the CMP had 11 false-positive cases (size range, 0.5–1.1 cm) and IO images from the LNP had 21 false-positive cases (size range, 0.5–1.4 cm). However, no false-positive cases were found in renal lesions with the size ≥1.5 cm in differentiating between solid and cystic renal lesions using DECT.

Detecting enhancement in renal lesions is very important for choosing the treatment strategies. A cut-off value of 15–20 HU has been used to determine the contrast enhancement in renal lesions.^{13,18} Although recent CT technologies have improved, a number of artefacts can lead to pseudoenhancement.¹⁹ In our study with a cut-off value of 20 HU for contrast enhancement, two and nine simple renal cysts demonstrated pseudoenhancement on linearly blended images from the CMP and LNP, respectively.

Currently, the similar CT numbers of renal lesions between VNC and TNC images are conflicting.^{12–14} In our study, the CT numbers of renal lesions on VNC images from the two phases were comparable to those on TNC images, especially in solid lesions with any sizes or any lesions ≥1.5 cm in size. However, the cystic lesions <1.5 cm showed discrepancies in CT numbers between TNC and VNC images. Among several studies including our study, the conflicting results of CT numbers between TNC and VNC images might be due to the different type of reference tissue used. The renal cortex and aorta reveal strong attenuation differences between pre- and post-contrast images, showing an abundant amount of iodine deposition. Meanwhile, the muscles and liver parenchyma relatively reveal a lesser degree of enhancement. The post-processing algorithm might have been optimized for strongly enhancing structures rather than for

Table 3. CT numbers of renal lesions and renal cortex on virtual non-contrast (VNC) and true non-contrast (TNC) images

CT number					
Variable	TNC	VNC		<i>p</i> -value ^{<i>a</i>}	<i>p</i> -value ^{<i>b</i>}
		CMP	LNP		
All renal lesions	30.3 ± 22.3	28.8 ± 21.5	26.4 ± 21.2	0.545	0.022
<1.5 cm	20.0 ± 26.4	19.0 ± 24.5	18.8 ± 24.5	0.059	<0.001
≥1.5 cm	9.9 ± 13.7	8.6 ± 13.4	9.0 ± 12.5	0.075	0.199
Cystic lesions	36.8 ± 25.9	31.8 ± 25.5	29.6 ± 25.4	0.024	0.001
<1.5 cm	35.9 ± 27.6	29.4 ± 26.3	26.8 ± 26.2	0.007	<0.001
≥1.5 cm	41.3 ± 14.8	43.4 ± 18.3	43.1 ± 16.6	0.401	0.528
Solid lesions	23.2 ± 14.8	24.3 ± 14.5	22.9 ± 14.1	0.068	0.530
<1.5 cm	18.1 ± 16.3	19.5 ± 18.0	15.5 ± 18.1	0.326	0.569
≥1.5 cm	26.3 ± 13.2	27.1 ± 11.4	27.2 ± 10.6	0.058	0.143
Renal cortex	33.3 ± 8.4	34.3 ± 7.8	33.2 ± 7.7	0.252	0.337

CMP, corticomedullary phase; LNP, late nephrographic phase.

Data are presented as mean ± standard deviation.

^aComparison between TNC images and VNC images on CMP.

^bComparison between TNC images and VNC images on LNP.

those that do not. This hypothesis might be also supported by our findings that VNC images were more accurate for solid renal lesions that showed greater enhancement than for cystic renal lesions that show weaker enhancement. Another potential explanation is that the settings of DECT scan were slightly different among the studies.^{12–14}

There are several limitations in our study. First, this was a retrospective study and might have a selection bias. Second, the post-contrast images of the CMP and LNP in our study were not the optimal single-phase abdominal CT protocol that is commonly used in daily practice. Third, the relatively short follow-up period for some renal lesions without considering the CT numbers or enhancement patterns and the lack of pathological proof might be another limitation for diagnosing benign as a standard reference. Moreover, some RCCs may contain macroscopic fatty tissue,²⁰ although almost solid renal masses with macroscopic fatty tissue that had no change in size during the follow-up imaging study were AMLs. However, long-term follow-up for simple renal cysts would be unethical because of

the patient's cost and additional exposure to radiation. Fourth, we did not use the iodine quantification technique in evaluating the enhancement of renal lesions. Several recent studies have reported the utility of iodine quantification on DECT in distinguishing enhancing from non-enhancing renal lesions.^{15,16} Further studies should be performed to evaluate whether this technique is superior to standard enhancement measurement or can overcome the issue of pseudoenhancement in renal cysts. Fifth, we did not perform qualitative analysis for IO and linearly blended images. Finally, although DECT may be helpful to evaluate hyperdense renal lesions, it will be impossible for all patients to perform DECT of the abdomen in routine clinical care, which can give a limitation for practical utility of DECT.

In conclusion, our study demonstrated that DECT may be used for differentiating solid lesion from benign cystic lesion presenting as hyperdense renal lesions incidentally detected on single-phase post-contrast CT, particularly those with a size of ≥1.5 cm. However, more development of sophisticated post-processing algorithms appears to be needed to improve specificity, especially for small renal lesions.

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