Detectability of Urinary Stone Size and Compositions by Various Scanning Parameters in Dual Energy CT

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INTRODUCTION

Most urinary stones contain two or more mixed materials, and therefore, it is essential to identify, quantify, analyze and compare the individual components of a stone. In this regard, several composition analysis techniques, such as X-ray diffraction crystallography, infrared spectroscopy, scanning electron microscopy with energy dispersion, thermogravimetry, polarized microscopy, and wet chemical analysis, have been used to define the standards against which urinary stone composition as per DECT can be compared. In this study, we set the chemical analysis results of urinary stones as the reference standard, and we compared these standard results with those obtained under various DECT conditions and different phantom thicknesses.

AIM

The purpose of this study was to estimate the optimal dual-energy computed tomography(DECT) condition for the accurate detection of different sizes and compositions of urinary stone.

METHOD

A total of 15 urinary stones were chemically analyzed, and these chemical compositions served as the reference standard against which we compared the uric acid and non-uric acid compositions determined by DECT.

The stones were placed inside a bolus and scanned with a dual source CT scanner under various selected dual-energy conditions (A to X) for various thicknesses of a solid water phantom. Spiral dual-energy scans were performed by using a dual-source, 64 slice/128-slice CT system as per clinical protocols (0.5/0.5 mm and 1.5/1.0 mm Recon) and automatic exposure control. Scanning was performed with two different slices settings (64 and 128-slice) and three phantom sizes (small, medium and large), resulting in a total of five image data sets. These data sets were analyzed by means of the software tool SIEMENS SyngoVia (onboard the CT system) for both sensitivity (number of urinary stone detections) and accuracy (diameter of detected urinary stones). Moreover, the DECT estimated urinary stone composition was verified against the chemical analysis results.

FIG. 1. Images of three phantom set-ups used un study. A, Phantom Ⅰ (height : 10 cm). B, Phantom Ⅱ (height : 16 cm). C, Phantom Ⅲ (height : 22 cm). Each phantom and Bolus has volume 30 × 30 × 1 cm

RESULTS

① Urinary stone detectability measurement results

Figure 2 presents the assessment of the urinary stone detectability for various dual energy settings and phantom thicknesses; it can be noted that conditions A (12 detections, 80%, Phantom Ⅰ), I, J, K, L (11 detections, 73%, Phantom Ⅱ) and condition Q, R, S and T (11 detections, 73%, Phantom Ⅲ) afford high detectability. The DECT ability to detect urinary stones is higher at the setting of 1.5/1.0 mm with slice thickness/increment (mm) of 0.5/0.5 mm. For a given scan conditions, the DECT ability to detect urinary stones is highest in the thinnest phantom Ⅰ.

② Measurement error average of urinary stone diameter

The evaluation of the urinary stone diameter measurement error was performed only for Stones 1 and 3, which were detected across all conditions (A to X). From Fig 2, we note that the evaluation error of the urinary stone diameter measurements is the lowest under condition S(Stone 1 (0.68 mm), Stone 3 (0.11 mm)) with Phantom Ⅲ, and the highest under condition M (Stone 1 (1.28 mm) and Stone 3 (0.33 mm)). We also note that measurement errors of the urinary stone diameter with 0.5/0.5mm slice thickness/increment are less than those with 1.5/1.0mm slice thickness/increment under all conditions.

③ Composition analysis matching of urinary stones

Figure 3 presents the evaluation of urinary stone composition matching for various dual energy conditions. The highest degree/percentage of composition matching is achieved under condition A (11 matches, 92%) with Phantom Ⅰ and the lowest degree of composition matching is observed under conditions U, V, and X (6 matches, 86%) with Phantom Ⅲ. The urinary stone composition matching is lower for the slice thickness/increment setting of 1.5/1.0 mm as the thickness of the phantom increases.

DE scan condition	Phantom (cm)	Collimation (Ch)	Energy (kVp)	Slice thickness (mm)	Increment (mm)
A	30 × 30 × 10	64	80/sn140	0.5	0.5
B	30 × 30 × 10	128	80/sn140	0.5	0.5
C	30 × 30 × 10	64	100/sn140	0.5	0.5
D	30 × 30 × 10	128	100/sn140	0.5	0.5
E	30 × 30 × 10	64	80/sn140	1.5	1
F	30 × 30 × 10	128	80/sn140	1.5	1
G	30 × 30 × 10	64	100/sn140	1.5	1
H	30 × 30 × 10	128	100/sn140	1.5	1
I	30 × 30 × 16	64	80/sn140	0.5	0.5
J	30 × 30 × 16	128	80/sn140	0.5	0.5
K	30 × 30 × 16	64	100/sn140	0.5	0.5
L	30 × 30 × 16	128	100/sn140	0.5	0.5
M	30 × 30 × 16	64	80/sn140	1.5	1
N	30 × 30 × 16	128	80/sn140	1.5	1
O	30 × 30 × 16	64	100/sn140	1.5	1
P	30 × 30 × 16	128	100/sn140	1.5	1
Q	30 × 30 × 22	64	80/sn140	0.5	0.5
R	30 × 30 × 22	128	80/sn140	0.5	0.5
S	30 × 30 × 22	64	100/sn140	0.5	0.5
T	30 × 30 × 22	128	100/sn140	0.5	0.5
U	30 × 30 × 22	64	80/sn140	1.5	1
V	30 × 30 × 22	128	80/sn140	1.5	1
W	30 × 30 × 22	64	100/sn140	1.5	1
X	30 × 30 × 22	128	100/sn140	1.5	1

TABLE 1. Conditions pertaining to urinary stone analysis

Under the same conditions, the percentage of urinary stone component matching is the lowest for the thickest phantom (Phantom Ⅲ).

④ Results of comprehensive urinary analysis

Condition A corresponded to the highest capability in both detecting urinary stones and analyzing the urinary stone components among conditions A to Z, whereas condition S afforded the lowest stone diameter error. The settings common to condition A and S are the 64-slice, 0.6 mm collimation setting and the slice thickness/increment rate setting 0.5/0.5 mm. Considering the previous results, the most accurate urinary stone analysis is afforded for lower values of the slice thickness/increment. Thus, condition A, which afforded the highest detectability of urinary stones and composition matching, can be a good choice for dual energy scanning settings.

In previous studies, the DECT scanning of medium and large phantoms afforded 100% accuracy (40/40) regardless of the collimation setting, however, the accuracy was limited by the urinary stone size and other fixed DECT scan parameters. In this study, small urinary stones with sizes of <3.5 mm could be accurately analyzed with the application of optimal DECT scan parameters. However, detection was only possible when the stone diameter was ≥ 4.5/2.5mm (for uric acid stones) or ≥2.0/1.5mm for fusion (apatite & oxalate) stones under all dual energy conditions.

In general, DECT system vendors recommend that the slice thickness should be set between 1mm and 2 mm which is one of the constraints for urinary stone detection, and that the overlapping ratio should be ~30%; however, as per our aforementioned findings, the best result is obtained with the setting of slice thickness/increment rate of 0.5/0.5 mm and not the vendor recommended setting of 1.5/1.0 mm. Although vendors in general state that stones with diameters of <3.5 mm may be colored incorrectly or not detected at all under other non-standard settings, our study shows that out of 15 urinary stones (12 with a diameter of <3.5 mm and 3 with a diameter of >3.5 mm), ~80% of the urinary stones were accurately detected, with the stone diameter error being as small as 0.6 mm, and the composition matching ability being as high as 92%. Thus, there is results must clearly be considered when applying urinary stone DECT scan protocols in clinical settings.

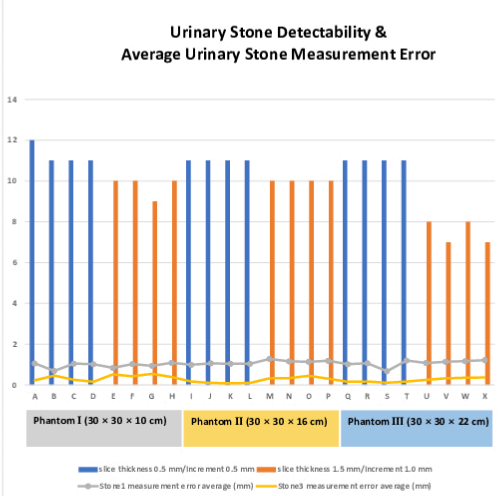

FIG. 2. Results of urinary stones detectability and average measurements error for various dual energy condition (A to X) and phantom thickness (Ⅰ to Ⅲ).

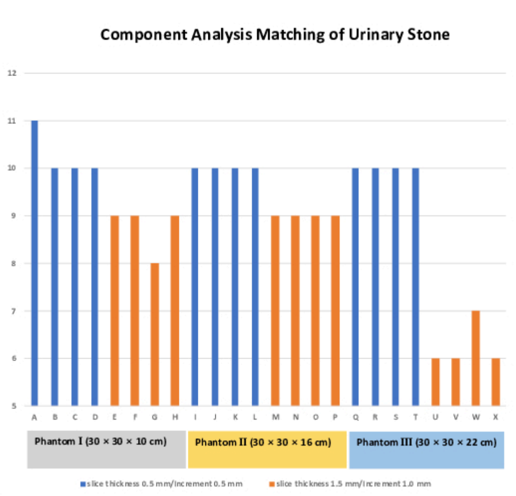

FIG. 3. Results of urinary stone composition matching for each dual energy condition (A to X) and phantom thickness (Ⅰ to Ⅲ)

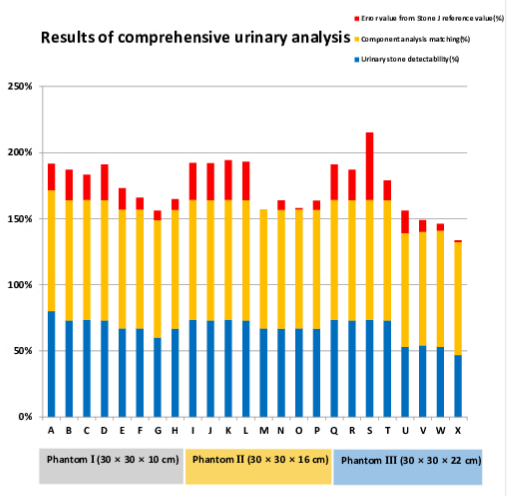

FIG. 4. Comprehensive results corresponding to urinary stone detectability, measurement error, and composition matching ability for various dual energy (A to X) and phantom thicknesses (Ⅰ to Ⅲ)

CONCLUSIONS

The appropriate selection of scan parameters in the DECT examinations of patients with urinary stones is of paramount importance because the analysis results vary as a function of DECT scan parameters. In particular, for a given set of scan parameter, obese patients, affords a poorer urinary stone analysis result. In our study, condition A(64-slice/0.6 mm collimation, phantom dimensions of 30 × 10 cm, peak kilovoltage setting of 80/sn140 kVp, slice thickness of 0.5 mm, and increment of 0.5 mm), afforded the best results in terms of urinary stone detection and composition matching; thus, this setting can be suitable for urinary for urinary stone analysis with the use of DECT.

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