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Evaluation of optimal parameters for using low-dose computed tomography to diagnose urolithiasis

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ABSTRACT

Urolithiasis is a common disease; patients suspected of suffering from urolithiasis will be examined by abdomen x-ray, Sono, Intraudio Videonous Urography (IVU) and Computed Tomography (CT). The detection rates for calculus in above examinations are respectively: 50–70% (*x*-ray), 50–60% (Sono), 70–90% (IVU) and 97% (CT). In addition, the effective doses are respectively: 0.63 mSv (*x*-ray), no radiation dose (Sono), 2.6 mSv (IVU) and 8–16 mSv (CT). Although CT has the highest detection rate for calculus, it also has the highest radiation dose. This research sought to lower the radiation dose by using CT scans with different dose conditions of standard dose (SD), 50% SD, 25% SD, and 15% SD to diagnose patients who suffer from urolithiasis and thus explore the feasibility of examining urolithiasis via CT with lower dose conditions. This research simulated the examination of patients with RANDO phantom, collocating PMMA slice phantom and pig's kidney. Fake calculuses made of five different materials of different sizes were put into the phantom and scanned individually. The results of the scanned images were given to two physicians who had many years of diagnostic experience to interpret the urolithiasis images. This study explored the different image qualities of CT with different dose conditions. In addition, this research used thermoluminescent dosimeters (TLD) to measure the radiation doses and compared the results with the dose values shown on the screen of the CT scanner to estimate the dose conversion factor (k). The research results showed that a low-dose CT was able to provide good image quality and thus have a lower radiation dose. Therefore, a low-dose CT is suggested the main examination method to diagnose patients with urolithiasis.

1. Introduction

Urolithiasis is a common disease. Its prevalence rate and recurrence rate are affected by genetic, dietary, and daily routine factors, with rates of up to 20–25% in the Middle East (Pak, 1998), and a high rate in Taiwan. The recurrence rate for urolithiasis is remarkably high; 50% within 5–10 years and 75% within 20 years (Trinchieri et al., 1999; Sutherland et al., 1985). Besides the high recurrence rate, the disease causes nausea, vomiting, sweating, and the condition is described as more painful than parturition. Doctors usually use an intravenous urogram (IVU) during diagnosis for the examination of urolithiasis, but this method is time-consuming and a torturous for patients. Smith et al. used computer tomography (CT) as the initial image mode to examine urolithiasis, acute abdominal pain and hematuresis (Smith et al., 1995). In addition to its fast process, CT also has 97% sensitivity (the rate of positive diagnostic results for those who have urolithiasis) and 96% specificity (the rate of negative diagnostic results for those without urolithiasis) for urolithiasis (Smith, et al., 1996), which is much higher than the 70–90% rates for IVU (Miller et al., 1998). The effective dose of an abdominal examination is approximately 8–16 mSv when CT is used to examine urolithiasis (Cohnen et al., 2003), and the average effective dose with IVU is approximately 2.6 mSv (Yakoumakis et al., 2001). Although CT has a faster process, higher sensitivity and higher specificity, the dose is also higher. Many epidemiologic studies show that CT examination can increase cancer risk. Approximately 1.5–2.0% of cancers can be attributed to radiation exposure during CT examination in the US (Brenner et al., 2001; Brenner and Hall, 2007; Smith-Bindman et al., 2009). Urolithiasis is a type of disease with a high recurrence rate, so the dose should be strictly controlled. Some recent related studies have explored using low dose computer tomography (LDCT) to diagnose this disease and different setting dose conditions can cause different

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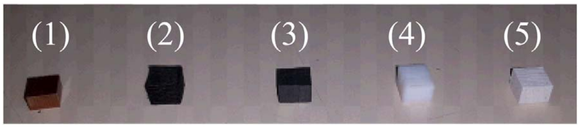

Fig. 1. Five simulated calculuses, the constituent materials of which are respectively: (1) phenolic, (2) nylon, (3) graphite, (4) PTFE, and (5) plaster.

radiation exposures (Drake et al., 2014; Sohn et al., 2013; Park et al., 2014; Kwon et al., 2015). This research discusses the relationship between different dosage conditions and image qualities with LDCT in dose conditions and proposes an optimized dose setting suggestion.

2. Research materials and methods

2.1. Image quality judgment using fake kidney calculuses

The research uses a 16-multi-slice helical CT scanner (HITACHI Supria) with 120 kV and 1.0625 pitch. Five groups of substitute materials were used to simulate kidney calculuses in this study: (1) phenolic, (2) nylon, (3) graphite, (4) PTFE, and (5) plaster. The respective average CT values of the above substitute materials (fake calculuses) are: 148 ± 34, 276 ± 11, 485 ± 15, 772 ± 72, and 853 ± 41, as shown in Fig. 1. Each fake calculus is cropped to be 3 mm, 4 mm, 5 mm, and 6 mm. While the photography scanning was processing, one layer of the RANDO phantom is replaced by poly(methyl methacrylate) (PMMA) layer, and there were several cylindrical holes in this PMMA layer, as shown in Fig. 2.

Water and pig kidney were put into the hole of the PMMA layer phantom to simulate the human kidney, and two designed settings were carried out. The first setting put fake kidney calculuses inside the pig's kidney in the hole of the PMMA phantom layer. The second setting put the fake kidney calculuses inside the water which in the hole of the PMMA phantom layer. The respective CT values of human kidney, pig kidney, PMMA, and water were 36 ± 8, 34 ± 8, 130 ± 25, and 2 ± 8. At each setting, the RANDO phantom with a layer replaced by the PMMA phantom layer (containing the fake calculus) was scanned using a CT in a laying down posture. The scan range is the same as in a general Abdomen CT, of which the superior border includes the diaphragm and the inferior margin includes half of the pubic symphysis. Four dose conditions were used to set the dose conditions, including irradiation conditions of 206.3 mAs (standard dose computer tomography, SDCT), 103.15 mAs (LDCT: 50% SDCT), 51.58 mAs (LDCT: 25% SDCT), and 30.95 mAs (LDCT: 15% SDCT). Image qualities were judged by means of the resolution (minimum size of the calculuses that could be seen) at different operating dose conditions. The image quality results were provided by two diagnostic radiologists who have over four years' experience of urolithiasis image interpretation. Image qualities were classified into one of three classes: “clear,” “obscure,” or “cannot be interpreted,” based on the results given by the diagnostic radiologists.

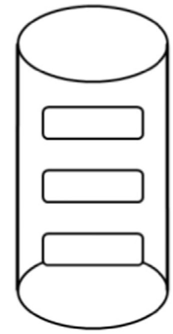

Fig. 3. PMMA cylindrical bar for placing TLD.

2.2. Dose assessment

After the image quality was verified, TLD chips were then into the RANDO phantom to measure the effective dose contribution of different examination conditions. In total, 179 TLD chips were selected through screening procedure, in which their homogeneity and reproducibility (Chang et al., 2011) were deemed satisfactory. These chips were used to measure and evaluate the organ doses and effective doses. Before being placed into the RANDO phantom, the TLD chips were first put into the cylindrical PMMA bar to fix their position, as illustrated in Fig. 3. Then, the cylindrical PMMA bar was placed in the specific place of RANDO phantom to carry out dose assessment. The positions and number of PMMA bars (with TLD inside) in the organs inside the RANDO Phantom are shown in Table 1. Each cylindrical PMMA bar was put with three TLDs to obtain the average value as the dose representative of this point. The organs listed in Table 1 are deemed radiosensitive, as recommended by the International Commission on Radiological Protection, ICRP

Table 1
Positions and number of PMMA bars (with TLD inside) in the organs inside the RANDO Phantom.

Organ or Tissue	Layers of RANDO Phantom (distribution number of PMMA bar)
Brain	2(2) , 4(2)
Saliva	7(2)
Gonad	31(2) , 34(2)
Thyroid	9(2)
Esophagus	13(1) , 15(1) , 17(1) , 19(1)
Mammary gland	17(4)
Lungs	13(2) , 15(2) , 17(2) , 19(2)
Liver	22(2)
Stomach	21(1) , 22(1)
Colon	25(2) , 31(2)
Bladder	32(32
Skin	19(2)
Bone surface	16(1)
Red bone marrow	15(1) , 30(1)
Other tissues or organs	6(1) , 10(1) , 12(2) , 18(2) , 22(2) , 28(2) , 34(2)

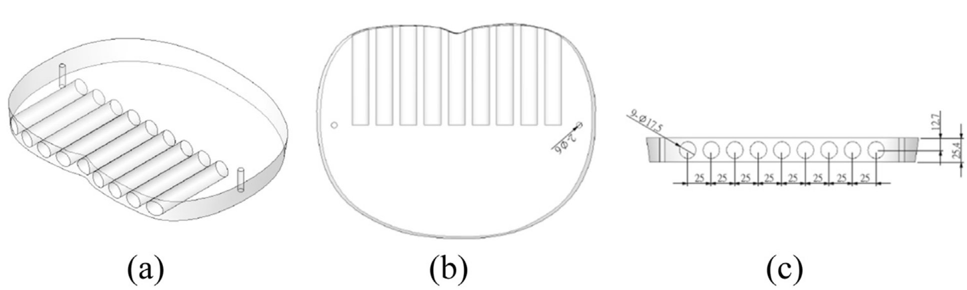

Fig. 2. The PMMA layer that was used to replace a layer of a RANDO phantom, (a) stereogram (b) top view (c) side view.