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반복적 재구성 기법과 저용량 조영제를 이용한 토끼 신장 CT: 기존 영상과의 비교연구

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Abstract

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Purpose: This study aimed to investigate the image quality of rabbit kidney computed tomography (CT) obtained by using a small volume of contrast material and iterative reconstruction.

Materials and Methods: Twenty sedated rabbits were used in this study. In the study group, 4 mL of contrast material and iterative reconstruction were used. In the control group, 6 mL of contrast material and filtered back projection were used. First, 350 mgI/mL contrast material was administered. After 1 week, the procedure was repeated with 240 mgI/mL contrast material. Two radiologists evaluated image quality in consensus. For qualitative image assessment, sharpness, noise, texture, streak artifacts, and overall quality were rated and compared. For quantitative analysis, the CT attenuation values, image noise, signal-to-noise ratios (SNR), contrast-to-noise ratios (CNR), and figures of merit (FOM) were calculated and compared.

Results: The study group images were sharper and had less noise, fewer streak artifacts, and better overall quality (all, $p<0.05$). However, the image texture was worse ($p<0.05$). Although the CT attenuation values were lower or comparable in the study group, the image noise was 42% lower with 350 mgI/mL contrast material and 36% lower with 240 mgI/mL contrast material (both, $p<0.05$). The SNR, CNR and FOM were higher in the study group at each dynamic phase, regardless of contrast material concentration (all, $p<0.05$).

Conclusion: Iterative reconstruction and a small volume of contrast material can yield kidney CT images with quality comparable to those obtained with filtered back projection and a conventional volume of contrast material.

Keywords: computed tomography, contrast material, image quality, contrast-induced nephropathy

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CONTENTS

INTRODUCTION

The widespread use of computed tomography (CT) raises concerns about the hazards of contrast material exposure. Contrast-induced nephropathy (CIN) is common; it occurs in 2-12% of patients after they undergo contrast-enhanced CT (1). CIN accounts for approximately 10% of the cases of hospital-acquired renal failure and is associated with increases in morbidity, mortality, medical expenses, and length of hospital stay (2). Many reports have suggested that total iodine load correlates well with the risk of CIN development (3, 4). Furthermore, a recent guideline from European Society of Urogenital Radiology recommends that the volume of contrast material should be reduced to prevent CIN (5). Because kidney CT is indicated for patients with suspected renal pathology, which is a main risk factor for CIN development, the kidney CT protocol should specify the smallest amount of diagnostically appropriate iodine-based contrast material.

Although it is simple to use a small volume or low-concentration contrast material in practice, the resulting decrease in CT attenuation may lower image quality and affect diagnostic accuracy. One possible solution may be iterative reconstruction (IR), which reduces image noise without compromising spatial resolution and, hence, has started to replace filtered back projection (FBP), the conventional reconstruction method. Iterative Model Reconstruction (IMR; Philips Healthcare, Cleveland, USA) is a recent knowledge-based IR system that, by using accurate system models, results in 70-83% less image noise than does FBP (6, 7). If we use both IR and a small volume of contrast material in the kidney CT protocol, we may acquire acceptable-quality CT images and reduce the patient's total iodine load, which may be beneficial for those at risk of CIN development. However, to control other anthropological factors that may affect image quality and to avoid the harm of radiation exposure, a preliminary study that uses an animal model is appropriate.

Therefore, the aim of our study was to investigate the use of IR and a small volume of contrast material for kidney CT in a rabbit model. We compared the subjective and objective qualities of images obtained with two CT protocols: (1) small contrast volume with IR and (2) conventional contrast volume with FBP reconstruction. We compared these protocols by using two different concentrations of contrast material to assess the possibility of further reduction of the total iodine load.

MATERIALS AND METHODS

Materials

This study was approved by the animal care and use committee at our institution, and we complied with the National Institutes of Health guidelines for use of laboratory animals.

Twenty adult male New Zealand white rabbits that weighed 2.8–3.3 kg were included in this study. In the study group, 4 mL of contrast material was used and images were reconstructed with IMR. In the control group, 6 mL of contrast material was used and images were reconstructed by using FBP. Each of 20 rabbits was randomly assigned to one of these groups and underwent kidney CT with 350 mgI/mL of contrast material. One week later, all of the 20 rabbits were randomly assigned to one of the groups and underwent kidney CT, but 240 mgI/mL contrast material was used instead.

Image acquisition

Before undergoing CT, the rabbits were anesthetized with an intramuscular injection of 5 mg/kg-body weight tiletamine/zolazepam (Zoletil 50; Virbac, Carros, France) and 2 mg/kg-body weight of 2% xylazine hydrochloride (Rompun; Bayer, Seoul, Korea). A 22-gauge intravenous catheter was inserted into the marginal ear vein for the administration of contrast material.

All scans were performed with the same 64 channel CT scanner

(IQon CT; Philips Medical Systems, Bothell, USA). The kidney CT protocol consisted of a precontrast phase and four dynamic post contrast phases, as did our previous rabbit kidney CT protocol (8). The scan range was 12 cm and started from the level of the 10th thoracic vertebra body superior endplate. We used the bolus tracking technique, and the first contrast-enhanced scan was acquired 5 s after the attenuation value reached 100 Hounsfield units (HUs) in the abdominal aorta for the uppermost slice. Images were subsequently scanned at 15 s and 35 s for the corticomedullary phase, and at 65 s for the nephrographic phase.

For the study group, 4 mL of contrast material and 2 mL of normal saline flush were injected, whereas for the control group, 6 mL of contrast material was injected. Thus, in both groups a total 6 mL of different preparation of contrast material was administered. A power injector (Envision CT injector; Medrad, Indianola, USA) was used to administer aforementioned contrast material preparation to each rabbit at the same rate of 0.3 mL/s. In the first experiment, 350 mgI/mL contrast material (Iversense 350; Taejoon Pharm, Seoul, Korea) was used. In the second experiment, the procedure for the first experiment was repeated with 240 mgI/mL contrast material (Iversense 240; Taejoon Pharm, Seoul, Korea). Hence, there were four combinations of contrast material concentration and volume; one set of CT images was acquired for each combination.

The specific CT scan parameters were as follows: detector collimation, 0.625 x 64 mm; scan field of view, 137 x 137 mm; rotation time, 0.33 s; beam pitch, 0.7; slice thickness, 3 mm with 3 mm intervals; and reconstruction intervals of 1 mm. We used a fixed 80 kVp for the CT scan because the size and body weight of the rabbits was comparable to that of a neonate (9). Both angular and z-axis automatic tube current modulation were applied by using automatic exposure control (DoseRight; Philips Healthcare, Cleveland, USA) with a reference Dose Right Index level of 8.

The axial and coronal images were reconstructed for each dynamic phase by using FBP for the control group and IMR level 1 with medium sharpness for the study group. The reconstruction setting of the study group was determined after a pilot study in which nine possible options were evaluated from three different degrees of edge sharpness and noise reduction.

Qualitative image analysis

Image quality was quantitatively and qualitatively analyzed by two radiologists (SYK and JYC, 11 and 21 years of experience in genitourinary imaging, respectively) who were blinded to the CT protocol information. After the randomization of the four CT datasets, the reviewers graded qualitative parameters on a 4-point scale in consensus. Qualitative image parameters such as sharpness, noise, texture, presence of streak artifacts, and overall quality were evaluated (10).

The image sharpness of the urinary tract contours was determined (1, blurry; 2, poorer than average; 3, better than average; 4, sharpest). Similarly, image noise and streak artifacts were categorized (1, image noise/streak artifacts present and unacceptable; 2, image noise/streak artifacts present and interfering with visualization of adjacent structures; 3, image noise/streak artifacts present but not interfering with visualization of adjacent structures; 4, minimal or no noise/artifacts). Previous studies have suggested that knowledge-based IR could cause a pixelated image texture; if a radiologist is unaware of this possibility, the assessment of image quality may be affected. Hence, the image texture was graded as suggested by previous literature (1, blocky appearance or change affecting diagnostic confidence; 2, perceptible change; 3, no noticeable change after changing the window setting; 4, no noticeable change) (11-14). Finally, the overall image quality was determined on a 4-point scale (1, nondiagnostic; 2, suboptimal; 3, standard; 4, excellent).

Quantitative image analysis

The reviewers manually drew circular regions of interests (ROIs) at each anatomical structure to determine the CT attenuation values in consensus. When drawing ROIs, vessels, fat infiltration, prominent artifacts, and areas of focal changes in parenchymal attenuation were carefully avoided, and homogeneous areas were selected. To minimize possible inaccuracies from single measurement, all measurements were conducted twice and the average value was used for statistical analysis. The reviewers determined the CT attenuation value of the abdominal aorta at the level of the right kidney hilum at 5 s and the values of the renal cortex, outer medulla, and inner medulla from each side of the kidney during the subsequent dynamic phases. The CT attenuation value of the renal pelvis was determined at 65 s.

For quantitative analysis, the parameters of CT attenuation, image noise, signal-to-noise ratio (SNR), contrast-to-noise ratio (CNR), and figure of merit (FOM) were compared between the study and control groups. For each dynamic phase, the standard deviation of the CT attenuation value of the paraspinal muscles was defined as image noise. The SNR was calculated by dividing the CT attenuation value of the corresponding anatomical structure by the image noise. The CNR was determined by subtracting the CT attenuation value of the paraspinal muscles from that of corresponding anatomical structure and dividing this difference by the image noise.

To compensate for the differences in tube currents and radiation doses among the CT scans, we evaluated the FOM as the ratio of CNR^2 to the effective radiation dose. Since CNR^2 was proportional to the radiation dose, the FOM values enabled the comparison of CNRs independent of the tube current and radiation dose (15, 16). To convert the dose-length product into an effective radiation dose, we used a conversion factor of 0.0485, which is the mean value of neonate male and female considering comparable body volume and weight to those of rabbit in our study (17).

Statistical analysis

The independent t-test and Mann-Whitney U test were applied to compare the qualitative and quantitative image qualities between two groups, as appropriate. A p-value less than 0.05 indicated statistical significance. All statistical analysis was performed by using a software package (IBM SPSS Statistics for Windows, Version 21.0. Armonk, USA).

RESULTS

Results of the Qualitative analysis

The results of the qualitative image quality comparisons are summarized in Table 1. Although there were exceptions, the results of qualitative image comparisons between the study and control groups tended to be consistent regardless of the contrast material concentration. For all dynamic phases, the study group images were sharper and had less noise than the control group images (all, $p<0.05$). However, the image texture was worse in all of the study group images (all except one, $p<0.05$), except for the image obtained at 5 s with 240 mgI/mL contrast material ($p=0.063$). Streak artifacts were absent in all images obtained at 5 s and 15 s. The qualitative scores for streak artifacts were not different between two groups for the 35 s phases (both, $p>0.05$). However, the study group scores for streak artifacts were lower for 65 s phases in both concentration of contrast material (both, $p<0.05$). With one exception, the overall image quality was better in the study group (all except one, $p<0.05$), irrespective of contrast material concentration; a statistically significant difference was not found between the images obtained at 35 s phase with 240 mgI/mL contrast material ($p=0.280$).

With one exception, significant differences were not seen between the qualitative image scores of the study group given the 350 mgI/mL contrast material and those of the one given the 240 mgI/mL contrast material (all except one, $p>0.05$). However, the image texture was worse in the images obtained at 5 s in the 350 mgI/mL group (p=0.023). Representative CT images of each group obtained at 35 s and 65 s are presented in Figure 1 and Figure 2, respectively.

Results of the Quantitative analysis

CT attenuation values — The CT attenuation values of each anatomical structure according to corresponding dynamic phase and contrast material concentration are shown in Table 2. Most of the CT attenuation values at the aorta at 5 s and at the renal cortex at 15 s and 35 s were not different between the study and control groups given the same contrast material (all except one, $p>0.05$). However, less enhancement was seen in images obtained at 35 s from the study group given 350 mgI/mL contrast material ($p<0.000$). Among the images obtained at 15 s with 350 mgI/mL contrast material solution, the attenuation value at the outer medulla was higher in the study group than in the control group ($p<0.000$). However, the CT attenuation values of the outer medulla at 15 s and at 35 s as well as the value of the inner medulla at 15 s were lower in the study group (all, $p<0.05$). The CT attenuation values of the inner medulla at 35 s and the renal pelvis at 65 s were not different between the study and control groups of the same contrast material (all, $p>0.05$). Between the two study groups, better degrees of enhancement were seen for the anatomical structures of the rabbits given the 350 mgI/mL solution than for those of rabbits given the 240 mgI/mL solution (all except one, $p<0.05$); the exception was for the inner medulla image obtained at 15 s (p=0.215).

Image noise and radiation dose — The mean value of image noise was lower in the study group than in the control group in both contrast material concentration. With the 350 mgI/mL contrast material, the mean value for the image noise of the study group was 3.96, which was 42% lower than that of the control group ($p<0.000$). With the 240 mgI/mL contrast material, the image noise of study group was 3.18, which was 36% lower than the control group value of 8.84 ($p<0.000$). Between the study groups, the image noise of the group given the 240 mgI/mL solution was lower than that given the 350 mgI/mL solution ($p<0.000$). Regardless of contrast material volume and concentration, the mean effective radiation dose was not different between compared groups (all, $p>0.05$). The specific data are shown in Table 3.

Comparison of SNR, CNR, and FOM — For all dynamic phases, the SNR, CNR, and FOM of each anatomical structure were higher in the study group than in the control group, regardless of contrast material concentration (all, $p<0.05$). At each dynamic phase, Figure 3 contains box-and-whisker plots that show comparisons of SNR, CNR, and FOM between groups for each contrast material volume and concentration.

DISCUSSION

In our study, most of the qualitative parameter were better among images obtained with a small volume of contrast material than among those obtained with the conventional volume. The only exception was image texture, which was worse in both study groups than in the corresponding control groups. For each concentration of contrast material, the overall CT attenuation values at the subrenal structures in the study group were lower than or similar to those in the corresponding control group. However, less image noise was seen in the study group than the control group of the same contrast material (350 mgI/mL, 42% less; 240 mgI/mL, 36% less). Accordingly, at all dynamic phases, SNR, CNR, and FOM values were higher in the images of rabbits given a small volume of contrast material than in the images of those given the conventional volume; this finding was consistent regardless of the contrast material concentration and suggests that the smaller volume of contrast material provides better quantitative image quality than does the conventional volume.

We focused on whether a small volume of contrast material would yield comparable image quality than the conventional volume if the images were reconstructed with an IR algorithm. The main difference between the study and control groups was the volume of the administered contrast material; two-thirds of the conventional volume was administered to the study group. Accordingly, the total iodine load were decreased, which resulted in lower CT attenuation values (18). However, because the reduction in image noise from IR was greater than the decrease in CT attenuation, the quantitative image parameters (SNR, CNR, and FOM) were considerably higher in the study group. Furthermore, except for image texture, the qualitative image quality was better in the study group than in the control group. Our findings suggest that the noise reduction resulting from a knowledge-based IR algorithm could compensate for lower CT attenuation values and allow for comparable overall image quality with a smaller volume of contrast material.

The kidney serves unique excretion function including the excretion of contrast material, which may affect the enhancement and artifact pattern in the kidney CT. Concentrated urine in the pelvocalyceal system during the nephrographic phase is a major source of streak artifacts, which may limit the evaluation of the kidney parenchyma and focal lesions (19). Under low tube voltage, streak artifacts are more prominent because the penetration by X-ray photons is reduced (20). In our study, the study group images from nephrographic phase images (obtained at 65 s) showed a negligible streak artifacts irrespective of contrast material concentration; this finding suggests that IR may suppress streak artifacts despite the 80 kVp setting (Figure 2.). This result appeared to contradict a previous study which reported that the use of low-osmolar contrast material resulted in more streak artifacts (21). This discrepancy may have resulted from the application of IR in our study group, because FBP reconstruction was used in the previous literature. As streak artifacts result from corrupt sinogram patterns due to lack of projection data, IR has been shown to effectively suppress these streak artifacts (14, 22-23).

One disadvantage of IR is that it yields an unnaturally blocky image appearance; this finding has been reported several times (11-14). Images were especially pixelated at 35 s of the corticomedullary phase in our study when the primary purpose is to differentiate adjacent subrenal structures. Although a blocky image appearance itself does not indicate poor image sharpness, unfamiliarity with this image texture may influence the judgment of radiologists. Thus, future research is needed to assess how unnatural pixelated image texture affects diagnostic accuracy. Another disadvantage is the considerable computation time, which depends on the number of dynamic phases and scan volume (24). In our study, reconstruction of a single kidney CT required approximately 5-10 minutes. Improvements in computing resources may allow IR to be incorporated into daily practice.

The overall degree of enhancement in the study group given 240 mgI/mL contrast material was less than or similar to that seen in the study group given the 350 mgI/mL contrast material. However, the image noise was 20% less in the 240 mgI/mL group. As a result, no statistical differences were found between two study groups from different contrast concentration for the SNR, CNR, and FOM values of the aorta images obtained at 5 s or of the renal cortex and inner medulla images obtained during the corticomedullary phases. Thus, a greater reduction of the total iodine load may be possible without severe deterioration of image quality, which could be beneficial for patients at risk for CIN.

In our study, we used a fixed peak voltage of 80 kVp because volume of the rabbit's body is small. This low peak voltage setting might influence our result in two ways. First, image noise increases in a low tube voltage setting (25). This may have accentuated the differences in image noise between the study and control groups in our study. Second, the iodine attenuation value increases under low peak voltage since the mean photon energy is closer to that of the K absorption edge of iodine (33.2 keV) (26). This may have caused the poor degree of enhancement in the study group images. In general, our findings are consistent with previous studies that have reported that the application of IR with a low peak voltage can produce acceptable image quality with the advantages of a smaller volume of contrast material and a lower radiation dose in abdominal CT imaging (27, 28). However, since the minimum peak voltage setting provided by the CT scanner was 80 kV, we cannot further reduce the peak voltage in our study. Our use of 80 kVp for all groups resulted in similar radiation doses. In future studies, the use of a lower peak voltage setting in our study design may produce results comparable to those in previous studies.

This study has several limitations. First, we examined normal kidneys and evaluated the quality of CT images. Since the CT attenuation value and the degree and timing of enhancement are different from those of conventional kidney CT, further research with a disease phantom model would be desirable to evaluate the diagnostic accuracy of this CT protocol (29, 30). Similarly, we performed the kidney CT protocols in an animal model to exclude other possible patient-related factors that might affect image quality. A pilot study with a healthy human population should be performed before our results are clinically applied to patients. Third, we evaluated the effects of contrast material volume and concentration in isolation; however, other contrast material-related factors, such as injection rate or split bolus method, could also be further optimized to acquire better image quality but are beyond the scope of our study.

In conclusion, the use of IR and a small volume of contrast material yielded CT images with objective and subjective qualities comparable to those obtained with FBP and the conventional contrast volume in a rabbit model. With the use of a low concentrated contrast material, a greater reduction in the total iodine load may be possible without severe deterioration of image quality, a result that could be beneficial for patients at risk for CIN development.

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TABLES AND FIGURES

Table 1. Comparison of qualitative image quality for each contrast material concentration.

Qualitative score	350 mgI/mL		240 mgI/mL		P value 1*	P value 2†	P value 3‡
	Study	Control	Study	Control			
5 s							
Image sharpness	2.8 ± 0.4	1.7 ± 0.5	2.4 ± 0.8	1.2 ± 0.4	0.000	0.000	0.143
Image noise	2.9 ± 0.3	1.7 ± 0.5	2.3 ± 0.8	1.5 ± 0.5	0.000	0.000	1.000
Image texture	2.5 ± 0.5	3.8 ± 0.4	3.3 ± 0.7	3.7 ± 0.5	0.000	0.063	0.023
Streak artifacts	4.0 ± 0.0	4.0 ± 0.0	4.0 ± 0.0	4.0 ± 0.0	1.000	1.000	1.000
Image quality	2.8 ± 0.4	1.8 ± 0.4	2.4 ± 0.5	1.7 ± 0.5	0.001	0.029	0.143
15 s							
Image sharpness	2.9 ± 0.3	1.9 ± 0.3	2.8 ± 0.4	1.7 ± 0.5	0.000	0.000	0.739
Image noise	2.9 ± 0.3	2.0 ± 0.0	3.0 ± 0.0	1.9 ± 0.3	0.000	0.000	0.739
Image texture	2.7 ± 0.5	3.8 ± 0.4	3.3 ± 0.5	3.9 ± 0.3	0.000	0.023	0.052
Streak artifacts	4.0 ± 0.0	4.0 ± 0.0	4.0 ± 0.0	4.0 ± 0.0	1.000	1.000	1.000
Image quality	3.0 ± 0.7	2.0 ± 0.0	3.1 ± 0.3	2.1 ± 0.3	0.002	0.000	0.796

35 s							
Image sharpness	2.7 ± 0.7	2.0 ± 0.0	2.7 ± 0.5	1.8 ± 0.4	0.007	0.003	0.796
Image noise	3.0 ± 0.0	2.1 ± 0.3	3.0 ± 0.0	2.0 ± 0.0	0.000	0.000	1.000
Image texture	2.0 ± 0.0	3.9 ± 0.3	2.1 ± 0.6	4.0 ± 0.0	0.000	0.000	0.739
Streak artifacts	3.7 ± 0.5	3.3 ± 0.5	4.0 ± 0.0	3.5 ± 0.5	0.143	0.063	0.280
Image quality	2.8 ± 0.4	2.0 ± 0.5	2.4 ± 0.5	2.1 ± 0.3	0.005	0.280	0.143
65 s							
Image sharpness	2.9 ± 0.3	2.0 ± 0.0	2.9 ± 0.3	1.8 ± 0.4	0.000	0.000	1.000
Image noise	3.0 ± 0.0	2.1 ± 0.3	2.9 ± 0.3	2.0 ± 0.0	0.000	0.000	0.739
Image texture	2.6 ± 0.5	3.9 ± 0.3	3.2 ± 0.6	4.0 ± 0.0	0.000	0.007	0.075
Streak artifacts	3.8 ± 0.4	2.9 ± 0.3	3.9 ± 0.3	3.1 ± 0.6	0.001	0.005	0.739
Image quality	3.3 ± 0.7	2.1 ± 0.3	3.0 ± 0.0	2.0 ± 0.0	0.001	0.000	0.280

Unless otherwise specified, data are presented as mean ± standard deviation. P value 1= Comparison between the study and control groups given 350 mgI/mL contrast material. P value 2† = Comparison between the study and control groups given 240 mgI/mL contrast material. P value 3‡ = Comparison between the study group given 350 mgI/mL contrast material and the study group given 240 mgI/mL contrast material.

Table 2. Comparison of the CT attenuation values at the aorta and subrenal structures

	350 mgI/mL		240 mgI/mL		P value 1*	P value 2†	P value 3‡
	Study (HU)	**Control (HU)**	**Study (HU)**	**Control (HU)**			
Aorta							
5 s	736 ± 115	678 ± 157	485 ± 64	460 ± 96	0.315	0.257	0.000
Renal cortex							
15 s	531 ± 110	557 ± 73	373 ± 68	389 ± 75	0.390	0.479	0.000
35 s	255 ± 28	313 ± 54	215 ± 39	222 ± 32	0.000	0.508	0.001
Outer medulla							
15 s	227 ± 33	176 ± 32	155 ± 25	220 ± 34	0.000	0.000	0.000
35 s	508 ± 46	557 ± 71	406 ± 58	465 ± 70	0.019	0.000	0.000
Inner medulla							
15 s	80 ± 9	92 ± 21	76 ± 8	82 ± 4	0.027	0.006	0.215
35 s	819 ± 110	773 ± 194	699 ± 128	695 ± 135	0.356	0.921	0.003
Renal pelvis							
65 s	1111 ± 501	1142 ± 453	699 ± 128	645 ± 284	0.842	0.819	0.002

Unless otherwise specified, data are presented as mean ± standard deviation. HU = Hounsfield units. P value 1= Comparison between the study and control groups given 350 mgI/mL contrast material. P value 2† = Comparison between the study and control groups given 240 mgI/mL contrast material. P value 3‡ = Comparison between the study group given 350 mgI/mL contrast material and the study group given 240 mgI/mL contrast material.

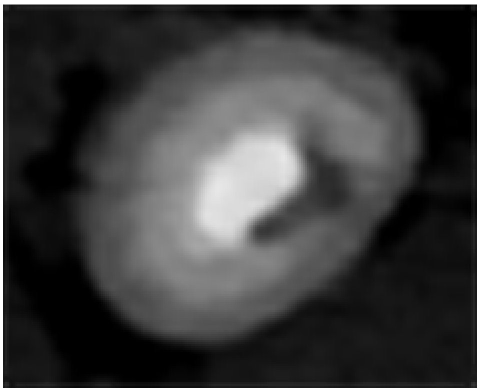
Table 3. Comparison of image noise and radiation dose

	350 mgI/mL		240 mgI/mL		P value 1*	P value 2†	P value 3‡
	Study	Control	Study	Control			
Image noise	3.96 ± 0.9	9.35 ± 1.1	3.18 ± 0.6	8.84 ± 0.9	0.000	0.000	0.000
Effective dose (mSv)	2.83 ± 0.1	2.78 ± 0.2	2.71 ± 0.2	2.69 ± 0.1	0.105	0.684	0.075

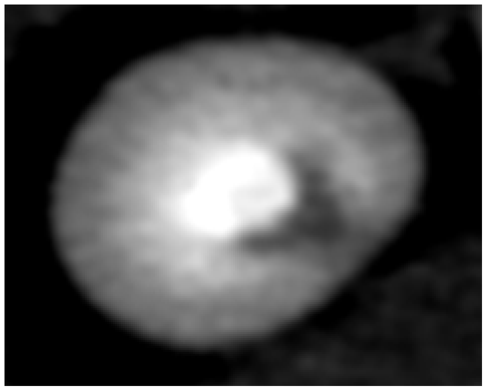
Unless otherwise specified, data are presented as mean ± standard deviation. P value 1= Comparison between the study and control groups given 350 mgI/mL contrast material. P value 2† = Comparison between the study and control groups given 240 mgI/mL contrast material. P value 3‡ = Comparison between the study group given 350 mgI/mL contrast material and the study group given 240 mgI/mL contrast material.

Figure 1. Representative axial images of right kidney obtained at 35 s for each group. The images are displayed at the same window width of 900 HU and level of 450 HU settings. Between the groups given the 350 mgI/mL contrast material, the overall quality of the image of the study group (A) was better than that of the control group (B), although the image texture was worse in the study group (blocky appearance). Similarly, between the groups given 240 mgI/mL contrast material, the qualitative image quality of the study group (C) was better than that of the control group (D), despite worse image texture of the study group.

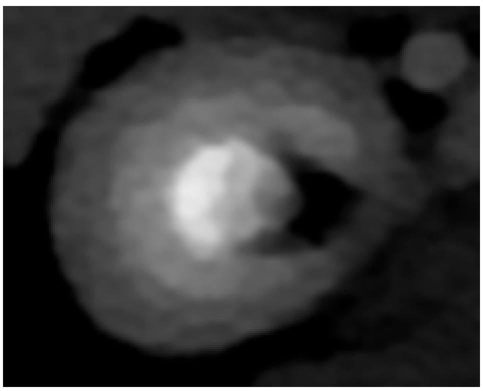
(A)



(B)



(C)



(D)

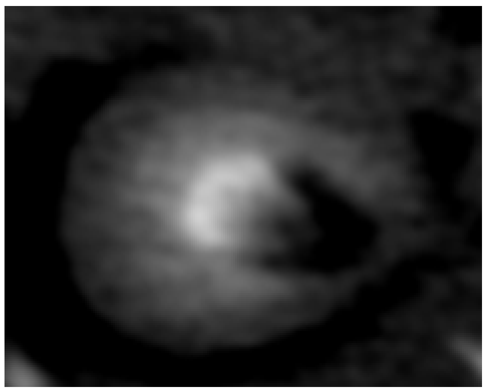


Figure 2. Representative axial images of left kidney obtained at 65 s for each group. The images are displayed with the same window width of 500 HU and level of 350 HU settings. The axial CT images of the control groups given 350 mgI/mL contrast material (B) and 240 mgI/mL contrast material (D) show noticeable streak artifacts that extend to the periphery of the kidney parenchyma. However, the axial images of the study groups given 350 mgI/mL contrast material (A) and 240 mgI/mL contrast material (C) depict well-defined boundaries of subrenal structures and negligible streak artifacts.

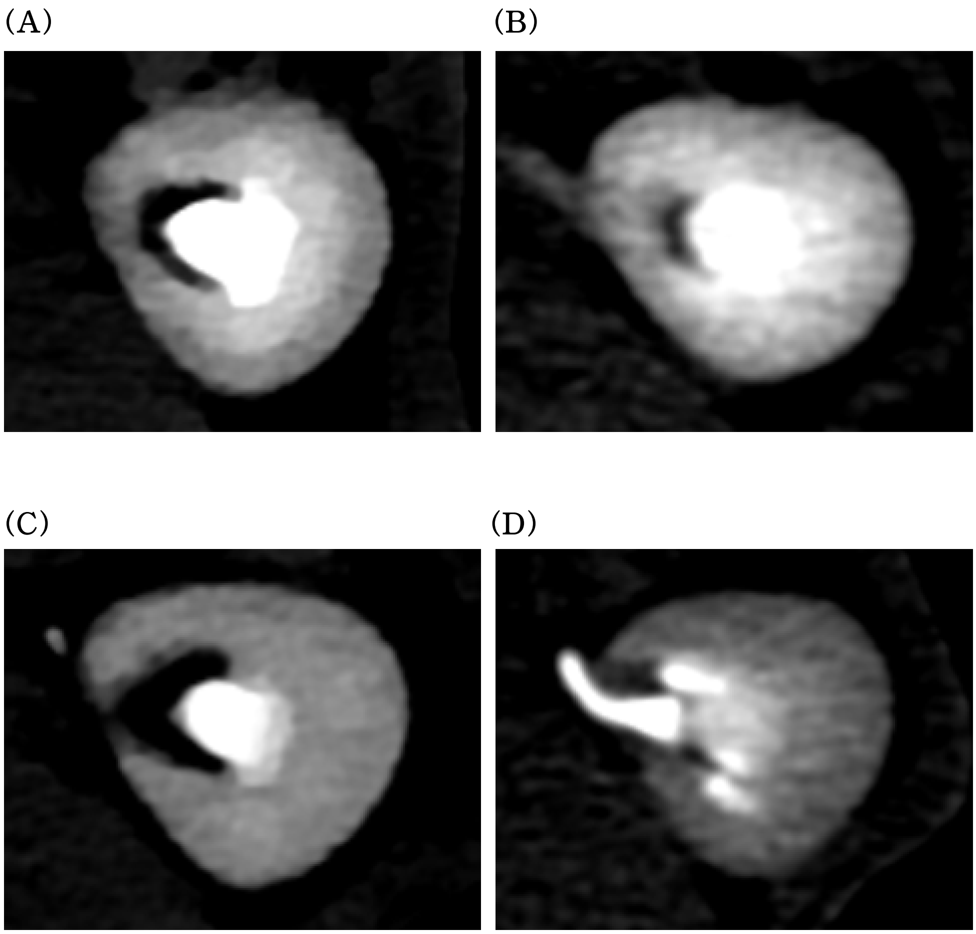
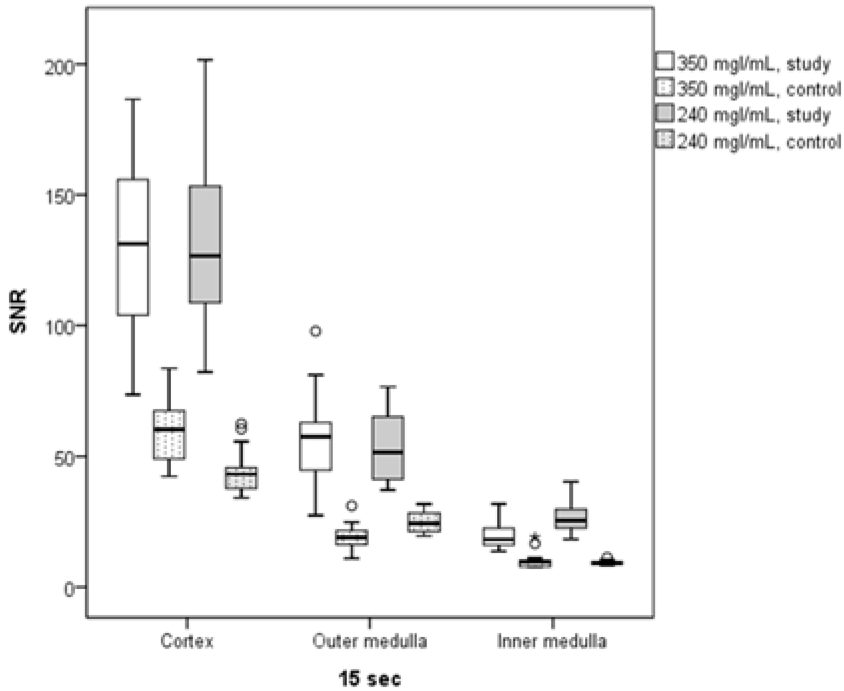
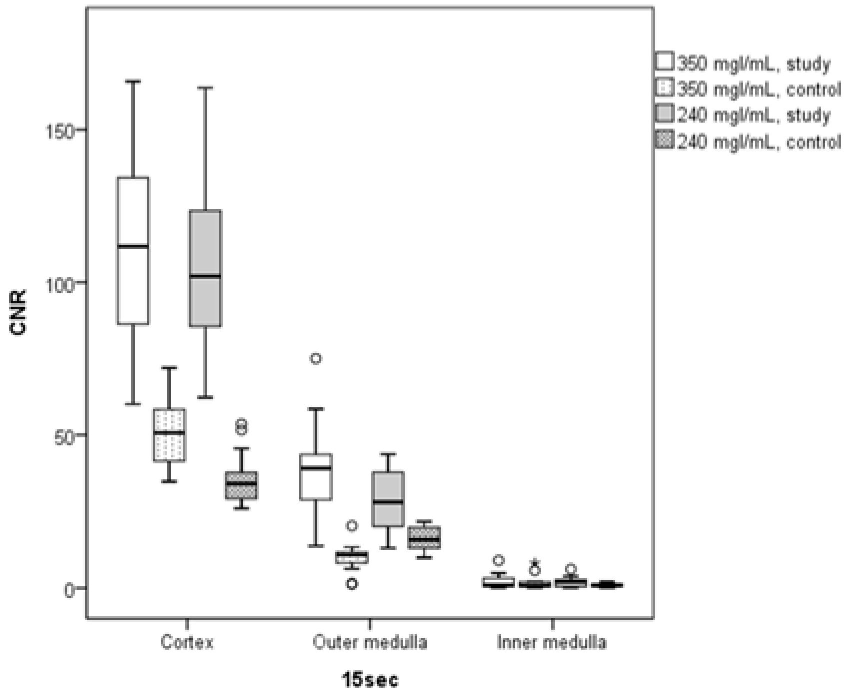


Figure 3. Box-and-whisker plots show comparisons of the SNR, CNR, and FOM values for each subrenal structure according to each dynamic phase and contrast material concentration. Ends of boxes are 25th and 75th quartiles and lines across middles of boxes are medians. Maximum and minimum values are displayed with whiskers connecting points to center box. During the corticomedullary phases of 15 s and 35 s, the median values of SNR (A, D), CNR (B, E), and FOM (C, F) at each subrenal structure were higher in the study group than in the control group, regardless of contrast material concentration. During subsequent nephrographic phase of 65 s, the quantitative image parameters of SNR (G), CNR (H), and FOM (I) were better in the study group than in the control group in both contrast material concentration.

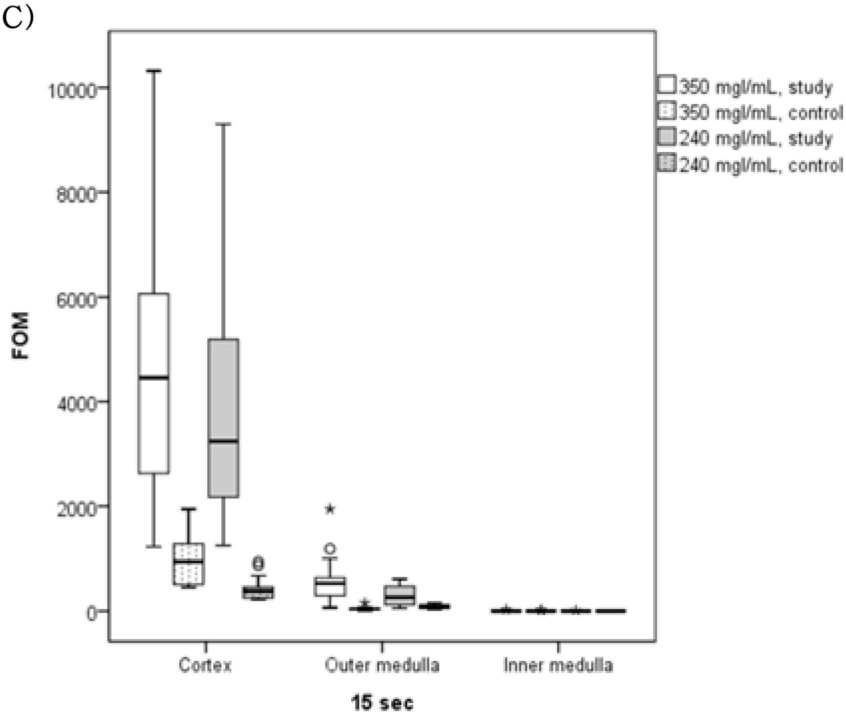
(A)



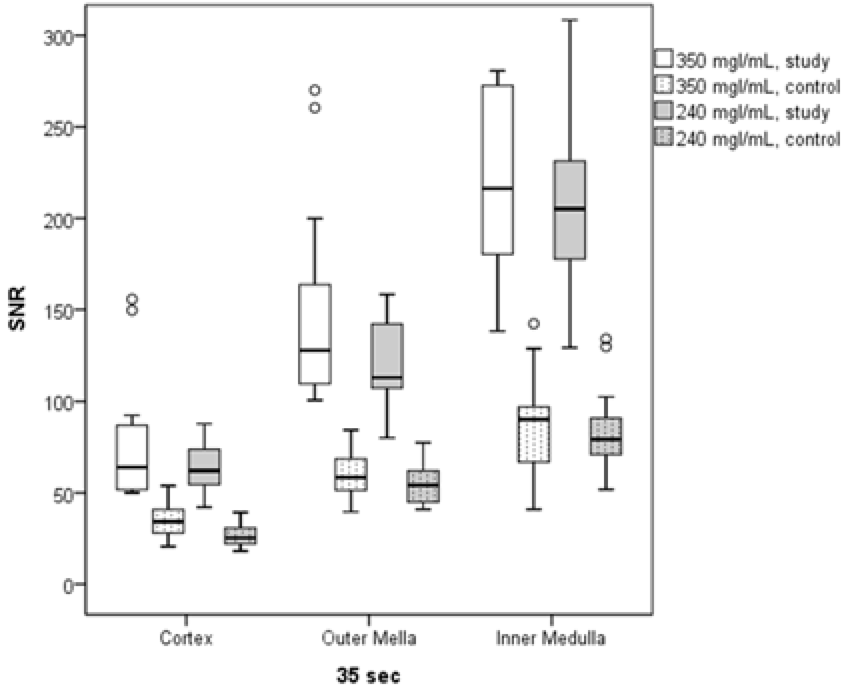
(B)


350 mgI/mL, study
350 mgI/mL, control
240 mgI/mL, study
240 mgI/mL, control
150
100
50
0
CNR
Cortex
Outer medulla
Inner medulla
15sec

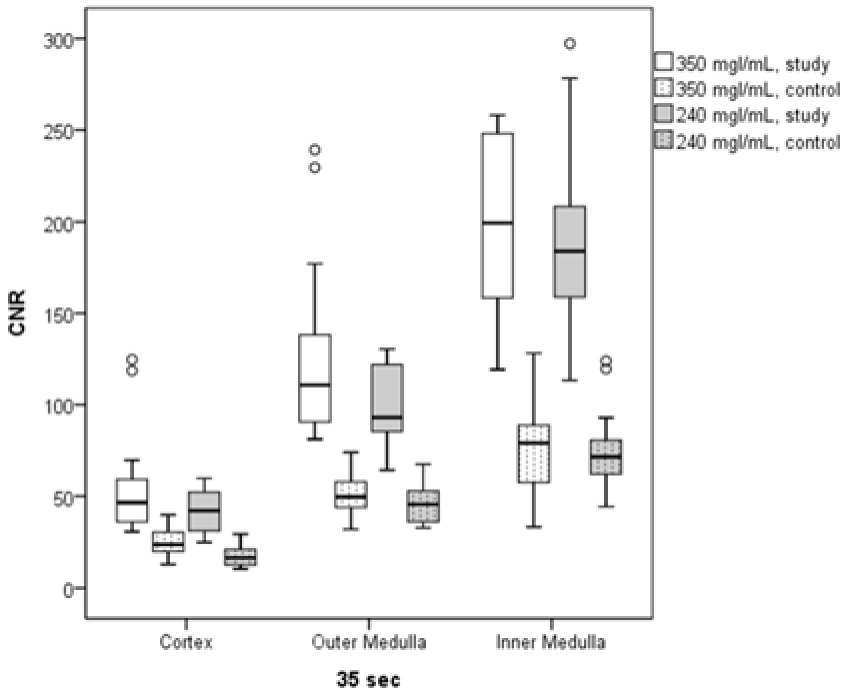
(C)


350 mgI/mL, study
350 mgI/mL, control
240 mgI/mL, study
240 mgI/mL, control
10000
8000
6000
4000
2000
0
FOM
Cortex
Outer medulla
Inner medulla
15 sec

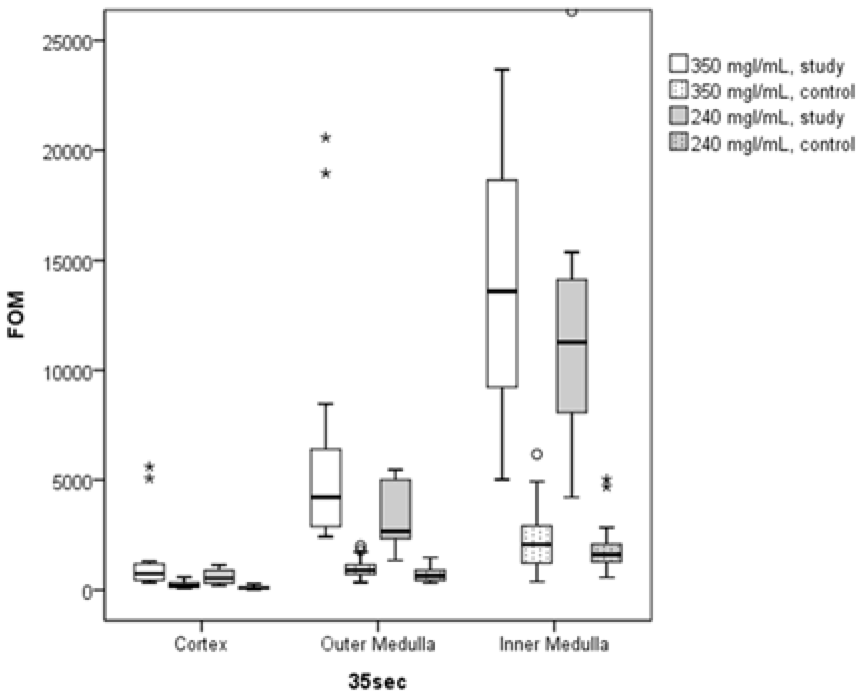
(D)


350 mgI/mL, study
350 mgI/mL, control
240 mgI/mL, study
240 mgI/mL, control
SNR
300
250
200
150
100
50
0
Cortex
Outer Mella
Inner Medulla
35 sec

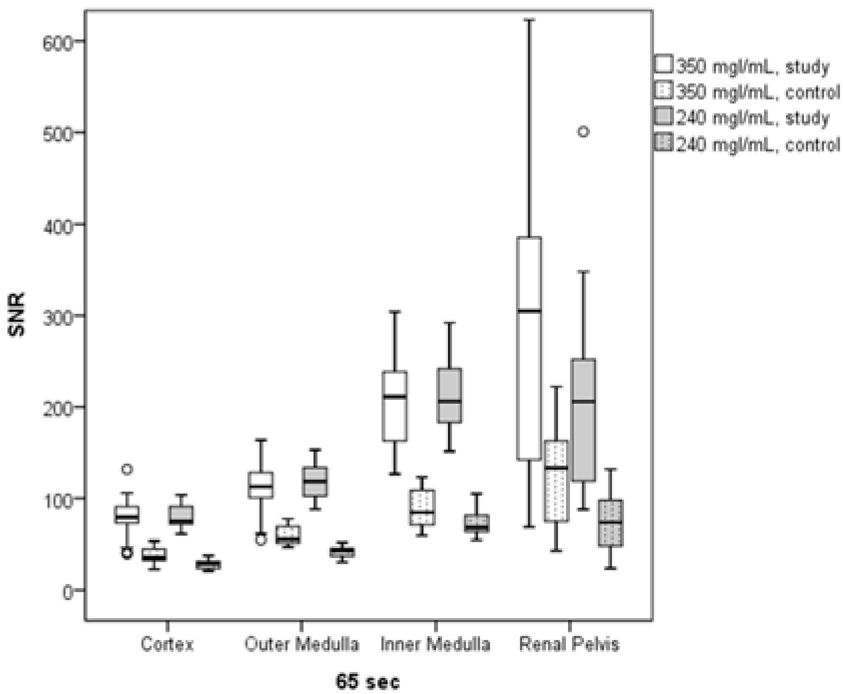
(E)


350 mgI/mL, study
350 mgI/mL, control
240 mgI/mL, study
240 mgI/mL, control
CNR
300
250
200
150
100
50
0
Cortex
Outer Medulla
Inner Medulla
35 sec

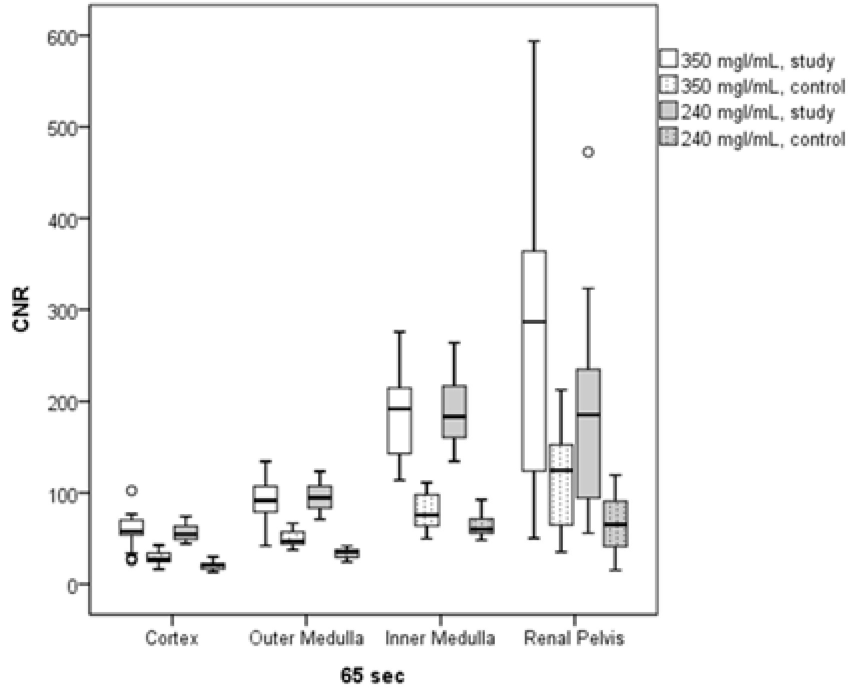
(F)


25000
20000
15000
10000
5000
0
FOM
350 mgI/mL, study
350 mgI/mL, control
240 mgI/mL, study
240 mgI/mL, control
Cortex
Outer Medulla
Inner Medulla
35sec

(G)

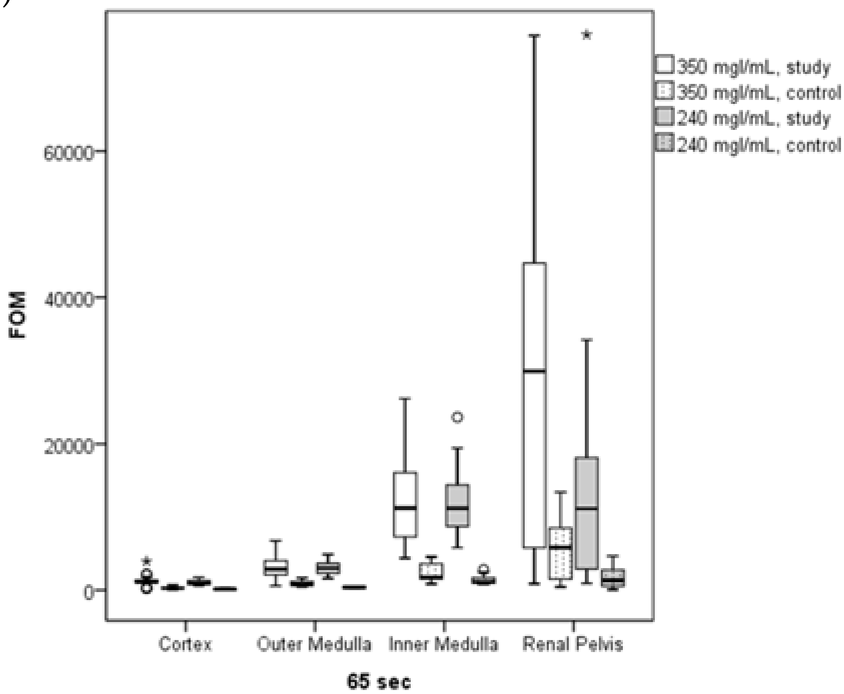

600
500
400
300
200
100
0
SNR
350 mgI/mL, study
350 mgI/mL, control
240 mgI/mL, study
240 mgI/mL, control
Cortex
Outer Medulla
Inner Medulla
Renal Pelvis
65 sec

(H)



600
500
400
300
200
100
0
CNR
350 mgI/mL, study
350 mgI/mL, control
240 mgI/mL, study
240 mgI/mL, control
Cortex
Outer Medulla
Inner Medulla
Renal Pelvis
65 sec

(I)



60000
40000
20000
0
FOM
350 mgI/mL, study
350 mgI/mL, control
240 mgI/mL, study
240 mgI/mL, control
Cortex
Outer Medulla
Inner Medulla
Renal Pelvis
65 sec

요약(국문초록)

반복적 재구성 기법과 저용량 조영제를 이용한 토끼 신장 CT: 기존 영상과의 비교연구

김리현

의학과

서울대학교 대학원

서론: 본 연구에서는 반복적 재구성 기법(iterative reconstruction)과 저용량 조영제를 사용한 토끼 신장 CT를 기존의 재구성 기법인 여과 역투사법(filtered back projection)과 조영제 용량을 사용한 CT와 비교하여 그 영상의 질을 비교 평가하고자 한다.

방법: 실험에 사용된 토끼는 총 20마리로서, 무작위로 10마리씩 실험군과 대조군으로 배정되어 2종류의 조영제를 사용한 신장 CT를 촬영하였다. 실험군에서는 4mL의 조영제와 반복적 재구성 기법을 적용하였고, 대조군에서는 6mL의 조영제와 여과 역투사법(filtered back projection)을 이용하였다. 첫 번째 실험에서는 350 mgI/mL 농도의 조영제를 사용하였으며, 1주일 후 다시 무작위로 토끼들을 실험군과 대조군으로 배정한 후 240 mgI/mL 농도의 조영제로 2차 실험을 진행하였다. CT영상의 질 평가는 2명의 비뇨영상의학 전문의의 합의로 이루어졌다. 4점 척도로 영상의 선예도 (sharpness), 영상 잡음 (noise), 영상 질감 (texture), 줄무늬 인공물 (streak artifact), 전반적인 영상의 질의 5가지 항목을 정성적으로 평가하였다. 정량적 평가 항목으로는 평균 CT 감쇄 값 (attenuation value), 영상 잡음 (noise), 신호 대 잡음비 (SNR), 대조도 대 잡음비 (CNR) 및 성능 지수 (FOM)을 계산하였다. 통계적 방법으로 독립 표본 t 검정과 Mann-Whitney U 검정을 통해 실험군과 대조군에서의 CT영상의 질을 서로 비교하였다.

결과: 정성적 비교 평가 결과, 실험군에서 유의하게 영상 잡음 (noise)과 줄무늬 인공물 (streak artifact)이 적었고 보다 나은 영상의 선예도 (sharpness)와 전반적인 영상의 질을 보여주었다. ($p<0.05$). 하지만, 영상의 질감 (texture)은 실험군에서 오히려 떨어졌다 ($p<0.05$). 평균 CT 감쇄 값 (attenuation value)은 실험군이 대조군에 비해 낮거나 비슷한 정도를 보였다 ($p<0.05$). 하지만 영상 잡음 (noise)이 실험군에서 현저하게 낮아져 대조군에 비해 350 mgI/mL과 240 mgI/mL 조영제를 사용했을 때 각각 42%, 36% 감소하였다 ($p<0.05$). 따라서 신호 대 잡음비 (SNR), 대조도 대 잡음비 (CNR) 및 성능 지수 (FOM) 모두 실험군에서 대조군에 비해 유의하게 높은 값을 보였다 ($p<0.05$).

결론: 4mL 조영제와 반복적 재구성 기법(iterative reconstruction)을 적용한 토끼 신장 CT는 기존의 6mL 조영제와 여과 역투사법(filtered back projection)을 사용한 CT에 상응하는 정도의 영상의 질을 보여주었다.

주요어: 전산화 단층 촬영, 조영제, 영상의 질, 조영제 유발 신증

학 번: 2014-25047