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견관절의 전산화 단층촬영 관절조영술에서 영상재구성과 관전압의 최적화

Optimization of Image Reconstruction and Tube Voltage in CT Arthrography of Shoulder

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Optimization of Image Reconstruction and Tube Voltage in CT Arthrography of Shoulder

by

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① 본인의 논문을 보존이나 인터넷 등을 통한 온라인 서비스 목적으로 복제할 경우 저작물의 내용을 변경하지 않는 범위 내에서의 복제를 허용합니다.

② 본인의 논문을 디지털화하여 인터넷 등 정보통신망을 통한 논문의 일부 또는 전부의 복제.배포 및 전송 시 무료로 제공하는 것에 동의합니다.

2. 개인(저작자)의 의무

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② 서울대학교는 본 논문에 대한 공개의 유보나 해지 신청 시 즉시 처리해야 합니다.

논문 제목 : 견관절의 전산화 단층촬영 관절조영술에서 영상재구성과 관전압의 최적화

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ABSTRACT

Introduction: To determine an optimal reconstruction method and tube voltage in computed tomography (CT) arthrography of the shoulder regarding radiation dose and image quality.

Materials and Methods: : The institutional review board approved the study and written informed consents were obtained. Sixty-two CT exams were prospectively included. CT scans were obtained twice in each patient at 120kVp and 140kVp in two different shoulder positions, while other scanning parameters were kept constant. For each scan, we obtained two axial image-sets of 2.0 mm: direct reconstruction and thin-slab averaging reformation. Image quality was subjectively compared regarding contrast and noise between reconstruction methods and between 120kVp and 140kVp. Mean attenuation of intraarticular contrast media, signal-to-noise ratio (SNR), contrast-to-noise ratio (CNR) and radiation dose were quantitatively compared between 120kVp and 140kVp.

Results: In comparison between reconstruction methods, thin-slab averaging reformation showed better image quality than direct reconstruction in all cases. In qualitative assessment, contrast was better in 120kVp, whereas noise was more. In quantitative analysis, mean attenuation of intraarticular contrast media was higher (2210 HU±474 vs 1873 HU±427; $p<0.001$), and noise more (26.1±5.8 vs 20.9±4.7; $p<0.001$) in 120kVp than 140kVp. There was no significant difference between 120kVp and 140kVp in SNR (89.9±29.8 vs 94.3±28.9;$p= 0.17$) and CNR (87.4±29.3 vs 91.3±28.4;$p= 0.21$). Lowering tube voltage from 140kVp to 120kVp reduced radiation dose by 33 %.

Conclusion: Thin-slab averaging reformation improves image quality by decreasing noise in CT arthrography. Moreover, use of 120 kVp in combination with thin-slab reformation achieves a decrease in radiation dose compared to 140 kVp without significant loss of image quality.

Keywords: CT arthrography

shoulder

low kVp

radiation dose

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INTRODUCTION

Multidetector computed tomography (MDCT) with excellent spatial resolution has increased image quality of computed tomography (CT) arthrography and has been used in a growing number of indications. Although magnetic resonance (MR) imaging or MR arthrography is most commonly used for shoulder imaging, CT arthrography has shown high diagnostic performance and provides precise answers to the location and the extent of complete or articular-sided rotator cuff tear (1-2), labral lesions (3-5), or cartilage lesions (6). In addition, comparable, even higher diagnostic performance of CT arthrography than MR imaging has been reported in the detection of capsulolabral lesions and rotator cuff tears (7-8). Recent studies have shown further improvement of diagnostic performance of CT arthrography in the diagnosis of rotator cuff tear or labral tear when stress positions such as abduction and external rotation (ABER) or external rotation-active supination (ERAS) was added to neutral position (5, 9). In clinical setting, CT arthrography is sometimes referred in that it is less expensive, needs a shorter examination time, and is a good choice for patients contraindicated to MR exams.

A major disadvantage of CT arthrography compared to MR imaging or MR arthrography is radiation exposure. The shoulder joint is in close proximity to the thyroid and irradiation should be kept as low as possible. However, the shoulder is thick and composed of dense bony structures in large part, which makes images prone to high level of noise. Moreover, intraarticular injection of iodine-based contrast media also causes beam hardening artifacts and decreases image quality. Therefore, there is a need for an adjustment of CT parameters to optimize image quality and minimize patient irradiation.

The possibility of radiation dose saving using low tube voltage without altering diagnostic capabilities have been suggested in previous studies with chest CT (10-11), pulmonary CT angiography (12), aortic CT angiography (13) and coronary CT angiography (14-16). To our knowledge, there is no study or recommendation on the optimal tube voltage for CT arthrography of the shoulder, nor on how tube voltage affects image quality. According to the reported studies, CT arthrography of the shoulder was performed at 120 kVp (4, 6-7, 9, 17-18) or 140 kVp (19-20) at different institutions, and some studies have used both (3, 21).

In addition, image quality can also be affected by reconstruction method. As one of the image postprocessing technique, thin-slab averaging reformation has been known to cancel image noise across the source thin sections by averaging the pixel values within the slab, and it has been increasingly used to deal with image noise in modern thin-section CT (22-26).

Therefore, the purpose of our study was to compare image quality of CT arthrography of the shoulder between direct reconstruction and thin-slab averaging reformation and between 120 kVp and 140 kVp protocols and to determine an optimal tube voltage and reconstruction method regarding radiation dose and image quality.

MATERIALS AND METHODS

Our institutional review board approved this study and written informed consents from all the patients were obtained.

Study populations

In our institution, patients suspected of having internal derangement of the shoulder are usually referred to MR arthrography. However, CT arthrography was suggested for (a) some patients with symptoms of internal derangement, (b) patients who have previously undergone shoulder surgery and (c) patients for whom MR imaging was contraindicated. We prospectively examined 73 CT arthrography of the shoulder in 71 patients between April and September 2012. Patients were referred for CT arthrography for suspected superior labrum anterior-to-posterior (SLAP) (n = 49), post-operation evaluation of SLAP (n = 15), recurrent shoulder dislocation (n = 4), and suspected rotator cuff tear in patients for whom MR imaging was contraindicated (n = 5). Eleven patients were excluded due to poor distension of the shoulder joint with contrast media solution or uneven distribution of contrast media solution within the joint (n= 8), severe beam hardening artifact to the shoulder joint due to the chemoport on the ipsilateral chest wall (n=1), and inappropriate acquisition protocol due to technical error (n=2). Finally, 62 shoulders in 60 patients (43 male and 17 female; mean age, 35.4 years; range, 18-68 years) were included.

Arthrography

Intraarticular positioning of a 22-guage needle at the glenohumeral joint was performed by an anterior approach, which was guided by fluoroscopy. After verifying of intraarticular position of the needle tip, a mixture of 13mL of meglumine ioxitalamate (Telebrix 30 Meglumine; Guerbet, Aulnaysous-Bois, France) and 7mL of normal saline was injected. A variable amount ranging from 10 to 20 mL of iodinated contrast solution was injected into the joint.

CT arthrography

CT acquisition was performed immediately after intraarticular injection of contrast media solution to avoid absorption of contrast media solution and loss of capsular distension. We obtained CT scans with symptomatic shoulder in two different patient positions at two different tube voltages (120 kVp and 140 kVp); (a) the neutral position with the arm resting at the patient's side and the thumb pointing upward and (b) the stress position (ERAS) (5). Tube voltage was randomly assigned to different positions; consequently, 35 exams performed the first scan (neutral position) at 120 kVp and the second scan (stress position) at 140 kVp, and 27 exams performed the other way round. The time gap between the two sequential scans was about 264.4 seconds (range 161-532 seconds). Other scanning parameters except tube voltage were kept constant in the two scans. Scanning covered from the upper part of the acromioclavicular joint to the lower margin of the axillary recess.

CT scanning was performed with a 64-section CT scanner (Brilliance 64; Philips Medical Systems, Best, the Netherlands) at a rotation speed of 0.75 second per rotation, a current of 200 mAs, and a detector collimation of 64 x 0.625 mm. For reconstruction, we used type D reconstruction filter, a 512 x 512 matrix and 15 cm field of view. Two types of axial reconstruction image-sets for each scan were obtained: the first was reconstructed directly from the raw projection data with the section thickness of 2.0 mm and the reconstruction interval of 2.0 mm (protocol A). The second reconstruction was accomplished through two stages. First, thin-section image datasets with the section thickness of 1.0 mm and the reconstruction interval of 0.7 mm were prepared. From these data, we made images with the section thickness of 2.0 mm and the interval of 2.0 mm by applying thin-slab averaging reformation (protocol B) (24).

Image analysis

Images were reviewed by two experienced musculoskeletal radiologists of 14 and 5 years' experience who were blinded to scan parameters and reconstruction protocols. Each reader was provided with a total of four image-sets per a CT exam, which consisted of four axial image-sets obtained using two different kVp and two different reconstruction methods. We used the preset window width of 2000 and level of 800 for all images.

A. Comparison of image quality between reconstruction protocol A and protocol B

Initially, two readers compared a pair of axial image sets with the two reconstruction protocols at the same tube voltage. The reconstruction method of the better image quality regarding image noise was chosen. Image noise was simply defined as image mottling and streak artifacts.

B. Qualitative analysis of image quality between 120 kVp and 140 kVp protocols

For comparison of image quality between 120 kVp and 140 kVp protocols, we used a pair of image sets at the two different kVps, which was reconstructed by the less-noise protocol as chosen above. Image quality was subjectively assessed regarding followings; a) contrast between intraarticular contrast media and soft tissue such as cartilage, labrum and muscles, b) image noise as described above. The image-set showing the better quality was chosen for each assessment factor.

C. Quantitative analysis of image quality between 120 kVp and 140 kVp protocols

Quantitative assessment was performed by a resident of 4 years' experience in radiology. Individual regions of interest (ROI) of 15~25 mm2 were placed over contrast media solution within the synovial cavity (HUCM), and the deltoid muscle (HUmuscle). Attenuation values in Hounsfield units were measured in each ROI. HUCM within the synovial cavity was measured twice in the adjacent slices and averaged. The background noise was based on the assessment of the standard deviation measurement within air in anterior and lateral background, where we placed each ROI and averaged the values for final calculation of the background noise. With these measurements, signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were calculated according to following equations: SNR = HUCM / background noise, CNR= (HUCM – HUmuscle)/ background noise.

Measurement of radiation dose

To evaluate radiation dose during CT examination, volume CT dose index ($CTDI_{vol}$) was recorded, which was provided by the scanner system referring to a standard 32 cm body phantom.

Statistical analysis

Calculations for statistical analysis was performed with SPSS software (SPSS forWindows, version 15.0; SPSS, Chicago,Ill). Statistical significance of the results of a qualitative analysis of image quality was assessed with the binomial test. Interobserver agreement for a qualitative assessment of image quality was assessed by using kappa statistics. Results of a quantitative analysis of image quality and radiation dose measurements were compared between a pair of image-sets at the two different kVps, using the paired t-test. A P value of less than .05 was considered to indicate a significant difference.

RESULTS

Comparison of image quality between reconstruction protocol A and B

Both reader 1 and reader 2 selected protocol B rather than protocol A for having the better image quality due to less noise and streak artifacts in all CT exams. Interobserver agreement was perfect, that is, two readers agreed the better image quality of thin-slab averaging reformation images in all cases, given other acquisition parameters are equal (Fig 1).

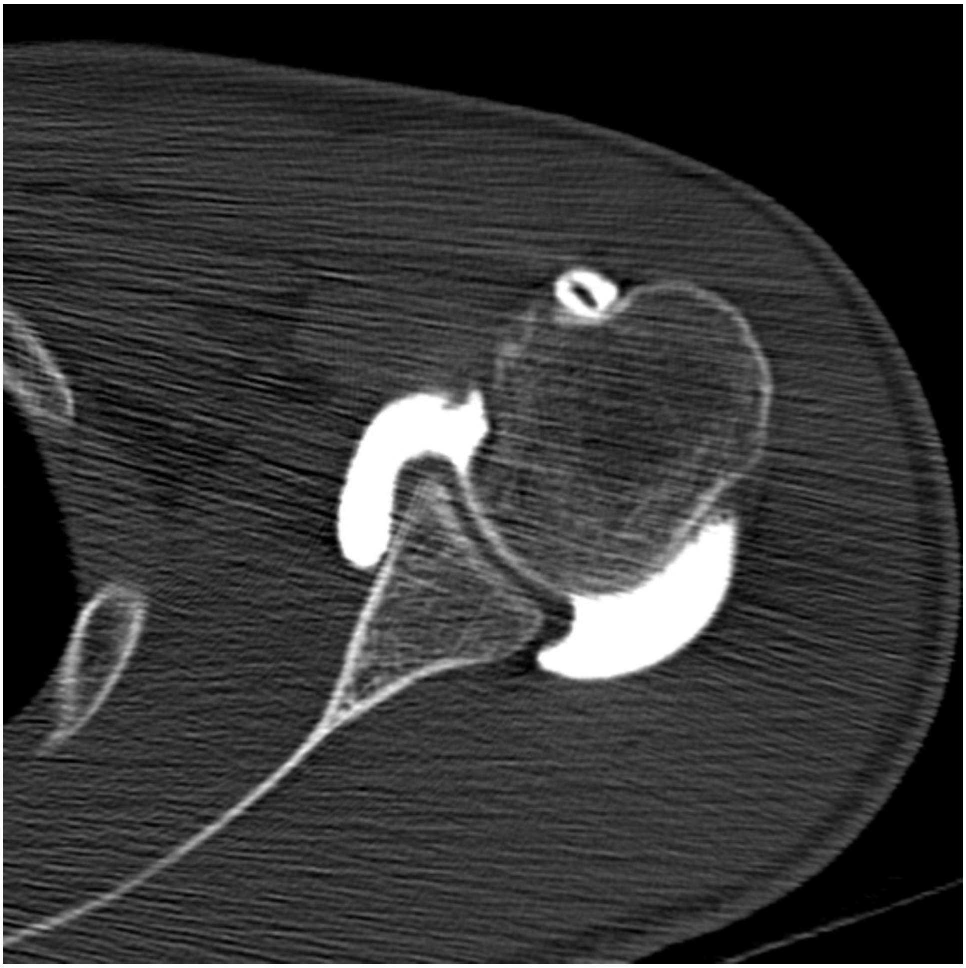

Fig. 1a

Fig. 1b

Figure 1: Axial CT arthrographic images obtained with two different reconstruction methods in a 24-year-old man for postoperative evaluation of SLAP. (a) The image was reconstructed directly from raw projection data with the section thickness of 2.0mm and the reconstruction interval of 2.0mm. (b) The image was obtained through two steps. Primary thin-section images were reconstructed with the section thickness of 1.0mm and the reconstruction interval of 0.7mm. Then, thin-slab averaging reformation was applied to generate this image with the section thickness of 2.0mm and the interval of 2.0mm. The image looks smoother with lesser noise.

Qualitative analysis of image quality between 120 kVp and 140 kVp protocols

In comparison between a pair of image-sets of different kVp, obtained with reconstruction protocol B, contrast was shown to be superior in 120 kVp ($P < 0.001$), whereas noise and streak artifacts were less in 140 kVp ($P < 0.001$) (Fig 2). Table 1 shows apparently high agreement between the two readers, however, the kappa values were very small. This phenomenon is known as 'kappa paradox' due to asymmetrical distributions of agreement (27), hence we did not mind the low kappa values.

Fig. 2a

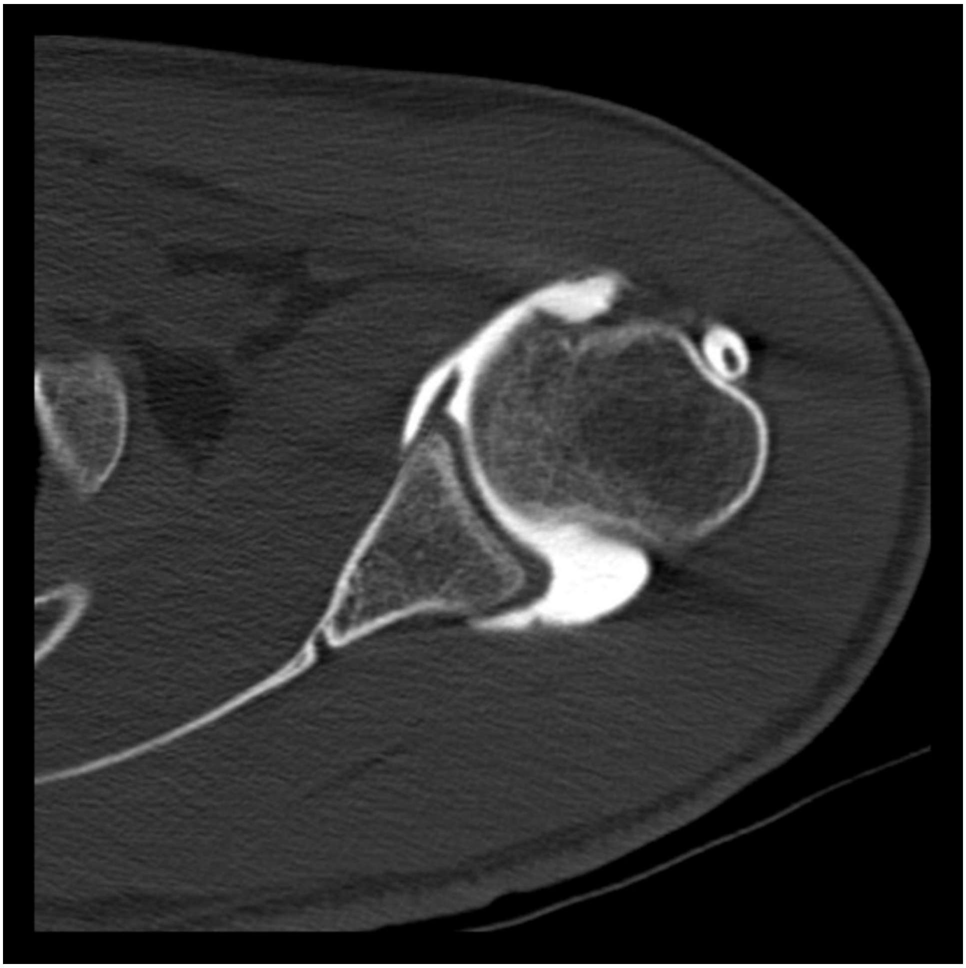

Fig. 2b

Figure 2: Axial CT arthrographic images obtained with two different kVp in a 25 year-old-man for suspected SLAP. (a) The image was taken at 120 kVp, and shows better contrast between intraarticular contrast media solution and adjacent soft tissues. (b) The image was taken at 140 kVp, and shows lesser image noise.

Table 1. Qualitative assessment of image quality at 120 kVp and 140 kVp protocols

	Contrast is better in		Noise is lesser in	
	120 kVp	140 kVp	120 kVp	140 kVp
Reader 1*	59 (95%)	3 (5%)	2 (3%)	60 (97%)
Reader 2*	49 (79%)	13 (21%)	4 (7%)	58 (93%)
Interobserver agreement				
Observed agreement	0.81		0.90	
κ value	0.19		-0.05	

* Data are number of exams with a percentage in parentheses.

Quantitative analysis of image quality between 120 kVp and 140 kVp protocols

Attenuation measurement within the synovial cavity and the deltoid muscle, and noise levels from the background are listed in the Table 2. Mean attenuation of contrast media solution in synovial cavity was higher in 120 kVp than 140 kVp (2210 HU ± 474 vs 1873 HU ± 427; $p < 0.001$). Mean attenuation of the deltoid muscle were not significantly different between 120 kVp and 140 kVp (60.9 HU ± 8.9 vs 60.5 HU ± 9.2 ; $p = 0.78$). The background noise level was higher in 120 kVp (26.1 ± 5.8) than 140 kVp (20.9 ± 4.7) ($p<0.001$). There were no significant differences between 120 kVp and 140kVp for SNR (89.9 ± 29.8 vs 94.3 ± 28.9; $p= 0.17$) and CNR (87.4 ± 29.3 vs 91.3 ± 28.4; $p= 0.21$), respectively.

Table 2. Quantitative assessment of image quality at 120 kVp and 140 kVp protocols

	120 kVp	140 kVp	Percentage difference in 120 kVp vs 140 kVp	p value
HU_{CM} (HU) *	2210 ± 474	1873 ± 427	+0.18	< 0.001
HU_{muscle} (HU)	60.9 ± 8.9	60.5 ± 9.2	+0.01	0.78
Background noise (HU) *	26.1 ± 5.8	20.9 ± 4.7	+0.25	< 0.001
SNR	89.9 ± 29.8	94.3 ± 28.9	-0.05	0.17
CNR	87.4 ± 29.3	91.3 ± 28.4	-0.04	0.21

Data are the mean ± standard deviation.

* The measurements show statistically significant difference between 120 kVp and 140 kVp protocols.

Radiation exposure

The mean scan coverage for z-axis was 20.3 ± 0.5 cm. In comparison between 120 and 140 kVp scans, there was significant difference in $CTDI_{vol}$; 13.0 mGy ± 0.4 vs 19.2 mGy ± 0.6 ($p < 0.001$). Lowering tube voltage from 140 kVp to 120 kVp resulted in dose reduction of 33 %.

DISCUSSION

In this study, we found that thin-slab averaging reformation improved image quality by decreasing image noise in CT arthrography of the shoulder. In addition, use of 120 kVp shows higher contrast and higher level of image noise compared to that of 140 kVp. Overall, without significant image quality loss, radiation dose saving of 33% can be achieved by lowering kVp from 140 kVp to 120 kVp.

Radiation dose during CT arthrography of the shoulder has been rarely studied. A limited number of data showed that effective radiation dose for shoulder imaging ranges 2.4~2.8 mSv, using 16-channel or higher MDCT, tube voltage of 120 kVp or 140 kVp, and tube current from 120 to 240 mAs (7, 20). This range of tube voltage, which is preset in most of MDCT scanners for routine standard imaging, generally results in good image quality without excessive tube load (11). However, an optimal kVp needed for CT arthrography of the shoulder with respect to radiation dose and image quality has not been investigated.

Radiation exposure, theoretically, is reduced exponentially with lowering tube voltage (15). Several recent studies have investigated the feasibility of low tube voltage CT protocols keeping up with the needs for reducing patient irradiation in CT exams, and have shown that lowering tube voltage can effectively reduce radiation dose without substantially decreasing image quality (10-16). Sigal-Cinqualbre et al. (11) observed radiation dose saving of 41-56 % by lowering tube voltage from 120 kVp to 80 kVp in chest CT, and other studies with coronary CT angiography reduced radiation dose by 24-44% by lowering tube voltage from 120 kVp to 100 kVp (12, 14).

Radiation dose saving, however, gives rise to an issue of image quality. In general, lowing kVp increases image noise (12, 28), which potentially decrease image quality. This is of concern especially in CT arthrography of the shoulder due to high level of streak artifacts by adjacent dense bony structures and high concentration of intraarticular iodine-based contrast media.

It has been suggested that high image noise can be compensated by high contrast in low dose CT exams. Several recent studies have showed that lowering tube voltage resulted in an increase of noise as well as attenuation of iodine-based contrast agents, and thus CNR and SNR were not significantly affected (11-12, 14-15). Possible explanation for an increase of attenuation of iodine-based contrast material is as followings; K-edge energy of iodine is 33.2 keV. A representative photon energy is approximately 72 keV at tube voltage of 140 kVp, and 66keV at 120 kVp. In other words, photon energy is getting closer to K-edge energy of iodine with lowering tube voltage, and results in more attenuation of iodine. Our study also showed that lowering kVp from 140 kVp to 120 kVp increased the background noise by 25%, at the same time, increased attenuation of contrast media solution by 18%, resulting in no significant change in SNR and CNR.

In addition, lower kVp and subsequent high image noise fortunately can be well tolerated in CT arthrography of the shoulder. It is because of inherent high tissue contrast of bony structure, and a high contrast interface between intraarticular structures by intraarticular contrast media solution (3), which enables accurate diagnosis of pathologies of intraarticular structures. Thanks to high contrast between the structures of the shoulder, we also have a wide chance of adjusting window width, that is, by widening window width we can reduce noise magnitude and subsequently reduce perceived noise at the expense of contrast (24).

We adopted a postprocessing method, so called thin-slab averaging reformation. In an initial step of the technique, primary thin-section images are reconstructed from CT volume data with a thickness of 1 mm or less. Then, a slab that is located between two parallel clipping planes perpendicular to the chosen direction is reconstructed. All voxels within the slab are averaged and displayed as a single thick section. With this method, image noise is reduced compared with that of noisy thin-section source images (22, 24). At the same time, it smoothes the image texture qualitatively, which was shown to affect the lesion detectability (23-24, 29).

Our results also showed that the better image quality with less noise was achieved with thin-slab reformation in comparison to direct reconstruction, even nominal section thickness was same (2.0mm) for both. Therefore, the use of thin-slab averaging reformation is considered to be valid in CT arthrography of the shoulder, which is inherently of high image noise as described above, particularly when lower tube voltage is applied.

We have obtained two scans for CT arthrography of the shoulder in neutral and ERAS positions, which improve the diagnostic accuracy of SLAP tears of the glenoid labrum (5). This allowed us to compare two image-sets of the same patient which are equal in all conditions except kVp and eliminate confounders by the patient factors, whereas previous studies performed by randomly assigning patients to different tube voltages (11-12, 14-15). Unfortunately, however, we could not control the time point of each scan and a time interval (mean 264.4 seconds) between the two sequential scans was inevitable. This might affect attenuation of contrast media solution because of contrast media absorption over time. Because this had been expected as one of the limitations of this study, we intended to minimize this time-dependent factor by randomization of the order of scan at 120 and 140 kVp.

Our study has some other limitations as followings: First, we used $CTDI_{vol}$ for radiation dose measurements, provided by CT scanner. Effective dose was not estimated, because there is no known reference of the anatomic-specific conversion factor for the shoulder region. That means we could not assess the absorbed organ doses or determine the risk of radiation-induced carcinogenesis, but $CTDI_{vol}$ is thought to be enough for comparison of radiation dose between two different kVp and calculation of radiation dose saving. Second, we did not control patients' weight or body-mass-index (BMI) which may affect image quality. Park et al. reported that attenuation of the contrast-filled vessels decreased, noise increased, and subsequently SNR and CNR decreased, as BMI increased (15). Other study also showed that noise increased exponentially with patients' weight (11). However, we believe that the effect of BMI might be minimal, considering that the shoulder region has relatively less subcutaneous or visceral fat compared to chest or abdomen. Third, we performed this study with a specific CT scanner (Brilliance 64; Philips Medical Systems, Best, the Netherlands). Considering that each CT scanner produces different image quality even with the same acquisition protocol, the applicability of our results to other CT scanners needs further investigation. Forth, the accuracy of a specific diagnosis of shoulder pathology was not assessed in this study. The applicability of this CT protocol in the diagnosis of various shoulder pathologies also needs to be warranted.

In conclusion, thin-slab averaging reformation improves image quality by decreasing noise in CT arthrography of the shoulder. Moreover, use of 120 kVp in combination with thin-slab averaging reformation achieves a significant decrease in radiation dose compared to that of 140 kVp without significant loss of image quality.

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국문초록

목적: 견관절의 전산화 단층촬영 (computed tomography, CT) 관절조영술에서 서로 다른 영상재구성 방법을 사용하였을 때, 그리고 120kVp와 140kVp의 관전압을 사용하였을 때의 영상화질을 비교함으로써, 방사선 피폭선량과 영상화질의 관점에서 최적의 관전압을 결정하고자 한다.

대상과 방법: 전향적으로 수집한 62예의 견관절 CT 관절조영술 검사를 대상으로 하였다. 각 검사별로 120kVp와 140kV의 관전압에서 두 번의 촬영을 시행하였고 이 때 관전압 이외의 모든 조건은 동일하게 하였다. 각 촬영에 대해서 다음과 같은 두 가지 방법으로 영상재구성을 시행하였다: 첫번째, 2mm 두께로 직접 영상재구성을 하여 축상 영상을 얻었고, 두번째 thin-slab averaging reformation의 방법을 이용하여 2mm 두께의 축상 영상을 얻었다. 두 가지의 다른 영상재구성방법 및 관전압으로부터 얻은 영상을 각각 비교하여 대조도 및 영상잡음의 측면에서 정성적 영상화질을 평가하였다. 또한, 120kVp와 140kVp에서 시행한 영상에서 관절강 및 삼각근의 감쇄계수, 바탕 잡음, 신호대 잡음비 및 대조도대 잡음비를 정량적으로 측정하여 영상화질을 평가하였다. 방사선 피폭선량은 volume CT dose index을 이용하여 평가하였다.

결과: 두 가지 영상재구성방법에 따른 영상화질 평가에서 모든 검사에서 thin-slab averaging reformation를 사용하였을 때 영상잡음이 적어 영상화질이 우수하였다. 120kVp와 140kVp의 관전압을 이용하여 얻은 영상을 비교하였을 때 대조도는 120kVp에서 높은 반면 영상잡음은 140kVp에서 낮았다. 정량적 분석에서, 관절강내의 조영제의 감쇄는 120kVp에서 140kVp보다 의미있게 높았고 (2210 HU±474 vs 1873HU±427; $p<0.001$), 영상잡음은 140kVp에서 120kVp보다 의미있게 낮았다 (20.9±4.7 vs 26.1±5.8); $p<0.001$). 120kVp과 140kVp 영상의 비교에서 신호대 잡음비 (89.9±29.8 vs 94.3±28.9; p= 0.17)와 대조도대 잡음비 (87.4±29.3 vs 91.3±28.4; p= 0.21)는 의미있는 차이가 없었다. 피폭선량은 관전압을 140kVp에서 120kVp로 낮추었을 때 약 33% 감소하였다.

결론: 견관절의 CT 관절조영술에서 thin-slab averaging reformation의 영상재구성 방법을 사용하여 영상잡음을 줄임으로써 영상화질을 높일 수 있다. 또한, 120kVp의 관전압을 사용하였을때 140kVp의 관전압을 사용하였을 때에 비해 영상화질의 저하가 없으면서도 피폭선량을 의미있게 낮출 수 있다.

주요어: CT 관절조영술, 어깨, 관전압, 방사선량

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