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Comparison of Image Quality of Shoulder CT Arthrography Conducted Using 120 kVp and 140 kVp Protocols

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Objective: To compare the image quality of shoulder CT arthrography performed using 120 kVp and 140 kVp protocols.
Materials and Methods: Fifty-four CT examinations were prospectively included. CT scans were performed on each patient at 120 kVp and 140 kVp; other scanning parameters were kept constant. Image qualities were qualitatively and quantitatively compared with respect to noise, contrast, and diagnostic acceptability. Diagnostic acceptabilities were graded using a one to five scale as follows: 1, suboptimal; 2, below average; 3, acceptable; 4, above average; and 5, superior. Radiation doses were also compared.
Results: Contrast was better at 120 kVp, but noise was greater. No significant differences were observed between the 120 kVp and 140 kVp protocols in terms of diagnostic acceptability, signal-to-noise ratio, or contrast-to-noise ratio. Lowering tube voltage from 140 kVp to 120 kVp reduced the radiation dose by 33%.
Conclusion: The use of 120 kVp during shoulder CT arthrography reduces radiation dose versus 140 kVp without significant loss of image quality.
Index terms: *Shoulder CT arthrography; Radiation dose; Tube voltage; Image quality*

INTRODUCTION

Computed tomography (CT) arthrography of the shoulder provides precise information regarding the location and extent of complete or articular-sided rotator cuff tears (1, 2), labral lesions (3-5), and cartilage lesions (6). In addition, comparable or even higher diagnostic performance has been reported for CT arthrography than magnetic resonance (MR) imaging for the detection of capsulolabral lesions and rotator cuff tears (7, 8). Furthermore, recent studies have shown further improvements in the performance of CT arthrography for the diagnosis of rotator cuff tears or labral tears when stress positions, such as, abduction and external rotation (ABER) and external rotation-active supination (ERAS), are added to the neutral position (5, 9). In the clinical setting, CT arthrography is often said to be less expensive, to need a shorter examination time, and to be a good choice for patients contraindicated for MRI.

The associated radiation exposure is a major disadvantage of CT arthrography. In particular, the shoulder joint is in close proximity to the thyroid, and thus, radiation exposure should be kept as low as possible. However, the shoulder is thick and largely composed of dense bony structures, which make images prone to high levels of noise. Moreover,

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the intraarticular injection of iodine-based contrast medium also causes beam hardening artifacts and reduces image quality. Therefore, we considered adjustment of CT parameters was required to optimize image quality and minimize radiation exposure.

The possibility of radiation dose reduction using low tube voltages, while maintaining diagnostic capabilities, has been previously suggested in chest CT (10, 11), pulmonary CT angiography (12), aortic CT angiography (13), and coronary CT angiography (14-16) studies. However, to the best of our knowledge, no study has been performed or recommendation made on the optimal tube voltage for CT arthrography of the shoulder, or addressed the relation between tube voltage and image quality. Furthermore, in published reports shoulder CT arthrography has been performed at 120 kVp (4, 6, 7, 9, 17, 18) or 140 kVp (19, 20), or both (3, 21).

Therefore, the purpose of the present study was to compare the image qualities obtained by CT arthrography of the shoulder using 120 kVp and 140 kVp protocols.

MATERIALS AND METHODS

Our Institutional Review Board approved this study and written informed consent was obtained from all patients.

Study Populations

At our institution, patients suspected of having internal derangement of the shoulder are usually referred to MR arthrography. However, CT arthrography is performed on; 1) patients with a history of poor quality MR images or without arthrography, 2) patients younger than 40 years with symptoms of instability or a superior labral anterior-to-posterior (SLAP) lesion, 3) patients that have previously undergone shoulder surgery, and 4) patients for whom MRI is contraindicated or who cannot afford the cost of MR arthrography. We prospectively examined the 65 shoulder CT arthrograms of 64 patients between April and September 2012. Patients were referred to CT arthrography for; suspected SLAP lesion (n = 43), post-operation evaluation of SLAP (n = 13), recurrent shoulder dislocation (n = 4), or for suspected rotator cuff tear when MRI was contraindicated (n = 5). Eleven patients were excluded due to poor distension of the shoulder joint, eight for uneven distribution of contrast media solution within the joint (n = 8), one for severe beam hardening artifact at the shoulder joint caused by a chemoport on the ipsilateral chest wall, and two for an inappropriate acquisition protocol due to technical error. Finally, 54 shoulders of 53 patients (41 male and 12 female; mean overall age, 36.1 years; range, 20–68 years) were included.

Arthrography

Intraarticular positioning of a 22-guage needle at the glenohumeral joint was performed using an anterior approach under fluoroscopic guidance. After verifying intraarticular position of the needle tip, a mixture of 13 mL of meglumine ioxitalamate (Telebrix 30 Meglumine; Guerbet, Aulnaysous-Bois, France) and 7 mL of normal saline was injected. Different amounts of iodinated contrast solution (range 10 to 20 mL) were injected.

CT Arthrography

CT acquisition was performed immediately after the intraarticular injection of contrast media solution to avoid absorption of contrast media solution and loss of capsular distension. CT scans were obtained of symptomatic shoulders in two different patient positions at two different tube voltages (120 kVp and 140 kVp): 1) the neutral position with the arm resting at the side and the thumb pointing upward, and 2) the stress position (ERAS) (5). Tube voltage was randomly assigned to the different positions; consequently for 27 shoulders of 27 patients (22 male and 5 female; mean age 38.5 years; range, 22–68 years) we performed the first scan (neutral position) at 120 kVp and the second scan (stress position) at 140 kVp, and for 27 shoulders of 26 patients (19 male and 7 female; mean age 33.5 years; range, 20–55 years) we performed scans the other way round. The time gap between the two scans was about 267 seconds (range 188–532 seconds). Scanning parameters other than tube voltage were identical for the two scans.

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 a type D reconstruction filter, a 512 x 512 matrix, and a 15 cm field of view. To reduce image noise, axial reconstruction was accomplished using two stages (Fig. 1). First, thin-section image datasets (section thickness 1.0 mm and reconstruction interval 0.7 mm) were prepared, and from this data, we reconstructed images of section thickness 2.0 mm with an interval of 2.0 mm by thin-slab-averaging reformation (22).

Image Analysis

Qualitative analysis was performed by two experienced musculoskeletal radiologists with 14 and 5 years of experience who were blinded to scan parameters. Quantitative analysis was performed by a resident with 4 years experience in radiology. Each reader was provided with two image-sets per CT examination, consisting of two axial image-sets obtained at 120 kVp and 140 kVp. A preset window width of 2000 and a level of 800 were used for all images.

Qualitative Analysis of the Image Qualities of the 120 kVp and 140 kVp Protocols

Image qualities were subjectively assessed with respect to the following; 1) contrast between intraarticular contrast media and soft tissues, such as, cartilage, labrum, and muscles, and 2) image noise as defined as image mottling and streak artifacts. The image-set with the better quality was chosen for each assessment factor. In addition, image diagnostic acceptability was graded using a five-point scale, as follows: 1, suboptimal; 2, below average; 3, acceptable; 4, above average; and 5, superior. Reader scores were averaged.

Quantitative Analysis of the Image Qualities of the 120 kVp and 140 kVp Protocols

Regions of interests (ROIs) were placed over contrast media solution within the synovial cavity (HU_{CM}), and within deltoid muscle (HU_{muscle}). Attenuation values in HU were measured in each ROI. HU_{CM} values were measured twice in adjacent slices and averaged. Image noise was defined as the standard deviation of background measurements.

To calculate background noise, individual ROI of 15–25 mm^2 were placed over anterior and lateral backgrounds and the standard deviations of each ROI were averaged. Using these measurements, signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were calculated using the following equations: SNR = HU_{CM}/background noise, CNR = (HU_{CM} - HU_{muscle})/background noise.

Measurement of Radiation Dose

To quantify radiation doses during CT examinations, volume CT dose indices ($CTDI_{vol}$) were recorded. These were provided by the scanner system and were originally determined using a standard 32 cm body phantom.

Statistical Analysis

Statistical analysis was performed using SPSS software (SPSS for Windows, version 15.0; SPSS Inc., Chicago, IL, USA). The statistical significances of the results of the

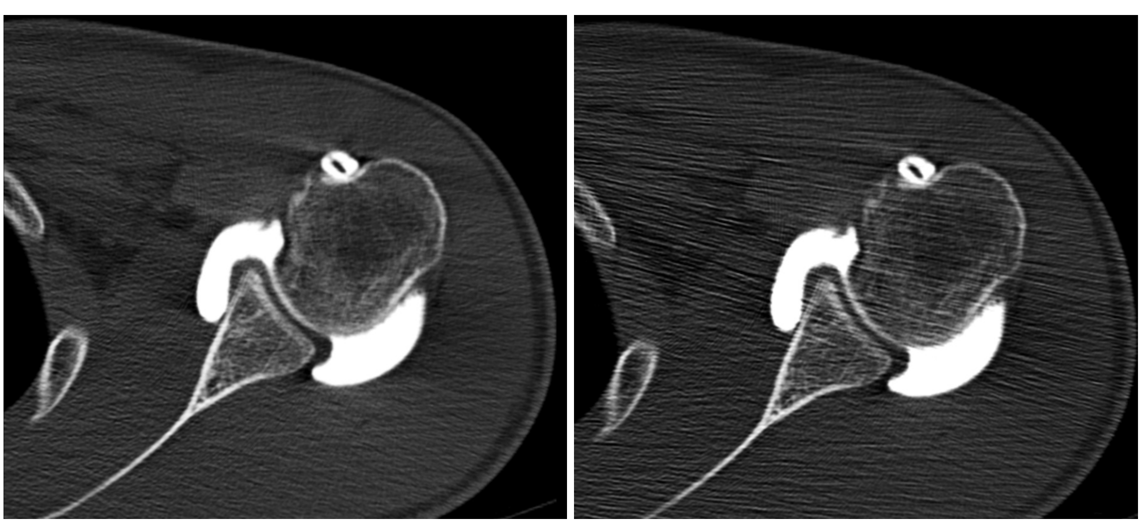

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Fig. 1. Axial CT arthrographic images obtained by thin-slab-averaging reformation and conventional reconstruction in 24-year-old man for postoperative evaluation of SLAP lesion.
A. Thin-slab-averaging reformation (used in this study). Image was obtained using two steps. Primary thin-section images were reconstructed using section thickness of 1.0 mm and reconstruction interval of 0.7 mm. Then, thin-slab-averaging reformation was applied to generate this image with section thickness of 2.0 mm and interval of 2.0 mm. **B.** Conventional reconstruction (for comparison). Image was reconstructed directly from raw projection data with section thickness of 2.0 mm and reconstruction interval of 2.0 mm. Image looks less smooth and noisier than that obtained by thin-slab-averaging reformation.

qualitative analyses of contrast and noise were assessed using the binomial test. Given the subjective nature and potential interobserver variability of the diagnostic acceptability grading system, the results were averaged across both readers and then Wilcoxon's signed rank test was used to compare the averaged grades of the two protocols. The results of quantitative analysis of image quality and radiation dose were compared using the paired *t* test or Wilcoxon's signed rank test after checking data for normality using the Kolmogorov-Smirnov test. Null hypotheses of no difference were rejected when *p* values were < 0.05.

RESULTS

Qualitative Analysis of the Image Qualities of the 120 kVp and 140 kVp Protocols

A comparison of paired image sets showed contrast was superior at 120 kVp ($p < 0.001$), but that noise was less at 140 kVp ($p < 0.001$) (Fig. 2). All image-sets obtained scores of ≥ 3 (acceptable). Diagnostic acceptability scores were non-significantly different ($p = 0.135$) (Table 1).

Quantitative Analysis of the Image Qualities of the Two Protocols

Attenuation measurements within synovial cavities and deltoid muscles, and background noise levels are listed in Table 2. Mean attenuation of contrast media solution in synovial cavities was higher at 120 kVp than at 140 kVp (2219 ± 450 HU vs. 1878 ± 433 HU; $p < 0.001$). However, mean attenuations of deltoid muscles were not significantly different (60.8 ± 9.3 HU vs. 60.7 ± 9.7 HU for 120 kVp and 140 kVp, respectively; $p = 0.920$). The background noise levels were higher at 120 kVp (25.9 ± 5.8 vs. 21.0 ± 5.0) ($p < 0.001$), but SNR values were non-significantly different (90.8 ± 28.9 vs. 94.2 ± 29.2 for 120 kVp and 140 kVp, respectively; $p = 0.316$) as were CNR values (88.3 ± 28.4 vs. 91.2 ± 28.7, respectively; $p = 0.388$), respectively.

Radiation Exposure

Mean z-axis scan coverage was 20.3 ± 0.5 cm. $CTDI_{vol}$ values were significantly different for the two protocols (13.0 ± 0.4 mGy vs. 19.2 ± 0.6 mGy for 120 kVp and 140 kVp; $p < 0.001$). Lowering the tube voltage from 140 kVp to 120 kVp resulted in a dose reduction of 33%.

DISCUSSION

In this study, the use of 120 kVp was found to provide greater contrast and higher image noise levels than 140 kVp. Overall, without significant image quality loss, the study shows that a radiation dose saving of 33% can be achieved by lowering kVp from 140 kVp to 120 kVp.

Radiation doses during shoulder CT arthrography have received little research attention. A limited amount of published data shows that effective radiation doses for shoulder imaging range from 2.4–2.8 mSv for 16-channel or higher multidetector computed tomography (MDCT), the

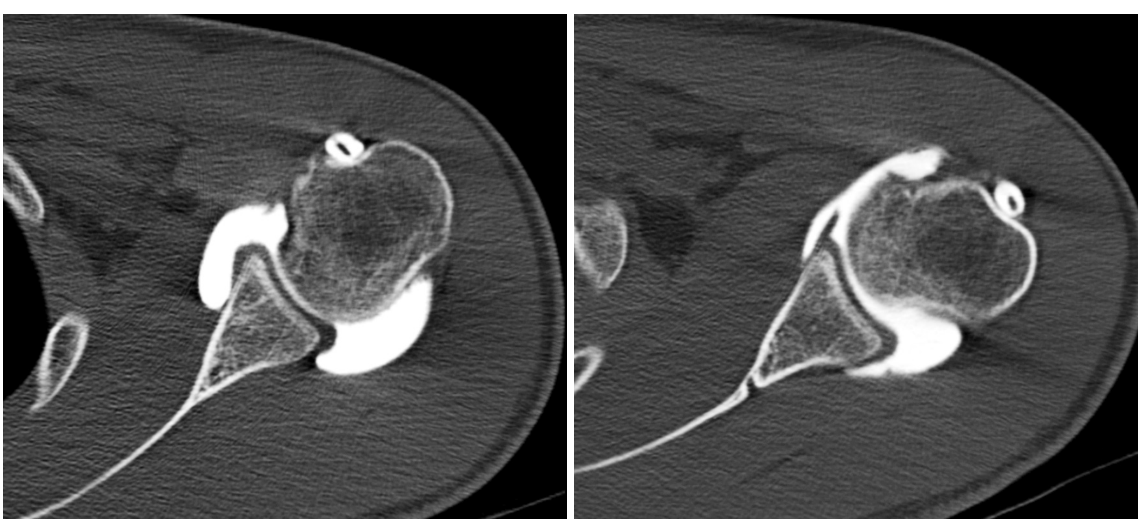

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Fig. 2. Axial CT arthrographic images obtained at 120 kVp and 140 kVp in 24-year-old man for postoperative evaluation of superior labral anterior-to-posterior lesion.
A. Image was taken in neutral position at 120 kVp, and shows better contrast between intraarticular contrast media solution and adjacent soft tissues and more noise than image obtained at 140 kVp. **B.** Image was taken in stress position at 140 kVp.

tube voltages used are either 120 kVp or 140 kVp, and tube currents range from 120 to 240 mAs (7, 20). This range of tube voltage, which is preset in most MDCT scanners used for routine standard imaging, generally results in good image quality without excessive tube load (11). However, the optimal kVp needed for shoulder CT arthrography based on considerations of radiation dose and image quality has not been determined.

Theoretically, radiation exposure, is reduced exponentially by lowering tube voltage (15). Several recent studies have investigated the feasibility of low tube voltage CT protocols in-line with the requirement to reduce radiation exposure during CT examinations, and shown that lowering tube voltage can effectively reduce exposure without substantially decreasing image quality (10-16). Sigal-Cinqualbre et al. (11) observed a radiation dose saving of 41–56% by lowering tube voltage from 120 kVp to 80 kVp for chest CT, and other studies on coronary CT angiography reported 24–44% reductions in exposure by lowering tube voltage from 120 kVp to 100 kVp (12, 14).

However, radiation dose saving can cause image quality problems. In general, lowing kVp increases image noise and potentially decreases image quality. This is of special concern for CT arthrography of the shoulder due to the high levels of streak artifacts caused by adjacent dense bony structures and high concentrations of intraarticular iodine-based contrast media.

It has been suggested that high image noise can be compensated by increasing the amount of contrast administered for low dose CT examinations. Several recent studies have shown that lowering tube voltage increases noise and the attenuation of iodine-based contrast agents, and thus, CNR and SNR were not significantly affected (11, 12, 14, 15). One possible explanation for the increased attenuation of iodine-based contrast materials is based consideration of the K-edge energy of iodine (33.2 keV) and a representative photon energy of 72 keV at a tube voltage of 140 kVp and of 66 keV at 120 kVp. In other words, photon energy approaches the K-edge energy of iodine on lowering tube voltage, which results in more iodine attenuation. In the present study, we also found lowering kVp from 140 kVp to 120 kVp increased background noise by 23%, but increased contrast media attenuation by 18%, and that resultantly SNR and CNR did not change significantly.

Furthermore, lower kVp and high image noise can be well tolerated during shoulder CT arthrography, because the high inherent tissue contrast of bony structures and the high contrast interface between intraarticular structures provided by intraarticular contrast media solution (3), which in combination facilitate the accurate diagnoses of the pathologies of intraarticular structures. Thanks to high contrast between shoulder structures, window width can be widened, which reduce noise at the expense of contrast (22).

In the present study, we adopted a postprocessing method, that is, 'thin-slab-averaging reformation' (Fig. 1). Initially, primary thin-section images were reconstructed from CT volume data at a thickness of ≤ 1 mm. Then a slab located between two parallel clipping planes perpendicular to the chosen direction was reconstructed. All voxels within the slab were then averaged and displayed as a single thick

Table 1. Qualitative Analysis of Image Quality at 120 kVp and 140 kVp Protocols

		120 kVp	140 kVp	*P*
Contrast is better in	Reader 1	51/54 (94%)	3/54 (6%)	< 0.001
	Reader 2	41/54 (76%)	13/54 (24%)	< 0.001
Noise is higher in	Reader 1	52/54 (96%)	2/54 (4%)	< 0.001
	Reader 2	50/54 (93%)	4/54 (7%)	< 0.001
Diagnostic acceptability score		3.94 ± 0.57	4.05 ± 0.59	0.135

Note.— Data are number of examinations with percentage in parentheses.

Table 2. Quantitative Analysis of Image Quality at 120 kVp and 140 kVp Protocols

	120 kVp	140 kVp	95% CI of Mean Difference	*P*
HU_{CM} (HU)*	2219 ± 450	1878 ± 433	255.9–426.1	< 0.001
HU_{muscle} (HU)	60.8 ± 9.3	60.7 ± 9.7	-2.9–3.3	0.920
Background noise (HU)*	25.9 ± 5.8	21.0 ± 5.0	3.4–6.4	< 0.001
SNR	90.8 ± 28.9	94.2 ± 29.2	-10.2–3.3	0.316
CNR	88.3 ± 28.4	91.2 ± 28.7	-9.4–3.7	0.388

Note.— Data are mean ± standard deviation. *Measurements show statistically significant difference between 120 kVp and 140 kVp protocols. CI = confidence interval, CNR = contrast-to-noise ratio, HU = Hounsfield unit, HU_{CM} = attenuation measurement of contrast media solution, HU_{muscle} = attenuation measurement of deltoid muscle, SNR = signal-to-noise ratio section. Using this method, image noise was reduced at the expense of sharpness as compared with noisy thin-section source images (22-24).

We have performed two shoulder CT arthrography scans in neutral and stress (ERAS) positions, which improves the diagnostic accuracy for SLAP tears of the glenoid labrum (5). This technique allowed us to compare two image-sets obtained in same patients that were identical in all respects except for kVp and to eliminate patient-associated confounders, whereas in previous studies, patients have been randomly assigned to different tube voltages (11, 12, 22). However, we were unable to control scan timings and a time interval between the two scans was inevitable. This could have affected the attenuation of the contrast media solution due to contrast absorption. Because this study limitation was appreciated, we attempted to minimize the effect by randomizing scan orders.

The study has some other limitations that require consideration. First, we used $CTDI_{vol}$ values provided by the CT scanner for determining radiation doses. Effective dose was not estimated, because no anatomy-specific conversion factor is available for the shoulder region. However, $CTDI_{vol}$ values were considered sufficient to compare the radiation dose of the two protocols and to calculate radiation dose reductions. Second, we did not control for patient weight or body mass index (BMI), which could affect image quality (11, 15). However, we believe that the effect of BMI was probably minimal, as the shoulder region has relatively less subcutaneous and visceral fat than the other body regions, such as, the chest or abdomen. Moreover, as mentioned above, two image-sets of two different kVps were available for each patient, which allowed us to perform paired comparisons and avoid the confounding effects of BMI. Third, we performed this study with a specific CT scanner, and thus, the applicability of our results to other CT scanners needs further investigation. Fourth, the accuracies of shoulder pathology diagnoses were not assessed. We suggest that the applicability of the 120 kVp CT protocol to the diagnosis of various shoulder pathologies be validated.

In conclusion, the use of 120 kVp for CT arthrography of the shoulder was found to achieve a significant reduction in radiation dose as compared with 140 kVp without significant loss of image quality.

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