Original research

Reduction of radiation dose in adult CT-guided musculoskeletal procedures

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Abstract

Objective: We examine the effect of manually reducing CT scanner tube voltage (kVp) and current (mA) on patient radiation dose and procedural success during CT-guided musculoskeletal procedures on adults. We hypothesize that patient radiation dose can be reduced while maintaining procedural success. *Materials and methods:* This project was performed as an operational test of change. Scanner kVp and mA were manually reduced during CT-guided musculoskeletal procedures over a 6-month period (n = 20). Bilateral cases served as their own controls. The remaining control cases were obtained by retrospective review of our picture archiving and communication system. Default scanner voltage and current were recorded for all dose reduced cases. Using an experimentally derived formula, we calculated what the total exam DLP would have been had the default settings been used. In addition, a 32 cm acrylic body phantom was scanned using the recorded default and reduced settings for the dose reduced cases. *Results:* Radiation dose reduction for all procedures vs. control cases was statistically significant at 68% (p < 0.001). Average dose reduction for all procedures vs. calculated normal dose was statistically significant at 69% (p < 0.001). Average radiation dose for all cases using phantom scans was statistically significant at 72% (p < 0.001). All procedures were successful. *Conclusion:* Our study shows that significant reduction in radiation dose without reduction in procedural accuracy can be achieved by simply lowering the CT scanner voltage and current from their default settings.

Keywords: radiation dose; CT-guided procedure; musculoskeletal procedure.

Introduction

While computerized tomography (CT) guided procedures represent a small portion of total CT examinations, their radiation dose can be significant to both patients and imaging personnel. For many musculoskeletal lesions, especially those which are deep or purely osseous, CT is the modality of choice for image guidance [1, 2].

Image guided percutaneous biopsy offers multiple benefits over open biopsy including minimal invasiveness with decreased morbidity and recovery time, ability to direct needle to areas most likely to yield diagnostic specimens, high accuracy, and lower cost [1]. Dupuy et al reported 93% accuracy for CT-guided needle biopsy of musculoskeletal neoplasms [3].

With increased public scrutiny on radiation risks, optimizing and balancing image quality while keeping radiation dose as low as reasonably achievable (ALARA) is vital [4]. Artner et al. have demonstrated the effectiveness of CT dose reduction strategies during CT-guided spinal, periradicular, and sacroiliac joint injections [5-7]. However, to the authors' knowledge, no prior studies have examined the effectiveness of CT dose reduction over a wide spectrum of CT-guided musculoskeletal procedures in the adult population. The purpose of the study is to examine the effect of manually reducing CT scanner tube voltage (kVp) and current (mA) on patient radiation dose and procedural effectiveness during CT-guided musculoskeletal procedures on adults.

Materials and methods

This project was performed as an operational test of change. The IRB approval was obtained. The procedures

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were performed by a single board certified musculoskeletal radiologist who manually reduced tube voltage (kVp) and current (mA) from the CT scanner's default settings during 20 CT-guided musculoskeletal procedures performed on adults over a 6-month period from 9/2013 to 3/2014. The practitioner reduced the settings taking into account body part, patient body habitus, and patient age. Tube voltage was reduced by an average of 25% for helical scans and by 9% for snapshot CT snapshot mode. Tube current was reduced by an average of 38% for helical scans and by 35% for CT snapshot mode. Default settings, adjusted settings, and dose length product (DLP) were recorded. We chose the total DLP to estimate the total surrogate radiation to the patient as we felt this was a better representation than a dose index such as $CTDI_{vol}$ as it takes into account the entire length of the patient scanned rather than a single slice and sums the radiation doses from the initial helical scan with the snapshot mode portion. All cases were performed on a 16-slice multidetector CT (Lightspeed RT 16; General Electric Medical Systems, Waukesha, WI, USA) with CT snapshot mode (GE SmartView). Radiation doses were calculated assuming a standard 32 cm acrylic body phantom.

Three bilateral cases (2 subtalar injections and 1 ankle injection) served as their own controls, as one side was performed with default tube voltage and current while the other side was performed with reduced current and voltage. The remaining 17 control cases were obtained by searching the picture archiving and communication system (PACS) for CT-guided musculoskeletal procedures matched for body part and procedure performed over the year prior to the dose reduction cases (i.e. sacroiliac joint injection vs. sacroiliac joint injection, femur biopsy vs. femur biopsy, etc.).

Our department's workflow for CT-guided MSK procedures begins with placing a skin marker over the region of interest. Anteroposterior and lateral scout views of the region of interest are then obtained and the position of the skin marker is adjusted if needed. Using these scouts and prior diagnostic studies the radiologist selects the cranial

and caudal boundaries for a helical CT to just cover the lesion/joint of interest. A skin entry point is selected. CT snapshot mode is used for needle guidance, during which three adjacent CT slice still images are obtained when the foot pedal is pressed.

The default scanner voltage and current were recorded for all dose reduced cases. For the same collimation (3i) and scan length, the following relationship was experimentally derived for our procedural CT scanner (kVp ranged from 80 to 120): $DLP_2 = DLP_1 * \frac{mA_2}{mA_1} * \left(\frac{kVp_2}{kVp_1}\right)^{2.638}$. We calculated what the total exam DLP would have been had the default settings been used.

In addition, a 32 cm acrylic body phantom was scanned using the default and reduced settings which had been recorded for the dose reduced cases.

Procedures were comprised of three types: Joint injection/aspiration, bone biopsy, and soft tissue biopsy/drainage. Biopsies were considered successful if the sample was diagnostic on pathology report. Joint injection/aspiration was considered successful if the needle tip was imaged within the joint space. A post hoc calculation of statistical power for a decrease in procedural success rate from 99% to 95% during dose reduced procedures is 0.18.

Statistical significance was calculated with SPSS software (version 22.0; IBM, Armonk, NY, USA) utilizing the Mann-Whitney U test.

Results

A total of 20 CT-guided MSK procedures (6 joint aspirations/injections, 10 bone biopsies, and 4 soft tissue biopsies/drainages) were performed. Table 1 summarizes the radiation doses and radiation dose reduction of each group, including calculated DLPs and scans of phantoms. Table 2 summarizes the contribution of the helical scan and snapshot mode to the total radiation dose for reduced dose cases. Table 3 summarizes the default protocol and dose reduced CT scanner settings which were used.

Table 1 Summary of radiation dose reduction.

Case type	Protocol	n	Mean radiation dose (DLP in mGy-cm)	95% CI (DLP in mGy-cm)	Average dose reduction (%)	p-value
All cases	Reduced dose	20	111.8	68.98 - 154.55	68	< 0.001
	Normal dose	20	351.2	264.00 - 438.13		
Calculated normal dose	Normal dose	20	375.3	246.28 - 504.25	69	<0.001
Phantom cases - all	Reduced dose	20	95.57	61.47 - 129.67	72	< 0.001
	Normal dose	20	303.9	225.66 - 382.17		
Joint aspirations/injections	Reduced dose	6	117.3	-52.54 - 287.06	71	0.041
	Normal dose	6	342.3	29.7 - 654.92		
Bone biopsies	Reduced dose	10	104	71.21 - 136.83	68	< 0.001
	Normal dose	10	336.4	246.81 - 426.01		
Soft tissue biopsies/drainages	Reduced dose	4	122.8	42.07 - 203.59	65	0.029
	Normal dose	4	401.3	178.52 - 624.01		

Table 2 Summary of radiation dose reduced cases.

Dose reduced case	Helical DLP (mGy-cm)	Snapshot mode DLP (mGy-cm)	Total DLP (mGy-cm)
1	112.28	10.04	122.32
2	50.85	13.3	64.15
3	27.7	0.85	28.55
4	27.57	1.92	29.49
5	19.2	1.44	20.64
6	418.33	20.08	438.41
7	112.28	14.07	126.35
8	101.05	16.08	117.13
9	74.87	1.00	75.87
10	59.03	6.36	65.39
11	80.05	26.88	106.93
12	59.03	11.59	70.62
13	139.69	67.82	207.51
14	119.39	15.08	134.47
15	63.21	22.26	85.47
16	46.49	4.15	50.64
17	53.23	0.8	54.03
18	118.41	1.59	120.00
19	164.85	8.31	173.16
20	139.13	5.00	144.13
Average Percentage of total DLP	89.00	11.00	

Of note, the radiation dose reduction for all procedures vs. control cases was statistically significant at 68% (p < 0.001). Average dose reduction for all cases vs. calculated normal dose was statistically significant at 69% (p < 0.001). Average radiation dose for all cases using phantom scans was statistically significant at 72% (p < 0.001). When compared to control cases, statistically significant radiation dose reduction was also observed for each type of procedure; 71% (p = 0.041) for joint aspirations/injections, 68% (p < 0.001) for bone biopsies, and 65% (p = 0.029) for soft tissues biopsies/drainages.

Before reducing the CT tube current and voltage we recorded the default current and voltage for each case. Using these default settings we were able to calculate what the DLP would have been had the current and voltage not been reduced. When compared to these calculated DLPs, our dose reduction was 69%. We also scanned a 32 cm acrylic body phantom using both default and reduced settings which had been recorded for reduced dose cases. The results for these phantom scans showed a 72% reduction in DLP, which agrees well with the 69% reduction we demonstrated vs. calculated radiation doses, and 68% reduction vs. control cases. Given the small number of cases, we thought these added points of comparison may be useful.

All procedures were successful with 13 biopsies being diagnostic, six joint aspirations/injections having the needle tip imaged within the joint space, and one pelvic abscess drainage having successful drain placement with return of purulent material. No procedural complications were observed.

Table 3 Default protocol and dose reduced CT scanner settings used.

| Procedure	Helical CT				Snapshot CT			
	Dose reduced		Protocol		Dose reduced		Protocol	
	kVp	mA	kVp	mA	kVp	mA	kVp	mA
SI joint injection	100	200	120	280	100	40	100	60
SI joint injection	80	180	120	280	80	40	120	60
Subtalar injection	80	17	120	44	80	30	80	80
Subtalar injection	80	70	120	100	80	40	120	60
Subtalar injection	80	60	120	100	80	20	80	40
Hip aspiration	100	360	140	440	100	40	120	60
biopsy iliac	100	200	120	440	100	40	120	60
biopsy iliac	100	160	120	280	100	40	120	40
biopsy iliac	80	340	120	440	100	15	120	25
biopsy iliac	80	220	120	280	80	40	80	60
biopsy sacrum	100	200	120	280	100	20	120	25
biopsy ischium	80	220	120	300	120	25	80	25
biopsy acetabulum	100	280	120	440	100	30	100	60
biopsy femur	100	18	120	80	80	30	80	80
biopsy femur	80	280	120	440	80	120	80	280
biopsy tibia	100	14	120	80	100	25	120	60
biopsy thigh soft tissue	80	120	120	200	80	15	120	25
biopsy thigh soft tissue	80	130	120	165	80	60	80	80
biopsy chest wall	100	300	120	440	80	40	100	60
pelvic abscess drainage	120	200	120	280	120	30	120	30

Discussion

When compared with control cases, we achieved a statistically significant average radiation dose reduction of 68% without loss of procedural success. This is less than the 87% dose reduction demonstrated by Patel et al for musculoskeletal biopsies in the pediatric population and less than the 85-94% dose reductions achieved by Artner et al. for spinal, periradicular, and sacroiliac joint injections [2, 5-7]. As we experienced no loss in procedural success, this suggests that we may have room to further decrease radiation doses. It should be noted that for the purposes of consistency, once a reduced scanner voltage and current were selected, they were not changed (either lowered if image quality was more than sufficient or increased if image quality was too poor). We did not encounter any instances where image quality was too poor to safely perform the procedure; however this remains a possibility in practice. Practitioners should feel free to increase and decrease scanner current and voltage to achieve sufficient image quality to safely perform the procedure at hand with the extent of radiation dose reduction ultimately limited by the image quality with which an individual practitioner feels comfortable.

With decreased radiation dose comes decreased image quality, as demonstrated by Figure 1. This is offset by a couple of factors. Firstly, there is nearly always prior diagnostic quality imaging available for comparison. Second, a diagnostic quality image is not necessary to visualize high contrast structures such as needles, joint spaces, and osseous lesions. Only enough radiation should be used to visualize structures that need to be seen during the procedure at hand, that is the ALARA principle [4].

In cases where lesions are close to sensitive structures, such as arteries and nerves, dose reduction may not be appropriate as image quality needs to be maintained to visualize and avoid these critical structures. One such case is demonstrated by Figure 2. Ill-defined soft tissue lesions which are difficult to visualize on CT are also not good candidates for radiation dose reduction as they may be impossible to see with decreased image quality. In such cases, radiation may be avoided all together by utilizing ultrasound or MRI guidance. Figures 3 demonstrate such a case. In our experience, sternal biopsies are also not good candidates for dose reduction.

As shown in Table 2, the initial helical scan contributes 89% of the total radiation dose; with the snapshot mode contributing the remaining 11%. This suggests that the area for greatest potential dose reduction lies not only with decreasing current and voltage during this initial helical scan, but by judiciously limiting the length of this helical scan to only the area of interest. Likewise, smaller radiation dose savings can be accomplished by doing the same with during the snapshot mode. This is the reason we chose to represent total patient radiation dose with DLP rather than $CTDI_{vol}$ as it takes into account not only the radiation dose to an individual slice of the patient, but to how much of the patient has been irradiated. If the $CTDI_{vol}$ for the helical and snapshot mode portions of the exam were equal, the DLP for the helical portion will nearly always be higher than the snapshot mode due to the sheer number of slices imaged.
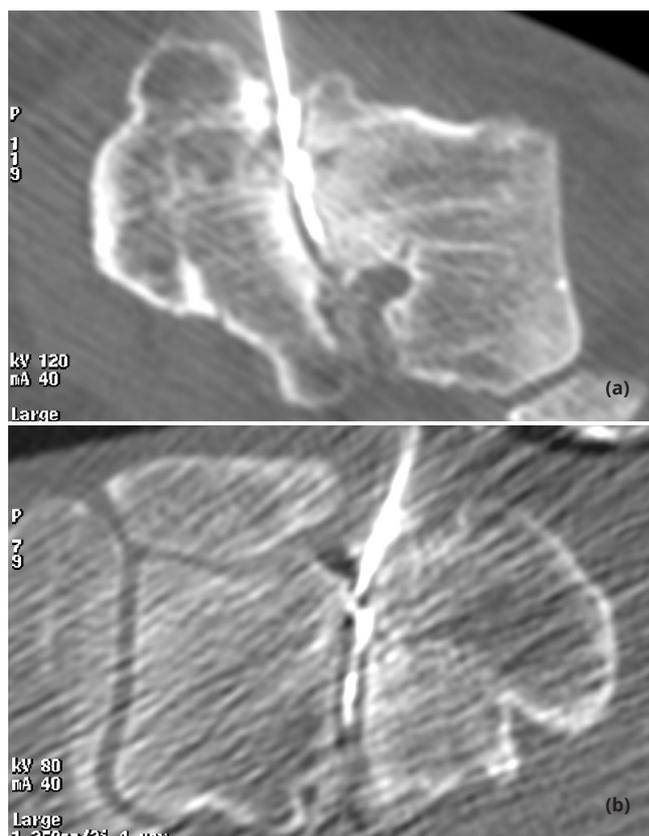
Figure 1 71-year-old male with bilateral ankle pain and subtalar osteoarthritis. (a) Right subtalar joint injection at default scanner settings. (b) Left subtalar joint injection at reduced dose settings. Notice the increased image noise and decreased image quality compared to image 1a.
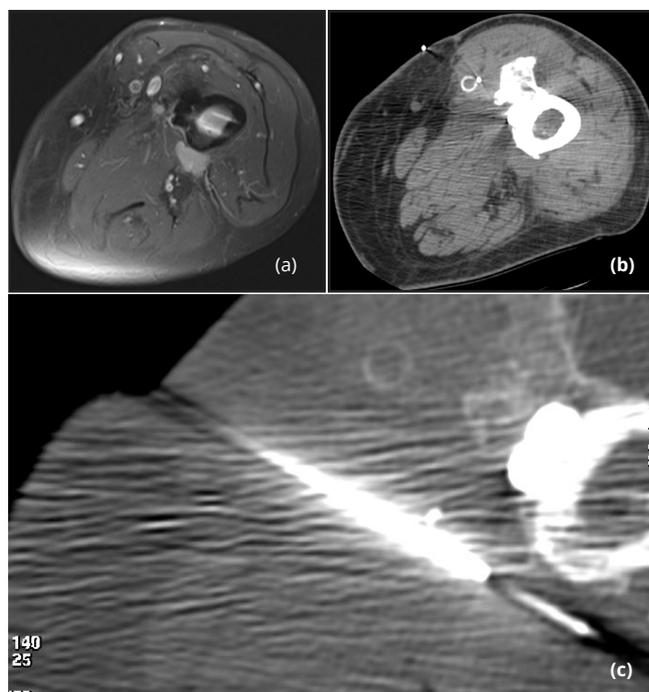
Figure 2 66-year-old male with pathology proven pleomorphic undifferentiated sarcoma. (a) Post-gadolinium T1 weighted MRI demonstrating an enhancing lesion posterior to the femur. (b) Helical unenhanced CT of the soft tissue lesion posterior to the femur. Note that the lesion is much more difficult to see than on contrast enhanced MRI. Also note the position of the femoral artery. (c) CT-guided biopsy of the lesion posterior to the femur. Note the proximity of the femoral artery to the biopsy needle. Maintenance of appropriate image quality is necessary to ensure adequate visualization of sensitive structures near the path of the biopsy needle to avoid unintended damage.

Figure 3 41-year-old female with biopsy proven proliferative myositis. (a) Fat suppressed T2 weighted image of a left lateral gastrocnemius lesion. (b) Helical unenhanced CT of the left lateral gastrocnemius lesion. Note how ill-defined and subtle this lesion is on CT compared to MRI. (c) CT-guided biopsy of the ill-defined left lateral gastrocnemius lesion. With image quality degradation associated with dose reduction, this lesion may have been impossible to see under CT. Radiation likely could have been avoided all together as this would have been a good candidate for ultrasound or MRI guidance.

The major limitation to this study is its small population size. A post hoc statistical power calculation suggests that we would only detect a decrease in procedural success from 99% to 95% (i.e. a five-fold increase in failure rate) during dose reduced procedures 18% of the time; however radiation dose reductions for all groups of procedures were significant. Control procedures are limited as well as no two CT-guided procedures are exactly alike. Bilateral cases served as their own controls and are as close to true controls as possible. However, comparisons between procedures done on different people are limited by different scan lengths, patient body habitus, and bone mineral density. As all dose reductions were done manually with varying degrees of reduction based on region of interest, patient body habitus, and patient age, repeatability of this study is limited. However, even if this study is not exactly repeatable, it serves to illustrate that a practitioner can simply manually lower current and voltage from their default settings and obtain significant radiation dose reduction to the patient. The degree to which a radiologist is willing to decrease radiation dose, and therefore image quality, will vary based on the individual. The DLPs we observed were slightly different between real dose reduced cases and phantom cases performed at the same settings. This may have been due to automatic current modulation, but it raises the point that calculation of exact radiation doses is not a simple task. Keep in mind that $CTDI_{vol}$ and DLP are just approximations of the true patient radiation dose.

In Table 1, a few of the 95% confidence intervals are quite high, for example "joint aspirations/injections". This is likely due to the procedures being carried out on different body parts on patients of differing body habitus. A subtalar joint injection will have quite a different radiation dose than a sacroiliac joint injection.

At our institution, aside from using CT snapshot mode, there are currently no specific protocols to reduce patient radiation dose for musculoskeletal CT-guided procedures, and practitioners generally use the default CT scanner settings.

Conclusion

Our study shows that significant reduction in radiation dose without reduction in procedural accuracy can be achieved by simply lowering the CT scanner voltage and current from their default settings. With careful screening and case selection, in some cases radiation may be avoided all together by utilizing ultrasound or MRI image guidance.

Conflicts of interest

The authors declare no conflicts of interest.

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