Effect of Body Habitus on Radiation Dose During CT Fluoroscopy-Guided Spine Injections

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Key words: CT fluoroscopy, radiation dosimetry, epidural injections, spine therapy, body habitus

Summary

This study investigated the degree to which body habitus influences radiation dose during CT fluoroscopy (CTF)-guided lumbar epidural steroid injections (ESI).

An anthropomorphic phantom containing metal oxide semiconductor field effect transistor (MOSFET) detectors was scanned at two transverse levels to simulate upper and lower lumbar CTF-guided ESI. Circumferential layers of adipose-equivalent material were sequentially added to model patients of three sizes: small (cross-sectional dimensions 25×30 cm), average (34×39 cm), and oversize (43×48 cm). Point dose rates to skin and internal organs within the CTF beam were measured. Scattered point dose rates 5 cm from the radiation beam were also measured.

Direct point dose rates to the internal organs ranged from 0.05-0.11 mGy/10mAs in the oversized phantom, and from 0.18-0.43 mGy/10mAs in the small phantom. Skin direct point dose rates ranged from 0.69-0.71 mGy/10mAs in the oversized phantom and 0.88-0.94 mGy/10mAs in the small phantom. This represents a 180-310% increase in organ point dose rates and 24-36% increase in skin point dose rates in the small habitus compared with the oversize habitus. Scatter point dose rates increased by 83-117% for the small compared to the oversize phantom.

Decreasing body habitus results in substantial increases in direct organ and skin point doses as well as scattered dose during simulated CTF-guided procedures. Failure to account for individual variations in body habitus will result in inaccurate dose estimation and inappropriate choice of tube current in CTF-guided procedures.

Introduction

CT fluoroscopy (CTF) is an increasingly utilized imaging modality used to perform procedures such as spine interventions, biopsies, aspirations, and drain placements¹⁻⁷. In some procedures, CTF is being used in place of conventional fluoroscopy for imaging guidance. During such CTF procedures, the operator is required to select tube current settings for use during the procedure; patient body habitus is a major consideration in making this selection. In practice, however, tube current selection varies widely among proceduralists, and adjustments for body habitus are not always made in a systematic fashion⁸. Understanding the impact of body habitus on dose during CTF procedures is therefore important both for assisting the selection of an appropriate tube current, as well as for comparing the relative radiation exposure of CTF procedures to those performed with conventional fluoroscopy.

Although the relationship between body habitus and radiation dose in diagnostic CT imaging has been extensively investigated⁹⁻¹⁶, dose estimation in CTF procedures is more compli-

* This work was presented in abstract form at the 2013 American Roentgen Ray Society Annual Meeting, Washington, D.C., April 2013.

Figure 1 Scout CT image of prone phantom demonstrating inner (*) and outer (**) layers of 4.5-cm-thick circumferential adipose-equivalent material. A single layer was applied to simulate average body habitus, and two layers were applied to simulate oversize habitus.

Figure 2 Experimental setup. A) Anthropomorphic phantom with MOSFET detectors positioned to detect exposure associated with upper and lower lumbar spine interventions. B) Phantom positioned prone in the scanner, with a single layer of simulated adipose tissue in place.

Figure 3 Point dose rates for each organ as a function of body habitus for the upper lumbar intervention. Note: error bars indicate standard deviation.

Figure 4 Point dose rates for each organ as a function of body habitus for the lower lumbar intervention. Note: error bars indicate standard deviation.

cated than in diagnostic CT due to several factors unique to CTF. These include the absence of table translation, narrow beam collimation, and repetitive but partial exposure of organs. As a result, some methods for estimating radiation exposure during diagnostic CT such as CT dose index (CTDI) and anatomic region-specific conversion factors are not applicable to CTF¹⁷⁻¹⁹. Estimates of the effect of body habitus on the dose derived for helical scanning using these methods therefore cannot be directly applied to interventional techniques. Radiation dose estimation in CTF therefore requires alternative dosimetry strategies.

The purpose of this study is to investigate the degree to which body habitus influences dose during CTF-guided procedures using an anthropomorphic physical phantom. We used a phantom equipped with metal oxide semiconductor field effect transistor (MOSFET) sensors and capable of modeling patients of varied body habitus in order to calculate point organ dose rates during simulated CTF-guided lumbar spine epidural steroid injections. We hypothesized that decreasing body habitus would increase organ dose during CTF lumbar spine interventions, and that correction for habitus would be important for accurate estimation of radiation dose during CTF procedures.

Materials and Methods

Neither institutional review board approval nor Health Insurance Portability and Accountability Act compliance was required, as this was a phantom study.

Anthropomorphic Phantom

A commercially available anthropomorphic male phantom (model 701-D, CIRS, Norfolk, VA, USA) containing metal oxide semiconductor field effect transistor (MOSFET) detectors (model 1002RD, Best Medical Canada, Ottawa, Canada) was utilized to measure point organ doses during CT fluoroscopy. The phantom is composed of 2.5 cm thick sections of material that simulates the density of human soft tissue. Each section contains pre-drilled, numbered holes for individual dose detectors, with positions corresponding to the location of internal organs.

In order to simulate patients of varying body habitus, individual layers of 4.5 cm-thick adipose-equivalent material (model 701 Fat Lay-

ers, CIRS, Norfolk, VA, USA) were wrapped circumferentially around the phantom (Figure 1). Two layers of adipose-equivalent material were applied to simulate oversize habitus (cross sectional dimensions: 43 × 48 cm), a single layer was applied to simulate average habitus (34 × 39 cm), and the phantom alone was used to simulate small habitus (25 × 30 cm).

MOSFET Detectors

The MOSFET detectors, with an active detector area of 200 × 200 μm (total dimensions of 2.5 mm width × 1.3 mm thickness × 8 mm length), were calibrated for a beam energy of 120 kVP, using methods previously described²⁰. The MOSFET sensors, attached to an AutoSense system (Best Medical Canada, Ottawa, Canada), provide near-instantaneous results and the ability to repeat measurements in a single session.

In order to simulate common patterns of direct organ exposure during CT fluoroscopy (CTF)-guided spine interventions, two representative lumbar levels were chosen for radiation dose measurements, and MOSFET detectors were placed into the anthropomorphic phantom at the predetermined organ locations (Figure 2). The axial levels selected were a lower lumbar level, corresponding to the approximate level of the L5 vertebral body, and an upper lumbar level, corresponding to the approximate level of the L2 vertebral body. These particular levels were selected to represent the particular sets of organs exposed during the majority of lumbar spine injections. Organs represented at the lower lumbar level included: skin, vertebral bone marrow, sigmoid colon, and cecum. The upper lumbar level included: skin, vertebral bone marrow, small intestine, colon, and kidney. The phantom axial slice numbers and numerical locations of each MOSFET detector utilized to measure dose are provided in Table 1.

Radiation Dose Measurement

The phantom was scanned in the prone position to simulate positioning used in lumbar steroid injections (Figure 2). For measurements of both the upper and lower lumbar levels, the appropriate phantom section number was centered in the scanner. A single initial axial CT fluoroscopic image was performed to ensure the detectors were located directly in the path of the CT fluoroscopic beam; detector positioning was confirmed based on the immediate detector

Table 1 Location of MOSFET detectors in an anthropomorphic phantom.

	Organ	Phantom Slice Number	Location
Upper Lumbar	Bone marrow	27	211
	Kidney	27	212
	Small bowel (anterior)	27	207
	Small bowel (lateral)	27	208
	Colon	27	210
	Skin	27	Skin surface
Lower Lumbar	Bone marrow	29	218
	Colon (sigmoid)	29	216
	Colon (cecum)	29	217
	Skin	29	Skin surface

dose readout as well as visual confirmation based on the CT fluoroscopic image obtained. Direct point doses to the organs of interest located within the radiation beam for each type of intervention were then recorded during 30 seconds of continuous CT fluoroscopy using the following scan parameters: 2.5 mm beam collimation, tube current 100 mA, 120 kVp, and DFOV of 36.0 cm. Because three contiguous 2.5 mm images are obtained during CTF activation, the total length of direct exposure from the CTF beam along the z-axis was 7.5 mm. Measurements were repeated three times at each level.

Scatter point dose rates were simultaneously recorded from the detectors in the phantom section corresponding to the alternate intervention level, which were located outside the CTF beam. The upper and lower lumbar interventions were located 5 cm apart on the anthropomorphic phantom; thus our scatter dose measurements were obtained at 5 cm from the radiation beam.

Data Analysis

For direct point dose measurements, a mean point dose and standard deviation for each organ were calculated from the three sets of dose measurements for each detector position. Scatter dose rates were calculated as the mean of detector positions in the phantom section outside the radiation beam. All recorded point doses were normalized to dose per second of CTF time per 10 mA to determine the point dose rate (mGy/10 mAs).

Statistical analysis was performed using SAS statistical software (SAS Institute, Inc., Cary, NC, USA). For each simulated intervention,

overall differences among all body habitus types were assessed using the Kruskal-Wallis test. Differences between individual habitus types were assessed using the Wilcoxon rank sum test.

Results

Individual organ point dose rates (mGy/10 mAs) for the small, average, and oversize phantoms are presented in Table 2. Skin was the organ that experienced the highest direct dose rates, ranging from 0.69-0.71 mGy/10 mAs in the oversized phantom to 0.88-0.94 mGy/10 mAs in the small phantom. Direct dose rates to the internal organs ranged from 0.045-0.11 mGy/10 mAs in the oversized phantom, and from 0.18-0.43 mGy/10 mAs in the small phantom. Organ dose rates were generally comparable between the upper and lower lumbar interventions.

Comparison of the relative change in dose rates between the oversized, normal, and small phantoms is presented in Figures 3 and 4 for the upper and lower lumbar interventions, respectively. At both the upper and lower vertebral levels, the highest internal organ point dose rates were observed in the small phantom. Individual organ point dose rates increased 40-115% between the normal and the small phantoms, and increased 180-310% between the oversized and the small phantoms. The differences among mean direct internal organ dose rates for the small, average, and oversize phantoms were statistically significant ($p < 0.05$) for both the upper and lower lumbar interventions (Table 3). Skin dose increased the least of any

Table 2 Individual organ point dose rates at various body sizes.

Intervention	Organ	Small Phantom (mGy/10mAs)	Average Phantom (mGy/10mAs)	Oversize Phantom (mGy/10mAs)
Upper Lumbar	Bone marrow	0.28 ± 0.004	0.13 ± 0.007	0.07 ± 0.004
	Kidney	0.43 ± 0.008	0.22 ± 0.004	0.11 ± 0.001
	Small bowel (anterior)	0.28 ± 0.01	0.20 ± 0.01	0.10 ± 0.001
	Small bowel (lateral)	0.38 ± 0.01	0.19 ± 0.002	0.09 ± 0.004
	Colon	0.41 ± 0.01	0.20 ± 0.005	0.10 ± 0.002
	Skin	0.94 ± 0.01	0.75 ± 0.003	0.69 ± 0.02
	Scatter (at 5 cm)	0.050 ± 0.011	0.036 ± 0.012	0.023 ± 0.007
Lower Lumbar	Bone marrow	0.18 ± 0.003	0.097 ± 0.003	0.045 ± 0.001
	Colon (sigmoid)	0.32 ± 0.004	0.17 ± 0.005	0.089 ± 0.001
	Colon (cecum)	0.35 ± 0.008	0.18 ± 0.005	0.094 ± 0.006
	Skin	0.88 ± 0.01	0.77 ± 0.01	0.71 ± 0.01
	Scatter (at 5 cm)	0.044 ± 0.009	0.033 ± 0.007	0.024 ± 0.005

Note – point dose data are mean $\pm$ SD.

organ among the phantoms, but still demonstrated a 24-36% increase in dose between the oversize and the small phantoms.

Mean scatter dose rates obtained from detectors positioned 5 cm from the center of the CTF beam during each simulated intervention ranged from 0.023-0.024 mGy/10 mAs in the oversized phantom, 0.033-0.036 mGy/10 mAs in the average size phantom, and 0.044-0.050 mGy/10 mAs in the small phantom. As with the direct point dose rates, the scatter point dose rates increased as body habitus decreased. For example, scatter point dose rates for the small habitus increased by 83-117% compared to the oversize phantom. The magnitude of increase of the scatter dose rates with decreasing body habitus was less than the magnitude of increase observed with direct organ dose rates.

Discussion

Our investigation found that decreasing body habitus results in significant increases in point organ dose rates during simulated CTF procedures. Compared to the oversize phantom, point dose rates for the small phantom increased between 180-310% for internal organs, and between 24-36% for skin during simulated lumbar injections. Scatter dose rates measured at 5 cm from the beam also roughly doubled for the small phantoms compared with the oversize phantoms. These findings highlight the degree to

which decreasing body size results in increases in organ dose during CTF-guided interventions, and reinforce the need to take body habitus into account when considering radiation dose from such procedures.

Although the effect of habitus on dose in diagnostic CT scanning has been previously investigated, dosimetric techniques used for diagnostic scans are not accurate for estimating the dose for interventional techniques where a single small area is repeatedly exposed to the radiation beam without motion of the CT table^{17,18}. Previous investigators have used a variety of methods to estimate dose from stationary table intermittent-mode CTF-guided procedures. Dose estimates based on CTDI or dose length product using anatomic region-specific conversion factors (k-factors) have been employed by some investigators^{2,21,22}. However, the CTDI concept has marked limitations when applied to CTF procedures. First, it is not applicable to examinations where there is no translation of the CT table, and will overestimate peak dose from such studies by up to a factor of two^{17,18}. Second, although anatomic region-specific conversion factors (k-factors) have been described to convert the dose-length product (a value derived from CTDI_{vol}) to effective dose (ED), these conversion factors have been shown to result in inaccurate estimation of ED by up to a factor of 30 when the scan length is < 2 cm^{19,23}. Because most CTF procedures use scan lengths of <1 cm, the

Table 3 Comparison of mean internal organ point doses (excluding skin) by habitus.

Intervention	Dose Type	Statistic	Organ Dose by Habitus			Overall P-value*	Average vs Oversize	Average vs Small	Oversize vs Small
			Small	Average	Oversize		P-value**	P-value**	P-value**
Upper Lumbar	Direct	Mean (SD)	0.35 (0.07)	0.19 (0.03)	0.09 (0.01)	0.002	0.009	0.009	0.009
		Min,	0.28,	0.13,	0.07,				
		Median, Max	0.38, 0.43	0.20, 0.22	0.10, 0.11				
	Scatter	Mean (SD)	0.05 (0.01)	0.04 (0.01)	0.02 (0.01)	0.113	0.275	0.275	0.049
		Min,	0.03,	0.02,	0.01,				
		Median, Max	0.06, 0.06	0.04, 0.05	0.03, 0.03				
Lower Lumbar	Direct	Mean (SD)	0.28 (0.09)	0.15 (0.05)	0.07 (0.03)	0.027	0.049	0.049	0.049
		Min,	0.18,	0.10,	0.04,				
		Median, Max	0.32, 0.35	0.17, 0.18	0.09, 0.09				
	Scatter	Mean (SD)	0.04 (0.01)	0.03 (0.01)	0.02 (0.01)	0.012	0.076	0.076	0.009
		Min,	0.03,	0.02,	0.01,				
		Median, Max	0.05, 0.05	0.04, 0.04	0.03, 0.03				

Note – Dose units are mGy/10mAs.
 Statistical analysis based on N= 5 detector locations in the upper lumbar location and N = 3 detector locations in the lower lumbar location.
 * P-value based on Kruskal-Wallis test of difference among medians.
 ** P-value based on Wilcoxon rank sum test of difference among medians.

use of conversion factors to calculate ED in these procedures could result in significant inaccuracies. Finally, the standardized cylindrical phantoms used to quantify CTDI are sized for “typical” adult body habitus, and thus inherently fail to account for the effects of varied body habitus on individual patient dose¹⁷. As an alternative, dosimetry based on computer models using Monte Carlo simulations have been used, and have the advantage of estimating an average organ dose more precisely by taking into account partial organ exposure^{24,25}. Nevertheless, these simulations typically do not take variations in body habitus into account. Physical dosimetry using small MOSFET detectors in an anthropomorphic phantom, as we have employed in this investigation, is capable of measuring a point dose accounting for very narrow z-axis coverage, while the addition of varying thicknesses of adipose-equivalent material allows for simultaneous correction for body habitus.

Our study found that scatter dose rates were small compared with direct dose rates during CTF. This is not surprising given the narrowly collimated radiation beam used in CTF. We also found that similar to direct point dose rates, scatter dose also decreased with increasing habitus, although the magnitude of decline was less than the magnitude seen with direct organ doses. As a proportion of the total dose, the contribution from scatter increases in patients with larger body sizes.

The results of this study have implications for clinical practice. Tube current selection for CTF procedures is at the discretion of the operator, and ideally balances the need for adequate anatomic visualization, which generally improves with increasing tube current, against the desire for individual patient dose reduction achieved by decreasing tube currents. When performing procedures on patients of small body habitus, proceduralists may decrease tube current to prevent excessive dose. Conversely, compared

to patients of average body habitus, proceduralists may need to increase tube current to maintain image quality for visualization of soft tissue and bony landmarks. There is, however, wide variation in the degree to which tube current may be adjusted by individual operators to account for changes in body habitus, even in similar procedures on the same population of patients⁸.

Our results demonstrate that small patients should have tube current reduced compared to average patients to avoid relatively increased organ dose. A tube current reduction of approximately 50% would have been necessary to keep point organ dose rates in the small phantom equivalent to the average phantom. Conversely, increasing tube current by up to approximately 85% for oversized patients would not have resulted in increased direct organ dose compared with patients of average size. Although increases in tube current of this magnitude would result in increased skin dose, this increase would still fall well below the threshold doses for radiation-related deterministic effects on the skin for typically utilized CTF procedure times and tube current settings^{26,27}.

We have found in general that a tube current of 30-40 mA is adequate for lumbar interventions in most average sized patients. The results of our investigation suggest that modified tube current settings of 10-20 mA and 50-70 mA would be appropriate for small and oversized patients, respectively. Tube current adjustments of this order of magnitude would ensure that organ doses would not be substantially increased in patients with smaller or larger than average habitus. Previous investigations have suggested that patients with an AP diameter of >30 cm on the scout image can be considered oversized⁸, and in practice, we have found that an AP diameter of <20 cm can generally be used to define patients of small body habitus.

These guidelines should be kept in mind when selecting tube current for individual procedures, although it should be strongly emphasized that dose considerations must not supersede the need for adequate anatomic visualization sufficient to allow for technical success and to minimize procedural complications. In some cases of extreme body habitus, complicated or sensitive anatomy, or young patient age, these tube current parameters will need to be appropriately adjusted upward or downward. In particular, for procedures on patients with a very large body habitus, the tube current may need to be adjust-

ed upwards outside of this suggested range to maintain image quality sufficient to perform the procedure safely. Proceduralists must remember that the overall radiation dose from CTF is small compared with a diagnostic CT scan, and the theoretical risk from a marginal increase in radiation exposure will be much smaller than the immediate risk of performing an interventional procedure near sensitive anatomy without appropriate guidance.

There are several limitations to this study. First, in this investigation we measured organ point doses in the incident radiation beam using MOSFET detectors. Portions of organs outside of the beam would receive much lower doses. As a result, for CTF procedures, where only portions of organs are exposed, the point organ doses should not be interpreted as equivalent to absorbed organ doses. If these point doses were inappropriately used to calculate effective dose without adjusting for partial organ exposure, total patient dose would be significantly overestimated. Nevertheless, in this investigation, we were interested in the relative magnitude of change in dose among varying body sizes, which can readily be compared using point doses. Second, our scatter dose estimations are based on a limited number of detectors at a fixed distance away from the incident CTF beam. To determine the overall contribution of scatter to total patient dose during a procedure, a more complete profile of scatter dose along the z-axis would be necessary. Third, our phantom simulated three discrete sizes of body habitus, and assumed that increasing patient size would be due to increases in subcutaneous fat. In reality, patients would exist along a continuum of various body sizes, which may or may not match the phantom sizes we used, and would have fat distributed in differing anatomic locations, with varying contribution from muscle and organ tissue. Finally, we chose to model two particular interventions related to the lumbar spine. Although the effect of varying body habitus on dose during interventions in different parts of the body might be expected to be generally comparable, this question was not directly addressed in our investigation.

Conclusions

In conclusion, decreasing body habitus results in substantial increases in direct organ and skin doses as well as scattered dose during sim-

ulated CTF procedures. Failure to account for individual variations in body habitus will result in inaccurate estimation of radiation dose during such procedures. Understanding the effect

of habitus on dose in CTF-guided procedures can help proceduralists determine appropriate tube current settings for these procedures minimize patient dose.

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