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FULL PAPER

Tuning of automatic exposure control strength in lumbar spine CT

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Objective: To investigate the impact of tuning the automatic exposure control (AEC) strength curve (specific to Care Dose 4D®; Siemens Healthcare, Forchheim, Germany) from “average” to “strong” on image quality, radiation dose and operator dependency during lumbar spine CT examinations.

Methods: Two hospitals (H1, H2), both using the same scanners, were considered for two time periods (P1 and P2). During P1, the AEC curve was “average” and radiographers had to select one of two protocols according to the body mass index (BMI): “standard” if BMI < 30.0 kg m⁻² (120 kV–330 mAs) or “large” if BMI > 30.0 kg m⁻² (140 kV–280 mAs). During P2, the AEC curve was changed to “strong”, and all acquisitions were obtained with one protocol (120 kV and 270 mAs). Image quality was scored and patients' diameters calculated for both periods.

Results: 497 examinations were analysed. There was no significant difference in mean diameters according to hospitals and periods ($p > 0.801$) and in quality scores

between periods ($p > 0.172$). There was a significant difference between hospitals regarding how often the “large” protocol was assigned [13 (10%)/132 patients in H1 vs 37 (28%)/133 in H2] ($p < 0.001$). During P1, volume CT dose index (CTDIvol) was higher in H2 (+13%; $p = 0.050$). In both hospitals, CTDIvol was reduced between periods (–19.2% in H1 and –29.4% in H2; $p < 0.001$).

Conclusion: An operator dependency in protocol selection, unexplained by patient diameters or highlighted by image quality scores, has been observed. Tuning the AEC curve from average to strong enables suppression of the operator dependency in protocol selection and related dose increase, while preserving image quality.

Advances in knowledge: CT acquisition protocols based on weight are responsible for biases in protocol selection. Using an appropriate AEC strength curve reduces the number of protocols to one. Operator dependency of protocol selection is thereby eliminated.

Lower-back pain and sciatica affect up to 40% of people in western countries. These conditions are major causes of work-related disability and are costly to society.^{1–4} As lumbar disc herniation is the most common cause of sciatica, cross-sectional imaging, either with CT or MRI, is routinely performed. Despite requiring ionizing radiation, CT is frequently used first because it is readily available and less expensive than MRI.^{5,6} The challenge with CT is to minimize the radiation dose delivered,⁷ to maintain diagnostic accuracy (and/or image quality) and to tailor the dose to patient body habitus. Adequate adaptation can be reached either through manual selection of tube current according to the body mass index (BMI) or through automatic exposure control (AEC) systems that adapt tube current to patient absorption measured on scout view.^{5,8} However, the relationship between tube current and patient absorption differs within and between AEC

systems as illustrated in Figure 1.^{9–12} AEC systems, such as Auto mA® (GE Healthcare, Milwaukee, WI), are based on a single straight–linear relationship that maintains constant noise, whereas other systems, such as Care Dose 4D® (Siemens Healthcare, Forchheim, Germany), are based on several curvilinear relationships, named “strength curves” by the manufacturer, and are labelled “very weak”, “weak”, “average”, “strong” or “very strong”. These curvilinear relationships are characterized by increased noise in large patients and reduced noise in small patients, compared with normal individuals. Most importantly, increased noise is a limiting factor of lumbar spine CT scanning, as it is associated with increased intra- and interobserver variability.⁵

The default strength curve recommended by the manufacturer and selected at the time of unit installation is most

often set to “average”. Although this setting provides satisfactory dose modulation for scanning the chest and abdomen regardless of patient size, it is not so for the lumbar spine because of the increased noise in large individuals.⁸ In these individuals undergoing lumbar spine CT, the radiographer needs to select a specific higher dose protocol. However, this degree of individual dose adjustment also brings risk to normal sized patients and, if the higher dose protocol is inadvertently selected, these patients will be exposed to unnecessary high levels of radiation. In a recent annual local survey on CT radiation dose intended to provide data to the Federal Radiation Protection Agency, we observed that a series of consecutive patients had been scanned with higher dose protocols regardless of their weight. Although we had already drawn the attention of our radiographers to the need to adhere to written local guidelines for protocol selection, we thus suspected that there might still remain an operator dependency in this selection.

In 2011, the CT manufacturer (Siemens Healthcare) delivered an updated AEC release (Care Dose 4D VA11) enabling a user to assign a AEC strength curve specifically to each body region. This study, therefore, aimed first to solve the primary issue of operator dependency in protocol selection by replacing two weight-based protocols for lumbar spine CT by a single strength-curve-based protocol, and second to test whether the necessary image quality could be maintained with this protocol in all patients without increasing the radiation dose.

METHODS AND MATERIALS

Patient population

The current quality assurance retrospective study received approval from the local ethics committee, and informed consent was waived. CT examinations of the lumbar spine performed in two community hospitals (H1 and H2—both members of the same health group), during two time periods (May 2011: P1 and November 2011: P2) were considered.

All consecutive lumbar spine CT examinations obtained during both time periods were considered, except those in patients aged less than 18 years, or who had repeated CT examinations within the same month or who had a history of lumbar spine trauma or surgery.

Acquisition parameters

Each hospital was equipped with one commercially available 64 detector row 128-slice CT scanner (Somatom® Definition AS Plus; Siemens Healthcare). The AEC software release for Care Dose 4D was VA10 during P1 and VA11 during P2 in both hospitals.

During P1, acquisition parameters were identical in both hospitals. Collimation was 64×0.6 mm, pitch factor was 0.8:1 and the reconstruction width of the first axial series was 1.0 mm. With AEC VA10 release, a single strength curve had to be selected for all body regions. This curve was named “average” (Figure 1). In our clinical practice, this resulted in satisfactory image quality for chest and abdominal CT scans but not for the lumbar spine scans in obese patients. Therefore, tube potential and index of image quality of AEC (named “quality reference

mAs”) were set, respectively, at 120 kV and 330 effective mAs for normal sized patients (named “standard” protocol) and at 140 kV and 280 effective mAs for obese patients (named “large” protocol). The ratio in volume of CT dose index (CTDIvol) between both protocols corresponded to a 23% dose increase using the “large” protocol. The criteria for assigning patients to the “large” protocol were a BMI higher than 30.0 kg m^{-2} and weight >90 kg; these parameters were collected by the radiographer during anamnesis before scanning the patients.

During P2, acquisition parameters were also identical in both hospitals. Collimation and pitch remained unchanged. The VA11 release, installed between P1 and P2, enabled us to select one specific strength curve for each body region. The “strong” strength curve was selected by the radiologist who is in charge of the radiation dose quality control process in our department. This radiologist modified the AEC curve only for lumbar spine examinations and applied it to obese patients as defined by the AEC (*i.e.* those with an abdominal diameter >33 cm, a threshold arbitrarily fixed by the manufacturer), while he maintained the average curve for all other patients. The tube potential and reference tube current were, respectively, set at 120 kV and 270 effective mAs in order to deliver a similar dose to extremely obese patients as that delivered with the “large” protocol (140 kV and 280 effective mAs) and the “average” strength curve during P1.

Image reconstruction and archiving

Axial and sagittal 2-mm-thick slices were reconstructed using an iterative I30 strength 3 kernel (SAFIRE; Siemens Healthcare) and sent to our picture archiving and communication (PACS) system (Telemed SA, Louvain-la-Neuve, Belgium). Image reconstruction parameters were the same during both periods. All lumbar spine CT examinations obtained during both periods in both hospitals were retrieved from our PACS system and archived in a specific data file on a unique PACS server. Patient information and simulated tube charge presets were erased from the images, which were then randomly renumbered using random tables from Fisher and Yates.¹³

Assessment of patient diameter

Since abdominal diameter influences tube output when using AEC,⁸ patient abdominal diameters were recorded to determine whether or not there was a difference in typical patient sizes in the two time periods and between the two hospitals. As only one lateral scout view was obtained for planning the helical acquisition, and as axial slices have small fields of view that prevent measuring the outer patient diameter, we retrospectively used specific tables (provided by the manufacturer) characterizing the AEC curve strengths (Figure 2). The relative change in delivered effective tube current time product was calculated by dividing the mean delivered tube current time product by the default tube current time product, as displayed in the dose report. Using this relative change, the graph displayed in Figure 2 enabled us to estimate the patient diameter as a function of the AEC curve strength. The “average” AEC strength curve was selected for all patients during P1 in both hospitals. For P2 in both hospitals, AEC strength curves were selected depending on the diameter of the patient—“average” for <33 cm and “strong” for >33 cm.

Figure 1. Automatic exposure control strengths: different settings for modulation are possible, those used by Siemens Healthcare (Forchheim, Germany) are curvilinear and enable a fine tuning of the strength of the attenuation based mAs-adaptation depending on the user preferences. One single strength could be selected for all body regions with the VA10 release during P1, whereas one strength per acquisition mode could be selected with the latest VA11 release during P2. The attenuation-based mA adaptation of GE (General Electric Healthcare, Waukesha, MI) warranting a constant noise is displayed as a straight line.

Assessment of variations in protocol selection during P1

In order to detect possible variations in selecting the scanning protocol owing to patient BMI, we compared the proportions of patients scanned with the “large” protocol between hospitals during P1.

Assessment of image quality

In order to compare image quality between both periods, one general radiologist and one neuroradiologist (with 12 and 23 years’ of experience in reading CT scans, respectively), who were blinded to the acquisition parameters and to the AEC strength curve, scored the image quality according to a five-point scale:

Figure 2. Patient’s diameter estimated from the scout view, according to the relative change in mAs (mean delivered mAs divided by default protocol mAs) and the selected automatic exposure control (AEC) strength curve.

1, unacceptable for diagnosis; 2, significant image noise but still having diagnostic value; 3, acceptable noise and image quality suited for diagnosis; 4, little image noise and good image quality; and 5, almost no noise and excellent image quality.

Assessment of radiation dose

Individual dose reports corresponding to each CT examination were recorded, including patient age and gender, tube potential, nominal and mean delivered effective tube current time products expressed in effective mAs (mAs_{eff}), CTDI_{vol} and dose-length product (DLP) of helical acquisitions.

Statistical analyses

Differences in proportions were tested with the use of exact Pearson χ^2 tests. Patient diameters and image quality scores were submitted to analysis of variance tests with two between-group factors (hospital and period).

RESULTS

Patient population

13 patients were excluded because of prior lumbar spine surgery. The study was thus based on 497 patients (230 males and 267 females) with a mean age of 52 years ($\pm$ standard deviation of 16 years). The number of patients scanned in each period and for each hospital are displayed in Table 1, along with their corresponding mean diameters. There was no statistical difference in the abdominal diameter between both hospitals ($p = 0.801$) and periods ($p = 0.928$). During P1, the proportion of patients with a diameter >33 cm was 18% (24/132) in H1 and 24% (32/133) in H2 ($p = 0.292$).

Comparison between hospitals in assigning patients to the “large” protocol

During P1, the proportion of patients scanned with the “large” protocol was 10% (13/132) in H1 and 28% (37/133) in H2 ($p < 0.001$). During P2, no “large” protocol was selected for either hospital.

Average radiation dose before and after modifying automatic exposure control strength curve

In both hospitals and during both periods, dose reports mentioned no more than one helical acquisition in each patient, with no patient having had two acquisitions. CTDI_{vol}, dose-length product and size-specific dose estimates calculated according to the report of the American Association of Physicists in Medicine¹⁴ are displayed in Table 2 for both hospitals and periods. Mean CTDI_{vol} was 13% higher in H2 than in H1 ($p = 0.050$) during P1 and 1% lower ($p = 0.825$) during P2. Between P1 and P2

CTDI_{vol} was reduced by 19% in H1 ($p < 0.001$) and 29% in H2 ($p < 0.001$).

Image quality

The image quality score ranged from 2 to 5 regardless of reader, hospital or period, with no scan being scored 1 (unacceptable) during either period. Mean scores ranging from 3.4 to 3.9 according to hospitals, periods and readers are presented in Table 3. There was no statistically significant difference in the mean image quality scores between periods for either hospital (p ranging from 0.172 to 0.801). For both readers and periods, the mean image quality scores were not statistically significantly different between hospitals (p ranging from 0.110 to 0.472), except for Reader 1 during P1 ($p < 0.001$).

DISCUSSION

This study shows the following: (1) significant variations in the selection of CT scan protocol between radiographers in two hospitals of the same health group can occur; (2) selection differences may result in a higher dose that is not justified or explained by differences in patient diameters; (3) the use of a “strong” strength AEC curve (rather than the historically more frequently used “average” curve) enables the scanning of all patients with one unique protocol, while maintaining mean image quality score and avoiding unacceptable examinations; and (4) the radiation dose delivered with modern scanners can be much lower for these examinations than the reference surveys in similar populations^{15–19} and can be further improved by tuning the AEC strength curve.

Technical factors, such as patient centering and lengthening or shortening the scan, are well-known parameters managed by radiographers that influence the overall radiation dose delivered to patients.^{20–23} Radiographers continue to have an important role in optimizing these parameters.

It might be deduced from the results of this study that patients might have been exposed to an additional dose as the consequence of being unnecessarily allocated to a “higher dose” protocol. In our analysis, we found that during the first period a 13% difference in CTDI_{vol} between the two hospitals. Although this difference did not reach statistical significance (with a p -value of 0.050), the trend in dose increase is likely to be attributed to an “incorrect” (either overly conservative or overly liberal) allocation of patients to the “large” acquisition protocol in one hospital. Indeed, although the number of patients with an abdominal diameter >33 cm did not significantly differ between both hospitals, the proportion of allocation to the large protocol did, being significantly higher in one hospital than in the other (28% in H2 vs 10%

Table 1. Number of included patients with mean abdominal diameters according to the hospitals and periods

Parameters	Hospital 1		Hospital 2	
	Period 1	Period 2	Period 1	Period 2
Patients (n)	132	136	133	96
Mean diameter $\pm$ standard deviation (cm)	30.9 $\pm$ 4.1	31.4 $\pm$ 3.2	31.4 $\pm$ 3.9	31.0 $\pm$ 3.5

Period 1 is May 2011, and Period 2 is November 2011.

Table 2. Average CTDIvol, dose-length products and size-specific dose estimates (SSDEs) according to the hospital and the period

Hospital and period	CTDIvol (mGy)	DLP (mGy cm)	SSDE (mGy)
Hospital 1			
Period 1	24.0 ± 12.1	352 ± 197	28.6 ± 14.4
Period 2	19.4 ± 8.1	292 ± 143	23.1 ± 10.8
Hospital 2			
Period 1	27.2 ± 14.4	405 ± 245	32.4 ± 17.1
Period 2	19.2 ± 10.4	283 ± 157	22.8 ± 12.4

Period 1 is May 2011, and Period 2 is November 2011.

SSDEs are calculated according to The American Association of Physicists in Medicine.¹⁴

Data are presented as mean ± standard deviation.

in H1). We thus retrospectively demonstrated that radiographers in one hospital were not as strict as those in the other hospital in assigning “large” protocols to only obese patients. Reasons for these differences might include a fear to produce inadequate image quality or simply a poor adhesion to guidelines. A low rate of adherence to guidelines has been reported among radiologists,²⁴ but is rarely investigated among radiographers.²⁵ It has been previously suggested that the radiographer’s choice of a higher dose protocol might be linked to local radiologists’ preference of a higher image quality. This argument, however, appears to not hold true in all cases. In our study, radiologists of both hospitals belonged to the same health group and had been active in both hospitals. In addition, radiology department guidelines for conducting CT examinations, which were approved by all radiologists, were strictly the same in both hospitals. Finally, we retrospectively investigated why differences in protocol selection were observed between both hospital sites. We found that a possible cause could be that the higher dose protocol was selectable

immediately next to the normal dose in the “spine” CT menu in H2, whereas in H1 the higher dose protocol had been located by the head radiographer in another menu that needed two additional mouse clicks to be opened.

In changing the AEC strength curve from “average” to “strong”, one would expect to observe an increase in delivered radiation dose. Bearing this in mind, we empirically updated scanning parameters. This enabled us to warrant that obese patients would have an equivalent dose during the second period to what they would have received during the first period, while avoiding triage bias. However, the updated scanning parameters (reduced reference effective mAs), which reduced the dose delivered to non-obese patients, were also expected to have a potential risk of reducing the image quality in all non-obese patients. This was not observed, and the image quality scores did not change between both periods, probably reflecting that our original settings were not yet as low as reasonably achievable.

Table 3. Image quality scores as a function of the reader, hospital and period (mean and standard deviation)

	Image quality score	
Reader 1		
Hospital 1		
Period 1	3.43 (0.81)	$p = 0.801$
Period 2	3.60 (0.82)	
Hospital 2		
Period 1	3.98 (0.56)	$p = 0.172$
Period 2	3.78 (0.68)	
Reader 2		
Hospital 1		
Period 1	3.85 (0.37)	$p = 0.244$
Period 2	3.79 (0.49)	
Hospital 2		
Period 1	3.90 (0.32)	$p = 0.432$
Period 2	3.86 (0.40)	

Period 1 is May 2011, and Period 2 is November 2011.

All dose descriptors [CTDIvol, size-specific dose estimates (SSDEs) and DLP] decreased during the second period compared with those of the first period, and were among the lowest ever reported for lumbar spine CT examination (Table 4).^{15–19} In order to avoid confusion while comparing our CTDIvol values to various survey data, we also provide the SSDEs that take into account the population characteristics in terms of patient diameter (Table 2). Moreover, as the current tuning of the AEC had no major impact on image quality, the proposed strategy in strength curve selection appears efficient for dose optimization while simultaneously getting rid of operator dependency in protocol selection.

This study has some limitations. First, since only two hospitals were compared, the observed differences in protocol allocation between hospitals could not be generalized. Second, because our study was retrospective, it was not feasible to prospectively assign one hospital to the new AEC tuning while maintaining the original settings at the other. Third, only two radiologists assessed the image quality. Their respective scores might therefore not exactly reflect the opinion of a larger group of radiologists. However, since the study was retrospective and there had been no complaints about image quality of lumbar spine examinations from any member of the department and from

Table 4. Comparison of dose-length products from CT examinations of the lumbar spine

Study/survey	25th percentile (mGy cm)	75th percentile (mGy cm)
Current study during P1 ^a	229	439
Current study during P2 ^a	191	333
Germany 2011 ¹⁵	NA	500
France 2011 ¹⁶	NA	750
Switzerland 2010 ¹⁷	282	896
Luxembourg 2010 ¹⁸	403	700
Belgium 2010 ¹⁹	475	870

The average patient diameter in this study is 31 ± 3.5 cm.

P1 and P2 are two time periods.

75th percentile corresponds to the diagnostic reference level.

25th percentile is provided as an indicator of optimized dose.

The average values for both hospitals as observed in the present study are shown in Table 2 and are at the level of P25 in Switzerland.

^aValues of the present study during P1 and P2 are pooled from the two hospitals involved.

any referring physicians, one could reasonably hypothesize that the observed scores would also be similar from a larger group of readers.

Fourth, image quality was assessed only once. This however reflects usual clinical practice since examinations are not routinely interpreted twice. Fifth, some differences in assessing image quality of the same examinations were elicited between radiologists. Variations between radiologists in reading lumbar spine examinations are very frequent.^{5,26} Having said that, our readers scored all images as acceptable for diagnosis, so the differences between them were therefore not clinically relevant. Sixth, we assigned acquisition protocols to patients according to BMI but used calculated diameters in order to estimate the correctness of these assignments. Because correlations between

BMI and patient diameters are not very strong (correlation was weaker between a patient's diameter and BMI than correlation between patient circumference and BMI), we cannot exclude that actual differences in BMI could have, at least in part, justified differences in protocol assignment.²⁷

Finally, the tuning of AEC strength curve is specific to one manufacturer only, and the scope of the strength curve tuning is therefore quite narrow.

In conclusion, tuning of AEC strength curves from "average" to "strong" for large patients and reducing the default tube current by 20% in all patients for scanning the lumbar spine maintains image quality, while reducing the delivered radiation dose and eliminating operator variations in protocol assignment.

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