Methods for CT Automatic Exposure Control Protocol Translation Between Scanner Platforms

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Purpose: An imaging facility with a diverse fleet of CT scanners faces considerable challenges when propagating CT protocols with consistent image quality and patient dose across scanner makes and models. Although some protocol parameters can comfortably remain constant among scanners (eg, tube voltage, gantry rotation time), the automatic exposure control (AEC) parameter, which selects the overall mA level during tube current modulation, is difficult to match among scanners, especially from different CT manufacturers.

Methods: Objective methods for converting tube current modulation protocols among CT scanners were developed. Three CT scanners were investigated, a GE LightSpeed 16 scanner, a GE VCT scanner, and a Siemens Definition AS+ scanner. Translation of the AEC parameters such as noise index and quality reference mAs across CT scanners was specifically investigated. A variable-diameter poly(methyl methacrylate) phantom was imaged on the 3 scanners using a range of AEC parameters for each scanner. The phantom consisted of 5 cylindrical sections with diameters of 13, 16, 20, 25, and 32 cm. The protocol translation scheme was based on matching either the volumetric CT dose index or image noise (in Hounsfield units) between two different CT scanners. A series of analytic fit functions, corresponding to different patient sizes (phantom diameters), were developed from the measured CT data. These functions relate the AEC metric of the reference scanner, the GE LightSpeed 16 in this case, to the AEC metric of a secondary scanner.

Results: When translating protocols between different models of CT scanners (from the GE LightSpeed 16 reference scanner to the GE VCT system), the translation functions were linear. However, a power-law function was necessary to convert the AEC functions of the GE LightSpeed 16 reference scanner to the Siemens Definition AS+ secondary scanner, because of differences in the AEC functionality designed by these two companies.

Conclusions: Protocol translation on the basis of quantitative metrics (volumetric CT dose index or measured image noise) is feasible. Protocol translation has a dependency on patient size, especially between the GE and Siemens systems. Translation schemes that preserve dose levels may not produce identical image quality.

Key Words: CT protocols, automatic exposure control, tube current modulation, phantoms

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INTRODUCTION

The development of CT protocols on a given scanner requires significant technical familiarity with CT and a great deal of clinical experience as a radiologist to determine the optimal trade-off between adequate diagnostic image quality and low radiation dose. Furthermore, a large number of different protocols are used on any modern CT scanner, specific to head, chest, abdomen and pelvis, and other niche imaging applications. It is not uncommon for a clinical CT scanner to have 200 to 300 protocols loaded onto it, of which perhaps 20 are used with frequency.

Because CT scanners are important diagnostic workhorses at most medical centers, the number of CT scanners at each institution can range from 1 to 3 for small facilities to 30 or more for large regional health systems. In such an environment, there is usually a range of different types of CT scanners, typically different models from the same commercial vendor, and often,

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CT scanners from several different vendors are located at a given institution. This heterogeneity reflects changes in purchasing preferences over the lifetime of the CT scanner inventory. In this common situation, radiologists (with CT technologists and medical physicists) are faced with the challenge of converting existing, well-established CT protocols from one CT scanner to different scanners, in some cases newer scanners from the same CT manufacturer and in some cases new scanners from different manufacturers. Because it is unrealistic to develop a complete set of new CT protocols for every type of CT scanner that is available at a given institution, it is useful to have a method by which CT protocols from one scanner (referred to in this paper as the reference scanner) to one or more secondary CT scanner systems.

In the era when fixed x-ray tube current protocols were common, translating CT protocols on the basis of similar dose metric levels was relatively straightforward. However, automatic exposure control (AEC) with x-ray tube current modulation (TCM) is now widely used in CT, especially in thoracic and abdominopelvic CT applications [1]. With the use of AEC, protocol translation becomes much more complicated, especially among different CT manufacturers [2,3].

Developing objective methods to translate CT protocols from one scanner to another requires that either radiation dose levels or CT image quality (essentially image noise) be used as the translational metric, that is, the parameter that is held constant as a CT protocol is propagated from one scanner to another. In this study, radiation dose levels were quantified using the volumetric CT dose index ($CTDI_{vol}$), which is a ubiquitous quantity that is reported by all modern CT scanners on the operator's console. If radiation dose levels are kept constant through the protocol conversion exercise, the assumption is that similar image quality levels (between the reference scanner and the secondary scanner) will result. There are a number of assumptions (similar reconstruction kernels, reconstructed slice thicknesses, reconstructed field of view, etc) required for this to be true, but in principle, this is a reasonable assumption.

Another approach to matching protocols among different CT scanners is to attempt to maintain the same image quality (noise, as measured by the standard deviation in Hounsfield units [HU], σ_{HU}) as a given protocol is translated from the reference to the secondary scanner. This approach is tailored more toward matching the appearance of images as seen by the radiologist but is also dependent on the selection of similar reconstruction kernels (and whether iterative reconstruction techniques are used) among CT scanners.

In this investigation, radiation dose levels as quantified by $CTDI_{vol}$ and image quality (as quantified by σ_{HU}) were used to develop conversion techniques between protocols between one reference scanner and two different secondary CT systems.

METHODS

The translation scheme used in this study assumes that there is a reference scanner with a list of well-established protocols, and the goal is then to translate these protocols to a secondary CT scanner of different make and/or model. The focus of this effort is to develop AEC parameters that match either "dose" ($CTDI_{vol}$) or measured image noise among scanners.

The Phantom

A variable-diameter ("wedding cake") phantom was constructed from 5 poly(methyl methacrylate) (PMMA) cylindrical phantoms (Fig. 1A). Each phantom had a length of 15 cm; the physical phantom diameters were 13, 16, 20, 25, and 32 cm. When the density of PMMA (ρ = 1.19 g/cm^2) is factored in, the phantoms had water-equivalent diameters of 15, 18, 22, 27, and 34 cm, approximating patient diameters from a newborn to a large adult. The phantoms were stacked longitudinally and held together in tension with a PMMA rod through a centering hole. The central axis of the phantom was positioned at the system's isocenter, with the small-diameter phantoms supported with foam blocks. The phantom was oriented such that the 32-cm cylinder was at the "head" position of the table and the 13-cm phantom was at the "feet" position.

CT Scanners

The phantom was imaged using 3 clinical CT scanners. The reference scanner was a GE LightSpeed 16 (GE Medical Systems, Waukesha, Wisconsin), which contains an extensive set of patient protocols developed by the chief CT radiologist at our institution. One secondary scanner was a GE VCT (GE Medical Systems), and the other secondary scanner was a Siemens Definition 128 AS+ (Siemens Medical Systems, Erlangen, Germany).

The standard abdominal and pelvic protocol at 120 kV was used on all scanners. Details of the technique factors are provided in Table 1. Several parameters were held constant between protocols; the tube potential was set to 120 kV in all cases, and all images were reconstructed with a 400-mm field of view and a slice thickness of 5 mm. The standard kernel was used on the GE scanners, and the B40 kernel was used on the Siemens scanner. The large-body bowtie filter was used in all cases. On each scanner, the phantom was imaged repeatedly over a wide range of AEC parameter values: noise index on the GE systems and the quality reference mAs on the Siemens scanner.

The AEC metric on the GE scanners, the noise index, was designed by the manufacturer to be directly proportional to image noise. The tube current ranged from 100 to 440 mA on the LightSpeed 16 and from 100 to