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The Effect of Extrinsic Material and Radiation Dose on Model-Based Iterative Reconstruction Chest Computed Tomography Reconstruction Time: A Phantom-Based Study

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ABSTRACT

Objective: Compare effect of extrinsic materials and radiation dose levels on image processing times for model-based iterative reconstruction (MBIR) in computed tomography.

Methods: Chest computed tomography scans were performed on a phantom with three different levels of clothing and medical equipment at three tube current settings to reflect differing radiation doses. Reconstruction time for MBIR was recorded, and objective image quality was assessed via noise within the phantom mediastinum. Reconstruction time and noise were compared between scans, with noise also compared between MBIR and matching filtered back projection (FBP) images.

Results: Reconstruction times (minutes:seconds) ranged from 37:31 to 42:24. Times were generally faster with less extrinsic material and prolonged among high-dose scans when materials were present. On both the MBIR and FBP images, noise levels were improved with higher radiation doses, although for MBIR only minimally, and the relative effect of extrinsic materials at a given radiation dose was also minimal. In addition, noise was better with MBIR than FBP reconstruction for all conditions.

Conclusions: Typical MBIR reconstruction times are faster with less extrinsic materials in the scan field of views, and removing extraneous blankets or medical devices could positively affect workflow over the course of the day. In addition, MBIR reconstruction times are also shorter when using lower dose protocols in situations requiring extensive materials.

RÉSUMÉ

Objectif : Comparer l'effet de matériaux extrinsèques et des niveaux de dose de rayonnement sur le temps de traitement des images pour la reconstruction itérative basée sur un modèle (MBIR) en tomodensitométrie.

Méthodologie : Des images TDM de la poitrine ont été prises sur un fantôme avec trois niveaux différents de vêtements et d'équipement médical à trois réglages du courant du tube afin de refléter différentes doses de radiation. Le temps de reconstruction pour la MBIR a été enregistré et la qualité objective des images a été évaluée selon le bruit dans le médiastin du fantôme. Le temps de reconstruction et le bruit ont également été comparés entre la MBIR et les images par appariement des rétroprojections filtrées (FBP).

Résultats : Le temps de reconstruction (minutes:secondes) allait de 37:31 à 42:24. Le temps était habituellement plus court lorsqu'il y avait moins de matériaux extrinsèques et plus long pour les scans à dose élevée lorsque les matériaux étaient présents. Sur les images MBIR comme sur les images FBP, le niveau de bruit était amélioré avec une dose de radiation plus élevée, même si l'amélioration était minimale dans le cas des images MBIR, et l'effet relatif des matériaux extrinsèques à une dose de radiation donnée était6 aussi minimal. De plus, le bruit était meilleur dans la reconstruction MBIR que dans la reconstruction FBP sous toutes les conditions.

Conclusion : Les temps de reconstruction MBIR typiques sont plus rapides lorsqu'il y a moins de matériaux extrinsèques dans le champ de balayage, et le retrait des couvertures ou des appareils médicaux inutiles pourrait avoir une incidence positive sur le flux de travail dans la journée. De plus, les temps de reconstruction MBIR sont aussi plus courts avec des protocoles à plus faible dose dans les situations exigeant un matériel important.

Conflicts of interest: Troy Anderson, GE CT Applications Specialist.

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Introduction

The increased use of computed tomography (CT) scan in recent years and associated concerns regarding patient radiation exposure have been the impetus for the development of dose reduction strategies, including several image reconstruction algorithms. Model-based iterative reconstruction (MBIR) is an image reconstruction algorithm that has emerged as a method to increase signal-to-noise ratio with less radiation dose while maintaining diagnostic quality images [1]. However, with use of MBIR, reconstruction times can be lengthy [2]. These prolonged reconstruction times are one reason why clinical use has been limited, as processing delays can both impede workflow and limit the number of scans that can be performed using MBIR processing. Our investigation considered the effect of extrinsic material and radiation dose on reconstruction times. Based on conversations with GE Healthcare representatives, we hypothesised that both increasing extrinsic material and decreasing radiation dose would lengthen MBIR reconstruction time. The reasoning for expected longer reconstruction times with greater extrinsic materials was that more time would be needed for the production of a more complex final image; the reasoning for expected longer processing times with lower dose scans was based on an extrapolation from small field of view imaging, with the thought that the initial data would be intrinsically noisier and require more processing to reach an acceptable image quality. We also wished to examine differences in objective image quality, quantified as image noise, between the MBIR and filtered back projection (FBP) techniques and particularly whether or not the anticipated improvement in image quality when using MBIR was consistent at differing levels of radiation dose and extrinsic material.

Methods

A female phantom (RANDO; The Phantom Laboratory, Salem, NY) was used. The RANDO phantom is built on a human skeleton with materials radiologically equivalent to human soft tissues. The phantom is sectioned into 2.5 cm thick slabs, with slab numbers 11–20 representing the chest section (25 cm total length). CT scanning of the chest section was performed with a 64-detector row CT scanner (750HD; GE Healthcare, Milwaukee, WI) at 100 kVp and the following three different tube current settings: 160 mA (100% dose), 80 mA (50% dose), and 15 mA (10% dose). These settings were based on our usual scanning practice, with our routine clinical chest CT parameters considered as full dose; the only variation from typical scanning was the non-use of automatic tube current modulation to limit potential variability. All other scan parameters were held constant as follows: pitch 0.984:1; rotation time 0.6 s; scan field of view 50 cm; display field of view 38 cm; collimation 4.0 cm; matrix 512 $\times$ 512; standard reconstruction algorithm. Scan time for each individual scan was 4.5 seconds. MBIR was performed on a dedicated server (Veo; GE Healthcare).

The phantom was imaged with three levels of extrinsic material as follows: (1) nothing added (no materials); (2) clothing added (light clothing and a single blanket); and (3) extensive materials added (light clothing with three blankets, two 1000 cc IV bags and ventilation tubing). Three scans of each radiation dose with each level of extrinsic material for a total of 27 scans were performed.

There is no data log for transfer times to and from the MBIR processing computer on the scanner console. However, as there is an icon on the scanner console to indicate when MBIR is occurring, reconstruction times were recorded from the scanner console using a video log, a video camera recording of the icon beside a stop watch. Thus, processing time for each data set could be determined by monitoring the icon for changes.

Image quality was assessed via image noise on 0.625 mm thick axial images. One consistent 5 cm^2 region of interest was placed within the identical location of the phantom mediastinum across all scans. From this region of interest, the image noise (standard deviation of Hounsfield Units [HU]) was recorded for each scan. This noise measurement allowed standardised comparison of MBIR images to standard noniterative FBP images.

Mean values and standard deviations for the outcome of reconstruction time were examined at each level of clothing and radiation dose, as well as for the nine treatment groups generated by cross-classification on these two variables. Two-way analysis of variance (ANOVA) was used to assess differences in the respective effects of extrinsic material and radiation dose on reconstruction time, as well as the consistency of each of these effects at differing levels of the other. With statistically significant interaction, differences across the three levels of one factor were further compared at each level of the other. If statistically significant difference was subsequently detected within a particular level, pairwise comparisons were undertaken using Tukey's procedure. Similarly, the outcome of noise was examined in regard to its relationship with radiation dose, amount of extraneous material, and additionally, algorithm (MBIR or FBP), the latter to evaluate the consistency of improved image quality of MBIR over FBP at differing levels of radiation and materials, respectively. Two-way ANOVA, as used for reconstruction time analysis, was subsequently extended to the general linear model to accommodate three factors. Again, if interactions were statistically significant, pairwise comparisons were assessed using least-squares means and Tukey's adjustment for multiple comparisons. All analysis was undertaken using the PROC GLM procedure provided by the SAS software, version 9.4 (SAS Institute Inc, Cary, NC).

Results

The shortest and longest mean reconstruction times (minutes:seconds) were 37:31 (SD = 24.8 seconds; 50% dose, no materials added) and 42:24 (SD = 12.5 seconds; 100% dose, maximum extrinsic material), respectively. Mean reconstruction times by radiation dose and amount of extrinsic material are presented in Figure 1. Two-way