Original Investigation

Computed Tomography Window Blending : Feasibility in Thoracic Trauma

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Rationale and Objectives: This study aims to demonstrate the feasibility of processing computed tomography (CT) images with a custom window blending algorithm that combines soft-tissue, bone, and lung window settings into a single image; to compare the time for interpretation of chest CT for thoracic trauma with window blending and conventional window settings; and to assess diagnostic performance of both techniques.

Materials and Methods: Adobe Photoshop was scripted to process axial DICOM images from retrospective contrast-enhanced chest CTs performed for trauma with a window-blending algorithm. Two emergency radiologists independently interpreted the axial images from 103 chest CTs with both blended and conventional windows. Interpretation time and diagnostic performance were compared with Wilcoxon signed-rank test and McNemar test, respectively. Agreement with Nexus CT Chest injury severity was assessed with the weighted kappa statistic.

Results: A total of 13,295 images were processed without error. Interpretation was faster with window blending, resulting in a 20.3% time saving ($P < .001$), with no difference in diagnostic performance, within the power of the study to detect a difference in sensitivity of 5% as determined by post hoc power analysis. The sensitivity of the window-blended cases was 82.7%, compared to 81.6% for conventional windows. The specificity of the window-blended cases was 93.1%, compared to 90.5% for conventional windows. All injuries of major clinical significance (per Nexus CT Chest criteria) were correctly identified in all reading sessions, and all negative cases were correctly classified. All readers demonstrated near-perfect agreement with injury severity classification with both window settings.

Conclusions: In this pilot study utilizing retrospective data, window blending allows faster preliminary interpretation of axial chest CT performed for trauma, with no significant difference in diagnostic performance compared to conventional window settings. Future studies would be required to assess the utility of window blending in clinical practice.

Key Words: CT postprocessing; CT dynamic range; CT windowing; chest CT; thoracic trauma.

INTRODUCTION

Rapid and accurate interpretation of computed tomography (CT) images is an essential component of managing acutely traumatized patients based on the "golden hour in shock" (1) principle that calls for immediate recognition and treatment of life-threatening injuries. The CT findings of code-trauma patients are interpreted and verbally communicated in a real-time fashion while the patient is still on the CT table as soon as the first axial reconstructions are available. This immediate interpretation allows the trauma surgeon to plan surgical intervention or transfer the patient to the intensive care unit or a major trauma center within minutes of image acquisition, as has been previously described in mass casualty incidents (2–4) and in combat (5). Because the dynamic range acquired by CT is greater than can be displayed on an 8-bit or 10-bit clinical workstation monitor (6), each examination must be thoroughly reviewed in at least three distinct window and level settings optimized for soft tissue, lung, and bone to optimally visualize critical injuries that may only be evident in a specific window setting. In high-acuity situations or mass casualty incidents where multiple CT scanners may be operating simultaneously, a technique to eliminate the need for adjustment of window and level settings has the potential to expedite the image review process and streamline patient throughput during the "golden hour."

Through image processing techniques, the wide dynamic range of CT can be compressed to a reduced number of grayscale shades to allow simultaneous display of the full range of medically useful information in a single pass, without needing

Acad Radiol 2018; ■:■■–■■

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Received November 22, 2017; revised December 17, 2017; accepted December 28, 2017.
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https://doi.org/10.1016/j.acra.2017.12.029

TABLE 1. Abbreviated List of Findings Determining Classification by Nexus CT Chest Criteria (13)

Major clinical significance	Pneumothorax or hemothorax, requiring chest tube
	Aortic or great vessel injury
	Multiple rib fractures, requiring surgical intervention or epidural nerve block
	Thoracic spine or scapular fracture, requiring surgical intervention
	Pulmonary contusion, requiring mechanical ventilation for respiratory failure
	Esophageal, tracheal, or bronchial injury, requiring surgical intervention
Minor clinical significance	Pneumothorax or hemothorax, not requiring evacuation procedure but observed as an inpatient
	Multiple rib fractures, not requiring surgical intervention or epidural nerve block
	Sternal, thoracic spine, or scapular fracture, not requiring surgical intervention
	Esophageal, tracheal, or bronchial injury, not requiring surgical intervention
No clinical significance	Hemothorax, pneumothorax, pneumomediastinum, pulmonary contusion/laceration, not requiring intervention or inpatient observation

CT, computed tomography.

to change window or level settings. Several methods have previously been described to achieve this goal including window blending (7,8), companding (9), nonlinear CT windows (10), histogram equalization (11), and adaptive histogram equalization (12). None of these methods have achieved widespread clinical use, and many suffer from various artifacts and unfamiliar modification in relative attenuation of the fundamental radiographic densities.

In this study, we evaluate a custom postprocessing window blending algorithm that is performed on reconstructed images and allows the full dynamic range of CT to be visualized on a single image, without requiring any adjustment in window or level settings. In contrast to several previous methods, the normal relationships between the fundamental anatomic CT densities are largely maintained. We focused this pilot investigation on chest CT, as the thorax contains the widest range of attenuation in the body, and conventional CT images must therefore be reviewed in at least three window settings.

Our hypothesis is that window blending postprocessing will decrease the interpretation time of chest CTs performed for trauma without a statistically significant or clinically significant decrease in diagnostic performance. This study aims to demonstrate the feasibility of processing and interpreting CT images with a custom window blending algorithm, to compare the time required for preliminary verbal interpretation of axial chest CTs performed for trauma with window blending and conventional window settings (primary outcome), and to assess the diagnostic performance of each technique compared to a reference standard (secondary outcome).

MATERIALS AND METHODS

This study utilizing retrospective data was performed with approval from our institutional review board with waiver of informed consent, and was in compliance with Health Insurance Portability and Accountability Act regulations.

Case Selection

For the primary outcome (time for interpretation), sample size was calculated as 73 patients to detect a difference of 20 seconds with a standard deviation of 60 seconds, with 80% power and 0.05 significance. We aimed for a sample size greater than 100 patients to allow as a buffer in case of variations in interpretation time. For the secondary outcome (comparing sensitivity and specificity of the blended and conventional windowing), a post hoc power analysis was performed, as the number of discrete findings could not be reliably predicted in advance.

Patients were selected by searching the institutional Picture Archiving and Communication System (PACS) for consecutively performed contrast-enhanced chest CTs performed for trauma. Examinations performed at this level 1 trauma center and outside transfers were included in the search between July 1, 2015, and January 31, 2017. To ensure that a broad spectrum of traumatic thoracic injuries was included, injuries were stratified based on previously reported Nexus CT Chest expert panel determination of clinical significance of injuries seen on chest CT (13). This expert panel (composed of 10 senior physicians, including 6 emergency medicine physicians and 4 trauma surgeons) divided thoracic injuries into findings of major clinical significance, minor clinical significance, and no clinical significance (Table 1).

A total of 365 patients underwent a contrast-enhanced chest CT for trauma at this institution during the searched date range, and an additional 45 patients were transferred to this institution, having previously undergone a contrast-enhanced chest CT at an outside institution before transfer. These outside images were loaded into the PACS at our institution and interpreted by a staff emergency radiologist, with a formal report generated and stored in PACS (14). Outside examinations were included given that many patients are transferred with more severe injuries than patients brought in directly by local ambulance. The chest CT reports and clinical information of all 410 patients who underwent chest CT for trauma (365 performed at this institution and 45 performed elsewhere) were screened for inclusion in the study by the first author. Nexus CT Chest classification was determined based on imaging findings, operative reports, follow-up imaging, and clinical notes.

Of these 410 chest CTs, 22 (5.4%) contained findings of major clinical significance by Nexus CT Chest criteria. As these are the most critical injuries to identify, all 22 cases were