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A Novel CT Volume Index Score Correlates with Outcomes in Polytrauma Patients with Pulmonary Contusion

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Background. **Exact quantification of pulmonary contusion by computed tomography (CT) may help trauma surgeons identify high-risk populations. We hypothesized that the size of pulmonary contusions, measured accurately, will predict outcomes. Our specific aims were to (1) precisely quantify pulmonary contusion size using pixel analysis, (2) correlate contusion size with outcomes, and (3) determine the threshold contusion size portending complications.**

Methods. **Thoracic CTs of 106 consecutive polytrauma patients with pulmonary contusion were evaluated at a university-based urban trauma center. A novel CT volume index (CTVI) score was calculated based on the ratio of affected lung to total lung [slices of lung on CT × affected pixel region/lung pixel region × 0.45 (left side) + slices of lung on CT × affected pixel region/lung pixel region × 0.55 (right side)]. Multivariate analysis correlated CTVI and patient predictors' impact on outcomes.**

Results. **Of 106 polytrauma patients (mean ISS = 28 ± 1.2, AIS chest = 3.5 ± 0.1), 39 developed complications (acute respiratory distress syndrome [ARDS], pneumonia, and/or death). Mean CTVI was significantly higher in the group with complications (0.28 ± 0.03 *versus* 17 ± 0.02, $P = 0.01$). By multivariate analysis, CTVI predicted longer ICU LOS ($R^2 = 0.84$, $P < 0.01$). A receiver operating curve (ROC) analysis identified a CTVI threshold score of 0.2 (AUC 0.67, $P < 0.01$) for developing pneumonia, ARDS or death. Patients with CTVI scores of 0.2 or more had longer hospitalization, longer ICU LOS, more ventilator days, and developed pneumonia ($P < 0.01$).**

Conclusions. **Higher CTVI scores predicted prolonged ICU LOS across all sizes of pulmonary contusion. Pulmonary contusion volumes greater than 20% of total lung volume specifically identifies patients at risk for developing complications.**

Key Words: **computed tomography; volume index; pulmonary contusion; blunt chest injury; pixel analysis; thoracic trauma.**

INTRODUCTION

Patients with blunt thoracic trauma often have multiple injuries and the specific contribution of pulmonary contusion to outcomes has not been precisely established. The use of screening chest X-ray (CXR) lacks sufficient sensitivity and specificity in quantifying the grade and degree of contusion at admission because of its lack of ability to demarcate three-dimensional (3D) regions of lung contusion due to its two-dimensional (2D) image. Moreover, with the advent of computed tomography (CT), a reconstructed 3D view of pulmonary contusion volume can be calculated and correlated to outcomes. Attempts have been made to quantify pulmonary contusion volumes on CT [1–5]. However, these series vary in the methodology used to compare volumes, studied different patient populations, differed in study size, and differed with regard to outcomes measured (need for mechanical ventilation, development of complications such as pneumonia, acute respiratory distress syndrome [ARDS], and mortality). A universal method of quantifying pulmonary contusion on CT would be helpful so there is agreement about what outcomes are affected by pulmonary contusion and what size of pulmonary contusion defines a patient at risk for the development of complications. A technique

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that precisely quantifies pulmonary contusion may more accurately predict outcomes and help surgeons understand which population subsets are expected to develop complications based on contusion size.

We sought to accurately measure pulmonary contusion volume on CT and compare this to outcomes in polytrauma patients with blunt thoracic injury. We used a novel CT volume index (CTVI) score that was calculated based on the ratio of contused lung to total lung in order to approximate pulmonary contusion volumes accurately. Our hypothesis was that the size of pulmonary contusions, measured accurately, will predict outcomes. Our specific aims were to (1) precisely quantify pulmonary contusion size using pixel analysis, (2) correlate contusion size with outcomes, and (3) determine the threshold contusion size portending complications.

METHODS

This study received institutional approval and complied with human research protocols.

Patient Selection Criteria

All patients with blunt thoracic trauma who received a screening thoracic CT scan on admission from the time period of 1/1/2005 to 10/31/10 were included in the study. Patients were pooled from the Alameda County Medical Center trauma database, and images were obtained from the radiology Picture Archiving and Communication System (PACS). Excluded from the study were prisoners, pregnant women, and those under the age of 18. Among patients who were eligible for participation, demographic and clinical parameters were obtained from the medical record (identifying information, diagnoses, laboratory profile, trauma injury severity score (ISS), abbreviated injury score for chest (AIS – chest), pharmacologic data, and surgical procedures related to their injuries), as well as outcome measures specifically mortality, length of hospital stay (hospital LOS), length of stay in the intensive care unit (ICU LOS), development of complications (specifically pulmonary – pneumonia and ARDS), reintubations, and duration of mechanical ventilation (days on ventilator). Pneumonia was defined according to Centers for Disease Control and Prevention surveillance definition guidelines [6] and ARDS was defined according to the North American-European consensus conference established guidelines [7, 8].

Quantifying Pulmonary Contusion Size by Pixel Analysis

A quantitative contusion volume analysis was performed by the radiology software on the PACS system (Syngo Software Systems; Siemens Corporation, Berlin, Germany). Images consisted of 6360 5-mm axial thoracic CT slices. The CTVI score was calculated based on the ratio of affected lung to total lung [slices of lung on CT $\times$ affected pixel region/total lung pixel region $\times$ 0.45 (left side) + slices of lung on CT x affected pixel region/lung pixel region $\times$ 0.55 (right side)] (Fig. 1). Multiple CT scans were reviewed for volumetry analysis, including coronal sections, sagittal sections, and reconstructions to confirm that contusion volumes did not include hemothorax, pneumothorax, aberrant tissue, or foreign bodies.

Correlating CTVI Contribution to Complications

Next, to investigate whether CTVI score could predict outcomes in polytrauma patients, correlations between CTVI score and outcomes were made using univariate and multivariate techniques. Univariate correlations were made between continuous predictor variables (CTVI, age, ISS, AIS [chest], and duration of pharmacotherapy) and continuous outcome variables (hospital LOS, ICU LOS, and ventilator days). Based on predictor significance on univariate analysis and their collinearity characteristics in a correlation matrix, contributory predictor variables were selected into a multivariate model. Multivariate linear and logistic regression was then used to correlate predictors to outcomes (total hospital LOS, ICU LOS, days on the ventilator, re-intubations, and the development of pneumonia, ARDS, and mortality). Significant predictors contributing to the multivariate model were selected based on Type III Sum of Squares analysis.

Identifying the Contusion Size Predicting Development of Complications

We wished to investigate whether the development of complications (pneumonia, ARDS, and/or mortality) was associated with a particular contusion size. A receiver operating characteristic curve (ROC) was used to identify a threshold CTVI score that best predicted development of complications with maximal sensitivity and specificity. Using the same strategy employed previously to identify a group at risk based on a threshold pulmonary contusion volume [3, 5], our defined ROC threshold value was applied to the patient population and similarly analyzed for outcomes. An area-under-the ROC curve analysis (AUC) defined the predictive ability for CTVI to predict pneumonia, ARDS, and/or mortality.

Statistical Analysis

Comparisons between groups were made by Student's t-test and χ^2 analysis, where appropriate. Univariate correlations were performed and calculated with Pearson correlation statistics and multivariate correlations were performed by multiple linear and logistic regression analyses.

RESULTS

Patient Demographics and Development of Complications

The demographic characteristics of the study cohort are depicted in Table 1. Mean CTVI was significantly higher in the group with complications (0.28 ± 0.03 *versus* 17 ± 0.02, $P = 0.01$).

Correlating CTVI Contribution to Complications

Next, an analysis of the exact contribution of CTVI to outcomes was performed. Univariate analysis revealed that CTVI alone did not independently predict total hospital LOS, ICU LOS, or days on the ventilator ($R^2 < 0.20$ for all) suggesting that outcomes for polytrauma patients with blunt thoracic injury are multifactorial in nature. However, multiple predictors (including CTVI) contributed in part to outcomes, and it was opted to perform a multivariate analysis to correlate predictors to outcomes.

A model using CTVI, age, pharmacotherapy, pneumonia, and ARDS correlated with total hospital LOS ($R^2 = 0.92$, $P < 0.01$), ICU LOS ($R^2 = 0.84$, $P < 0.01$), and ventilator days ($R^2 = 0.66$, $P < 0.01$) (Table 2, Figs. 2 and 3). Both antibiotic duration of therapy and bronchodilator