Association of Body Mass Index With Increased Cost of Care and Length of Stay for Emergency Department Patients With Chest Pain and Dyspnea

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Background—High body mass index (BMI) increases the probability of indeterminate findings on diagnostic studies, length of stay, and cost of care for hospitalized patients. No study has examined the economic and operational impact of BMI in patients with chest complaints presenting to the emergency department (ED). The objective was to measure the association of BMI with the main outcomes of cost of care, length of stay (including time in the ED and time in the wards if admitted), and radiation exposure in patients presenting to the ED with chest pain and dyspnea.

Methods and Results—This was a prospective, 4-center, outcomes study. Patients were adults with dyspnea and chest pain, nondiagnostic electrocardiograms, and no obvious diagnosis. Patients were followed for the main outcomes for 90 days. Outcomes that were stratified by BMI in 5 categories, underweight, normal weight, overweight, obese, and morbidly obese, were compared using the Kruskall–Wallis rank test, and the independent predictive value of BMI was tested with multivariate regressions. Compared with medical costs for normal weight patients, costs were 22% higher for overweight patients (P=0.077), 28% higher for obese patients (P=0.020), and 41% higher for morbidly obese patients (P=0.015). Morbidly obese patients without computerized tomographic pulmonary angiography had the highest proportion (87%) of no significant cardiopulmonary diagnosis for 90 days after computerized tomographic pulmonary angiography. BMI was associated with increases in cost of care and length of stay for patients with chest pain and dyspnea. Morbidly obese patients had the highest proportion (87%) of no significant cardiopulmonary diagnosis for 90 days after computerized tomographic scanning stayed in the hospital 44% longer than normal weight patients (P=0.073), and morbidly obese patients with computerized tomographic scanning stayed in the hospital 44% longer than normal weight patients (P=0.083). BMI was not a significant predictor of radiation exposure.

Conclusions—BMI was associated with increases in cost of care and length of hospital stay for patients with chest pain and dyspnea. These results emphasize a need for specific protocols to manage morbidly obese patients presenting to the ED with chest pain and dyspnea.

Clinical Trial Registration—http://www.clinicaltrials.gov. Unique identifier: NCT01059500.

Key Words: body mass index ■ economics ■ health care economics and organizations ■ obesity

Annually, ≈15 million patients visit an emergency department (ED) with a chief complaint of chest pain or dyspnea. These complaints frequently prompt emergency care providers to evaluate for possible acute coronary syndrome and pulmonary embolism (PE). Although the majority of patients will ultimately have neither diagnosis, physicians order numerous laboratory tests and advanced imaging for patients with complaints referable to the chest. Those designing clinical protocols for evaluation of possible acute coronary syndrome and PE remain keenly interested in developing guidelines that maximize patient safety by achieving a high degree of diagnostic certainty while minimizing length of stay and cost. Toward this goal, it is important to recognize that salient patient phenotypes, such as patient body mass index (BMI), may predict more complex and costly care to achieve the same degree of diagnostic certainty as for a normal weight individual.

Obesity is highly relevant to the management of patients with chest complaints because it affects approximately one third of Americans and increases the risk of both cardiovascular and venous thromboembolic disease. Although previous literature has generally implicated obesity as associated with increased complexity and cost of medical care, the literature lacks specific evidence for obese patients with chest complaints. For example, obesity increases the probability of indeterminate findings on electrocardiography, nuclear
WHAT IS KNOWN

• Obesity complicates the performance of diagnostic studies, including electrocardiography and radiology.
• Obesity is associated with increased costs and length of stay for hospital visits for many medical and surgical conditions; however, no studies have investigated this association among patients with chest pain and dyspnea evaluated in the emergency department.

WHAT THE STUDY ADDS

• For patients presenting to the emergency department with chest pain and dyspnea, morbid obesity was associated with significantly increased costs of care and length of stay.
• Morbidly obese patients had the highest frequency of no significant cardiopulmonary diagnosis within 90 days after computerized tomographic pulmonary angiography.
• These findings substantiate the need for clinical protocols that optimize the use of imaging in patients with high body mass index and chest complaints.

scintillation scanning of the heart or lungs, and computerized tomographic pulmonary angiography (CTPA). A study performed in navy-enlisted personnel found that evaluation for chest pain was consistently in the top 5 diagnostic-related group codes in terms of total economic expenditures for the care of obese patients of all age groups. Obesity has been found to prolong the length of stay for numerous acute medical and surgical conditions. However, not all studies have shown an association between BMI and costs or length of stay. For example, 1 study showed no differences in length of stay or resource use between obese and nonobese patients presenting to the ED with abdominal pain. No studies have examined the association of BMI with costs or length of stay for patients with cardiology or respiratory issues.

The objective of this article was to document the length of stay, costs for care, and radiation exposure of patients stratified by BMI category, and test whether BMI category has independent predictive value for these dependent variables in a multivariate regression analysis.

Methods

Overall Design

This was a preplanned secondary analysis of a 4-center prospective study. Data were collected at 3 academic EDs (Carolinas Medical Center Main Hospital in Charlotte, NC; Beth Israel Deaconess Medical Center in Boston, MA; and the University of Mississippi Medical Center in Jackson, MS) and in 1 community hospital (Forsyth Hospital in Winston Salem, NC). The clinical trials identifier (NCT01059500) was posted on January 28, 2010, and the study was performed with an investigational device exemption from the U.S. Food and Drug Administration (IDE#125834). The study was approved by the Institutional Review Boards at all sites; study participants were clinicians and patients who both provided informed consent to participate.

Patient Selection

Under partial waiver of authorization, research assistants surveyed ED electronic tracking systems for patients with a stated reason for visit suggestive of chest pain or shortness of breath. All patients in this study had both chest pain (or discomfort, pressure, burning, squeezing, or similar term) and shortness of breath (or trouble breathing, dyspnea, or similar term) as part of the reason they visited the hospital, based on explicit written documentation of each in either the history of present illness or the review of systems. Patients were adult (>17 years of age) patients presenting to an ED and had to understand English or have a certified translator present for their primary language. All patients had a 12-lead ECG, and the patient had indicated the site hospital was his or her hospital of choice in the event of return ED visit. Patients were included in the study whether discharged from the ED or admitted to the wards.

We desired a sample of patients who had both chest pain and dyspnea but had no obvious diagnosis at the time of enrollment, and thus required diagnostic testing. Exclusion criteria included evidence of myocardial ischemia or infarction on computer interpretation 12-lead ECG, known diagnosis of acute PE within previous 24 hours (eg, call back for overread of a CT scan), obvious condition or diagnosis identified by the emergency physician as mandating admission (evidence of circulatory shock, severe hypoxemia, decompensated heart failure, altered mental status, hemorrhage, sepsis syndrome, arrhythmia, trauma, unstable social or psychiatric situation, stroke, aortic disaster, pneumonia), myocardial infarction, intraconary stent placement, coronary artery bypass graft within the previous 30 days, known cocaine use within past 72 hours based on patient or laboratory report, referral to the ED by a personal physician for admission, patients undergoing voluntary medical clearance for a detox center or any involuntary court or magistrate order, homelessness, out-of-town residence or other condition known to preclude follow-up, patients in police custody or currently incarcerated individuals, and patients who knew they were pregnant or in whom a pregnancy test was drawn as part of usual care and was found to be positive. Postenrollment exclusions included a positive urine cocaine test, incarceration within 14 days of enrollment, or patient elopement from medical care (ie, patients who left against medical advice). All patients and providers supplied written informed consent to participate in this study.

Outcomes were assessed up to 90 days with telephone follow-up using validated questionnaires, supplemented by structured review of each hospital’s comprehensive electronic medical record database. The criterion standards for acute coronary syndrome, PE, and other significant cardiopulmonary diagnoses have been defined previously. We defined a significant cardiopulmonary outcome as death from any cause, a diagnosis of acute coronary syndrome, PE, any major adverse cardiac events (dysrhythmia requiring treatment, acute heart failure, or pericarditis with effusion), aortic aneurysm or dissection, other pulmonary diagnoses (pneumothorax, pneumonia), dangerous mediastinal processes (Boerhaave syndrome, pneumomediatinum, or large mass), or hemorrhage related to treatment.

Radiation Dose Estimates

We used a fixed estimated mSv dose per examination using published tables for the main outcome measurement of effective radiation dose. We prospectively recorded the radiation doses for radiological studies that imaged the chest, including plain film chest radiography, radiotopic nuclear scanning (eg, cardiac and ventilation-perfusion scanning), computerized tomographic scanning, and fluoroscopy-guided studies (eg, cardiac catheterization and upper gastrointestinal series). Computerized tomographic imaging of other body parts (eg, the head, abdomen, pelvis, or extremities) was recorded but is not reported here.

Medical Costs

Cumulative in-hospital medical cost data for 30 days after enrollment were obtained from query of patient billing databases as we have described previously. Medical costs for all materials and services, regardless of reason (ie, not restricted to evaluation or treatment of
cardiopulmonary disease) were assessed from line item analysis of variable costs for imaging, pharmacy, laboratory, and other service groupings in the universal hospital claims submission form (UB-92 CMS-1450) commonly called the UB-92.19 These costs are most analogous to facilities costs; they do not include professional billing.

Length of Stay
Patients’ hospital length of stay was measured in days and fractions of days from the time of triage in the ED to the time of discharge from the hospital. ED length of stay was measured in fractions of days from the time of triage in the ED to the time of admission to the hospital or discharge from the ED.

Statistical Analyses

**BMI**
BMI was calculated for each patient using the standard BMI equation (Weight in pounds)/(Height in inches)² *703. We accepted either directly measured or patient-reported estimates of height and weight. In accordance with guidelines from the National Heart, Lung, and Blood Institute, the data were divided into the following 5 categories based on patients’ BMI: underweight, BMI<18.5; normal, 18.5≤BMI<25; overweight, 25≤BMI<30; obese, 30≤BMI<40; and morbidly obese, BMI≥40.

**Ninety-Day Outcomes**
The percentage of patients with a significant cardiopulmonary diagnosis and the percentage of patients who underwent CT pulmonary angiography with no significant diagnosis were calculated for each BMI category. Confidence intervals for each percentage were calculated by Wilson score interval.

**Nonparametric Analysis**
Kruskall–Wallis 1-way analysis of variance was used to test for differences between BMI categories in hospital length of stay, ED length of stay, costs, and radiation exposure. To identify where differences occurred, post hoc Wilcoxon rank-sum tests assessed whether a specific group’s rank-sum was significantly different than its expected rank-sum under the null hypothesis that all groups were equal with P<0.1 considered significant.

**Regression Analysis**
To test the independent predictive value of BMI data were fit to a log-linear regression for each of the following outcome (dependent) variables: length of hospital stay, costs, and radiation exposure. Natural log transformation of the dependent variables was chosen based on a previously described algorithm for choosing an estimator to model skewed data.20 Dummy variables represented the BMI categories underweight, overweight, obese, and morbidly obese. The BMI category normal served as the reference group. In the regression for length of stay only, a dummy variable was included for whether the patient had ≥1 CT scan. The CT dummy variable was interacted with each of the BMI category variables. In all 3 regressions, pre-defined independent predictor variables were included to control for demographics and medical conditions that we expected to affect medical costs: sex, race (white or nonwhite), diagnosis of acute coronary syndrome within 90 days, diagnosis of PE within 90 days, previous myocardial infarction, congestive heart failure, diabetes mellitus, hypertension, chronic obstructive pulmonary disease, active malignancy, and end-stage renal disease. Age was a continuous control variable. Statistical significance of each regression coefficient was evaluated using Student t test with P<0.1 considered significant. In the length of stay regression, joint significance of BMI category variables and their associated interaction terms were assessed with F tests.

**Software**
The statistical computations mentioned above were performed using the software StataSE 13 (College Station, TX).

**Results**
We enrolled 851 patients in the study, but 22 patients were omitted from the analyses because of missing height and weight data. Table 1 shows demographic characteristics of the patients in the data set. Of the 829 patients with height and weight data, 57% were female. Ages ranged from 5 to 94 years, and the mean and median age was 49 years. The patients were 50% black and 40% white. In addition to reported race, 6% of patients reported Hispanic ethnicity. The median BMI was 29.9 kg/m², and the interquartile range was 10.2 kg/m² (first to third quartiles, 25.1–35.2 kg/m²). The mean BMI was 31.0 kg/m², and the standard deviation was 8.12 kg/m². The overall rate of diagnosis of acute coronary syndrome within 90 days was 2.8% (0.0%, 3.0%, 4.9%, 2.3%, and 0.0% for underweight, normal weight, overweight, obese, and morbidly obese patients, respectively). The overall rate of diagnosis of PE within 90 days was 1.7% (0.0%, 1.2%, 0.4%, 3.1%, and 1.9% for underweight, normal weight, overweight, obese, and morbidly obese patients, respectively). Table 1 also reports the main outcome variables used subsequently in regression analyses and numbers of patients with complete data for each outcome. The median length of hospital stay was 0.37 days, the median costs were $1363, and the median radiation dose was 0.12 mSv. Outcome data in Table 2 show that >80% of all patients had no predefined significant cardiopulmonary diagnosis within 90 days, with the highest frequencies

### Table 1. Descriptive Statistics for Population Characteristics and Outcome Variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>Median</th>
<th>IQR</th>
<th>Mean or Proportion</th>
<th>Standard Deviation</th>
<th>Evaluable Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>49</td>
<td>18</td>
<td>49.29</td>
<td>14.56</td>
<td>828</td>
</tr>
<tr>
<td>Female (proportion)</td>
<td>n/a</td>
<td>n/a</td>
<td>0.57</td>
<td>n/a</td>
<td>829</td>
</tr>
<tr>
<td>White (proportion)</td>
<td>n/a</td>
<td>n/a</td>
<td>0.40</td>
<td>n/a</td>
<td>331</td>
</tr>
<tr>
<td>Black (proportion)</td>
<td>n/a</td>
<td>n/a</td>
<td>0.50</td>
<td>n/a</td>
<td>417</td>
</tr>
<tr>
<td>Other race (proportion)</td>
<td>n/a</td>
<td>n/a</td>
<td>0.10</td>
<td>n/a</td>
<td>81</td>
</tr>
<tr>
<td>Hispanic (proportion)</td>
<td>n/a</td>
<td>n/a</td>
<td>0.06</td>
<td>n/a</td>
<td>48</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>29.90</td>
<td>10.24</td>
<td>31.00</td>
<td>8.12</td>
<td>829</td>
</tr>
<tr>
<td>Hospital length of stay, d</td>
<td>0.39</td>
<td>0.99</td>
<td>1.44</td>
<td>7.93</td>
<td>812</td>
</tr>
<tr>
<td>Costs, $</td>
<td>1362.76</td>
<td>2485.81</td>
<td>3663.94</td>
<td>8946.28</td>
<td>808</td>
</tr>
<tr>
<td>Radiation exposure, mSv</td>
<td>0.12</td>
<td>8.00</td>
<td>4.94</td>
<td>3.74</td>
<td>817</td>
</tr>
</tbody>
</table>

BMI indicates body mass index; and IQR, interquartile range.
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of significant diagnosis in underweight and morbidly obese patients. When we examined the influence of body size on the rate of negative CT scanning, we found that morbidly obese patients had the highest frequency of no significant cardiopulmonary diagnosis after CT pulmonary angiography. Patients with morbid obesity also had the highest frequency of image results that were read as indeterminate by the site radiologist.

BMI Associations With Length of Stay and Costs
The Kruskall–Wallis equality-of-populations rank test showed a significant difference in hospital length of stay between BMI categories ($P=0.0846$; Figure 1). As shown in Figure 1, the median hospital length of stay increased as the BMI category progressed from underweight to morbidly obese. ED length of stay was not significantly different between BMI categories (Kruskall–Wallis, $P=0.341$). Overweight, obese, and morbidly obese patients were ≈10% more likely to be admitted than either normal or underweight patients. Admission status did not significantly affect the ED length of stay. The Kruskall–Wallis test also revealed a significant difference in costs among BMI categories ($P=0.0196$). As shown in Figure 2, the costs increased as the BMI category progressed from underweight to morbidly obese.

BMI Association With Radiation Exposure
The Kruskall–Wallis test did not reveal any significant differences in radiation dose among BMI categories ($P=0.344$; Figure 3). Also shown in Figure 3, the median radiation dose seemed to increase as the BMI category progressed from normal to morbidly obese. In a post hoc analysis, the underweight BMI category was omitted, but the Kruskall–Wallis test still did not reveal any significant differences in radiation dose among BMI categories ($P=0.320$).

BMI as a Predictor of Hospital Length of Stay, Medical Costs, and Radiation Exposure
Multivariate regression with the natural log of hospital length of stay as the dependent variable yielded an estimated R-squared value of 0.274 (Table 3). The coefficient on the morbidly obese variable was statistically significant ($P=0.073$), indicating that a morbidly obese patient who did not have a CT scan had a significantly longer length of stay than normal weight patients who did not have a CT scan. Using an F test, we find that the coefficient on the morbidly obese variable and the coefficient on its interaction term with CT scan were jointly significant ($P=0.083$), indicating that a morbidly obese individual who had a CT scan had a significantly longer length of stay than normal weight patients who did not have a CT scan. When using the natural log transformation, the following formula will give one the percentage change in the dependent variable associated with a dummy independent variable value of 1: $e^{\beta-1}$, where $\beta$ is the estimated coefficient. For instance, morbidly obese patients who did not have a CT scan stayed in the hospital ($e^{0.291-1}=0.34$) 34% longer than normal weight patients who did not have a CT scan, and morbidly obese patients who had ≥1 CT scan stayed in the hospital ($e^{0.291+0.075-1}=0.44$) 44% longer than normal weight patients who did not have a CT scan, on average, holding all other variables constant. The coefficient on the interaction of morbid obesity with CT scan was not

<table>
<thead>
<tr>
<th>BMI Category</th>
<th>Total in Category</th>
<th>Significant Diagnosis*</th>
<th>%</th>
<th>95% CI</th>
<th>CTPA Performed and No Significant Diagnosis*</th>
<th>%</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMI&lt;18.5</td>
<td>21</td>
<td>4</td>
<td>19</td>
<td>8–40</td>
<td>16</td>
<td>76</td>
<td>55–89</td>
</tr>
<tr>
<td>18.5&lt;BMIC&lt;25</td>
<td>174</td>
<td>23</td>
<td>13</td>
<td>9–19</td>
<td>141</td>
<td>81</td>
<td>75–86</td>
</tr>
<tr>
<td>25&lt;BMIC&lt;30</td>
<td>227</td>
<td>28</td>
<td>12</td>
<td>8–17</td>
<td>177</td>
<td>78</td>
<td>72–83</td>
</tr>
<tr>
<td>30&lt;BMIC&lt;40</td>
<td>234</td>
<td>45</td>
<td>15</td>
<td>11–20</td>
<td>234</td>
<td>78</td>
<td>73–82</td>
</tr>
<tr>
<td>BMI&gt;40</td>
<td>89</td>
<td>19</td>
<td>19</td>
<td>12–27</td>
<td>89</td>
<td>87</td>
<td>79–92</td>
</tr>
</tbody>
</table>

Confidence intervals were calculated by Wilson score interval. BMI indicates body mass index; CI, confidence interval; and CTPA, computerized tomographic pulmonary angiography.

*Defined in the Methods section.

Figure 1. Median length of hospital stay (d) for each body mass index (BMI) category.

Figure 2. Median costs (USD) for each body mass index (BMI) category.
was not significant. Besides morbid obesity, no other BMI categories with their associated interaction terms were jointly significant. Furthermore, the coefficient on the CT scan variable alone was not statistically significant ($P=0.194$), indicating that CT scanning did not significantly increase length of stay in normal weight patients. Of the control variables in the length of stay regression, those with statistically significant coefficients were age ($P<0.001$), nonwhite ($P=0.093$), diagnosis of acute coronary syndrome ($P=0.017$), diagnosis of PE ($P<0.001$), congestive heart failure ($P=0.075$), diabetes mellitus ($P=0.072$), hypertension ($P=0.061$), and end-stage renal disease ($P=0.074$). On average, an increase in patient age by 1 year increased the length of stay by 2.5%, holding all other variables constant. Also, patients who were identified as a race other than white stayed in the hospital 14% longer than white patients, on average. Diagnosis of acute coronary syndrome increased length of stay by 115%, diagnosis of PE

Table 3. Results of Multivariate Regression Analysis

<table>
<thead>
<tr>
<th>Variables</th>
<th>Hospital Length of Stay Regression, d</th>
<th>Costs Regression, USD</th>
<th>Radiation Regression, mSv</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underweight</td>
<td>0.460 (0.384)</td>
<td>−0.022 (0.234)</td>
<td>0.639 (0.526)</td>
</tr>
<tr>
<td>Overweight</td>
<td>0.064 (0.122)</td>
<td>0.195* (0.110)</td>
<td>0.041 (0.266)</td>
</tr>
<tr>
<td>Obese</td>
<td>0.177 (0.126)</td>
<td>0.250† (0.107)</td>
<td>0.228 (0.250)</td>
</tr>
<tr>
<td>Morbidly obese</td>
<td>0.291* (0.162)</td>
<td>0.343† (0.141)</td>
<td>0.382 (0.335)</td>
</tr>
<tr>
<td>CT</td>
<td>0.242 (0.186)</td>
<td>n/a†</td>
<td>n/a‡</td>
</tr>
<tr>
<td>Underweight×CT</td>
<td>−0.540 (0.629)</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Overweight×CT</td>
<td>0.182 (0.244)</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Obese×CT</td>
<td>−0.052 (0.239)</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Morbidly obese×CT</td>
<td>0.075 (0.292)</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Female</td>
<td>−0.084 (0.081)</td>
<td>−0.095 (0.078)</td>
<td>0.344* (0.188)</td>
</tr>
<tr>
<td>Age</td>
<td>0.025§ (0.003)</td>
<td>0.012§ (0.003)</td>
<td>0.018§ (0.007)</td>
</tr>
<tr>
<td>Nonwhite</td>
<td>0.135* (0.080)</td>
<td>0.278§ (0.078)</td>
<td>0.036 (0.191)</td>
</tr>
<tr>
<td>Diagnosis of ACS</td>
<td>0.766† (0.319)</td>
<td>1.642§ (0.216)</td>
<td>0.734 (0.514)</td>
</tr>
<tr>
<td>Diagnosis of PE</td>
<td>1.464§ (0.350)</td>
<td>1.192§ (0.349)</td>
<td>2.168§ (0.401)</td>
</tr>
<tr>
<td>Previous MI</td>
<td>0.146 (0.156)</td>
<td>−0.057 (0.152)</td>
<td>−0.184 (0.377)</td>
</tr>
<tr>
<td>CHF</td>
<td>0.293* (0.164)</td>
<td>0.111 (0.184)</td>
<td>−0.268 (0.362)</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>0.208* (0.116)</td>
<td>0.091 (0.103)</td>
<td>0.147 (0.262)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>0.179* (0.096)</td>
<td>0.174* (0.091)</td>
<td>0.470† (0.221)</td>
</tr>
<tr>
<td>COPD</td>
<td>0.105 (0.186)</td>
<td>0.488§ (0.167)</td>
<td>0.388 (0.339)</td>
</tr>
<tr>
<td>Active malignancy</td>
<td>−0.103 (0.270)</td>
<td>0.081 (0.318)</td>
<td>0.955* (0.534)</td>
</tr>
<tr>
<td>End-stage renal</td>
<td>0.714* (0.398)</td>
<td>0.750† (0.351)</td>
<td>−0.679 (0.716)</td>
</tr>
<tr>
<td>Intercept</td>
<td>−2.280§ (0.176)</td>
<td>6.183§ (0.179)</td>
<td>−2.147§ (0.381)</td>
</tr>
<tr>
<td>N</td>
<td>702</td>
<td>791</td>
<td>765</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.274</td>
<td>0.193</td>
<td>0.068</td>
</tr>
</tbody>
</table>

Dependent variables were natural log transformations of length of stay (d), costs (USD), and radiation exposure (mSv). Robust standard errors are in parentheses where applicable. ACS indicates acute coronary syndrome; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; CT, computerized tomography; MI, myocardial infarction; and PE, pulmonary embolism.

*Statistical significance at the 10% level.
†Statistical significance at the 5% level.
§Statistical significance at the 1% level.
‡Interactions not calculated for costs outcomes because the interaction term tests the hypothesis that body mass index (BMI) influenced the outcome associated with each CT performed. Although we think that BMI could influence length of stay for each CT, we had no reason to think that BMI should influence the costs for each CT scan. Similarly, for radiation, we considered each scan to deliver the same amount of radiation.
increased length of stay by 332%, congestive heart failure increased length of stay by 34%, diabetes mellitus increased length of stay by 23%, hypertension increased length of stay by 20%, and end renal disease increased length of stay by 104%, on average.

For the regression analyzing costs, Table 3 shows that compared with normal weight patients, overweight, obese, and morbidly obese patients all had significantly higher costs. Compared with normal weight patients, the costs were 22% higher for overweight patients \( (P=0.077) \), 28% higher for obese patients \( (P=0.020) \), and 41% higher for morbidly obese patients \( P=0.015 \), on average, holding all other variables constant. The coefficient on the underweight variable indicated that underweight patients had a 2% lower cost compared with normal weight patients, but this was not statistically significant \( P=0.926 \). As seen with length of stay, the control variables with statistically significant coefficients were age \( (P<0.001) \), nonwhite \( (P<0.001) \), diagnosis of acute coronary syndrome \( (P<0.001) \), diagnosis of PE \( (P=0.001) \), hypertension \( P=0.057 \), and end-stage renal disease \( P=0.026 \). Unlike the length of stay regression, chronic obstructive pulmonary disease had a statistically significant coefficient \( P=0.004 \), but congestive heart failure and diabetes mellitus were not significant. An increase in patient age by 1 year increased the costs by 1% on average. Patients who were identified as a race other than white had 32% higher costs than white patients, on average. Compared with patients without the conditions, costs were elevated 416% with diagnosis of acute coronary syndrome, 229% with diagnosis of PE, 19% with hypertension, 63% with chronic obstructive pulmonary disease, and 118% with end-stage renal disease.

Compared with the previous 2 regressions, the regression with the natural log of radiation exposure as the dependent variable accounted for little of the variation in the data \( R^2=0.068 \). Not 1 of the BMI categories was a significant independent predictor of radiation exposure. Of the control variables, sex, age, diagnosis of PE, hypertension, and malignancy were significant predictors of radiation exposure. Diagnosis of acute coronary syndrome did not increase radiation exposure. On average, females had 41% higher radiation exposure than males, holding all other variables constant \( P=0.068 \). An increase in patient age by 1 year increased radiation exposure by 2% on average \( P=0.012 \). Radiation exposure was elevated by 774% with diagnosis of PE \( P<0.001 \), 60% with hypertension \( P=0.034 \), and 160% with active malignancy \( P=0.074 \).

**Discussion**

We document that in ED patients with shortness of breath and chest pain, BMI was associated with significant increases in hospital length of stay and 30-day cumulative costs for medical care. In a multivariate model containing 216 control variables, overweight, obesity, and morbid obesity were associated with increased costs. Morbid obesity with CT scanning and morbid obesity without CT scanning were both associated with increased length of stay. Morbidly obese patients also had a higher rate of no significant cardiopulmonary diagnosis for 90 days after CT pulmonary angiography, which some may interpret as a higher rate of unnecessary imaging. We interpret some findings from the regression analysis as predictable and others as unexpected. We were not surprised that a new diagnosis of either acute coronary syndrome or PE was associated with increased costs for care. We were somewhat surprised to find that comorbid conditions had variable findings, with some conditions associated with increased costs of care (eg, age, chronic obstructive pulmonary disease, hypertension, and end-stage renal disease), whereas others were not (eg, congestive heart failure, diabetes mellitus, and active malignancy).

We were also surprised that female sex and a diagnosis of PE, but not acute coronary syndrome, were associated with increased radiation exposure.

The data in Figure 3 suggest that underweight patients had increased radiation exposure. However, the Kruskall–Wallis test was not significant. Visual inspection of Figure 3 raised our suspicion that underweight patients might have a higher prevalence of cancer as the explanation for the apparent increase, but none of the 21 underweight patients had active malignancies. More likely, the numerically higher median radiation exposure for the underweight category represents a spurious finding. Indeed, the median radiation exposure in underweight patients was only 0.12 mSv higher than the next highest median, which should be considered in view of the fact that the overall mean was 4.94 mSv with a standard deviation of 3.74 mSv.

Acknowledging the need to validate these findings in other settings, we think our data have 3 immediate implications on clinical operations. First, the data provide a basis for service line directors, administrators, and clinicians to predict that length of stay for patients undergoing CT pulmonary angiography will be higher than average if their patient demographic contains a high prevalence (eg, >30%) of obese patients. Second, the data underscore the need for more intensive physician education to use pretest probability and D-dimer testing to reduce unnecessary CT scanning.21,22 Third, for patients with high BMI whose pretest probability or D-dimer result mandate imaging, systems should have BMI-specific protocols in place, such as increasing the volume of iodinated contrast to reduce the rate of indeterminate image results on CT angiography.23,24

This study is limited in its estimate of radiation exposure on a per-procedure basis. As described previously, we chose this method over using data from the console report from the CT scan because we found these data unreliable and exclusive of nuclear and fluoroscopic studies, and we could find no device to directly measure radiation on or in the patient.2 Previous work suggests that the probable direction of this bias was to underestimate the radiation exposure for obese patients who may absorb more radiation from a given procedure.25

In conclusion, these data show that morbidly obese patients who present to an ED with dyspnea and chest pain have increased length of hospital stay and costs of care. Morbidly obese patients were more likely to have CT pulmonary angiography with no significant cardiopulmonary diagnosis. The findings substantiate the need for protocols to reduce unnecessary CT pulmonary angiography in patients with high BMI.

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Disclosures

None.

References

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