Variation in Diaphragm Position and Shape in Adults With Normal Pulmonary Function*

Thitiporn Suwatanapongched, MD†; David S. Gierada, MD; Richard M. Slone, MD, FCCP‡; Thomas K. Pilgram, PhD; and Peter G. Tuteur, MD, FCCP

Background: Diaphragm position and shape on chest radiographs are routinely used as indicators of normal or abnormal lung volume. However, previous population studies of normal diaphragm position and shape frequently lack objective radiographic measurements and documentation of pulmonary function, and do not account for the observed variability.

Study objectives: To determine the spectrum of diaphragm position and shape on chest radiographs using objective measurements, in patients with normal pulmonary function, and to identify the relationship of diaphragm position and shape to demographic variables and radiographic thoracic dimensions.

Design: Prospective cross-sectional observational study.

Setting: University hospital.

Patients: One hundred fifty-three adults with normal FEV₁ (≥ 80% predicted) and normal total lung capacity (80 to 120% predicted).

Measurements and results: Diaphragm position and shape relative to anatomic landmarks were determined from posteroanterior and lateral chest radiographs. We used descriptive statistics to calculate normal values, and linear correlation, two-tailed t tests, and multivariate analysis to relate findings to age, weight, gender, and thoracic dimensions. The right hemidiaphragm dome was positioned at 9.7 ± 0.8 thoracic vertebral levels (body plus disk space) [mean ± SD] below the top of the first thoracic vertebra (range, 7.4 to 11.3 vertebral levels), and the left hemidiaphragm dome was positioned at 10.2 ± 0.8 vertebral levels (range, 8.1 to 11.8 vertebral levels). The right hemidiaphragm radius was 13.8 ± 3.8 cm (range, 7.2 to 29.6 cm), and the ratio between the height and the anteroposterior dimension of the right hemidiaphragm was 0.23 ± 0.05 cm (range, 0.08 to 0.36 cm). The diaphragm tended to be lower with higher age, lower weight, and smaller transverse and anteroposterior thoracic dimensions (r = 0.22 – 0.47, p < 0.05), and flatter (larger radius) with higher age, weight, transverse thoracic dimension, pack-years smoked (r = 0.32 – 0.42, p < 0.0001), and male gender (p < 0.0001). The tested variables accounted for approximately one third of the variability in diaphragm position and shape (multivariate R² = 0.31 – 0.38).

Conclusions: The substantial variability in normal diaphragm position and shape is related to weight, age, and thoracic dimensions. Consideration of these factors may be useful when evaluating chest radiographs. (CHEST 2003; 123:2019–2027)

Key words: diaphragm; radiography; statistics; thoracic

Abbreviations: APD = anteroposterior dimension; BMI = body mass index; MTTD = maximum transverse thoracic dimension; RHH = right hemidiaphragm height

When interpreting chest radiographs, the position and shape of the diaphragm are routinely used to evaluate whether the lungs are underinflated, as with inadequate inspiratory effort or restrictive lung disease, or overinflated, as in emphysema or other obstructive lung diseases. Conventional teaching that

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the normal position of the right hemidiaphragm projects at about the anterior sixth rib\(^\text{1,2}\) appears to originate from a single study.\(^3\) This and other previous studies that have included data on the position and shape of the diaphragm in normal subjects have been limited by lack of data confirming normal pulmonary function,\(^3,5\) by subjective or roughly defined objective criteria to determine diaphragm position and shape,\(^3,9\) or by relatively small sample sizes.\(^4,10–14\)

Because there are little data in the literature defining the normal variation in diaphragm position and shape, qualitative radiographic assessment of lung volume is to a large extent based on clinical experience evaluating large numbers of radiographs. A more rigorous definition of the normal variation in diaphragm position and shape, based on easily recognized anatomic landmarks, and analysis of factors that might contribute to this variation, such as age and weight, may provide a more reliable basis for this assessment. Therefore, we conducted this study for two reasons: (1) to describe the spectrum of diaphragm position and shape on chest radiographs obtained in patients with normal pulmonary function, and (2) to identify the relationship of diaphragm position and shape to demographic variables, radiographic thoracic dimensions, and smoking history.

**Materials and Methods**

**Patient Selection**

The study protocol was approved by the local human studies committee. From 5,100 patients referred for pulmonary function tests at our institution between January and August of 2000, 492 patients had normal findings, excluding those who underwent lung transplantation. Of these 492 patients, 316 patients had an available two-view chest radiographic examination performed within 2 months of pulmonary function testing and were considered for inclusion. Of these, 78 patients were excluded due to a history of therapy that might affect lung volume or diaphragm position, including prior thoracic or chest wall surgery (n = 39), a radiation therapy port that included part of the lungs (n = 14), and underlying disease that could affect the lungs (n = 15, sarcoidosis, collagen vascular disease, pulmonary hypertension, amyloidosis, alveolar proteinosis) or volume of the abdominal contents (n = 10, cirrhosis). We also excluded 85 patients with abnormal radiographic findings, including pulmonary infiltrates or masses ≥ 3 cm in diameter; pleural effusions; cardiothoracic ratio > 0.55; thoracic compression fractures totaling > 50% of one vertebral body height; thoracic scoliosis > 15°; diaphragmatic eventration; and mediastinal masses. Patients with minor radiographic abnormalities, including calcified old granulomatous diseases (n = 14), mild scoliosis < 15° (n = 15), presence of a central venous catheter (n = 14) or an IV pacemaker (n = 4), and pulmonary nodules < 3 cm in diameter (n = 5), were not excluded.

The final study group consisted of 153 patients (Table 1), 60 men and 93 women. There were 18 patients aged 19 to 29 years, 22 patients aged 30 to 39 years, 38 patients aged 40 to 49 years, 36 patients aged 50 to 59 years, 18 patients aged 60 to 69 years, and 21 patients ≥ 70 years old. There were 89 white, 35 black, and 2 Hispanic patients. Eighty patients (52%) were nonsmokers. Nineteen patients (12%) had a smoking history of 0 to 10 pack-years, and 54 patients (36%) had a smoking history of ≥ 10 pack-years. For additional statistical analysis due to a relatively large proportion of obese patients in our population, we further classified the 153 patients into two subgroups based on a body mass index (BMI): BMI < 30 (n = 85, nonobese subgroup) and BMI ≥ 30 (n = 68, obese subgroup).\(^5\) Eighteen patients in the obese subgroup had a BMI ≥ 40.

**Pulmonary Function Testing**

Spirometry and whole-body plethysmography was performed using a Medgraphics system 1085 (Medical Graphics; St. Paul, MN), according to American Thoracic Society standards.\(^6\) Test results of all patients considered for inclusion in the study were reviewed by an experienced pulmonologist. The minimum criteria for classification as normal (and potential inclusion in the study) consisted of an FEV\(_1\) > 80% of predicted, an FEV\(_1\)/FVC ratio > 80% of predicted, and a total lung capacity (TLC), measured by body plethysmography, between 80% and 120% of predicted.\(^7\) In addition, the forced expiratory flow-volume curve was assessed to exclude subtle abnormalities such as minor conformational deviations. Indications for pulmonary function testing included chest symptoms, suspected COPD (chronic bronchitis or emphysema) or asthma, evaluation prior to bone marrow transplantation or other surgery, amiodarone therapy, history of asbestos exposure, evaluation as lung transplant donor, or undergoing testing and were considered for inclusion. Of these, 78 patients had an available two-view chest radiographic exami-

| Table 1—Demographic and Physiologic Characteristics of Study Population*  |
|--------------------------|--------------------------|--------------------------|--------------------------|
| Characteristics          | All                      | Nonobese                 | Obese                    |
| Patients, no.            | 153                      | 85                       | 68                       |
| Male/female gender, no.  | 60/93                    | 38/47                    | 22/46                    |
| Age, yr (range)          | 50 ± 16 (19–86)          | 49 ± 17 (19–86)          | 51 ± 14 (22–79)          |
| Height, cm (range)       | 168 ± 10 (144–191)       | 169 ± 10 (144–191)       | 167 ± 8 (152–186)        |
| Weight, kg (range)       | 88 ± 26 (45–202)         | 72 ± 13 (45–105)         | 107 ± 24 (75–202)        |
| BMI (range)              | 31 ± 9 (18–74)           | 25 ± 3 (18–29)           | 38 ± 9 (30–74)           |
| FEV\(_1\), L (% predicted) | 2.9 ± 0.8 (99 ± 11)     | 3.1 ± 0.9 (102 ± 10)     | 2.7 ± 0.6 (97 ± 12)      |
| FEV\(_1\)/FVC, % (% predicted) | 82 ± 5 (100 ± 6)     | 82 ± 5 (100 ± 6)         | 83 ± 4 (101 ± 5)         |
| TLC, L (% predicted)     | 5.5 ± 1.2 (100 ± 10)     | 5.5 ± 1 (102 ± 9)        | 5.2 ± 1 (98 ± 10)        |

*Values are presented as mean ± SD unless otherwise indicated. Nonobese = BMI < 30. Obese = BMI ≥ 30.
and participation in nonpulmonary research studies. Eighty-five percent of subjects underwent pulmonary function testing as outpatients.

**Chest Radiography**

Standard posteroanterior and lateral chest radiography was performed with patients in an erect position, at full inspiration. Radiographs were obtained during routine clinical care, with both the patients and technologists unaware that they would be used in this study. There were 106 digital images obtained from a Thoravision selenium detector system (Phillips Medical Systems; Shelton, CT) at a source-to-image distance of 200 cm with phototiming at 150 kilovolt peak. Forty-seven conventional screen-film chest radiographs were produced with a GX800 automatic chest radiographic system (Picker International; Highland Heights, OH) at a source-to-image distance of 180 cm with phototiming at 120 kilovolt peak.

**Radiographic Measurements**

Eight radiographic measurements were obtained on the posteroanterior chest radiographs and two on the lateral radiographs (Fig 1). Diaphragm position was determined from posteroanterior radiographs in three ways, by relating each hemidiaphragm dome to skeletal structures. The position of the right and left hemidiaphragm domes referenced to the thoracic spine (vertebral level) was the primary measure. This was determined as the level at which a horizontal line drawn tangent to the hemidiaphragm dome crossed the thoracic vertebral column. The superior endplate of the first thoracic vertebral body was used as the “zero” vertebral level, with each subjacent vertebral body assigned a value of 0.8 vertebral level and each disk space assigned a value of 0.2 vertebral level.

Diaphragm position was also determined as the vertical distance between a horizontal line tangent to the hemidiaphragm dome and a horizontal line drawn through the midpoint of the intersecting shadows of the anterior sixth and posterior tenth ribs (the crossing rib level), on each side. If the dome was positioned above the crossing rib level, the results were assigned a negative value. The height of the right and left lungs was used as a third indicator of diaphragm position, measured from the inferior margin of the second rib to the horizontal line drawn tangent to the hemidiaphragm dome.

Diaphragm shape was determined only on the right side. The radius of curvature of the right hemidiaphragm was used as a primary indicator. This was calculated based on measurements from the lateral projection of the distance between the anterior and posterior insertions of the right hemidiaphragm (anteroposterior dimension [APD]) and the perpendicular height from this line to the dome of the right hemidiaphragm (right hemidiaphragm height [RHH]). The following formula was used for calculating the right hemidiaphragm radius of curvature (radius) [Fig 2]:

$$\text{radius} = \frac{\text{APD}^2}{8 \times \text{RHH}} + \frac{\text{RHH}}{2}$$

We also used the RHH/APD ratio as another measure of diaphragm shape.

The maximum transverse thoracic dimension (MTTD) was measured on the posteroanterior projection as the greatest distance between the inner margins of the corresponding level of the rib cage. The transverse cardiac dimension was measured as the horizontal distance between vertical lines drawn tangent to the right and left heart borders. The cardiothoracic ratio was calculated as the transverse cardiac dimension divided by the MTTD.

**Figure 1.** Posteroanterior radiograph (top) showing measurements for right hemidiaphragm position and shape. A = right hemidiaphragm position relative to thoracic vertebral level; B = right hemidiaphragm position relative to crossing rib level; C = right lung height; D = MTTD. Horizontal solid white line is the line drawn tangent to the top of the right hemidiaphragm dome. Horizontal dotted white line is the line drawn through the midpoint of intersecting shadows of the anterior sixth and posterior tenth ribs. Lateral radiograph (bottom) shows measurements for right hemidiaphragm shape. E = right hemidiaphragm height; F = APD of right hemidiaphragm.
The radiographic measurements on the digital images were made using the Thoravision display and analysis software (Phillips Medical Systems). The measurements on conventional chest radiographs were made with an ordinary ruler. The results from both posteroanterior and lateral conventional screen-film radiographs were corrected for linear magnification by using a conversion factor of 0.97, based on comparisons of measurements obtained from an adult chest phantom imaged with both selenium-detector and conventional screen-film systems. In the first 15 patients, all measurements were made independently by three chest radiologists. Interobserver agreement was high, with intraclass correlation coefficients of $0.94$ for all measurements. For statistical analysis, measurements made by one chest radiologist were used for all 153 patients in the study.

**Statistical Analysis**

Descriptive statistics, Student t test, and Pearson correlation were performed using Excel 5.0 (Microsoft; Redmond, WA). Descriptive statistics are reported as mean ± SD. Backward stepwise multivariate regression analysis was performed to model the relationship between diaphragm position and shape and predictor variables, using JMP software (SAS Institute; Cary, NC). When certain radiographic measurements could not be made for various reasons (eg, relevant osseous structures not visible, anterior diaphragm insertion not sharply defined, or a costophrenic angle outside the field of view), the remaining obtainable measurements were included in the analysis. Specifically, the thoracic vertebral level, RHH, APD, and radius could not be measured in one patient, the crossing rib level could not be measured on both sides in one patient and on the left in one patient, and the MTTD could not be measured in six patients.

**RESULTS**

**Diaphragm Position and Shape**

The mean right hemidiaphragm dome position was at $9.7 ± 0.8$ vertebral levels. This is slightly above the inferior endplate of the tenth thoracic vertebral body (T10), and $0.9 ± 2.3$ cm above the right crossing rib level. The mean left hemidiaphragm dome position was $0.5$ vertebral levels lower than the right, $0.3 ± 2.4$ cm below the left crossing rib level (Table 2). The mean position of the right and left hemidiaphragm domes was higher in the obese subgroup (Table 2). In the nonobese subgroup, the right hemidiaphragm dome was higher than the left in $93\%$ of cases, by $0.5 ± 0.3$ vertebral levels, or $1.5 ± 0.9$ cm. The right was higher than the left in $85\%$ of obese patients, and in $91\%$ of all patients.

There was substantial variability in diaphragm position. In the nonobese subgroup, the right hemidiaphragm dome was positioned at or above $9.0$ vertebral levels (the superior endplate of T10) and $2.5$ cm above the crossing rib level in $14\%$, and at or below $11.0$ vertebral levels (the superior endplate of T12) and $2.5$ cm below the crossing rib level in $13\%$ (Fig 3). A similar variation was seen on the left, and in the total study population.

There was also substantial variation in diaphragm shape, both when assessing the total study population and in the nonobese subgroup (Table 2). In the nonobese subgroup, the right hemidiaphragm radius of curvature was $>16.9$ cm in $10\%$ and $<9$ cm in $10\%$, and the RHH/APD ratio was $>0.29$ in $10\%$ and $<0.18$ in $10\%$.

There was strong correlation between the measurements of right hemidiaphragm position relative to the thoracic spine and relative to the crossing rib level ($r = 0.82$, $p < 0.0001$) and right lung height ($r = 0.72$, $p < 0.0001$); a similar correlation was present on the left. The right hemidiaphragm radius...
were grouped according to weight deciles (Fig 5). Variation With Weight

The trends were also seen when patients were grouped according to age deciles (Fig 4). Variation With Age

Pearson correlation indicated a slight tendency for the diaphragm to be lower and flatter with increasing age (Table 3). Among all patients, the right hemidiaphragm was lower in the oldest age quartile (62 to 86 years; mean, 10.1 ± 0.7 vertebral levels) compared to the youngest quartile (19 to 37 years; mean, 9.5 ± 0.8 vertebral levels) [p < 0.005], and was flatter in the oldest quartile (mean radius, 15.4 ± 5.0 cm; mean RHH/APD ratio, 0.21 ± 0.06) compared to the youngest quartile (mean radius, 11.9 ± 2.1 cm; mean RHH/APD ratio, 0.26 ± 0.04) [p ≤ 0.0002 for both]. The trends were also seen when patients were grouped according to age deciles (Fig 4).

Variation With Weight

As weight increased, the diaphragm tended to be higher and have a larger radius (Table 3). Among all patients, the right hemidiaphragm was higher in the heaviest quartile (100 to 202 kg; mean, 9.2 ± 0.6 vertebral levels) compared to the lightest quartile (46 to 68 kg; mean, 10.2 ± 0.8 vertebral levels) [p < 0.0001], and the radius was larger in the heaviest quartile (mean radius, 15.7 ± 3.1 cm) compared to the lightest quartile (mean radius, 11.8 ± 3.9 cm) [p < 0.0001]. The trends were also seen when patients were grouped according to weight deciles (Fig 5).

Variation With Gender

There was no difference in diaphragm position between men and women, with mean right hemidiaphragm position in men and women of 9.7 vertebral levels (p = 0.74), and mean left hemidiaphragm position of 10.1 vertebral levels and 10.2 vertebral levels, respectively (p = 0.43). The right hemidiaphragm radius of curvature was larger in men (mean, 15.5 ± 3.7 cm) than in women (12.8 ± 3.5 cm) [p < 0.0001], a relationship that also held for the nonobese subgroup. However, the mean RHH/APD ratio was similar in men (0.22) and women (0.23) [p = 0.35].

Variation With Radiographic Thoracic Dimensions and Smoking History

The diaphragm tended to be higher and have a larger radius as MTTD and right hemidiaphragm APD increased (Table 3). The diaphragm tended to have a larger radius as the number of pack-years smoking increased, but its position was not convincingly correlated with smoking history (Table 3).

Multiple Regression Analysis

Because of the potential for interdependence among some variables (eg, weight and thoracic dimensions), we assessed the relationship of diaphragm position and shape to the demographic and radiographic variables in Table 4 using backwards stepwise multiple regression analysis. Using the thoracic vertebral level as an internal reference for diaphragm position eliminates the influence of height, so height was not included in the analysis of diaphragm position, but was included in the analysis of diaphragm shape. Since APD was used to calculate radius, it was not used in the multivariate model for radius, but was used in the model for position. Due to the substantial proportion of nonsmokers and a nonnormal distribution of pack-years among the

Table 2—Results of Radiographic Measurements*

<table>
<thead>
<tr>
<th>Variables</th>
<th>All Patients (n = 153)</th>
<th>Nonobese Patients (n = 85)</th>
<th>Obese Patients† (n = 68)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diaphragm position</td>
<td></td>
<td></td>
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<tr>
<td>Thoracic vertebral level</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Right</td>
<td>9.7 ± 0.8 (7.4–11.3)</td>
<td>10.0 ± 0.7 (8.1–11.3)</td>
<td>9.4 ± 0.7 (7.4–11.0)</td>
</tr>
<tr>
<td>Left</td>
<td>10.2 ± 0.8 (8.1–11.8)</td>
<td>10.4 ± 0.8 (8.5–11.8)</td>
<td>9.8 ± 0.7 (8.1–11.0)</td>
</tr>
<tr>
<td>Crossing rib level, cm†</td>
<td></td>
<td></td>
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<tr>
<td>Right</td>
<td>−0.9 ± 2.3 (−7.3–3.4)</td>
<td>−0.1 ± 2.3 (−7.3–3.4)</td>
<td>−1.8 ± 1.9 (−6.2–2.6)</td>
</tr>
<tr>
<td>Left</td>
<td>0.3 ± 2.4 (−7.4–4.7)</td>
<td>1.0 ± 2.3 (−6.1–4.7)</td>
<td>−0.6 ± 2.1 (−7.4–3.4)</td>
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<tr>
<td>Lung height, cm</td>
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<tr>
<td>Right</td>
<td>20.6 ± 2.5 (13.5–26.7)</td>
<td>21.6 ± 2.3 (15.7–26.7)</td>
<td>19.4 ± 2.1 (13.5–25.6)</td>
</tr>
<tr>
<td>Left</td>
<td>22.1 ± 2.6 (14.5–29.5)</td>
<td>23.1 ± 2.5 (16.6–29.5)</td>
<td>20.9 ± 2.2 (14.5–27.2)</td>
</tr>
<tr>
<td>Diaphragm shape</td>
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</tr>
<tr>
<td>Radius, cm</td>
<td>13.8 ± 3.8 (7.2–29.6)</td>
<td>12.8 ± 3.4 (7.2–29.6)</td>
<td>15.2 ± 3.8 (9.0–28.2)</td>
</tr>
<tr>
<td>RHH/APD ratio</td>
<td>0.23 ± 0.05 (0.08–0.36)</td>
<td>0.24 ± 0.05 (0.08–0.36)</td>
<td>0.22 ± 0.05 (0.12–0.36)</td>
</tr>
</tbody>
</table>

*Values are presented as mean ± SD (range). See Table 1 for definitions.
†Distance above or below crossing shadows of anterior sixth and posterior tenth ribs was assigned negative or positive value, respectively.
‡p < 0.001 compared to nonobese for all measurements except RHH/APD (p = 0.08) [two-tailed, unpaired t test].
As is commonly observed in clinical practice, we found substantial diaphragm position variability among patients with normal pulmonary function. In exploring the association between diaphragm position and multiple variables, increased weight had a relatively strong association with higher diaphragm position. This is commonly seen in practice, and causally noted in a previous study. We also found a correlation between thoracic dimensions and diaphragm position, and approximately 40% of the variability in diaphragm radius (Table 4).

**Discussion**

A previous major study defining normal diaphragm position on chest radiographs used the anterior ribs as an anatomic reference, and this is often recommended to those learning to interpret chest radiographs. However, referencing diaphragm position to the anterior ribs can be difficult, since the contours of the anterior ribs and diaphragm domes are not parallel, and the costal portions of the anterior ribs may not be clearly visible. Relating diaphragm position to the thoracic spine has been done previously, but to our knowledge has not been applied in population studies to define normal diaphragm position. We found both the thoracic spine and the crossing shadows of the anterior sixth and posterior tenth ribs to be consistently identifiable anatomic reference points for diaphragm position. With underexposed radiographs, the thoracic spine level was still readily identifiable, by counting and tracing the posterior ribs to the spine.

In our study, the average right hemidiaphragm position referenced to the thoracic spine in the nonobese patients was at 10.0 vertebral levels (ie, the superior endplate of T11), which is higher than in a previous study in which average diaphragm position was below 11 vertebral levels in 10 normal, nonobese subjects. This difference may be related to the nonclinical radiographic technique of the previous study, in which the projection was anteroposterior, and radiographs were obtained with each subject’s head, shoulders, buttocks, calves, and heels pressed firmly against a backboard. In addition, the patients of the previous study were older (mean, 62 ± 6 years).

We found that in nonobese patients, the right hemidiaphragm average position was almost exactly at the crossing rib level. In a previous study, the right hemidiaphragm dome was positioned between the inferior margin of the anterior fifth rib and the midpoint of the sixth anterior interspace in 94% of adults defined as normal based on "clinical evidence." Our results are roughly consistent with this, though the referenced point is not directly comparable.

As is commonly observed in clinical practice, we found substantial diaphragm position variability among patients with normal pulmonary function. In exploring the association between diaphragm position and multiple variables, increased weight had a relatively strong association with higher diaphragm position. This is commonly seen in practice, and causally noted in a previous study. We also found a correlation between thoracic dimensions and dia-
phragm position, i.e., lower position with narrower transverse dimension and lower APD. Given two individuals of the same gender, height, and age, who thus have approximately the same predicted TLC, one would expect the diaphragm to be lower in the individual with a smaller body habitus having narrower thoracic dimensions, in order to accommodate the same lung volume. Differences in intra-abdominal pressure or abdominal distensibility due to differences in fat deposition might also play a role.

Slightly lower diaphragm position in older subjects also was noted previously in a qualitative assessment of diaphragm position. We demonstrated a relatively weak correlation between diaphragm position and age; however, a trend toward lower diaphragm position with increased age was more apparent on examination of age quartiles and deciles, and age had a fairly strong influence in the multivariate analysis. One factor that may explain this is the increase in chest wall stiffness that occurs in aging. In order to maintain a given lung volume, diaphragm position would be expected to be lower in elderly subjects who have reduced thoracic cage compliance. The association between diaphragm position and age should not be related to changes in lung volume, since TLC remains stable or declines slightly with age. On examination of age deciles, diaphragm position was lower in the youngest decile (mean weight, 77 ± 19 kg) compared to the next decile (mean weight, 100 ± 37 kg), which may be due to the lighter body weight in the former group (p = 0.02).

Table 3—Pearson Correlation Coefficients Between Radiographic Measurements and Variables in 153 Patients

<table>
<thead>
<tr>
<th>Variables</th>
<th>Age</th>
<th>Height</th>
<th>Weight</th>
<th>Pack-years</th>
<th>APD</th>
<th>MTTD</th>
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<tbody>
<tr>
<td>Diaphragm position</td>
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<td>Thoracic vertebral level</td>
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<td></td>
<td></td>
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<tr>
<td>Right</td>
<td>0.23*</td>
<td>-0.05</td>
<td>-0.47*</td>
<td>0.13</td>
<td>-0.37*</td>
<td>-0.33*</td>
</tr>
<tr>
<td>Left</td>
<td>0.22*</td>
<td>-0.05</td>
<td>-0.44*</td>
<td>0.11</td>
<td>-0.40*</td>
<td>-0.33*</td>
</tr>
<tr>
<td>Diaphragm shape</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Radius, cm</td>
<td>0.37*</td>
<td>0.15</td>
<td>0.32*</td>
<td>0.35*</td>
<td>0.70*</td>
<td>0.42*</td>
</tr>
</tbody>
</table>

*p < 0.05.

Figure 4. Bar charts show right hemidiaphragm position (top, a) and shape (bottom, b) according to age deciles.

Figure 5. Bar charts show right hemidiaphragm position (top, a) and shape (bottom, b) according to weight deciles.
diaphragm shape with most previous studies, due to their use of different methods and subjective radiographic assessments with lack of clear definitions for shape. Our measurements of RHH were similar to those obtained by Reich et al; however, RHH alone might not be a good indicator of diaphragm shape because, as we found, it varies with body size. The RHH/APD ratio might be a better indicator of diaphragm shape than RHH alone, and RHH/APD is easier to estimate in practice than radius.

One limitation of our study is that the study population contains patients with chest symptoms who cannot be considered clinically normal. However, all patients had normal pulmonary function and no radiographic abnormalities expected to affect the lung volume measurements or diaphragm position and shape. Our population reflects patients routinely seen in a hospital-based practice. The findings may not be the same in an asymptomatic, nonreferred, unselected population. The study also lacks a direct comparison to patients with diseases that might affect diaphragm position. However, a lower and flatter diaphragm in patients with COPD compared to control subjects, and moderate correlation between radiographic features and pulmonary function abnormalities or pathology have been well documented in previous studies. Our purpose was to provide a more rigorous definition of the normal position and shape of the diaphragm, and identify factors that influence the variation.

In summary, the substantial variability in diaphragm position and shape in patients with normal pulmonary function was partially related to patient age, weight, and thoracic dimensions. The diaphragm tended to be lower with increased age, lower weight, and narrower transverse and anteroposterior thoracic dimensions, and flatter with increased age, greater weight, and wider thoracic dimensions. Consideration of these variables may be helpful when evaluating whether diaphragm shape and position are within the normal range.

References
5 Edge JB, Millard PJ, Reid L, et al. The radiographic

Table 4—Backwards Stepwise Multivariate Analysis of Predictor Variables

<table>
<thead>
<tr>
<th>Predictor Variables (Probability)</th>
<th>Measurements (n = 153)</th>
<th>Age</th>
<th>Weight</th>
<th>APD</th>
<th>Gender</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thoracic vertebral level</td>
<td>Right</td>
<td>0.001</td>
<td>0.001</td>
<td>0.007</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>0.007</td>
<td>0.03</td>
<td>&lt; 0.0001</td>
<td>0.31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diaphragm shape</td>
<td>Radius</td>
<td>&lt; 0.0001</td>
<td>&lt; 0.0001</td>
<td>0.38</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The relationship between pack-years smoked and diaphragm position in this group of patients with normal lung volume and normal expiratory flow rates was relatively weak. This was not surprising, since emphysema may be present in the lungs of smokers without measurable airflow obstruction. It is likely that some of our patients had mild emphysema, without spirometric abnormalities and below the resolution of the chest radiograph.

Weight, age, and APD had statistically significant independent relationships to diaphragm position in our multivariate model; however, this model accounted for only approximately one third of the variability in diaphragm position. In contrast to the performance of pulmonary function studies, the subjects of this study were not coached to obtain consistent maximal inspiratory efforts during chest radiography. Much of the remaining variability in diaphragm position may have been related to intersubject variation in inspiratory effort; however, this should reflect the variation found in clinical practice.

As age increased, the right hemidiaphragm had a larger radius of curvature and decreased RHH/APD ratio, and consequently a flatter appearance. Age-related changes in diaphragm shape also may be influenced by the age-related decrease in chest wall compliance, as noted for diaphragm position, as a lower and flatter diaphragm may be required to maintain TLC as the chest wall becomes more rigid. However, we found that the right hemidiaphragm radius was larger in men and as weight increased, but without a significant decrease in RHH/APD ratio. A greater radius with increased weight might be explained in part by a greater APD in heavier individuals, as weight and APD of the right hemidiaphragm were moderately correlated \((r = 0.53)\). The greater radius in men should be a function of size as well, since men are on average larger than women and a proportional increase in APD and RHH leads to a larger radius. Because of this geometric relationship, the diaphragm thus appears flatter in larger individuals with a greater APD.

It is not possible to compare our results regarding


