Multidetector computed tomography of diaphragm: Anatomic variants and diagnostic problems in adult population

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Received 14 June 2011; accepted 28 June 2011
Available online 3 August 2011

KEYWORDS
Multidetector CT; Diaphragm; Hiatus

Abstract Objective: Assess the multidetector computed tomography (MDCT) in the anatomic appearance of the diaphragm, its variants and defects.
Materials and methods: Retrospective study of 142 scans of patients in their 20s–80s using 64 rows MDCT from January 2010 to March 2011. According to Gale (1986), anterior diaphragm appearance on axial image is classified into type 1: continuous, type 2: discontinuous, and type 3: broad. Sagittal reformatted image is classified into type A: downward slope, type B: upward slope, and type C: flat. According to Caskey et al. (1989), posterior diaphragm defects are classified into type 1: localized defect with maintenance of its continuity, type 2: defect in parallel layers with maintenance of its continuity and type 3: loss of diaphragmatic continuity.
Results: Anterior diaphragm was assessed in 141 cases. On axial images, types 1, 2, and 3 were found in 36.9%, 41.1%, and 22.0% respectively. On sagittal reformatted images, types A, B, and C were found in 32.6%, 41.1%, and 26.2% respectively. One case had Morgagni hernia. Significant relationship between the types at the axial and sagittal images was found ($r = 0.205$, $P < 0.05$). 2.8% Posterior diaphragmatic defects. High significant relationship between the age and diameter of oesophageal hiatus was found ($P < 0.05$).

Conclusion: The multiplanar capability of MDCT is adding a new scope of assessment of diaphragm and its variants.

1. Introduction

The normal variations of the diaphragmatic anatomy, as well as diaphragmatic abnormalities, as demonstrated by computed tomography (CT) have been previously reported [1–6]. Defects and pseudotumours of the diaphragm have been described and attributed to congenital variations, respiratory effects, or aging [7].

Anatomically, the diaphragm is composed of two parts: the lumbar diaphragm and costal diaphragm [8]. CT allows an accurate depiction of the two crura, parts of the lumbar diaphragm that arise from the anterolateral surface of the first three right lumbar vertebrae and the first two left lumbar vertebrae. CT provides a precise image of the median and lateral arcuate ligaments, which are part of the lumbar section. The anterior or costal part of the diaphragm is usually more difficult to identify than the lumbar part on transverse images [9]. With the advent of computed tomography (CT) as an imaging modality for evaluating the thorax and abdomen, multiplanar CT reformations are very useful for studying diaphragmatic defects [10].

We aimed to assess the value of MDCT in depicting the anatomic appearance of the diaphragm, its variants and defects.

2. Patients and methods

2.1. Population of study

A retrospective study was performed in the period of January 2010 to March 2011 in Assuit university hospital. One hundred and forty-two chest and abdominal CT scans were reviewed retrospectively on workstation. Excluding postoperative cases and those who had congenital skeletal deformity. MDCT examinations were performed for various indications, including follow-up of known abdominal and chest and/or abdomen disorders, primary or metastatic tumour investigations, vascular pathology, and evaluation of infectious diseases. No MDCT scan had been obtained specifically to evaluate the diaphragmatic disease. All studies were performed on 64 rows MDCT with 0.65 mm slices. Either IV or oral contrast agents were administered depending on the clinical indication. All examinations were performed with the patient in the supine position holding an inspired breath.

Figure 1 Bar chart demonstrates the relation between axial images and sagittal images of anterior diaphragm.

Table 1 Relation between axial images and sagittal images of anterior diaphragm.

<table>
<thead>
<tr>
<th>Anterior diaphragm, axial images</th>
<th>Sagittal images of anterior diaphragm</th>
<th>Total</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Concave upward</td>
<td>Downward slope</td>
<td>Flat</td>
</tr>
<tr>
<td>Type 1</td>
<td>No.</td>
<td>22</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>15.6%</td>
<td>14.9%</td>
</tr>
<tr>
<td>Type 2</td>
<td>No.</td>
<td>17</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>12.1%</td>
<td>17.7%</td>
</tr>
<tr>
<td>Type 3</td>
<td>No.</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>5.0%</td>
<td>8.5%</td>
</tr>
<tr>
<td>Total</td>
<td>No.</td>
<td>46</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>32.6%</td>
<td>41.1%</td>
</tr>
</tbody>
</table>

*Spearman’s rho correlation.  
* Correlation is significant at the 0.05 level (2-tailed).  
** One case was excluded.
2.2. Multidetector CT image analysis

MDCT data in all subjects were based on axial scans and multiplanar reconstructed (MPR) images. All data were post processed using commercially available workstations. The reconstructed images were evaluated simultaneously by two radiologists.

2.2.1. Review of axial images was performed as followings

1. The anterior diaphragm was assessed according to Gale [11] into three major anterior diaphragmatic appearances:
   - Type 1 configuration, in which the curvature of the anterior muscle fibers was concave posteriorly and smoothly continuous with the anterolateral diaphragmatic fibers.
   - Type 2 configuration, in which the anterior muscle fibers appeared to be generally oriented at an angle to the lateral fibers within each scan plane and were, therefore, discontinuous in the midline.
   - Type 3 configuration, anterior muscle fibers lie almost entirely within a single scan plane, and hence they appear broad with angular, irregular, or poorly defined margins.

2. The posterior diaphragm was assessed according to Caskey et al. [12]; three types of defects in the contour of the diaphragm were defined.
   - Type 1 represents a localized defect in the thickness of the diaphragm but with maintenance of the continuity of the diaphragm. The width of the defect was typically approximately 5 mm. There was no evidence of protrusion of omental fat beyond the diaphragm.
   - Type 2 represents an apparent defect in the diaphragm in which the muscle fibers appear to separate into layers parallel to the diaphragmatic contour. The continuity of the diaphragm was maintained without protrusion of omental fat.
   - Type 3 represents any defect in which a portion of the diaphragm was absent with loss of diaphragmatic continuity. These defects varied from 5 mm in width to involvement of almost the entire hemidiaphragm with protrusion of omental fat.

3. The cross diameter of the esophageal hiatus was measured and evaluated for the presence of intrathoracic gastric herniation or intrahiatal omental fat.

4. Raised hemidiaphragm (eventration): complete or partial.

5. Presence of pseudotumour represents a focal mass-like area of lumbar diaphragm.
2.2.2. Review of Sagittal reformatted images was performed as follows
Gale [11] classified the anterior diaphragm into three types (types A–C) using 2 mm sagittal reformation images, based on the shape of the anterior diaphragmatic fibers traveling from the base of the pericardium to the xiphoid: type A: a downward slope, type B: an upward slope, and type C: a flat shape.

2.2.3. Review of coronal reformatted images was performed as follows
Using 5 mm coronal reformation images the continuity and integrity of the fibers of costal and lumbar parts of the diaphragm and the attachment of anterior diaphragm into the xiphoid process were assessed.

2.2.4. Statistical analysis
Statistical analysis of the results was performed using SPSS version 17 software. Data were expressed as mean ± SD (standard deviation) and number (percentage). Spearman rho correlation coefficient and Chi-square test were used to determine the significance between non-parametric data and the data were considered to be statistically significant when $P < 0.05$.

3. Result
One hundred and forty-two cases were included in the present study. The study group consisted of 86 (60.6%) males and 56 (39.4%) females, and the patients ranged in age from 20 to 86 years (mean age, $49.1 ± 15.4$ years). Anterior diaphragm was assessed in 141 out of 142 cases. 52 cases were (36.9%) type 1, 58 (41.1%) were type 2 and 31 (22.0%) were type 3 when considering the anterior diaphragm CT appearance on axial images Figs. 2–4.

On sagittal images, anterior diaphragm type A was found in 46 cases (32.6%), type B in 58 (41.1%), type C in 37 (26.2%) out of 141 cases Fig. 2–4.

Type A was seen in 36.9% of type 1 cases, type C was seen in 22% of type 3 cases, and type B was seen in 41.1% of type 2 cases. Statistically significant correlation of axial and sagittal images was found ($r = 0.205$, $P = 0.015$) Table 1 and Fig. 1.

No statistically significance was found among age groups or sex and CT appearance of the anterior diaphragm ($P > 0.05$).

The anterior diaphragm could not be assessed in one case who was a female in her 70s who had wide anterior diaphragmatic defect with intrathoracic gastric herniation and gastric volvulus Fig. 5.

Posterior diaphragmatic defects Fig. 6. were observed in four cases ranging in age from 40 to 70 years. Two males had a defect on the left side. One of them was type 1, and
the other one was type 2. Two females had a type 3-posterolateral defect, one of them was on the right side and the other one was on the left side with omental fat herniation. None of the cases in the 20s or 30s demonstrated defects.

Pseudotumour were found in 17 (12.0%) out of 142 cases Fig. 6. 82.3% of them in their 50s through 80s group. Only 1.4% of the cases in their 20s through 40s had pseudotumour.

Widening of oesophageal hiatus was found in 79 (55.6%) out of 142 cases Fig. 7. Thirty-three (58.9%) females and 46 (53.5%) males; with mean cross diameter was 19.41 ± 8.38 mm and 17.13 ± 5.158 mm for females and males respectively. A highly significant relationship between the age and diameter of hiatus with \( P \) value <0.05 Table 2.

Eventration of diaphragm was observed in five cases. Four of them were complete and located on the left side Fig. 8 and one was partial and observed on the right side.

4. Discussion

The diaphragm is a dome-shaped, musculotendinous structure located at the bottom of the pleural cavity and at the top of the abdominal cavity. CT provides a precise image of the two crura, median and lateral arcuate ligaments, which are part of the lumbar section. The anterior or costal part of the diaphragm is usually more difficult to identify than the lumbar part on transverse images [13]. Indeed, when the diaphragm abuts structures of similar attenuation, such as the liver or spleen, the outline of the diaphragm is not visible. These facts explain some of the limitations in the diagnosis of diaphragmatic tears at axial imaging [14].

Presently, MDCT enables acquisition of volumetric data, eliminating respiratory motion while providing good-quality sagittal and coronal reformation images that are well suited to the evaluation of the diaphragm and improve the accuracy of CT in the diagnosis of diaphragmatic injuries [15].

As described by Gale [11], the muscle fibers that extend from the dorsal surface of the xiphoid and anteromedial costal cartilages to the middle leaflet of the central diaphragmatic tendon are shorter than those that lie laterally and posteriorly. The direction of their orientation depends on the cephalocalatal position of the middle leaflet of the central tendon relative to the xiphoid. Thus, he described three appearances of diaphragm anteriorly and found 48% type 1, 28% type 2 and 11% type 3 of 176 cases. While, Cho et al. [16] found 30.9% type 1, 38.3% type 2, and 30.9% type 3 out of 81 cases. Nearly similar results with Gale series in the present study are found with 36.9% type 1, 41.1% type 2 and 22.0 % type 3 out of 141 cases, type 3 is the least group that is consistent with the Gale series’ results.
Gale [11] reported that if the middle leaflet is more cephalic than the xiphoid, then the anterior fibers curve downward from the middle leaflet to their insertions on the xiphoid and costal cartilages. As the muscular arch crosses the transverse scan plane, the intersection of the two forms a broad curvilinear arc concave posteriorly. Therefore, on CT scans the posterior and lateral fibers are part of a continuous arc of anterior diaphragm closed anteriorly by similarly sloped anterior fibers. If the apex of the middle leaflet of the central tendon is inferior to the xiphoid, the anterior diaphragmatic fibers extend upward from the central tendon to the xiphoid and anterior costal margins. On CT scans, the smoothly curved lateral and posterior diaphragmatic line appears to open anteriorly toward the sternum as the muscular arch intersects the scan plane. It the middle leaflet has a shallow curvature and is near the same cephalocaudal level as the xiphoid. Therefore, the short anterior fiber flattens near its leaflet attachment. As a result, the muscle fibers are more nearly parallel to the scan plane and therefore remain almost entirely within it. In this arrangement, the muscle fibers appear on CT scans as a broad band with an irregular, ill defined or angular margin.

According to this, on sagittal reformation images, we found type A in 32.6%, type B in 41.1%, and type C in 26.2% out of 141 cases regarding the shape of the anterior diaphragmatic fibers traveling from the base of the pericardium to the xiphoid compared to number of types A, B, C on the sagittal reforma-
tion images studied by Cho et al. [16] which were 33.3%, 22.2%, and 44.4% out of 81 cases respectively. Statistically significant correlation of axial and sagittal images was found ($r = 0.205$, $p < 0.05$) which is consistent with the study of Cho et al. [16] who found a significant agreement ($r = 0.868$, $p < 0.01$). No statistically significant correlation was found among age groups or sex and CT appearance of anterior diaphragm ($P > 0.05$).

An understanding of the anatomy of the anterior portion of the diaphragm is essential to the correct diagnosis of Morgagni hernia. The presence of bowel anterior to the heart, usually transverse colon on lateral chest radiographs or liver on ultrasound, suggests the presence of Morgagni hernia. But CT is the most sensitive as it gives excellent anatomical detail on the contents of the hernia and its complications such as strangulation [17]. Incidental findings of this condition in adults are less common with only 81 asymptomatic cases reported in a recent review accounting for only 3% of all treated diaphragmatic hernias. Hernia of Morgagni occurs through an anterior defect in the diaphragm but usually presents in adulthood through a paramedian defect. In contrast, it occurs in a central retrosternal location in children. It could be an incidental diagnosis in adulthood or can present with obstructing symptoms of the herniated viscera. Symptoms of these hernias are attributable to the herniated viscera [18]. One case was found in this study who was a female in 70s presented with epigastric pain and vomiting. MDCT depicted a wide anterior diaphragmatic defect with intrathoracic gastric herniation into the right hemithorax with the distal antrum and pylorus assuming a position cranial to the fundus and proximal stomach suggestive of mesenteroaxial gastric volvulus. In a review of the literature, Coulier and Broze, [19] and Rai et al. [20] have described similar series of cases of symptomatic hernias presented in elderly patients.

Discontinuity of the diaphragm between the crura and the lateral arcuate ligaments is a normal variation encountered in 11% of normal patients and should not be confused with diaphragmatic rupture [21]. The prevalence of posterior lateral diaphragmatic defects or asymptomatic Bochdalek hernia in
the adults demonstrated by CT was approximately 6%. An association with aging suggests that atrophy can be related to an acquired loss of diaphragmatic muscular integrity [22]. Only four among 142 cases were aged 40–70 years in this study. Two males out of four cases had posterior diaphragmatic defect, one was type 1 and the other was type 2. Another ones were two females had type 3-posterolateral defect with omental fat herniation.

Pseudotumours represent a “bunching” of muscular tissue. In association with diaphragmatic defects, they represent an area of markedly contracted muscle adjacent to an area void or nearly void of muscle tissue. The authors postulated that the cause of pseudotumours was related to the increasing laxity with age of the connective tissues that bind the diaphragm, as well as decreasing muscle tone, leading to nonuniform contraction and redundancy of the diaphragm. Differential diagnosis of these pseudotumours from pathologic lesions is based on their continuity peripherally with the diaphragm and their separation from the hollow viscera by subdiaphragmatic fat [23]. We demonstrated 12.0% of 142 cases reviewed had pseudotumour with an increase to 82.3% in the patients aged 50–80 years.

Eventration of the diaphragm is an abnormal elevation of an intact diaphragm. It can be congenital or acquired. Congenital eventration is the result of incomplete muscularization of part or the entire membranous diaphragm during foetal life, whereas the acquired form may be secondary to trauma, inflammation, or neoplastic invasion of the phrenic nerve [24]. The unbroken continuity differentiates it from diaphragmatic hernia. Total eventration shows marked left-sided predominance for which there is no acceptable explanation. Localized forms of the condition are relatively common, particularly in the elderly and predominantly affect the right hemidiaphragm at its anteromedial aspect. Differentiation from diaphragmatic paralysis is difficult in the latter condition almost no downward displacement occurs during deep inspiration whilst in eventration the hemidiaphragm usually shows some downward motion, as there are still some functioning muscle fibres peripherally [25]. Five cases were observed in our study, one observed on the right side was partial and occurred on the anteromedial aspect of the right hemidiaphragm. While the other four cases observed on the left side were complete with upward displacement of stomach and colon.

Hiatus hernia was diagnosed on CT when the diaphragmatic crura are separated by more than 15 mm, and the hernia produces a mass of soft-tissue density that protrudes above the hiatus and which may be surrounded by mesenteric fat and large hernias may result in the entire stomach entering the chest [26].

Figure 6  CT appearance of posterior diaphragm. Axial image (A) demonstrates left posterior diaphragm type 1 (long arrow); this is not a complete rent, as seen by the threadlike connection with pseudotumour beside it (short arrow) in 40 years old male patient. Axial image (B) demonstrates left hemidiaphragm posterior defect type 2 (arrow); apparent defect of its posteromedial aspect into layers parallel to the diaphragmatic contour in 55 years old male patient. Axial image (C) demonstrates type 3 (long arrow); focal posterolateral defect of the right hemidiaphragm with omental fat herniation in 60 years old female patient.
Widening of oesophageal hiatus was observed in 55.6% of cases with intrahiatal omental fat herniation in 9.9% of cases. Large hiatus hernia with intrathoracic gastric herniation was observed in two cases. One of them showed intrathoracic herniation of pancreas and omentum. A highly significant relationship between the age and diameter of hiatus was found.

The muscular diaphragm is a dome-shaped three-dimensional structure; transaxial images are often oblique to the diaphragm. Various imaging investigations may be used in diagnosis: Plain chest radiography, fluoroscopy, barium studies, ultrasound, helical CT, MDCT, magnetic resonance imaging, laparoscopy, and laparotomy but MDCT is the most-preferred non-invasive procedure among these [27]. The diaphragm can be thoroughly evaluated using axial and multiplanar reconstructed MDCT images, and diaphragmatic defects can be diagnosed much more easily and with greater certainty. Two major factors are mainly responsible for this improvement. Indeed, in-plane spatial resolution has increased for more precise visualization of subtle signs such as focal indentation of the liver on axial images, and a higher longitudinal spatial resolution has allowed more accurate analysis of the diaphragm [28].

Identification of morphology of diaphragm is important to enable correct and early diagnosis of diaphragmatic rupture and decrease the false negative or false positive results as not all diaphragmatic defects are rupture. Asymptomatic posterior defect or eventration may mimic diaphragmatic rupture. Therefore, the coronal and sagittal planes are better suited to the analysis of the diaphragm.

In conclusion, the multiplanar capability of multidetector CT is an emerging tool to depict the diaphragm adding a new scope of assessment of anterior and posterior diaphragm.
and its variations. Aging is commonly accompanied with posterior diaphragmatic defect, pseudotumour and widening of hiatus hernia. Agreement was found between axial and sagittal reformatted images. High significant relationship between the oesophageal hiatus hernia and age was also observed.

References


Figure 8 Fifty years female patient. Scout chest (A), axial, sagittal and coronal reformatted images (B, C, and D) demonstrate eventration of the left hemidiaphragm with colon lying beside it.


