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Morphologic variation of the diaphragmatic crura: a correlation with pathologic processes of the esophageal hiatus?

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The contributions of muscle fibers from the right and left diaphragmatic crura to the formation of the esophageal hiatus have been documented in several studies, none coming to a complete consensus on the number of anatomic variations or the prevalence of these variations in the human population. These variations may play a role in the pathogenicity of specific diseases that involve the esophageal hiatus, such as hiatal hernias. We examined a total of two hundred adult cadavers during 2000–2007. The variations in the diaphragmatic crura, particularly their muscular contributions to the formation of the esophageal hiatus, were grossly examined and revealed a bilateral occurrence of diaphragmatic crura in all 200 specimens. The results of the various morphological patterns of circumferential muscle fibers forming the esophageal hiatus were classified into six groups. The most common type (Type I, 45%) formed the esophageal hiatus from muscular contributions arising solely from the right crus. In Type II (20%) the esophageal hiatus was formed by muscular contributions from the right and left crura. In Type III (15%), the right and left muscular contributions arose from the right crus with an additional band from the left crus. Type IV (10%) showed that the right and left muscular contributions arose from the right crus, with two additional (anterior and posterior) bands arising from the left crus. Type V (5%) demonstrated the contributions arising solely from the left crus. In Type VI (5%) the right and left contributions originated from the left crus with two additional bands, one from the right crus and one from the left crus.

These variations may play a role in the pathogenicity of specific diseases that involve the esophageal hiatus such as hiatal hernia, gastroesophageal reflux disease and Dunbar's syndrome. (Folia Morphol 2008; 67: 273–279)

Key words: right crus, left crus, diaphragmatic crura, gastro-esophageal reflux disease, Dunbar's syndrome

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INTRODUCTION

The esophageal hiatus is an elliptic opening in the muscular part of the diaphragm though which the esophagus passes [25]. It lies on the left of the midline, approximately 1cm from the posterior border of the central tendon and approximately at the level of T10. The margins of the hiatus are formed by the arms of the diaphragmatic crura and median arcuate ligament, if it is present. Both the right and left crura are muscular bands arising from the anterior surfaces of the bodies and intervertebral fibrocartilages of the lumbar vertebrae L1 to L4 on the right and L2 or L3 on the left [26]. The medial tendinous margins of the crura pass forward and medialward and meet in the middle line to form an arch across the front of the aorta; finally these fibers converge to be inserted into the central tendon, forming the esophageal hiatus [27].

The contributions of muscle fibers from the right and left diaphragmatic crura to the formation of the esophageal hiatus have been documented in several studies, none reaching a complete consensus on the number of anatomic variations or the prevalence of these variations in the human population [26]. Despite this, the significance of variation in the musculature which forms the boundary of the orifice is little appreciated [7]. Any pathologic process or surgical procedure which violates the integrity of the wall of the hiatus will interfere with the function of maintaining a unidirectional passage of food and fluid from the esophagus to the stomach [2–4, 13]. This implies that knowledge of variations in the anatomic structure of the diaphragm is a matter of primary surgical importance.

The aims of our study, therefore, were to examine and delineate the anatomy and variations in the morphology of the diaphragmatic crura and to relate these results with clinical syndromes such as hiatal hernia, gastroesophageal reflux disease and Dunbar's syndrome.

MATERIAL AND METHODS

We examined a total of 200 adult cadavers, of which half were examined during the "Human Body" course at Harvard Medical School throughout the academic semesters between 2000 and 2006.The cadavers from Harvard consisted of 55 male and 45 female subjects with an age range of 55 to 89 years and a mean age of 71 years. One hundred additional cadavers were derived from St. George's School of Medicine during the three academic semesters of 2006 and the 2007. The cadavers from St. George's consisted of 22 female and 78 male subjects with an age range of 65 to 71 years and a mean age of 69 years. The specimens were without any grossly evident pathologies or surgical procedures affecting the esophagus or the stomach. All the cadavers were routinely fixed in formalin/phenol/alcohol solution. In order to correct for individual examiner variability each specimen was independently examined by each of the three co-authors, ML, CW and RL.

Following preliminary examination, images from all the dissected specimens were recorded with a Nikon digital camera (model: Coolpix S5) and studied using a computer-assisted image analysis system (Lucia software 5.0 [2000, edition for Windows XP], made by Nikon [Laboratory Imaging Ltd.]). The digital camera was connected to an image processor (Nvidia GeForce 6800 GT) and linked to a computer. Digitized images of the diaphragmatic crura were stored in the Lucia program (2048 $\times$ 1536 pixels) and converted to intensity grey levels from 0 bit (darkest) to 32 bit (lightest). After a standard 1 mm scale had been applied to all pictures, the program was able to use this information to calculate pixel differences between two selected points, such as the origin and termination of the crura, as previously described [17]. Specifically, the length was measured from the point of origin of the right and left arms of the diaphragmatic crura to the point of insertion. At the midpoint of each right and left arm of the diaphragmatic crura the arm was cut and the thickness and width measured. The results were analyzed with a t-test using Statistica Software for Windows, and values were considered statistically significant when $p < 0.05$.

RESULTS

The results revealed bilateral occurrence of diaphragmatic crura in all 200 specimens. However, the course and connections of the crura were subject to a wide range of variation. To facilitate comparisons between specimens and to analyze various morphological patterns of circumferential muscle fibers forming the esophageal hiatus, the results were classified into six groups (Fig. 1).

As regards the variations found in our study, the most common type (Type I, 45%) formed the esophageal hiatus from muscular contributions arising solely from the right crus (Fig. 2, 3). In Type II (20%), the esophageal hiatus was formed by muscular contributions from the right and left crura. In Type III (15%), the right and left muscular contributions arose from the right crus with an additional band

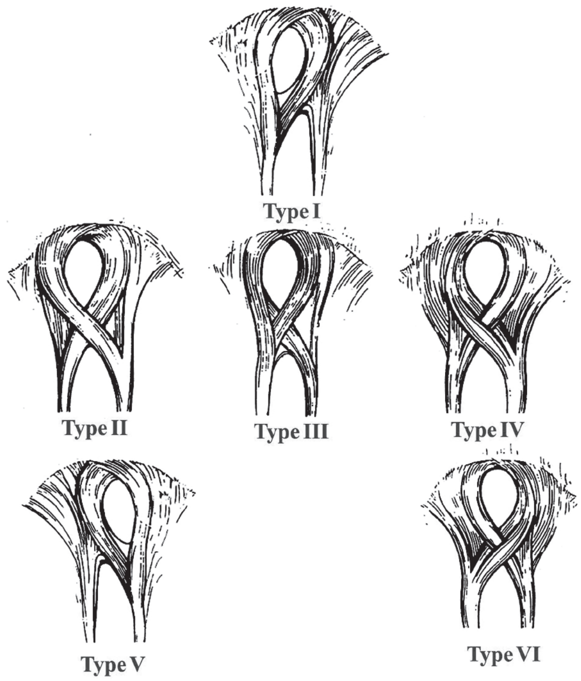

Figure 1. Diagrammatic representation of the different types of diaphragmatic crura observed in this study (modified with permission of [25]).

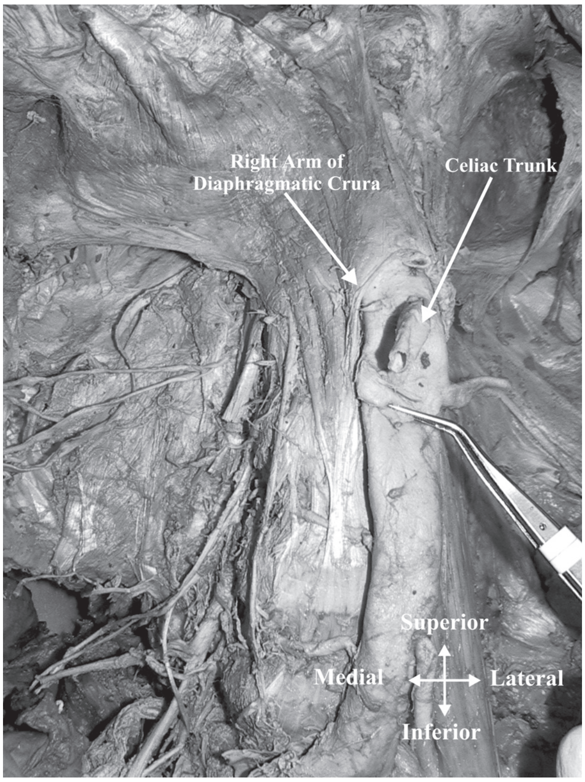

Figure 3. Taken from a lateral right view and depicting the right arm of the diaphragmatic crura. Notice that the right arm is contributing to the entire formation of the esophageal hiatus and is classified as Type I.

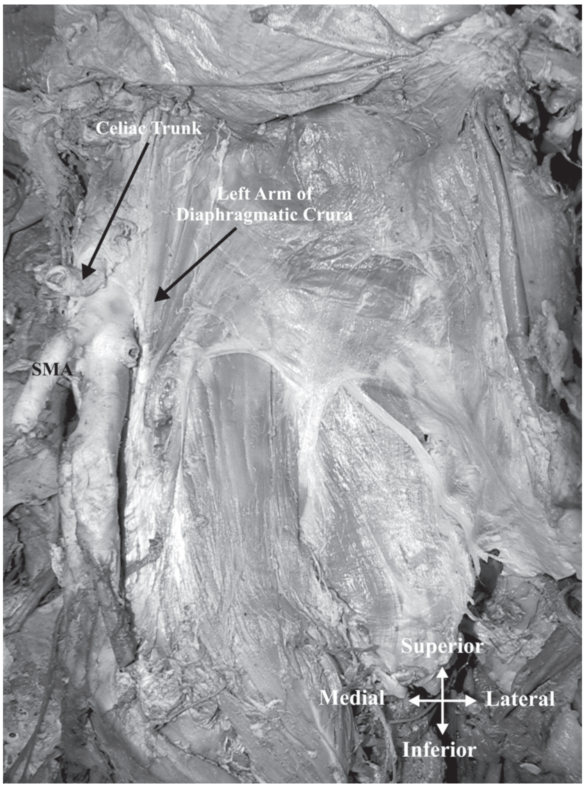

Figure 2. Taken from a lateral left view and depicting the left arm of the diaphragmatic crura. Notice that the left arm is not contributing to the formation of the esophageal hiatus and is classified as Type I; SMA — superior mesenthesic artery.

from the left crus, Type IV (10%) showed that the right and left muscular contributions arose from the right crus, with two additional (anterior and posterior) bands arising from the left crus. Type V (5%) demonstrated the contributions arising solely from the left crus. In Type VI (5%) the right and left contributions originated from the left crus with two additional bands, one from the right crus and one from the left crus.

The origins of the right and left arms from the diaphragmatic crura were also variable. In 45% of the specimens the right arm of the diaphragmatic crura originated from L1 to L4, in 32% from L2 to L4 (Fig. 4) and in the remaining 23% of the specimens from L2 to L3. On the left side in 2% of the specimens the left arm of the diaphragmatic crura originated from L1 and L3 (Fig. 5), in 40% from L2 and L3, in 30% from L2 and in the remaining 28% from L3.

The descending diaphragmatic arms of the crura were found to be thick with a mean diameter of 6.7 mm and a range of 3.2–8.1 mm, becoming tendinous and less muscular near their vertebral bodies

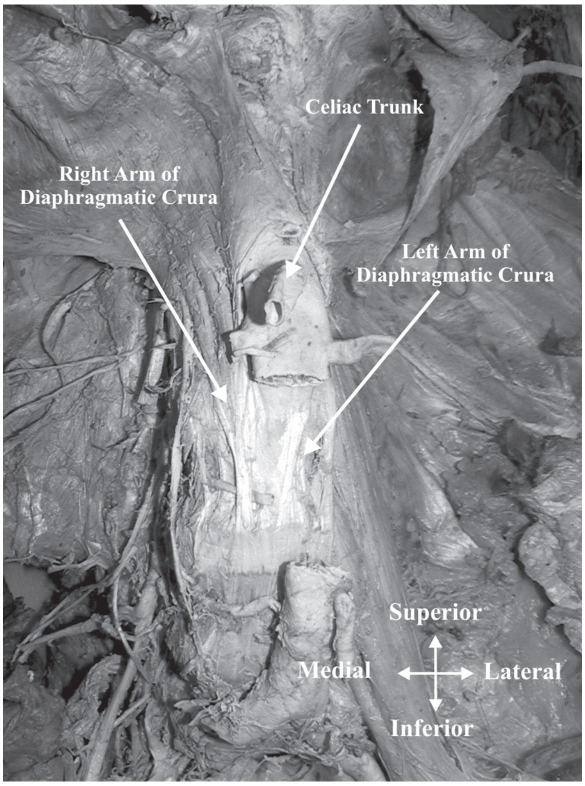

Figure 4. Both the right and left arms of the diaphragmatic crura are attached to L1–L4.

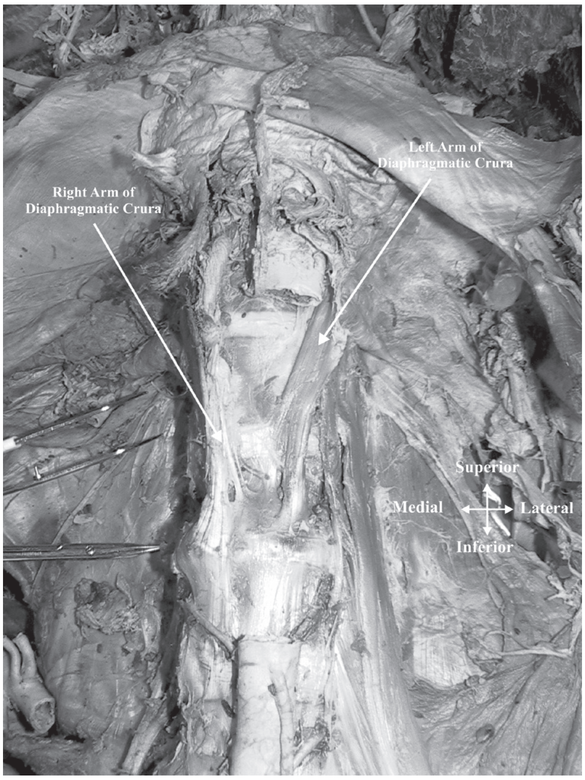

Figure 5. In this specimen the left arm of the diaphragmatic crura originated from L1 and L3. Notice its thick muscular nature in contrast to the right arm of the diaphragmatic crura which appears to be tendinous.

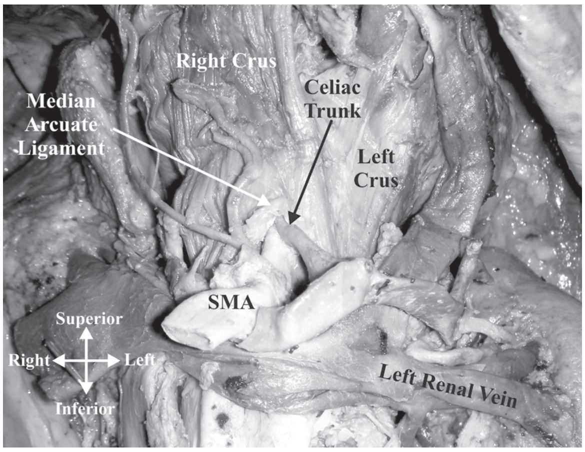

Figure 6. The descending diaphragmatic arms of the crura; SMA — superior mesenthesic artery.

(Fig. 5, 6). The mean length of the right diaphragmatic arm of the crura was found to be 15.5 cm with a range of 11.2–19.6 cm. The mean length of the left diaphragmatic arm of the crura was found to be 13.5 cm with a range of 9.6–16.1 cm. The mean location of the transformation from the muscular to the tendinous portion of the crura was found to be at a mean of 27% of the entire length of the crura at its distal end with a range of 22–31%. There was no significant difference between the types and dimensions of the arms of the diaphragmatic crura with regard to race, gender, age or the institution from which the cadavers were derived (Student's t-test; $p > 0.05$).

DISCUSSION

Our study of 200 human cadavers was performed in order to examine the variability of muscle fiber contributions from the diaphragmatic crura in the formation of the esophageal hiatus. Current data on this subject have been found to be highly variable in both the number of anatomic variations and their statistical occurrence. A more comprehensive study seemed necessary because of the clinical significance of the competence of the esophageal hiatus and the need for clarification of the disparity in data that is currently available.

Serveral studies have determined that the contribution of the crura to the formation of the esophageal hiatus is most commonly derived solely from muscle fibers from the right crus, designated as Type I in our study. The statistical variation has ranged from 100% [1, 7, 19–21, 24], 80% [12], 75% [15], 58% [6], 50% [16], 46% [11], to 36% [9]. In contrast, the study of 50 cadavers by Botha [6] showed that the esophageal hiatus was formed by the right crus alone in 10% of specimens. By comparison, 45% of our specimens showed the esophageal hiatus formed solely by the right crus with no contribution from the left crus. Furthermore, 20% of our cadavers displayed an equal contribution of muscle fibers from the right and left crura to their respective sides of the esophageal hiatus, designated as Type II in our study. As before, no general consensus could be reached concerning the prevalence of this equal contribution. Ranges of values have been anywhere from 100% [29], 32% [9], 25% [15], 20% [12], to 10% of cases [6].

Muscle fiber separation of the right and left crura was determined by Delattre et al. [12] to be such that both crura can be divided into medial and lateral bundles. In contrast, the study by Botha [6] found that 98% of right crura can be divided into medial, middle, and lateral bundles, and that 90% of left crura can be divided into medial and lateral bundles; our data correlate with this study in defining the division of the crura into these bundles. This same study found that in 62% of their cases the esophageal hiatus was formed by the right crus with a contributing band of muscle from the left crus. Our study, in contrast, revealed this same variation in 15% of cases, designated as Type III. Other authors have found this same variation, yet failed to acknowledge that the contribution from the left crus was a significant one. We were unable to determine if this disparity was due to individual observer variability or dissection technique.

Gastroesophageal reflux disease (GERD) is a normal physiologic phenomenon experienced intermittently by most people, particularly after a meal. Gastroesophageal reflux disease occurs when the amount of gastric juice that refluxes into the esophagus exceeds the normal limit, causing symptoms or complaints, such as esophagitis, with or without associated esophageal mucosal injury. Interestingly, GERD has been found in patients with normal lower esophageal sphincter competency, which suggests that there are certain extrinsic factors, possibly including efficacious tone of the crura that contribute to the presence or absence of this disease [12]. It has also been reported that active diaphragmatic contraction is an important factor in the generation of a high-pressure zone at the gastroesophageal junction, which may act as an extrinsic anti-reflux barrier [8, 30]. Over-emphasis of the lower esophageal sphincter has led surgeons to orientate therapy on the basis of the construction of an anti-reflux valve that leads to marked changes in the regional anatomy, which is often normal to begin with [12]. Understanding the anatomy of the esophageal hiatus could prove useful as it could allow for the selection of proper methods of treatment in patients with GERD. In particular, very little data are available regarding the contribution of the right and left diaphragmatic crura to the formation of the esophageal hiatus and their relation to the composition of the median arcuate ligament.

The lower esophageal sphincter or distal esophageal high pressure zone is a 3–5 cm area in the terminal esophagus serving as a competence valve that allows the passage of food into the stomach but prevents retrograde flow of contents from the stomach into the esophagus. Although the exact mechanism of this competence is not completely understood, established factors leading to failure include inadequate contraction of the intrinsic musculature of the distal esophagus, loose sling fibers of the gastric cardia, as well as transmitted pressure of the abdominal cavity, as is the case during the presence of a hiatal hernia [10]. In addition, esophageal and gastric distension have also been implicated as having an effect on the barrier function of the lower esophageal sphincter. Investigating this hypothesis not only mechanically but also actively through a crural-esophageal-gastric reflex action, Shafik et al. [23] recorded the electromyographic response of the crural diaphragm to individual balloon distension of the esophagus and stomach. These authors found that the crural diaphragm has a resting tone that relaxes after esophageal distension and contracts after gastric distension. This sphincter-like action of the crura appears to be a reflex and is mediated through the esophagocrural inhibitory and gastrocrural excitatory reflexes. The crural diaphragm therefore seems to share actively in the gastroesophageal competence mechanism. Similarly, Sun et al. [28] discovered that abnormal manometric and pH studies of the esophageal body and post-lower esophageal sphincter relaxation related to swallowing were not only functions of the diaphragmatic crura but also played an important role in the development of GERD. This study showed that the pressure of the lower esophageal sphincter significantly decreased after a test meal both in patients with known GERD and in healthy subjects. However, the tension of the crural diaphragm at rest in GERD patients was much lower than that observed in healthy subjects either during fasting or postprandially.

With the introduction of clinical radiology it has become evident that diaphragmatic hernias are relatively common. Type I or sliding hiatal hernias are characterized by an upward dislocation of the cardia in the posterior mediastinum. Although many are asymptomatic, the most common presenting symptoms relate to the coexistence of gastroesophageal reflux in these patients [10]. Recently, the use of prosthetic meshes for crural closure in laparoscopic anti-reflux surgery has resulted in a significantly lower rate of postoperative hiatal hernia recurrence, according to Granderath et al. [14]. This study concluded that measurement of the hiatal surface area dictates the method of surgical closure and serves as an effective means in preventing hiatal hernia recurrence and/or intrathoracic wrap migration. Depending on the configuration of the diaphragmatic crura, certain types demarcated in our study could have an impact on the success of such placement and subsequent operative outcome. For example, in Type VI (5%) the right and left contributions arise from the left crus with two additional bands, one from the right crus and one from the left crus. If the sutures anchoring the mesh were placed in an additional, smaller muscular contribution instead of the main band forming the right crus, the competency of hiatal closure with respect to how tightly the mesh is placed may be compromised by the altered contraction properties of the small contribution as compared to the right crus itself.

According to Skandalakis et al. [26], the placement of non-absorbable sutures in the crura (including the attached pleura) is absolutely necessary to narrow the hiatus for repair of a hiatal hernia. The surgeons must be sure that the sutures are in the tendinous portions of the crura and not in the muscular part only. If the surgeon chooses to close the hiatus anterior to the esophagus, non-absorbable sutures must partially incorporate the transverse ligament as well as the right and left arms of the crura [26].

Celiac artery compression syndrome, also termed Dunbar syndrome, is a rare condition associated with the potential clinical presentation of upper abdominal pain, weight loss, hyperemesis, and the presence of an epigastric bruit caused by inadequate blood flow through the celiac artery with resultant ischemia [18]. This syndrome is caused by unfavorable anatomic relationships at the aortic hiatus between the celiac artery, the superior mesenteric artery and the overlying structures, particularly the diaphragmatic crura. These anatomic relationships, in contrast to the syndrome they sometimes produce, are relatively common, which makes the detection of celiac artery compression only a prerequisite in the diagnosis of the clinical entity. The diagnosis ultimately depends on the relentless elimination of other possible causes for abdominal pain and on the knowledge that this curious syndrome does indeed exist [5]. Subsequently a more rapid diagnosis may be achieved with the acknowledgement that the angle of origination of the celiac trunk, as well as the angle of declination of the diaphragmatic crura, could have a potential effect on the compression of this artery [18]. If the diaphragmatic crura deviate acutely relative to the abdominal aorta/vertebral column, the celiac trunk may be constricted via the median arcuate ligament [22]. Certain configurations of the crura, such as hypertrophied right crus, a case demonstrated by Loukas et al. [18], could therefore predispose the celiac trunk to compression, such as hypertrophied right crus [18].

Currently fundoplication procedures are performed for hiatal hernia repair, as an anti-reflux procedure or for the surgical treatment of achalasia. Both these procedures, as well as the pathologic processes in patients that drive surgical treatment, are extremely common in modern medical practice. The authors believe that further studies need to correlate post-mortem findings with past clinical history and a subsequent predisposition to develop one of the above ailments. Unfortunately, in the present study we were unable to demonstrate to what degree these types of diaphragmatic crura contribute to the formation of hiatal hernia. Additionally, the advent of new imaging technologies including high-resolution spiral computed tomography, when coupled with increased knowledge of morphologic variations, could demonstrate more clearly the potential pathologic role of the diaphragmatic crura, so leading to the betterment of both diagnosis and subsequent management.

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