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ORIGINAL COMMUNICATION

The Pattern of the Thoracic Splanchnic Nerves as They Pass Through the Diaphragm

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The formation and structure of the greater, lesser, and least thoracic splanchnic nerves is highly variable in their intrathoracic as well as their subdiaphragmatic portion. Splanchnicectomies for pain control of otherwise intractable upper abdominal pain and other surgical procedures are dependent on the detailed knowledge of the anatomy of these nerves and their variations. Many commonly used anatomical illustrations depict the passage of the thoracic splanchnic nerves through the diaphragm uniformly as three nerves penetrating the crura in three separate locations along a rough superoinferior line. As this pattern does not correspond with our own sporadic observations, we performed a series of dissections to study the exact anatomy of this area. Dissections of 24 donors revealed that the most common pattern of diaphragmatic passage of these three nerves is through a single location in each crus. From this crural passageway, the three nerves then diverge to reach their targets, with the greater thoracic splanchnic nerve bending anteriorly at nearly 90° to enter the posterolateral edge of the celiac ganglion. Modern anatomical illustrations should depict these most common patterns of the subdiaphragmatic portion of the thoracic splanchnic nerves and mention the great variability of their formation and structure. Clin. Anat. 22:809–814, 2009.

Key words: thoracic splanchnic nerves; diaphragm; anatomical illustrations

INTRODUCTION

The greater, lesser, and least thoracic splanchnic nerves carry preganglionic visceral sympathetic efferent innervation from the thoracic sympathetic chain to the upper abdominal region, where they synapse within the celiac and aorticorenal ganglia and the renal plexus respectively. They also contain visceral afferent nerve fibers that carry pain sensation from the upper abdominal organs, including the pancreas, towards the central nervous system. Splanchnicectomy, the surgical interruption of these nerves, has been shown to be an effective treatment in the control of otherwise intractable abdominal pain caused by chronic pancreatitis, cancer of the pancreas or other organs in the region (Naidoo et al., 2001). Interruption of these nerve fibers can be performed at the intrathoracic level or at the subdiaphragmatic, retroperitoneal level, e.g., at the ganglia (Bradley and Bem, 2003). However, the outcome of these procedures can be variable and is in part dependent on the exact knowledge of the detailed anatomy of the greater, lesser, and least thoracic splanchnic nerves, and their variations (Bradley et al., 1998; Naidoo et al., 2001; Kang et al., 2007; Yang et al., 2008). Bradley and Bem (2003) noted that anatomic drawings of the area demonstrate little variation in the anatomy of the thoracic splanchnic nerves, while the authors, as many before them, had encountered considerable variation in the location and number of branches of these nerves. This variability refers to the numbers and levels of thoracic ganglia contributing fibers to the individual thoracic

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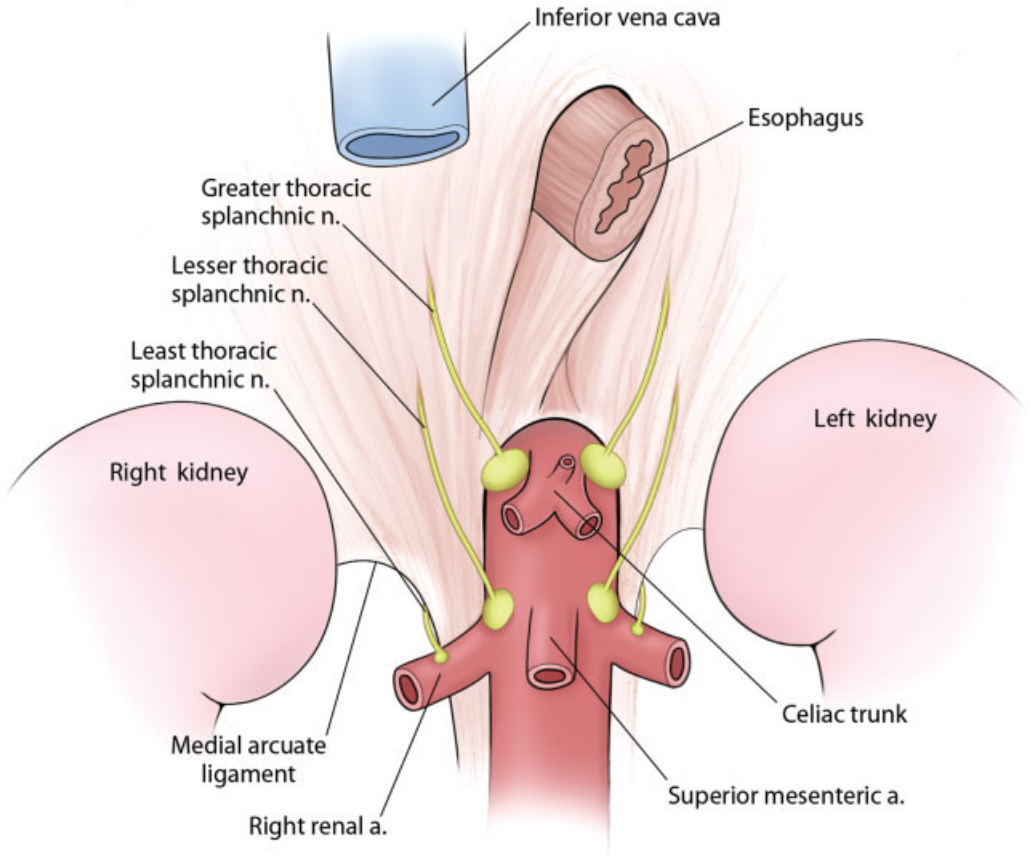

Fig. 1. A composite illustration depicting the pattern of thoracic splanchnic nerves as they pass through the crura of the diaphragm as seen in commonly used modern atlases.

splanchnic nerves as well as to the presence of the lesser and least nerves and accessory nerve fibers (Edwards and Baker, 1940; Jit and Mukerjee, 1960; Naidoo et al., 2001; Yang et al., 2008).

Not only the intrathoracic portions of the splanchnic nerves, but also the subdiaphragmatic distal portions are variable. Information on the variability of the anatomy of the distal portions of the thoracic splanchnic nerves may be important for the success of subdiaphragmatic neuroablative surgical approaches to pain control (Bradley and Bem, 2003). In addition, in other surgical interventions, e.g., the anterior approach to the lumbar spine in orthopedics, these structures may come into harms way if the anatomy is unclear (Samudrala et al., 1999). Previous studies on the exact anatomy of the thoracic splanchnic nerves have focused on their intrathoracic formation pattern (e.g., Edwards and Baker, 1940; Groen et al., 1987; Naidoo et al., 2001; Yang et al., 2008) or the shape and connections of the celiac ganglion (Struckhof, 1932; Paz and Rosen, 1989). Few newer studies addressed the question of the exact course of the nerves through the diaphragm towards ganglia and plexuses. Paz and Rosen (1989) described the greater and lesser thoracic splanchnic nerves commonly piercing the diaphragm lateral to the crus through a triangular opening, but they did not report on whether the nerves run together in one foramen. In their dissection series of 50 specimens, Jit and Mukerjee found that the greater and lesser thoracic splanchnic nerve usually passed through a common hiatus in the crus (Jit and Mukerjee, 1960, p 71).

Many commonly used anatomical illustrations depict the passage of the thoracic splanchnic nerves through the diaphragm uniformly as three nerves penetrating the right and left crura in three separate locations along a superoinferior line, with the greater thoracic splanchnic nerve continuing in a straight line towards the celiac ganglion (see Fig. 1). These illustrations can be found in anatomical atlases such as Netter (Netter, 2006), Gray's Atlas of Anatomy (Drake et al., 2007), Clemente (2006), and Thieme (Schuenke et al., 2006). However, in our own observations, the thoracic splanchnic nerves show a more varied pattern, in that the nerves often cruise together through the diaphragm, and the greater thoracic splanchnic nerve then bends sharply towards the celiac ganglion. Illustrations in atlases drawn directly from dissections show patterns similar to this observation, e.g., Grant's (Agur and Dalley, 2005), Gray's Anatomy (Williams et al., 1989), and Pernkopf (Pernkopf and Ferner, 1964).

TABLE 1. Incidence of Patterns of Passage of Thoracic Splanchnic Nerves Through the Right and Left Crura of the Diaphragm

Pattern	Right $N = 21$	Left $N = 23$	Total $N = 44$
GTS and LTS separate	1	0	1
GTS, LTS and LeTS separate	1	1	2
GTS and LTS together, LeTS separate	2	2	4
GTS separate, LTS and LeTS together	0	3	3
GTS, LTS and LeTS together	8	8	16
GTS and LTS together	9	9	18

GTS, greater thoracic splanchnic nerve; LTS, lesser thoracic splanchnic nerve; LeTS, least thoracic splanchnic nerve.

In order to determine the exact anatomy of the subdiaphragmatic portion of the greater, lesser, and least thoracic splanchnic nerves, we performed a series of dissections to answer the following questions: first, in what manner, i.e., separately or together, do the greater, lesser, and least thoracic splanchnic nerves pierce the diaphragm, and second, does the greater thoracic splanchnic nerve continue on a straight superoinferior line to connect with the celiac ganglion or does it curve at an angle?

MATERIALS AND METHODS

Anatomical dissections were performed on the bodies of 24 donors to reveal the patterns of thoracic splanchnic nerve passage through the diaphragm. There were 16 female and eight male bodies, the ages ranged from 54 to 92 years, and the majority were caucasian. The bodies were embalmed according to conventional methods used in routine anatomy classes. After cutting the clavicles and the thoracic and abdominal walls laterally in the anterior axillary line, the thoracic and abdominal viscera were removed. The right and left hemidiaphragms were trimmed down to a level just superior to the point of passage of the thoracic splanchnic nerves through the crura. After removal of the parietal pleura and dissection of the thoracic and abdominal sympathetic chain as well as the preaortic ganglia, the greater, lesser, and least thoracic splanchnic nerves were dissected in their full length from the ganglionic origins to their merging with the target structures.

The pattern of passage through the crus was noted for each thoracic splanchnic nerve, as was the angle of divergence from the passage through the crus of the greater thoracic splanchnic nerve. To determine the angle of divergence of the distal portion of the greater thoracic splanchnic nerve, a protractor was aligned with the intrathoracic part of the greater thoracic splanchnic nerve at the specimen, and the angle of divergence between the intrathoracic portion and the subdiaphragmatic

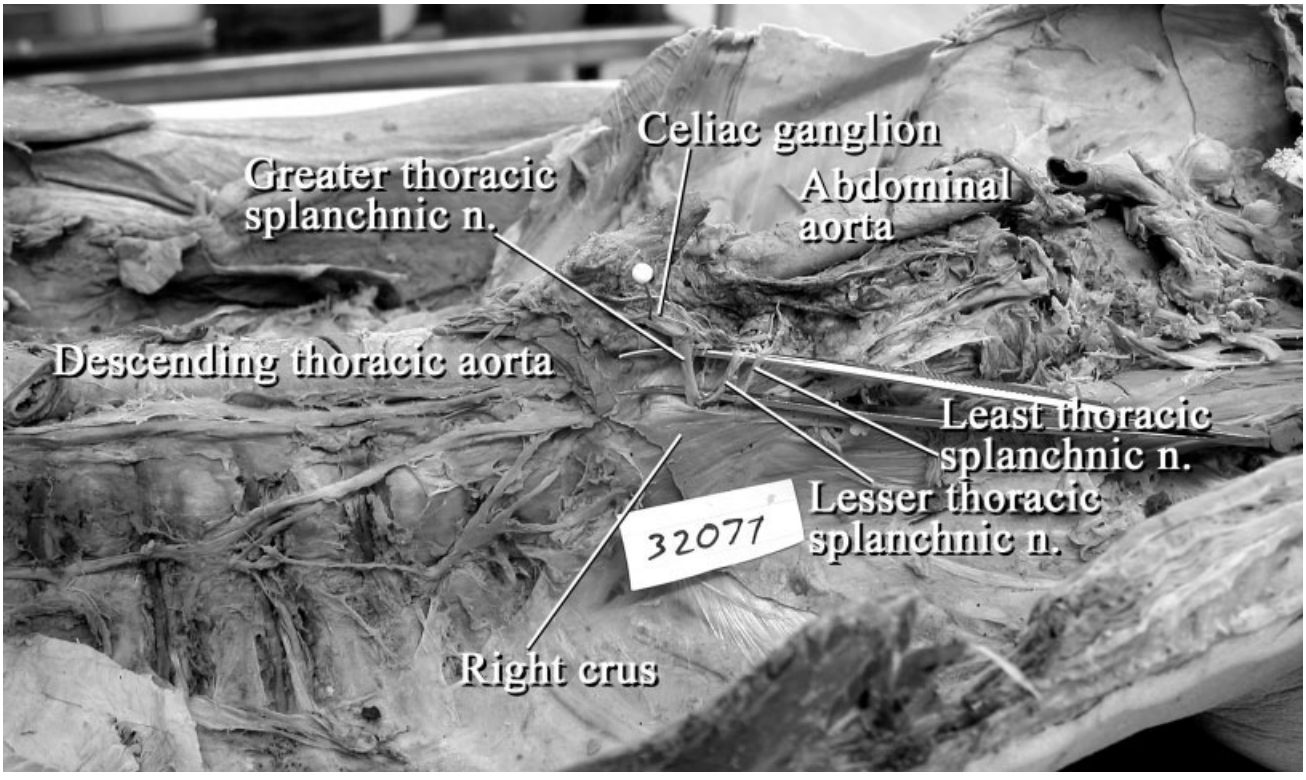

Fig. 2. The most common pattern of thoracic splanchnic nerves as they pass through the diaphragm is through a single hiatus.

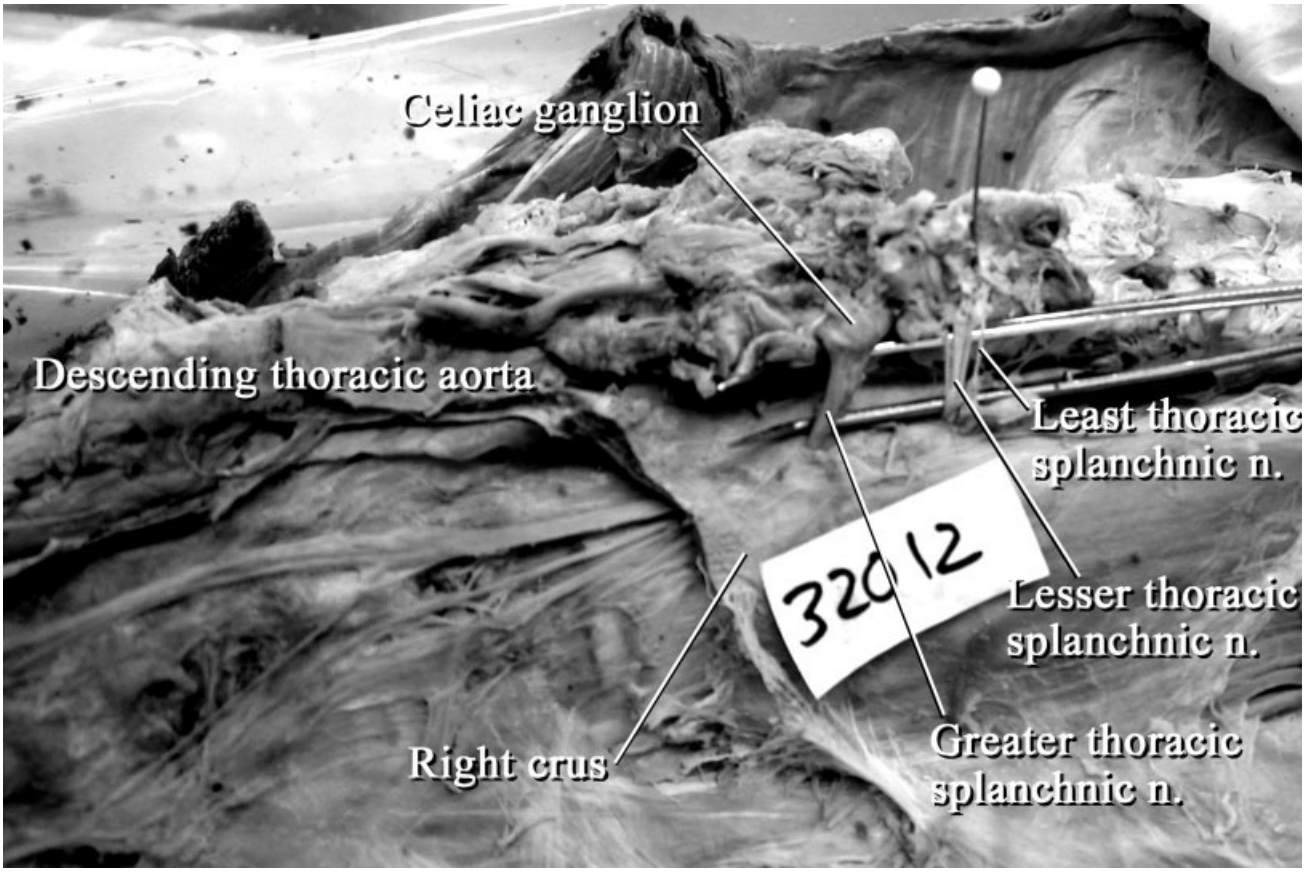

Fig. 3. A rare pattern of the thoracic splanchnic nerves as they pass through the diaphragm (three out of 43), with greater passing separately and lesser and least thoracic splanchnic sharing a common hiatus.

portion as it connected with the celiac ganglion was measured. The results were assigned to the following categories of angles: 0–15°, 30°, 45°, 60–70°, 90°, and >90°. Photographs were taken of both sides with a Nikon Coolpix 5700 camera. Some of the sides had been disturbed by student dissection, and therefore those sides were not recorded. Data were collected from 44 sides altogether. Data for the pattern of passage on both sides were available in 20 specimens, for the angle of the greater thoracic splanchnic nerve in 15.

RESULTS

In the 44 sides, we found all three thoracic splanchnic nerves in 25 sides [57%]; the greater and lesser thoracic splanchnic nerves were present in all sides, while the least thoracic splanchnic nerve was absent in 19 sides [43%]. In all, we observed six different patterns of passage of the thoracic splanchnic nerves through the crura of the diaphragm (see Table 1). The most common pattern, as they passed through the crus, was for the greater and lesser thoracic splanchnic nerves, or greater, lesser, and least thoracic splanchnic nerves to pass through a common hiatus (34 of 44 sides [77%], see Fig. 2). An uncommon pattern was a separate pathway for each of these nerves through the diaphragm (three of 44 sides, [7%]). The greater and lesser thoracic splanchnic nerves passed together, with the least running through its own hiatus, in four out of 44 [9%], while the greater ran separately, with the lesser and least sharing one hiatus, in another three out of 44 [7%] (see Fig. 3). In 13 out of

TABLE 2. Incidence of Angles at Which the Greater Thoracic Splanchnic Nerve Passes to the Celiac Ganglion After Passing Through the Diaphragmatic Crus

Angle	Right $N = 17$	Left $N = 18$	Total $N = 35$
0–15°	2	2	4
30°	1	2	3
45°	5	1	6
60–70°	3	2	5
90°	4	7	11
>90°	2	4	6

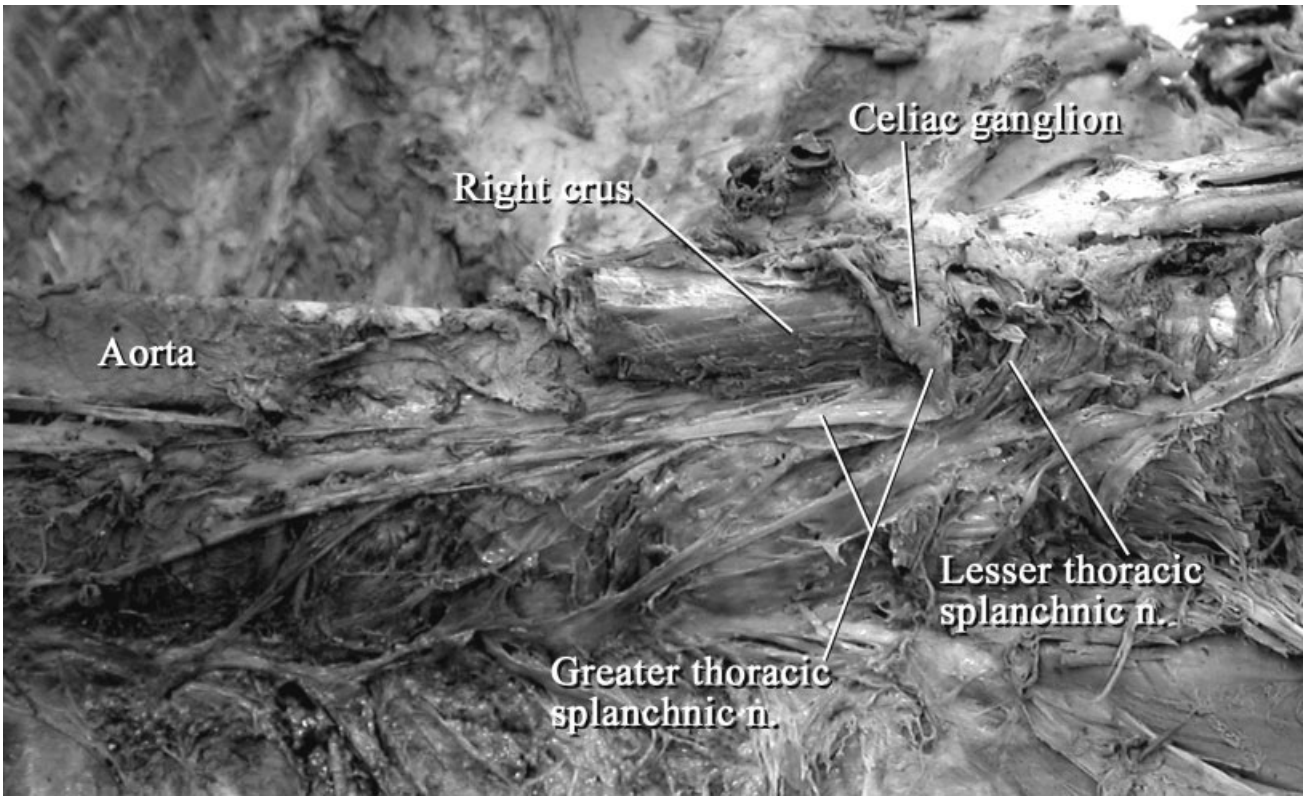

Fig. 4. The angle of greater thoracic splanchnic nerve as it passes through the crus of the diaphragm is usually 90° or greater.

20 individuals [65%] for which data on both sides were available, the number of thoracic nerves and the pattern of run through the diaphragm were identical on the right and the left posterior abdominal wall, while there were different patterns on the right and left side in seven individuals [35%].

The angle of the greater thoracic splanchnic nerve as it passed through the crus towards the celiac ganglion was determined in 35 sides, and it varied from 0° to greater than 90° (see Table 2). The most common angle was 90° (11 out of 35 [31.5%]), and an additional six out of 35 [17%] passed at an angle of greater than 90° toward the celiac ganglion (see Fig. 4). Eleven out of 35 nerves ran at angles between 45 and 70° [31.5%], and seven passed at angles of 0–30° [20%]. The angles were identical on the right and the left in eight individuals, while they differed in seven, e.g., 45° on the right and 90° on the left (see Table 3).

TABLE 3. Angles at Which the Greater Thoracic Splanchnic Nerve Passes to the Celiac Ganglion on Both Sides of 15 Individual Specimens

Specimen number $N = 15$	Right	Left	Identical angles
4	<15°	<15°	Yes
5	70°	90°	No
6	90°	60°	No
7	>90°	>90°	Yes
8	90°	90°	Yes
9	60°	<15°	No
10	30°	30°	Yes
11	45°	90°	No
14	45°	90°	No
15	60°	60°	Yes
16	45°	45°	Yes
17	45°	90°	No
18	90°	100°	No
21	90°	90°	Yes
22	>90°	>90°	Yes

On dissection of the thoracic sympathetic trunk, we observed a gradual medial deviation from its position on the necks of the upper ribs to a course along the vertebral bodies of T 11 and 12 towards the abdominal cavity, as previously described by Jit and Mukerjee (1960). The least thoracic splanchnic nerve traversed the diaphragm through the same hiatus as the sympathetic chain on both sides in two specimens (specimen numbers 15 and 23), a pattern also described by Jit and Mukerjee (1960).

DISCUSSION

As early as 1940, Edwards and Baker pointed out the need for reconsideration of anatomical illustrations of so-called ''normal anatomy'' of the thoracic splanchnic nerves. In their dissection study of the sympathetic thoracic system in 100 bodies, they had

found what they named the ''textbook'' version of the intrathoracic structure of the thoracic splanchnic nerves in only a small fraction of their dissections and felt thus called upon to remind their anatomical colleagues of the great variability of these structures. With the development of neuroablative surgery for control of otherwise intractable upper abdominal pain, the knowledge of the exact anatomy of the greater, lesser, and least thoracic splanchnic nerves has been mentioned as a decisive factor in the effectiveness of the procedure. New studies of the detailed anatomy of the intrathoracic structure of these nerves have confirmed the great variability of their formation (e.g., Naidoo et al., 2001, Yang et al., 2008), but rarely included data on the distal portions of the nerves. At the same time, our sporadic observations of the subdiaphragmatic pattern of distribution of the thoracic splanchnic nerves did not coincide with the common depiction of this area in currently used anatomical atlases.

Our study showed that the most common pattern for the thoracic splanchnic nerves to pass through the diaphragm was to run through a shared hiatus in the crus (34 out of 43 sides). This pattern can be seen in illustrations from atlases drawn directly from dissection and was also described by Jit and Mukerjee and earlier dissection studies cited by these authors (Jit and Mukerjee, 1960). On the other hand, a passing of the nerves through the crura of the diaphragm in three separate foramina or hiati was the least common pattern (three out of 43 sides), while it is the most commonly depicted pattern in current anatomical atlases. In addition, we found that the greater thoracic splanchnic nerve rarely runs towards the celiac ganglion in a straight superoinferior line or at an angle of less than 15° (three out of 33) as shown in these atlases, but more frequently at an angle of 90° and more (17 out of 33 sides), again a pattern not shown in currently used anatomical atlases.

The least thoracic splanchnic nerve was absent in 19 out of 43 bodies (43%), a number that concurs with eight previous studies, where absence rates varied from 1.7 to 83% (Naidoo et al., 2001), illustrating the high variability of the presence of a least thoracic splanchnic nerve. This fact is also reflected in illustrations in atlases drawn directly from dissections, e.g., Pernkopf (Pernkopf and Ferner, 1964) and Grant's (Agur and Dalley, 2005), where the least thoracic splanchnic nerve is not shown or not labeled.

These results confirm our previous sporadic observations and reflect Edwards' and Baker's perception of the need for caution with popular anatomical descriptions and illustrations of highly variable areas of the human body. In addition, the pattern of the formation and structure of the thoracic splanchnic nerves was not only variable from person to person but also between the right and left side in more than 35% of the specimens dissected in this series.

CONCLUSION

Previous dissection-based studies by other authors as well as the findings in this study provide evidence for the more common patterns and variations of the formation and course through the diaphragm of the thoracic splanchnic nerves. The greater and lesser thoracic splanchnic nerves, and least if present, most frequently traverse the diaphragm through one common hiatus, with the greater then taking a 90° turn toward the celiac ganglion. Anatomists and surgeons interested in the exact anatomy of the area should be aware of this pattern, as well as its variability. All modern anatomical illustrations should depict these most common patterns of the subdiaphragmatic portion of the thoracic splanchnic nerves and mention their general high variability in formation and structure.

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