A Review of the Thoracic Splanchnic Nerves and Celiac Ganglia

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Anatomical variation of the thoracic splanchnic nerves is as diverse as any structure in the body. Thoracic splanchnic nerves are derived from medial branches of the lower seven thoracic sympathetic ganglia, with the greater splanchnic nerve comprising the more cranial contributions, the lesser the middle branches, and the least splanchnic nerve usually T11 and/or T12. Much of the early anatomical research of the thoracic splanchnic nerves revolved around elucidating the nerve root level contributing to each of these nerves. The celiac plexus is a major interchange for autonomic fibers, receiving many of the thoracic splanchnic nerve fibers as they course toward the organs of the abdomen. The location of the celiac ganglia are usually described in relation to surrounding structures, and also show variation in size and general morphology. Clinically, the thoracic splanchnic nerves and celiac ganglia play a major role in pain management for upper abdominal disorders, particularly chronic pancreatitis and pancreatic cancer. Splanchnicectomy has been a treatment option since Mallet-Guy became a major proponent of the procedure in the 1940s. Splanchnic nerve dissection and thermocoagulation are two common derivatives of splanchnicectomy that are commonly used today. Celiac plexus block is also a treatment option to complement splanchnicectomy in pain management. Endoscopic ultrasonography (EUS)-guided celiac injection and percutaneous methods of celiac plexus block have been heavily studied and are two important methods used today. For both splanchnicectomies and celiac plexus block, the innovation of ultrasonographic imaging technology has improved efficacy and accuracy of these procedures and continues to make pain management for these diseases more successful. Clin. Anat. 23:512–522, 2010.

Key words: greater splanchnic nerve; splanchnicectomy; celiac plexus block; pancreatic cancer

INTRODUCTION

The thoracic splanchnic nerves and celiac ganglia have been of anatomical and clinical interest in the fields of pancreatic cancer and pancreatitis for many years, particularly for their role in pain management. Anatomical variation of the thoracic splanchnic nerves has been reported since the early 20th century, with variation in the nerve root level contributing to each splanchnic nerve being one of the most debated

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TABLE 1. Comparison of the Splanchnic Nerves Between Various Sources

<table>
<thead>
<tr>
<th>Source</th>
<th>Greater splanchnic nerve</th>
<th>Lesser splanchnic nerve</th>
<th>Least splanchnic nerve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standring et al. (2005a,b)</td>
<td>T5-T9 or T5-T10</td>
<td>T9-T10 or T10-T11</td>
<td>T12 or from LSN</td>
</tr>
<tr>
<td>Woodburne and Burkel (1994)</td>
<td>T5-T9 or T5-T10</td>
<td>T10-T11</td>
<td>T12</td>
</tr>
<tr>
<td>Moore and Dalley (2006)</td>
<td>T5-T9 or T5-T10</td>
<td>T10-T11</td>
<td>T12</td>
</tr>
<tr>
<td>Yang et al. (2008)</td>
<td>T5-T9 (21.7%, consecutive or not)</td>
<td>T10, T11 (32.6%)</td>
<td>T11, T12 (30.4%)</td>
</tr>
<tr>
<td>Hollinshead (1956)</td>
<td>T5-T9 or T5-T10</td>
<td>T9-T12</td>
<td></td>
</tr>
<tr>
<td>Reed (1951)</td>
<td>T4-T9</td>
<td>T9-T12</td>
<td></td>
</tr>
<tr>
<td>Edwards and Baker (1940)</td>
<td>T10-T11</td>
<td>T7-T12</td>
<td></td>
</tr>
<tr>
<td>Groen et al. (1987)</td>
<td>T6-T11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cunningham (1818)</td>
<td>T5-T9</td>
<td>T9-T10</td>
<td>T12</td>
</tr>
<tr>
<td>Anson (1966)</td>
<td>T5-T9</td>
<td>T9-T10</td>
<td>T12</td>
</tr>
<tr>
<td>Fisher and Bland (2006)</td>
<td>T5-T9</td>
<td>T9-T11</td>
<td></td>
</tr>
<tr>
<td>Waldman (2009)</td>
<td>T5-T10</td>
<td>T10-T11</td>
<td>T11-T12</td>
</tr>
<tr>
<td>Jankovic and Wells (2001)</td>
<td>T5-T10</td>
<td>T10-T11</td>
<td>T11-T12</td>
</tr>
<tr>
<td>Janfaza et al. (2000)</td>
<td>T5-T9</td>
<td>T9-T10</td>
<td>T12</td>
</tr>
<tr>
<td>Quain et al. (1867)</td>
<td>T5-T10</td>
<td>T10-T11</td>
<td></td>
</tr>
</tbody>
</table>

topics. A number of authors in the 1930s-1960s (Kuntz, 1934; Reed, 1951; Mitchell, 1953; Jit and Mukerjee, 1960) (Table 1) argued that the most superior contribution of the greater splanchnic nerve is as high as thoracic spinal cord segments 4 or 5, which was confirmed in 1990 by Stone and Chauvin (1990), who reported that 36.8% of greater splanchnic nerves originated above the T5 ganglion. Further work by Groen et al. (1987) on fetal dissections found the greater splanchnic nerve arising from one to four large branches, most frequently from the T8-T9 ganglia and as high as T6. The group also reported the lowest contribution from T11, initially proposed in 1956 by Hollinshead (1956) to be as low as the T12 ganglia.

Wrisberg (1780) first gave this nerve the name lesser splanchnic nerve in 1780 and its presence was later confirmed by Ludwik (1793). Variability for the lesser and least splanchnic nerves was also reported in the mid-20th century. In 1940, Edwards and Baker (1940) noted the origin of the lesser splanchnic nerve as high as T7, although it commonly originates between T10 and T11. Eleven years later, Reed (1951) reported the majority of lesser splanchnic nerves originate from T9-T12. Furthermore, Reed (1951) documented the least splanchnic nerve arising from the T11, T12, or both ganglia at the same time, while Jit and Mukerjee (1960) found the least splanchnic nerve arising from a single nerve root in 37% of cases. While most of the research during this time was focused on elucidating the level of origin for splanchnic nerves, Mitchell (1935) argued that the splanchnic nerves should be named for their level of origin and not their size, thus removing the greater, lesser, and least moniker. In his classification system, the nerves were superior, middle, and inferior splanchnic nerves, and in the case that only two were present, the superior and inferior splanchnic nerves (Mitchell, 1935).

Sympathectomies have been performed for many years and are one of the preferred procedures for correcting hyperhidrosis (particularly palmar hyperhidrosis) and facial blushing. Beginning in the 1930s, different spatial approaches for sympathectomies were performed, such as the anterior cervical by Telford (1935), anterior thoracic by Goetz and Marr (1944), and posterior extra-pleural by Cloward (1969). In addition to varying approaches, the sympathectomy, which traditionally involved resection of the cervico-thoracic ganglion, began to favor resection of the upper thoracic sympathetic ganglia (Henry, 1924; Adson and Brown, 1929; Ramsaroop et al., 2004).

Splanchnicectomy has historically been associated with treatment of pain related to pancreatic morbidity, particularly chronic pancreatitis. The first splanchnicectomy for pancreatitis was attempted in 1943 by Mallet-Guy (1943), and over the course of the next 8 years, Mallet-Guy continued with this procedure, reporting a 90% success rate of diminished pain due to chronic pancreatitis (Mallet-Guy et al., 1950). Furthermore, in 1983, Mallet-Guy (1983) contributed a report of 215 patients, in which 89% received adequate pain relief, complimenting his earlier report of a 90% success rate. While Mallet-Guy was an early leader in the field of splanchnicectomy, other authors also contributed to the field, notably Rienhoff and Backer (1947), who described pain relief in patients with calcific pancreatitis following bilateral splanchnicectomy.

Pain associated with pancreatic morbidity is among the most intense and severe pain, and for many years the celiac plexus has been a target for pain block. Kappis (1919) was the first to describe celiac plexus block in 1914, which eventually evolved into an alternative for abdominal malignancy pain management. The majority of these procedures developed by Kappis (1914, 1919) have been performed using a posterior percutaneous approach, using a long needle passed under CT guidance alongside the first lumbar vertebrae (Arcidiacono and Rossi, 2004). Until 1993, such transcutaneous blocks of the celiac plexus used minimal invasive neurolytic agents such as alcohol or phenol for alleviating pancreatic pain (Leksowski, 2001a,b). The neurolytic
agents were not favored by a number of surgeons, prompting Melki et al. (1993) to introduce video thoracoscopy for these procedures.

ANATOMY

According to standard anatomical texts (Hollinshead, 1956; Standring, 2005a,b; Moore and Dalley, 2006), the thoracic splanchnic nerves are comprised of medial branches from the lower seven thoracic sympathetic ganglia. Furthermore, the greater splanchnic nerve is derived from the fifth to ninth thoracic ganglia, with the potential for contribution from the tenth thoracic ganglia (Woodburne and Burkel, 1994; Snell, 2004; Standring, 2005a; Moore and Daley, 2006). In most cases, the greater splanchnic nerve is derived from the fifth to ninth thoracic ganglia, with the potential for contribution from the tenth thoracic ganglia (Woodburne and Burkel, 1994; Snell, 2004; Standring, 2005a; Moore and Daley, 2006). In most cases, the greater splanchnic nerve originates from four roots, before descending obliquely, giving off branches to the descending aorta and perforating the crus of the diaphragm (Gest and Hildebrandt, 2009), at which point it terminates on the celiac ganglion (Standring, 2005b).

The lesser splanchnic nerve is usually formed by the rami of the ninth and tenth thoracic ganglia and occasionally by the tenth and eleventh ganglia (Standring, 2005a). Before entering the abdomen, the lesser splanchnic nerve pierces the diaphragm with the greater splanchnic nerve before terminating on the aorticorenal ganglion. The least splanchnic nerve (also called the renal nerve) originates from the lowest thoracic ganglion and enters the abdomen with the sympathetic trunk before ending in the renal plexus (Standring, 2005a).

A study of six adult and 14 fetal cadavers by Naidoo et al. (2001) evaluated the anatomical variations of the thoracic splanchnic nerves. They reported the greater splanchnic nerve to be present in 100% of the cases, with an origin from T6 through T9 (73%). The lesser splanchnic nerve was present in 92% of the cases, with an origin from T10 and T11 (29%). The least splanchnic nerve was present in 55% of the cases, with an origin from T11 and T12 (14%) (Naidoo et al., 2001). In addition to frequency and origin of the greater splanchnic nerve, they noted that the number of roots contributing to the nerve varied between 3 and 10, with the widest range being from T4-T11 and the narrowest between T5-T7 (Naidoo et al., 2001). We demonstrate four very unique specimens with the greater splanchnic nerve arising from T6-T9 (Fig. 1), T6-T8 (Fig. 2), and T7-T8 (Fig. 3).
Fig. 2. In this specimen, the right side of the posterior mediastinum is visible with the GSN receiving contributions from T6, T7, T8, and T9. The diaphragm and liver have been removed. The lesser splanchnic nerve is shown also from T11. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

Fig. 3. In this specimen, the left side of the posterior mediastinum is visible with the GSN receiving contributions from T7 and T8. The diaphragm and liver have been removed. The lesser splanchnic nerve is shown also from T11 (broken) and T2. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]
Interestingly enough, Quain et al.'s (1867) anatomy depicts the greater splanchnic nerve as arising from T5, T6, T7, and T8 or T9 (Fig. 4).

In addition to research completed on cadavers, extensive work has been done on other species. Duzler et al. (2003) analyzed the thoracic splanchnic nerves in 12 New Zealand rabbits, noting that the greater and lesser splanchnic nerves were present in all specimens, as well as the least splanchnic nerve being present on the right side in 50% and left side in 75% of specimens. Duzler et al. (2003) noted that the greater splanchnic nerve originated from the level of T6-T12, while McLaughlin and Chiasson (1990) described a number of examples originating from the 11th and 12th thoracic ganglia. Specific attention has been paid to the lesser splanchnic nerve in rabbits, with reports of this nerve being thinner than the greater splanchnic nerve, as well as being present in only 57% of specimens (Langenfeld, 1988). In addition, Langenfeld (1988) observed in 1988 that roughly 50% of lesser splanchnic nerves were associated with the greater splanchnic nerve as it coursed toward the celiac plexus.

Similar to the research done on rabbits, studies have also been done on pigs. Orhan and Duzler (2007) recently reported a thoracic splanchnic nerve study on four female and four male pigs. In these eight specimens, they noted the greater splanchnic nerve in each one, with the lesser splanchnic nerve present in seven specimens on the right side and six on the left. In addition, the least splanchnic nerve was seen in five pigs on the right and three on the left side. Two further observations made by Orhan and Duzler (2007) reported all three thoracic splanchnic nerves as originating higher on the right side, as well as being longer and larger on this side. Anatomy texts (Standring, 2005a,b; Moore and Dalley, 2006) have described the celiac plexus as the largest autonomic plexus, which unites two large celiac ganglia and is situated at T12 and L1. Surrounding the celiac artery and the superior mesenteric artery is the celiac plexus. The celiac ganglia lie on either side of the celiac trunk medial to the adrenal glands and anterior to the diaphragmatic crura (Fig. 5). Specifically, the left ganglion is posterior to the origin of the splenic artery and the right ganglion is posterior to the inferior vena cava. Different regions of the celiac ganglion receive different nerves, as the upper part of the ganglion receives the greater splanchnic nerve and the lower part of each ganglion receives the termination of the lesser splanchnic nerve. In addition, the lower region subdivides into the aorticorenal ganglion, which also receives part of the lesser splanchnic nerve.

Variation in the morphology and location of the celiac ganglia is usually not as precise as reported in anatomical texts, leading Ward et al. (1979) to look at variations of the ganglia. Examination of 20 autopsied adult bodies revealed the celiac ganglia to vary in diameter from 0.5 to 4.5 cm, in number from one to five, and in location from the middle of L2 to the intervertebral disk between T12 and L1 (Ward et al., 1979). They further pinpointed the location of the ganglia by noting that the average distance of the ganglia below the celiac artery was 0.6 and 0.9 cm on the right and left, respectively, as well as usually being less than 1.5 cm in front of the anterior vertebral margin (Ward et al., 1979). Dal Pozzo et al. (1985) further extrapolated the location of the celiac ganglia, identifying the ganglia based on its relation to the diaphragmatic crura and adrenal glands. In a recent study by Zhang et al. (2006), celiac ganglia were at the level of T12 or L1 in 94% of the 65 cadavers studied, as well as in front of the diaphragmatic crura, medial to the adrenal glands and close to the aorta between the origin of the celiac trunk and superior mesenteric artery. Subsequently,
Zhang et al. (2006) measured the dimensions of the ganglia in 65 cadavers, with the largest being 21.43 ± 5.53 mm on the right side and 20.02 ± 10.13 mm on the left side. Physiologically, stimulation of the greater splanchnic nerves has effects on blood pressure. Experimental studies have shown that stimulation of splanchnic nerves in animals with high thoracic spinal cord transection increase blood pressure (Engeland and Gann, 1989; Stoddard et al., 1991). This is due to stimulation of the adrenal gland by the splanchnic nerve that leads to secretion of several neuroendocrine hormones (Bloom et al., 1987). In addition, stimulation of the splanchnic nerves produces hyperglycemic and glycogenolytic effects in sheeps, dogs and cats (Evans, 1971). This type of physiologic effect has led some researchers to believe that stimulation of greater splanchnic nerve can act as a new weight loss and diet regimen.

**PANCREATIC PAIN**

The thoracic splanchnic nerves and celiac ganglia are implicated in a number of clinical situations, with the common denominator of these cases being pain management. Two conditions commonly regarded as producing intense pain are pancreatic cancer and chronic pancreatitis, both of which have been linked to various procedures blocking the splanchnic nerves and celiac ganglia for pain management, as we will discuss later.

A major complaint of patients with chronic pancreatitis is the so-called abdominal pain syndrome, which is characterized by severe intermittent or by long-lasting and persistent pain. No current hypothesis on mechanisms of pain initiation and pain perpetuation in chronic pancreatitis can explain the various symptoms (Ceyhan et al., 2008). However, several hypotheses about mechanisms of pain generation in chronic pancreatitis have been postulated; these include “increased intraductal pressure,” “interstitial hypertension,” “pancreatic fibrosis via single or multiple strictures,” “pancreatic ischemia,” and “pancreatic pseudocysts” (Ceyhan et al., 2008). There is increasing evidence that pain in chronic pancreatitis and pancreatic cancer is triggered by pancreatic neuropathy. Damage to intrapancreatic nerves seems to support the maintenance and exacerbation of neuropathic pain (Ceyhan et al., 2008). In chronic pancreatitis, intrapancreatic nerves are invaded by immune cells. This observation led to the hypothesis...
that neuroimmune interactions play a role in the pathogenesis of chronic pancreatitis and the accompanying abdominal pain syndrome. Specifically for chronic pancreatitis, two unique theories for the etiology have emerged: (i) pancreatic ductal hypertension and (ii) neural and perineural inflammation and fibrosis of the pancreas (Inse, 1990; Merenger and Baillie, 1997; Di Sebastiano et al., 2000).

In contrast to patients with chronic pancreatitis, pancreatic cancer patients do not present with characteristic clinical symptoms, particularly in the early stages of the disease. Nonetheless, the two leading symptoms observed in patients with pancreatic cancer at admission to the hospital are weight loss (92%) and jaundice (82%). Similarly, pancreatic cancer cells infiltrate the perineurium of local nerves, which may in part explain the severe pain experienced by the patients. Furthermore, perineural invasion extending into extrapancreatic nerves may preclude curative resection and thus often leads to local recurrence. In recent years, the involvement of a variety of neurotrophins and neuropeptides in the pathogenesis of pancreatic pain was discovered (Ceyhan et al., 2008). Although the etiology of chronic pancreatitis is less concrete, pancreatic cancer pain is usually related to tumor invasion of the celiac and/or mesenteric plexus (Evans et al., 2001; Andtbacka et al., 2004).

**CLINICAL IMPLICATIONS AND TREATMENT**

**Splanchnicectomy**

Splanchnicectomy is a surgical procedure for the treatment of several disease conditions (Yang et al., 2008), such as chronic spastic constipation (Harjola and Ketonen, 1968), chronic intestinal pseudoobstruction (Khelif et al., 2007), hypertension (Freyberg and Peet, 1937), and upper abdominal pain from chronic pancreatitis, pancreatic cancer, or other upper abdominal cancers (Lang-Lazdunski et al., 2002). Dating back to the early work of Mallet-Guy in 1943, splanchnicectomy has proven to be an adequate treatment modality for pancreatic cancer and chronic pancreatitis. Over the years, a number of variations have been reported in regards to administration of the splanchnicectomy: (i) dissection of the nerves, (ii) splanchnicolysis by thermocoagulation, (iii) transection of the main trunks of the nerve, (iv) division with electrocautery or transection of the nerve branches, and (v) 1–2 cm segments of nerve excision (Stone and Chauvin, 1996; Maher et al., 1996; Kusano et al., 1997; Noppen et al., 1998; Moodley et al., 1999). The efficacy of splanchnicectomy is more than 80%, at which time patients are able to reduce their dosage of opiates by up to 40% of patients having an immediate effect, an advantage over more general phenol and alcohol methods, which usually taken 7–10 days for neurolysis to take place (Garcea et al., 2005). RFA produces predictable lesions in nerve block, as well as having an immediate effect, an advantage over more general phenol and alcohol methods, which usually taken 7–10 days for neurolysis to take place (Garcea et al., 2005). A report by Krishna et al. (2001) stating that video-assisted sympathectomy-splanchnicectomy led to complete pain relief in the treatment of pancreatic cancer. While the most frequent side-effect for these procedures was transient orthostatic hypotension, as a minimally invasive procedure, bilateral splanchnicectomy appears to relieve pain, improve quality of life, and reduce nociceptive dependence in patients suffering from pancreatic morbidity (Hammond et al., 2004). The use of radiographic imaging has also vastly improved the efficacy of splanchnicectomy, particularly evident for Fujita (1994) who in 1994 attempted neurolytic abdominal visceral sympathectomy-splanchnicectomy in 27 patients with cancer, following determination of the correct needle placement on CT image at the level of L1.

Radiofrequency ablation (RFA) is a technique that has recently been developed for relieving chronic abdominal pain using a derivative of splanchnicolysis by thermocoagulation. In this case, a high-frequency alternating current is used to heat tissues to produce thermal coagulation (Garcea et al., 2005). RFA produces predictable lesions in nerve block, as well as having an immediate effect, an advantage over more general phenol and alcohol methods, which usually taken 7–10 days for neurolysis to take place (Garcea et al., 2005). A report by Prithiv Raj et al. (2002) analyzed 107 patients, in which they reported up to 40% of patients having very good pain relief and only 15% of patients reporting poor pain relief.

**Celiac Plexus Block**

Celiac plexus block is a common alternative or adjunct therapy to splanchnicectomy techniques for pancreatic pain. Five techniques are among the procedures commonly used for celiac plexus blocks: (i) endoscopic ultrasonography (EUS)-guided celiac injection, (ii) percutaneous CT-guided injection, (iii) operative injection at the time of laparotomy, (iv)
and placed in the retroperitoneal space near the celiac plexus, enables the physician to perform repeated alcohol celiac plexus blocks (Hilgier and Rykowski, 1994; Rykowski and Hilgier, 1995; Vranken et al., 2001). A fixed catheter decreases the risk of severe neurological sequelae that may occur with repeated injections. Despite the wide use of EUS techniques during the past decade, further studies are needed to evaluate complications, cost, injection method, quality of life, and potential advantage for survival (Ashida and Chang, 2009).

**Paravertebral Anesthesia**

A number of cases of pancreatic pain management have been reported regarding paravertebral anesthesia, specifically a 1999 report by Saito et al. (1999) regarding dye injection into the thoracic paravertebral region entering the abdominal cavity through the medial and lateral arcuate ligaments. In these cases, Saito et al. (1999) hypothesized that fluid spread downward in the fascia, using the splanchnic nerves as a guide-wire. In a 2002 follow-up paper, Saito et al. (2002) injected dye into the endothoracic fascia at the level of T11 in the lower thoracic paravertebral region of 15 cadavers. In nine specimens, the dye spread along the greater and lesser splanchnic nerves and through the split in the crus of the diaphragm, which accompanies the splanchnic nerves. In six cadavers, the dye spread along the crus of the diaphragm to the celiac ganglion (Saito et al., 2002). The results of this article disproved an earlier report in 1992 by Lonnqvist and Hildingsson (1992) claiming that anesthetic injected in the thoracic paravertebral region spreads extensively longitudinally, but not into the lumbar paravertebral region. In addition, they commented that the causal boundary of the thoracic paravertebral block was T12, claiming the diaphragm sealed off the paravertebral space below the level of T12 (Lonnqvist and Hildingsson, 1992).

**CONCLUSIONS**

The thoracic splanchnic nerves and celiac ganglia are implicated in a number of clinical situations, with the common denominator of these cases being pain management. Two conditions commonly regarded as producing intense pain are pancreatic cancer and chronic pancreatitis, both of which have been linked to various procedures blocking the splanchnic nerves and celiac ganglia for pain management. Combining the intense pain with the evasive location of the pancreas has lead to development of a number of procedures and techniques aimed at providing adequate pain management. Arguably, the number of procedures dedicated to this anatomical location may not reflect poorly on the efficacy of these procedures but rather on the difficulty to provide adequate relief for such debilitating pain. In addition, most of these procedures have become advantageous in pain management for most upper abdominal disorders. With continued development of imaging technology, the
efficacy and accuracy of these technical procedures will continue to improve.

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