Research article

Anatomical variation of the sympathetic trunk and aberrant rami communicantes and their clinical implications

William Filion a,b,⁎, Clare Lamb a,⁎⁎

a Centre for Anatomy and Human Identification, Medical Sciences Institute, University of Dundee, Scotland, UK
b Faculty of Medicine and Health Sciences, McGill University, Quebec, Canada

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A B S T R A C T

Surgical interventions involving the sympathetic trunk are increasingly performed to alleviate symptoms of several disorders such as hyperhidrosis. Anatomical variation has been highlighted as one of the main causes behind surgical failure and symptoms recurrence following surgeries conducted on the chain or its surroundings. This study therefore aimed to record anatomical variants within spinal segments C8-T10 of the sympathetic trunk. Thirty Thiel-embalmed cadavers were investigated bilaterally. The stellate ganglion was recorded on 29 sides. Its size was significantly greater in males and on the right side when the coalescence extended to the subsequent ganglion. The intrathoracic nerve of Kuntz was observed on 21 sides and was significantly more prevalent in males. There was a significant positive association between the presence of this nerve and the descending ramus in the first intercostal space. Aberrant rami found between spinal root C8 and the ventral ramus of the first intercostal nerve were introduced as rami communicantes superi. Aberrant rami communicantes were recorded 50 times in total, of which 70% were found in males. Descending rami showed the highest prevalence in upper intercostal levels, especially in males within the first intercostal space. Aberrant neuronal pathways in upper levels were significantly more prevalent when the stellate ganglion was present. The scientific literature has proven to be stochastic as results were significantly higher in past studies in regard to some sympathetic variants. Anatomical findings of the current study as well as the inconsistency of previous data should be acknowledged and considered for better surgical planning.

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1. Introduction

The sympathetic division of the autonomic nervous system (ANS) is responsible for a wide array of visceral regulations which may have both physical and psychological repercussions when subjected to pathological changes. Exclusively arising from the intermediolateral nucleus of the spinal cord, sympathetic nerve fibres travel within the sympathetic trunk which extends from the base of the skull to the sacrococcygeal junction (LoDico and Leon-Casasola, 2014). The thoracic division of the sympathetic chain is composed of twelve thoracic ganglia which supply the aortic, cardiac and pulmonary plexuses while also innervating abdominal viscera via the celiac, superior and inferior mesenteric plexuses (Bankenahally and Krovvidi, 2016). The thoracic ganglia are located on the lateral side of the head or sometimes the neck of the ribs and are firmly covered by the endothoracic fascia as well as the parietal pleura. The chain and its ganglia are anterior to the intercostal vessels of posterior intercostal arteries from the ayzgos system and posterior intercostal arteries from the thoracic aorta (Crossman and Tunstall, 2016). Every thoracic ganglion communicates with its spinal nerve which becomes the intercostal nerve and its collateral branches within the neurovascular bundle (Roaz et al., 2019). In general, the five most superior ganglia have short white and grey rami communicantes whereas the seven lower ganglia present longer rami and give rise to the thoracic splanchnic nerves. The latter provide additional supply to the visceral pleura, potentially

Abbreviations: Sd, Standard deviation; P, p-value;
⁎ Correspondence to: 1005-1211 Berri St., Montreal H2L 0H6, Canada.
⁎⁎ Correspondence to: Medical Sciences Institute, Dow St., Dundee DD1 5EH, UK.
E-mail addresses: william.filion@mail.mcgill.ca (W. Filion), c.z.lamb@dundee.ac.uk (C. Lamb).

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alongside vagal afferent fibres, as well as celiac, aorticorenal and renal plexuses (Crossman and Tunstall, 2016; Wang et al., 2016; Boaz et al., 2019).

Pain, whether nociceptive (injurious inflammation and/or tissue damage), neuropathic (nerve damage and/or neurological disease), or nociceplic (central sensitization), is modulated by autonomous nerve fibres. Although the mechanisms of pain often overlap in between central and peripheral pathways and thus complicate the clinical presentation of various chronic polysympathetic symptoms (e.g., complex regional pain syndrome, fibromyalgia, irritable bowel syndrome), known anatomical features remain simple: parasympathetic nerves predominantly carry innocuous input whereas nociceptive information travels within afferent fibres of sympathetic nerves (Datta et al., 2017; Fitzcharles et al., 2021).

Given that preganglionic neurons synapse predominantly with postganglionic neurons within ganglia of the sympathetic trunk, the sympathetic trunk represents an intermediate relay station for sympathetic nerve fibres between the central nervous system and effector tissues (Crossman and Tunstall, 2016; Zheng et al., 2017). Besides from pharmaceutical treatments, surgeries involving this structure are increasingly performed to alleviate pain and any other symptoms of general, idiopathic and/or sympathetically-maintained disorders such as focal and compensatory hyperhidrosis, epileptic pain, angina pectoris as well as post-traumatic stress disorder (Sugimura et al., 2008). However, under certain circumstances, these procedures are yet to be fully effective as anatomical variations can represent an impediment to surgical outcomes if encountered (Yammine, 2014; Street et al., 2016).

Although they have garnered considerable attention among anatomists and medical practitioners (Sahudo et al., 2003; Shane Tubbs et al., 2016), anatomical variants have generally been recorded based on studies conducted on formaldehyde-embalmed cadavers. This embalming method sometimes generates rigid and dull coloured tissues which may impede the correct identification of structures. Conversely, Thiel-embalmed cadavers have been used for surgical practice given their life-like properties. This study therefore aims to delineate the anatomical variation of the sympathetic trunk from spinal segments C8 to T10 and its associated structures observed in cadavers of a Scottish population preserved using the Thiel soft-fix embalming (TSE) method (Thiel, 1992). Accordingly, results may eventually be used to highlight the potential impact anatomical variation may have on surgical outcomes following sympathetic surgeries, more specifically in regard to the presence of aberrant rami communicantes. Particular attention was given to the presence/absence, size and location of anatomical variants, namely the stellate ganglion (SG), the intrathoracic nerve of Kunz (INK), aberrant rami communicantes as well as any other associated sympathetic structures subject to variation, including thoracic ganglia (#) and the greater splanchnic nerve (GS).

2. Materials and methods

2.1. Sample

The anatomical examination undertaken as part of this study took place within the dissection room of the Centre for Anatomy and Human Identification (CAHID) at the University of Dundee. All dissection conducted was in compliance with the Human Tissue Act (Scotland) 2006. Thirty Thiel-embalmed individuals, who had been previously used for routine medical, scientific or surgical training were dissected. Each dissection was bilateral giving a total of 59 sides (the left side of one cadaver presenting extensive pleural plaques which altered the integrity of the sympathetic trunk was discarded). This sample of fourteen males and sixteen females was solely composed of Caucasian Scottish individuals aged between 49 and 103 years (x = 76.5 years).

2.2. Protocol

Anatomical examinations were conducted following a precise protocol in order to maintain a standardized data compilation. Prior to the beginning of the dissection, all individuals were put in a standard supine position in order to reduce the influence of upper limbs arrangement on the location of elements to be recorded. On cadavers for which the thorax had been left intact, a mid-sagittal incision was made from the jugular notch of the manubrium to the xyphoid process with a 10-blade scalpel. The skin was reflected on both sides prior to the sternum being cut in half using a bone cutter. The lateral side of the ribs as well as the anterior portion of the first intercostal space were cut using long scissors allowing both hemithoraces to be reflected on the abdomen, still attached to the diaphragm. Instead of eviscerating and thus potentially disrupting structures associated with the sympathetic trunk, the pericardium and the lungs were reflected on one side while further investigations were undertaken on the opposite pleural cavity. Some cadavers previously had their viscera removed but the sympathetic trunk was undamaged, generally from C8 to T10 levels. The endothoracic fascia and parietal pleura were simultaneously reflected to access the chain. To that end, a small incision was made on the sixth rib allowing for a safe incision using the inner surface of the bone as a visual reference ensuring that no aberrant rami communicantes were being cut. The incision was used to completely reflect the fasciae from the suprapleural membrane to the diaphragm using blunt dissection. As the parietal pleura was reflected, the chain and its rami could be seen clearly and further dissection of those structures was then planned accordingly. Each intercostal space was subsequently dissected using forces in order to delicately pick away the connective tissue around the neurovascular bundle. A 15-blade scalpel was also used to carefully remove surrounding adipose and connective tissues from the trunk and its rami, upon identification.

The lower part of the neck was then briefly dissected to access the site of the SG. For that purpose, the fat pad on the neck of the first rib from which the cervical portion of the trunk emerges was removed. The subclavian vessels were located and retracted so that the inferior trunk of the brachial plexus (C8-T1) was exposed. The supreme intercostal artery was often removed from between roots C8 and T1 before conducting further dissection of those neural structures. The SG was then cleaned when present. Otherwise, the inferior cervical ganglion (ICG) was exposed to confirm the absence of a fusion with the first thoracic ganglion. In both cases, the identification of the ansa subclavia was used to confirm the presence of those structures. Finally, photographs were systematically taken of the whole chain as well as any variant structures present.

Once the dissection was complete, several measurements were taken of each structure of interest (Fig. 1). For the SG, the length (from the superior pole to the inferior pole) and its position were recorded. Identification of the extent of its coalescence was made possible by removing the different layers of connective tissue surrounding the upper thoracic ganglia. The INK, when present, was treated as a normal intrathoracic ramus (IR) as its length (distance H) as well as its superior (SUP) and inferior (INF) distances from the chain were measured. IR in the subsequent intercostal levels were measured accordingly: distances A (length), B+E (superior distance from the chain) and C+G (inferior distance from the chain). Both the ascending (AR) and descending rami (DR) were recorded according to their length (respectively distances D and F) and their distal attachment point (DAP) on the intercostal nerve (respectively distances E and G) from the sympathetic trunk. Each structure was measured three times by each of the two independent observers to ensure consistency and precision as well as to calculate the intra-observer rate of error (± 0.27 mm) and the inter-observer rate of error (± 0.48 mm). Each thoracic ganglion was then recorded in regard to its position within the pleural cavity. When possible, the
origin of the GS nerve was assessed as well as any other variations of the sympathetic trunk. Moreover, the dissection included a close examination of the nerve fibres in order to confirm the nature of presumable aberrant rami communicantes. Neuronal pathways were then cut open to visually validate the presence of the aforementioned inner fibres using a telescopic magnifying lamp (e.g., optivisor). However, this was not always possible as the additional neuronal connections were sometimes too small to be properly observed. In such cases, nerve fibres were distinguished from blood vessels by their lack of lumens.

2.3. Statistical method

Data was compiled in an Excel® document which was used as a base for statistical analyses carried out using the IBM® SPSS® software. The intra-observer rate of error and the inter-observer variability were assessed using paired-samples t-tests. Normality was tested for each variable using Shapiro-Wilk’s tests. Under the assumption that the data was collected from a normally distributed population, parametric tests were considered suitable for the analyses; when both normality and equivariance were met, paired samples t-tests were used. In the presence of outliers within the distribution, Mann-Whitney U-tests were used in order to assess statistical significance of variables and their interaction with biological sex and laterality. A one-way ANOVA test was used to compare the prevalence of sympathetic variants between intercostal levels as well as by biological sex and side; Tukey’s method was systematically applied to assess significance. A χ² test with a Fisher’s Exact test were used to assess association between the prevalence of aberrant rami communicantes and the SG, when present. Comparisons between data compiled in Thiel-embalmed cadavers and data from previous studies relying on formaldehyde-based dissections was also determined using independent samples t-tests. A p-value of ≤ 0.05 was considered significant.

3. Results

3.1. Stellate variants

The SG, represented by the congenital fusion of the ICG with the first thoracic ganglion, (including SSEG, that is, a coalescence which extends to the second thoracic ganglion (T2) thus creating a “stellate segment” as recorded by Kommuru et al. in 2014) was recorded on 29 sides with a total prevalence of 49.15% within the sample. This structure was significantly more prevalent in males with 19 observed cases (67.86%) compared to ten in females (32.26%) (P = 0.01). Ten were located on the right side (33.34%) whereas 19 were on the left (65.52%), hence significantly more prevalent on the left-hand side in both biological sexes (P = 0.013). Almost every SG in females (90.00%) was located on the left side, whereas a generally equal distribution in between sides was recorded in males. The SG (excluding SSEG) (Fig. 3) was recorded on 22 sides with a total prevalence of 37.29%. This type of SG was recorded on 12 sides in males (20.34%) and ten sides in females (16.95%) as well as 14 cases on the left (23.73%) and eight on the right (13.56%). The SSEG alone was recorded seven times only in males. Five of those cases were located on the left side (71.43%) in comparison with only two cases on the right (28.57%). The bilateral prevalence of the SG was 31.82% whereas no case of bilateral SSEG was recorded. The mean size of the

Fig. 1. Schematic representation of the different measurements taken of sympathetic structures, when present. A. Intrathoracic ramus (IR) B. Superior distal attachment point (DAP) of IR when combined with length E. C. Inferior distal attachment point (DAP) of IR when combined with length G. D. Ascending ramus (AR) E. Distal attachment point (DAP) of AR F. Descending ramus (DR) G. Distal attachment point (DAP) of DR H. Intrathoracic nerve of Kuntz (INK) with its superior (SUP) and inferior (INF) distal attachment points.

Fig. 2. Schematic representation of the spectrum of variations of the intrathoracic nerve of Kuntz. Prevalence per types of INK: A. 19.05%, B. 42.86%, C. 9.52%, D. 4.76%, E. 14.29%, F. 4.76%, [orange dotted line: INK with additional communication with the sympathetic trunk] 4.76%. Types A, B and D were associated with a DR [red line] as they were sharing the same fascial sheath with the ramus on their lower insertion on the second intercostal nerve.

Fig. 3. Example of rami communicantes superi (SDR, SAR and SIR). Their identification is conditional to the presence of normal rami communicans (white arrows, ←) connecting the stellate ganglion (SG) to the spinal root CR (SRC8) and the ventral ramus of the spinal root T1 (T1VR). Note the presence of a descending ramus (DR) as well as an intrathoracic nerve of Kuntz (INK – Type A) in the first intercostal space.
SG was 24.48 mm (sd ± 4.35 mm) with a size range of [12.74–32.73] mm. The size of the SG was significantly greater in males with a range of [22.19–32.73] mm (mean = 26.62 mm (sd ± 2.92 mm)) compared to [12.74 – 28.22] mm in females (mean = 21.90 mm (sd ± 4.50 mm)) (P = 0.01). The mean size of the SSEG was 40.36 mm (sd ± 4.11 mm) with a size range of [36.04–46.72] mm. The general size of the SSEG was greater on the right side, although only two cases were recorded on this side. The dimension of the SG and the SSEG and their interaction with biological sex and side is presented in Table 1.

### 3.2. Intrathoracic nerve of Kuntz

The INK, consisting of an intrathoracic ramus within the first intercostal space, was recorded on 21 sides for a total prevalence of 35.59%. Its morphology was highly variable (Fig. 2) with connections either with the sympathetic trunk, normal white/grey rami communicantes of ganglion T1 / SG / SSEG, DR within the first intercostal space, ventral ramus of the first intercostal nerve or the first intercostal nerve itself with a DAP located farther away from the chain. There was a significant positive association between the presence of a DR in the first intercostal space and the prevalence of the INK as both rami where concurrently present in 61.90% of cases (P = 0.005) (Fig. 3). Its laterality was relatively balanced as 11 cases were recorded on the right side (36.67%) whereas ten cases were on the left (34.48%). This structure was found to be significantly more prevalent in males with 19 observed cases (53.57%) compared to six cases in females (19.35%) (P = 0.006). Its bilateral prevalence was 61.57% and seven of the eight bilateral cases were recorded in male individuals. The mean size of the INK was 23.15 mm (sd ± 3.14 mm) with a size range of [18.86–30.08] mm. Its superior DAP was 15.68 mm (sd ± 3.90 mm) away from the trunk in average whereas the inferior DAP had a mean distance of 10.37 mm (sd ± 3.58 mm).

### 3.3. Aberrant rami communicantes

Aberrant rami communicantes (excluding the INK) were recorded 50 times in 30 individuals, all intercostal levels combined (Fig. 4). 70% of those rami were found in males whereas only 30% of those cases were observed in female individuals. In general, aberrant nerves fibres located in the C8-T1 and first intercostal spaces were significantly more prevalent when the SG was present than when the ICG was unfused (± 2–3 rami, P = 0.014). Only two individuals presented symmetrical anatomy of the sympathetic trunk when comparing aberrant rami communicantes and the SG of both sides. Without considering variation pertaining to the location of thoracic ganglia, only 12 sides (20.34%) presented what is considered as an anatomically normal sympathetic trunk. The maximum length and DAP of aberrant rami communicantes were almost always under three centimetres long at the exception of one unique case of a bilateral IR as a result of an intercostal nerve fragmentation (discussed later). Tables 2 and 3 present a complete summary in regard to the prevalence and length of the undermentioned aberrant neuronal pathways.

Rami were found in the upper intercostal levels as well as in between the spinal roots C8 and T1 (C8-T1 space) branching off the SG or the ICG. No other studies in the current literature have reported their presence before. For this reason, these aberrant neuronal pathways have been introduced as the rami communicantes superiores (SRC); intrathoracic (SIR), ascending (SAR) and descending (SDR) ramus superiores (Fig. 3). They were considered as aberrant rami and compared to other intercostal spaces in the analyses. A total of 14 SRc were recorded (23.73%).

The IR, a communicative nerve branch connecting two successive intercostal nerves (excluding the INK), was recorded four times within the second intercostal space as well as in between the spinal root C8 (SRC8) and the ventral ramus of T1 (TVR). The SIR was only found on two occasions on the left side in males (Fig. 3). Two IR were found in the second intercostal space on both sides of one male individual. No other IR were found in the subsequent intercostal spaces and in female individuals.

The AR, a communicative nerve branch connecting one intercostal nerve to the precedent sympathetic ganglion above its level, was recorded four times solely in the upper thoracic levels. One case of SAR was observed in the left C8-T1 space of one male individual connecting the lower portion of a SG with the spinal root of C8 (Fig. 3). Two cases were found in the first intercostal spaces of both biological sexes, one on each side. One other case was recorded on the left side of one male in the fifth intercostal space. The AR ramus was also more prevalent in males, although only three cases (10.71%) were recorded in comparison with one in females (3.23%).

The DR, a communicative nerve branch connecting one intercostal nerve to the subsequent sympathetic ganglion below its level (Fig. 3), was recorded 42 times in total in the C8-T1 space as well as the first five intercostal spaces, except the fourth. Eleven cases were recorded in the C8-T1 space connecting the upper part of the SG to the TVR. Seven of those cases were located on the right (23.34%) and four on the left (13.79%). The length of the SDR was found to be significantly greater on the left side (Table 3) (P = 0.02). Sexual distribution of this ramus was balanced as five cases were male (17.86%) and six cases were female (19.35%). Twenty-two cases were then observed in the first intercostal space, evenly distributed between the right (11 cases; 36.67%) and left sides (11 cases; 37.93%). Fifteen of those cases were found in male individuals (53.57%) in comparison with seven in females (22.58%), as the prevalence of this ramus in the first intercostal space was significantly higher in males (P = 0.013). The DAP of the DR in the first intercostal space was significantly greater on the right side (P = 0.04); 11.31 mm (sd ± 3.24 mm) in average compared to 8.93 mm (sd ± 1.13 mm) on the left side. Four cases were found in the second intercostal space, solely located on the right side of male individuals. In the third intercostal space, three cases were recorded, only in males (10.71%). Two of those cases were located on the right while only one was found on the left side. Finally, two cases were recorded in the fifth intercostal space on the right side (6.67%); these two cases were found in both biological sexes.

### 3.4. Thoracic ganglia

A total of 589 thoracic ganglia were observed. In general, thoracic ganglia were found to be highly variable in terms of location. When the ICG was unfused, that is, 30 cases out of 59 sides (50.85%), ganglion T1 was found to be located mainly within the first intercostal space (21 cases out of 30; 70.00%), although some cases were
Fig. 4. Overview of the incidence of the anatomical variants of the sympathetic trunk on each side recorded in this study. [SG, yellow-hatched] Stellate ganglion, [INK, orange line] Intrathoracic nerve of Kuntz, [(S)IR, blue line] Intrathoracic rami, [(S)AR, green line] Ascending rami, [(S)DR, red line] Descending rami. This figure shows the incidence in percentage (and absolute numbers) of each structure by side regardless of the biological sex and their respective morphology.
GS nerve most often was T8 in 75% of cases (12 sides) followed by T7 portion of the chain from which the fibres were originating was seen arising directly from the sympathetic trunk in between two and T7 in five cases each (31.25%). The splanchnic nerve was also recorded in the second intercostal space in five cases out of 30; 16.66%). Ganglion T2 was identified to form a SSEG in seven cases – indicates that no cases were recorded for this category).

3.5. Greater splanchnic nerve

Origins from the GS nerve could only be observed on an irregular basis as some of the cadavers had already been partially dissected thus disrupting prevertebral structures. On 16 sides of ten cadavers, the GS nerve arose starting from T5 in two cases (12.5%) as well as T6 and T7 in five cases each (31.25%). The splanchnic nerve was also seen arising directly from the sympathetic trunk in between two ganglia in four cases (25%) on the right side, in which case the portion of the chain from which the fibres were originating was enlarged. The ganglion for which the nerve fibres were supplying the GS nerve most often was T8 in 75% of cases (12 sides) followed by T7 with a prevalence of 62.50% (10 sides). The size of the nerve fibres supplying the GS nerve were also highly variable.

3.6. Discrete variations

Intercostal nerves were found splitting into two or three diverging bundles of nerve fibres which would travel alongside one another within their intercostal space as a normal collateral branch or sometimes communicate with the subsequent intercostal nerve, therefore creating a particularly long IR. Intercostal nerve fragmentation was recorded six times. Half of those cases were found within the second intercostal space while the other half was found associated with the tenth intercostal nerve. Two bilateral cases were recorded in both instances. Only two cases of IR were recorded as other fragmented intercostal nerves would fuse again into one, usually ten centimetres away from the chain. The point of fragmentation was generally close to the trunk.

Additionally, the morphology of the sympathetic trunk itself may vary. Most of the time, the chain is formed by sympathetic ganglia connected to one another by intervening cords in which bundles of nerve fibres are running altogether. In the present study, these cords were seen to split into two distinct segments eventually fusing again together before reaching the next ganglion. Four cases have been recorded as bifurcation of the sympathetic trunk has been observed in between ganglia T1-T2, T2-T3, T3-T4 as well as T4-T5. In order to validate this characteristic, these segments have been verified and

## Table 2
Prevalence and length of aberrant rami by biological sex in upper thoracic levels.

<table>
<thead>
<tr>
<th>Intercostal space</th>
<th>Prevalence of aberrant rami (%)</th>
<th>Mean length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Intrathoracic rami (IR) (25 cases)</td>
<td>Ascending rami (AR) (4 cases)</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>CR-T1a</td>
<td>7.14</td>
<td>11.9</td>
</tr>
<tr>
<td>1st</td>
<td>53.57</td>
<td>25.31</td>
</tr>
<tr>
<td>2nd</td>
<td>7.14</td>
<td>66.79</td>
</tr>
<tr>
<td>3rd</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>4th</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>5th</td>
<td>3.57</td>
<td>19.42</td>
</tr>
<tr>
<td>Total (cases)</td>
<td>19</td>
<td>6</td>
</tr>
</tbody>
</table>

(– indicates that no cases were recorded for this category)

a SRC were not taken into considered for the calculation of the average length as their morphology is generally different.
b The INK is considered as an intrathoracic ramus (IR) in the first intercostal space.
c Length of the IR found in the second intercostal space was not taken into consideration for the calculation of the average length.

## Table 3
Prevalence and length of aberrant rami by side in upper thoracic levels.

<table>
<thead>
<tr>
<th>Intercostal space</th>
<th>Prevalence of aberrant rami (%)</th>
<th>Mean length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Intrathoracic rami (IR) (25 cases)</td>
<td>Ascending rami (AR) (4 cases)</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>CR-T1a</td>
<td>–</td>
<td>6.90</td>
</tr>
<tr>
<td>1st</td>
<td>36.67</td>
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<tr>
<td>2nd</td>
<td>3.45</td>
<td>66.66</td>
</tr>
<tr>
<td>3rd</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>4th</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>5th</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Total (cases)</td>
<td>12</td>
<td>13</td>
</tr>
</tbody>
</table>

(– indicates that no cases were recorded for this category)

a SRC were not taken into considered for the calculation of the average length as their morphology is generally different.
b The INK is considered as an intrathoracic ramus (IR) in the first intercostal space.
c Length of the IR found in the second intercostal space was not taken into consideration for the calculation of the average length.
identified not to represent normal nerve fibres branching off to supply local nervous plexuses or thoracic splanchnic nerves. Distance between the two segments was measured to vary from three to six millimetres.

The chain was also found to be located on the anterior surface of the vertebral column. Medial shifting of the trunk was then observed on two occasions (one bilateral case) in the lower thoracic levels, causing normal rami communicantes to be considerably longer than usual (up to four centimetres long). One thoracic ganglion was also located on the lateral aspect of the vertebral body of the tenth thoracic vertebra in result of the medial shifting of the chain, thus displaced from its usual location near the neck of the rib.

Moreover, normal white and grey rami communicantes connecting the intercostal nerves to the sympathetic trunk were seen running together or separately in order to connect the two structures in almost every cadaver. In this study, both white and grey rami communicantes of the thoracolumbar outflows were thus assumed to be present when thoracic ganglia were identified sending one or two bundle of nerve fibres to their associated intercostal nerve as they may or may not be seen sharing the small fascial sheath. Two unique cases of supernumerary rami communicantes were nonetheless recorded on the right side of one cadaver. Under those circumstances, the two thoracic ganglia (T4 and T5) were each giving rise respectively to three and four small rami communicantes which were amalgamating in a plexiform-like pattern upon reaching the intercostal nerve. Those rami communicantes were smaller in size and were only covered with a thin layer of epineurium which seemed to be in direct continuity with the periosteum of the ribs.

Finally, one anomalous ramus communicans was observed on the right side of one cadaver. In this case, the ramus was branching off the fifth thoracic ganglion, running posterior to the sympathetic trunk, spanning the sixth intercostal space to supply the seventh intercostal nerve. The latter was not receiving any rami communicantes from the seventh thoracic ganglion and was consequently the only neuronal pathway allowing communication in between this intercostal nerve and the sympathetic trunk was the posterior ramus communicantes branching off from the fifth thoracic ganglion. This peculiar configuration was verified by lifting the sympathetic trunk in order to assess whether the ramus was coming from the fifth or the sixth thoracic ganglia. The length of the posterior ramus communicans was measured to be approximately 6.4 cm.

### 3.7. Data analysis

When comparing data recovered from the scientific literature, a significant difference regarding the prevalence of the SG (P = 0.004), the INK (P = 0.009) and DR of the second (P = 0.035) and third (P = 0.051) intercostal spaces was highlighted. Most studies also recorded a higher density of sympathetic variants in upper thoracic levels. The INK was additionally shown to be more prevalent in dissected individuals than what could be assessed in the living (P = 0.027).

When comparing the weighted means of other studies to this paper’s findings, both the SG (P = 0.045) and the DR of the second (P = 0.04) and third (P = 0.035) intercostal spaces were significantly more prevalent in the former. In fact, the SG was prevalent in 49.15% of cases in this study whereas being recorded in more than a third of cases in most studies which were sampled from the scientific literature (Table 4). This discrepancy also applied to the DR in the second intercostal space where the ramus was found in only 13.34% of sides investigated in this study whereas being found in higher (at least 30% of cases in three other studies) or lower (or absent) proportions in the scientific literature (Table 6). Table 7 presents a similar significant distribution of the DR in the third intercostal space.

### 4. Discussion

#### 4.1. Cross-studies data comparison

Formalin-treated cadavers have already been highlighted for their convenient but sometimes inconsistent suitability in regard to educational as well as scientific usage (Healy et al., 2015). As this type of embalming method gives a stiff and almost achronomic result, data provided from cadavers that have been treated with this solution should perhaps be scrutinized. As this study represents the first investigation of the anatomical variation of the sympathetic trunk to be conducted on Thiel-embalmed cadavers, results obtained in this case were compared to what have been recorded and used by surgeons until now. Data collected in this study was thus compared to the results of previous research papers as well as one clinical assessment conducted on the living via transthoracic endoscopy (Wang et al., 2002). Studies for which all of the same sympathetic variants were recorded were compared (Tables 4–7).

Firstly, raw data analysis indicates that there is a significant difference in the scientific literature in regard to the prevalence of the SG (P = 0.004), INK (P = 0.008) and DR within the second (P = 0.035) and third (P = 0.051) intercostal spaces when all studies are compared as well as considering their respective sample sizes. The prevalence of other aberrant rami communicantes is considered either inconsistent or poorly recorded having statistical inferences to be challenging. For instance, almost half of the authors reported the presence of aberrant rami, sometimes with high prevalence rates while based on smaller sample sizes, in contrast with zero observed cases in other studies (Tables 6 and 7). Only the prevalence of the DR in the second intercostal space is recorded almost systematically, despite its overall prevalence being highly inconsistent (Table 6). That said, almost every study recorded an increase of density of sympathetic variants associated with upper thoracic ganglia T1 and T2 in comparison with subsequent intercostal levels. Additionally, when compared to studies conducted on cadavers, the prevalence of the INK was found to be significantly more prevalent through dissections than what can be observed in the living (P = 0.027).

When individually compared to the weighted mean of other studies, data gathered for this research is different from that recorded previously. The prevalence of the SG (P = 0.045) and the DR in the second (P = 0.04) and the third (P = 0.035) intercostal spaces is significantly higher in other studies, that is, when the weighted mean, excluding this study, is compared to the data presented herein. In other words, this research denoted a significantly lower prevalence of the SG and DR within those two intercostal spaces compared to other studies for which results were generally based on smaller sample sizes. Only the INK and other aberrant rami communicantes within the second and third intercostal levels were shown to be consistent with the current scientific literature. It is to be noted, however, that statistical significance could only be assessed regarding the structures recorded within the second and third intercostal spaces. In fact, no past studies recorded the entirety of the anatomical variation of the sympathetic trunk as they rather focused on one or two structures, usually the aberrant rami communicantes or the SG. Moreover, only one study (Shantharam et al., 2012) investigated the effect of sex disparity on the prevalence of one aberrant neuronal pathway, namely the INK. No additional information in regard to the influence of biological sex could be found in other research. Therefore, with the exception of the aforementioned inconsistency of reported values pertaining to anatomical variants in the scientific literature, no further conclusions can be reached from these comparisons.

Secondly, ethnic variation has been previously stated as a potential cause of morphological dissimilitude between groups. Esakkiammal et al. (2016) highlighted the possible causative relation between ethnic differences and the inconsistent anatomical...
variations of the INK in the scientific literature. However, studies referenced in this case which were based on similar biological populations did not necessarily record the same results, especially regarding aberrant rami communicantes. For instance, Cho et al. (2005) reported the highest prevalence rates for the DR in both the second and third intercostal spaces based on a sample composed of 42 Korean cadavers while Chung et al. (2002), Kommuuru et al. (2014) as well as Zhang et al. (2009), which were also based on the investigation of Asian subgroups, recorded different prevalence proportions. Additionally, sample sizes do not seem to explain this inconsistency as some studies based on the smallest sample sizes would sometimes record the highest prevalence of a given variant. Albeit possible, ethnicity as a cause of anatomical variation has yet to reach satisfactory evidence in regard to sympathetic variants. Environmental influence is perhaps insufficiently investigated and could refine the argument of ethnic variation.

Thirdly, the nature of formalin-treated cadavers could potentially represent an obstacle partly responsible for the inconsistency of results obtained in previous studies. Research has shown that inadequate preservation of human tissue, especially regarding color distortion as well as unnatural hardening of organic matter as a result from the formaldehyde embalming process, was sometimes associated with a difficult differentiation of nerves from other structures (Benet et al., 2014). Even in soft-fix cadavers, it is sometimes possible to dissect around what is initially believed to be an aberrant ramus communicans only prior to discovering that the presumed variant was in fact made of an anomalous thickening of connective tissue. The opposite is also possible as nerve fibres may be discarded as connective tissue or simply undetected. Fortunately, as the TSE method enables the nerve fibres to be seen within the epineurium, some rami communicantes found in this study were instead left untouched in order to obtain precise measurements and observations. This allowed for a visual identification of aberrant rami communicantes and their configuration, especially when the nerve fibres seemed to be crossing with one another or simply sharing the same fascial sheath. Conversely, this verification might prove challenging in formaldehyde-embalmed cadavers which could lead to the overrepresentation of different anatomical variants, especially small aberrant rami communicantes. The TSE method might then bring new perspectives on anatomical variation, especially of aberrant rami communicantes. That said, despite of the attention put into the dissection of the thirty individuals, it is still possible that very small rami communicantes may have been cut during the process of cleaning the intercostal spaces.

The inconsistency of results in the scientific literature could also be linked to a lack of standardisation in the scientific protocol especially in regard to the INK. A total of four distinct categories have been used by several authors (Chung et al., 2002) while some other studies had different interpretations concerning the identification of this ramus. For instance, where some authors see a split IR (Kuntz, 1927; Ramsaroop et al., 2001; Shantharam et al., 2012; Street et al., 2016), other could record this structure as a single INK (Zhang et al., 2009), associated with a DR (Cho et al., 2005; Zaidi and Ashraf, 2010) or simply with one additional communicative branch connecting the ramus to the SG (Esakkiammal et al., 2016). As a result, the DR could be underrepresented in some studies, and vice versa. Definitions of sympathetic structures to be recorded within the first intercostal space then seems to be overlapping or sometimes differing drastically. The prevalence of those rami perhaps ought to be reconsidered, especially when this precise information is to be used for surgical purposes or as a matter of comparison. In the current study as well as Chung et al. (2002), the DR of the first intercostal space was considered individually from the INK as its presence was more prevalent than the latter.

Finally, although the concept of an extensive fusion of the SG with the second thoracic ganglion (T2) is usually described in specialized surgical textbooks (Georgiou et al., 2014; De Paula Loureiro et al., 2018), the majority of studies do not clearly state the difference

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### Table 4

Prevalence and features of the stellate ganglion (SG) in the scientific literature.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Sample size (sides)</th>
<th>Stellate ganglion (%)</th>
<th>Stellate segment (%)</th>
<th>Bilateral incidence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chung et al. (2002)</td>
<td>66</td>
<td>84.8</td>
<td>9.1</td>
<td>–</td>
</tr>
<tr>
<td>Harman, 1900</td>
<td>12</td>
<td>75</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Kommuuru et al. (2014)</td>
<td>62</td>
<td>37</td>
<td>1.61</td>
<td>13</td>
</tr>
<tr>
<td>Ramsaroop et al. (2001)</td>
<td>36</td>
<td>92</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Saylam et al. (2009)</td>
<td>40</td>
<td>70</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Street et al. (2016)</td>
<td>40</td>
<td>70</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Zaidi and Ashraf (2010)</td>
<td>50</td>
<td>100</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Zhang et al. (2009)</td>
<td>50</td>
<td>80</td>
<td>–</td>
<td>64</td>
</tr>
<tr>
<td>Filion and Lamb, 2022</td>
<td>59</td>
<td>49.15</td>
<td>27.59</td>
<td>31.82</td>
</tr>
<tr>
<td>Weighted average:</td>
<td></td>
<td>73.45%</td>
<td>12.45%</td>
<td>34.41%</td>
</tr>
</tbody>
</table>

(- indicates that the information was not specified)

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### Table 5

Prevalence and features of the intrathoracic nerve of Kuntz (INK) in the scientific literature.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Sample size (sides)</th>
<th>Nerve of Kuntz (%)</th>
<th>Distance from the trunk (mm)</th>
<th>Bilateral incidence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cho et al. (2005)</td>
<td>84</td>
<td>59.5</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Chung et al. (2002)</td>
<td>66</td>
<td>68.2</td>
<td>7.3</td>
<td>48.1</td>
</tr>
<tr>
<td>Esakkiammal et al. (2016)</td>
<td>24</td>
<td>37.6</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Kirgis and Kuntz, 1942</td>
<td>88</td>
<td>90.9</td>
<td>–</td>
<td>59</td>
</tr>
<tr>
<td>Kuntz (1927)</td>
<td>96</td>
<td>62.5</td>
<td>–</td>
<td>43.75</td>
</tr>
<tr>
<td>Ramsaroop et al. (2001)</td>
<td>36</td>
<td>46</td>
<td>2.3–15.7</td>
<td>–</td>
</tr>
<tr>
<td>Shantharam et al. (2012)</td>
<td>112</td>
<td>37.5</td>
<td>6.80</td>
<td>26.79</td>
</tr>
<tr>
<td>Street et al. (2016)</td>
<td>40</td>
<td>40</td>
<td>12.6</td>
<td>–</td>
</tr>
<tr>
<td>Wang et al. (2002)a</td>
<td>140</td>
<td>5</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Zaidi and Ashraf (2010)</td>
<td>50</td>
<td>66</td>
<td>5.03</td>
<td>78.9</td>
</tr>
<tr>
<td>Zhang et al. (2009)</td>
<td>50</td>
<td>40</td>
<td>–</td>
<td>16</td>
</tr>
<tr>
<td>Filion and Lamb, 2022</td>
<td>59</td>
<td>35.59</td>
<td>13.03</td>
<td>61.54</td>
</tr>
<tr>
<td>Weighted average:</td>
<td></td>
<td>47.29%</td>
<td>8.59 mm</td>
<td>45.96%</td>
</tr>
</tbody>
</table>

(- indicates that the information was not specified)

a Study conducted on the living via endoscopic (trans)thoracic sympathectomy (ETS).
between the SG and what is considered as a SSEG. The available information about this structure is inconsistent and consequently problematic as the size and position might differ from a SG to a SSEG. It is yet to be proven whether this inconsistency is the problematic as the size and position might differ from a SG to a SSEG. It is yet to be proven whether this inconsistency is the consequence of invalid results due to a lack of standardisation in the way data are recorded as well as a consequence of the hypothesised inadequacy of the formaldehyde embalming method or simply a genuine lack of pattern in the prevalence of the anatomical variation in humans.

4.2. Clinical relevance

The anatomical variation of the sympathetic trunk and its associated structures have been proven to follow significant configurations in regard to their prevalence by biological sex and side as well as to be almost as important as structures considered morphologically normal. These variations may all be associated with a certain degree of clinical relevance and their presence or lack thereof ought to be acknowledged for better surgical planning.

4.2.1. Stellate ganglion

In the present study, the SG (including SSEG) was recorded in almost half of the investigated individuals and was significantly more prevalent in males with a prevalence of 67.86%. The SSEG has only been found in male individuals. This structure was always more than three centimetres long given that its coalescence extended to the second thoracic ganglion (T2). The size of the SSEG was significantly larger on the right-hand side, although its prevalence was higher on the left. More than 70.00% of the individuals with an extended fusion of the SG had a metastatic condition of different primaries, albeit no direct inferences can be drawn from this observation. The SG was also measured to be significantly bigger in males, although an almost equal number of cases were recorded on both sides in male individuals. Unfortunately, longitudinal studies investigating the incidence of Horner’s syndrome (Leao et al., 2003) do not specify its sexual distribution, despite the fact that this information might be of critical interest as the ignorance of the extent of the anatomical variations may represent one of the causes behind this post-operative complication. However, it should be noted that consulted cases of surgically-induced preganglionic Horner’s syndromes or other complications were usually observed on the right side of male individuals (Chaturvedi and Dash, 2010; Gonzalez-Aguado et al., 2012; Vicente et al., 2014; Giannaccare et al., 2016). These findings should also be reviewed before conducting procedures which are not necessarily altering the chain, such as SG block, as what could be believed as a safe anaesthetic site could possibly damage surrounding structures such as cerebral arteries or affect other neuronal pathways. In fact, the presence of a SG (or SSEG) may affect the density of aberrant neuronal pathways, the position of other surrounding structures as well as the expected position of the SG near surgical landmarks such as the Chassaing’s tubercle or the seventh cervical vertebral body (Abdi et al., 2004). The SG and its extensive fusion ought to be acknowledged as its presence might therefore be associated with irreversible and/or life-threatening complications, although this kind of post-operative morbidity is usually infrequent (Vicente et al., 2014; Datta et al., 2017).

As noted in this study, aberrant rami communicantes have been found to be significantly more prevalent when the ICG was fused to T1 (± 2–3 rami). This correlation between the presence of a SG and

<table>
<thead>
<tr>
<th>Reference</th>
<th>Ascending Ramus (AR) (%)</th>
<th>Descending Ramus (DR) (%)</th>
<th>Intercostal Ramus (IR) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cho et al. (2005)</td>
<td>5.9</td>
<td>46.4</td>
<td>0</td>
</tr>
<tr>
<td>Chung et al. (2002)</td>
<td>0</td>
<td>0</td>
<td>7.6</td>
</tr>
<tr>
<td>Kommuru et al. (2014)</td>
<td>0</td>
<td>1.61</td>
<td>0</td>
</tr>
<tr>
<td>Ramsaroop et al. (2001)</td>
<td>1.01</td>
<td>5.05</td>
<td>0</td>
</tr>
<tr>
<td>Street et al. (2016)</td>
<td>2.5</td>
<td>37.5</td>
<td>5</td>
</tr>
<tr>
<td>Zhang et al. (2009)</td>
<td>16</td>
<td>30</td>
<td>6</td>
</tr>
<tr>
<td>Filion and Lamb (2022)</td>
<td>0</td>
<td>13.34</td>
<td>3.34</td>
</tr>
<tr>
<td>Weighted average:</td>
<td>3.61%</td>
<td>20.07%</td>
<td>3.02%</td>
</tr>
</tbody>
</table>

* The weighted average has been calculated based on the sample size of each study: see Tables 4 and 5 for details.
the density of aberrant neuronal pathways within the C8-T1 and first intercostal spaces could potentially be used by medical practitioners to plan surgical procedures accordingly. The presence of a SG or SEG could then be linked to the need for a more extensive and careful dissection of the lower neck and/or upper levels of the posterior thoracic wall.

4.2.2. Aberrant rami communicantes

Aberrant rami communicantes represent additional routes which offer ways for sympathetic nerve fibres to bypass the normal sympathetic outflow located within the chain (Street et al., 2016). These alternative neuronal pathways can be missed when conducting any surgeries involving the sympathetic chain as their presence and morphology may vary considerably. However, significant findings of their prevalence and the interaction between biological sex and side could help prevent and ultimately reduce surgical failure and symptoms recurrence as well as avoid post-operative complications following certain types of procedures such as the endoscopic thoracic sympathectomy (ETS), sympathectomy and gangliectomy.

In the current study, the INK was more significantly found in male individuals. This additional ramus located in between the first and the second intercostal nerves is associated with surgical failure as it carries nerve fibres from the sympathetic trunk to the brachial plexus even when sections of the intervening cords have been clipped, burned, cut or resected (Esakkiammal et al., 2016). Particular attention should be paid in regard to the first intercostal space in order to ensure that any additional rami are being cut, especially in male individuals. The distal attachment point of this ramus was recorded to be located as far as 2.5 to three centimetres away from the chain. Surgeons should then extend their procedure three centimetres distally (laterally) within the first intercostal space as well as on both sides when conducting a bilateral sympathectomy, as the ramus has a bilateral prevalence of 61.57%. Furthermore, the most common morphology of the INK (type B - 42.86%) was found to be when the ramus was associated with a DR on its connection from the second intercostal nerve to the ventral ramus of the first intercostal nerve. In 61.90% of cases, the INK was present alongside one DR, associated or not to the additional ramus. There was indeed a significant positive association between both of their respective prevalence proportions within the first intercostal space. Identification of a DR branching off the SG should then be considered as an indication that an INK might be present. Surgeons should also bear in mind that this ramus presents a broad spectrum of morphological variation (Fig. 2). That being said, cadaveric recording of this nerve should be discerned prior to conducting a spinalnecotomcy or pre-vertebral surgeries.

Table 8

<table>
<thead>
<tr>
<th>Significant findings</th>
<th>Recommendations to surgeons</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) SG significantly more prevalent in males and on the left side. (SEG only found in males, mainly on the left side. Its size was always larger than three centimetres.)</td>
<td>a) Proceed with caution when operating on left upper thoracic levels of male individuals, thus reducing the risk for complications such as preganglionic Horner’s syndrome. The structure should be expected as far anterior to the neck of the second rib and near Chassaignac’s tubercle.</td>
</tr>
<tr>
<td>b) INK is morphologically variable and significantly associated with DR within the first intercostal space. Significantly more prevalent in males and found on both sides of the thoracic cage in 61.57% of cases. The ramus is connected on the T1VR in 42.86% of cases.</td>
<td>b) Extensive ablation/clipping should be considered laterally in the first intercostal space (bilaterally), especially in males or when a DR is branching off the SG.</td>
</tr>
<tr>
<td>c) Higher density of aberrant rami communicantes in the first five intercostal spaces. 70% of those rami were found in males. Their prevalence is asymmetrical. DAP of aberrant rami is almost always under three centimetres long, although DAP of seven centimetres have been recorded.</td>
<td>c) Extensive ablation/clipping should be considered, at least three centimetres laterally, in the first five intercostal spaces, especially in males.</td>
</tr>
<tr>
<td>d) DR significantly more prevalent in males and within the first intercostal space. e) The sympathetic trunk might bifurcate into two segments, shifted medially or vary in terms of ganglia location and origins of thoracic splanchnic nerves.</td>
<td>d) Extensive ablation/clipping should be considered laterally in the first intercostal space as well as between the SRc8 and T1VR, especially when a SG is present as well as in males.</td>
</tr>
<tr>
<td>e) Be aware of discrete variations associated with the morphology of the sympathetic trunk or its position (and its ganglia). Origins of thoracic splanchnic nerves should be discerned prior to conducting a spinalnecotomcy or pre-vertebral surgeries.</td>
<td>e) Be aware of discrete variations associated with the morphology of the sympathetic trunk or its position (and its ganglia). Origins of thoracic splanchnic nerves should be discerned prior to conducting a spinalnecotomcy or pre-vertebral surgeries.</td>
</tr>
</tbody>
</table>
recommendation also highlighted by Boaz et al. (2019). Besides this uncommon case, DAP of aberrant rami communicantes were measured to be located from five to 25 millimetres away from the chain, thus always under three centimetres. In fact, aberrant rami communicantes were generally located close to the trunk. However, some of those rami can be located far away from the chain, that is, the IR being the best example of this instance. It is to be noted that these aberrant rami could also be embedded within the intercostal adipose tissue of overweight individuals. Their identification might then prove difficult in such cases. In that respect, according to the findings of this study, sympathetic clipping would methodically involve a thorough exploration in situ for aberrant rami communicantes as they may bypass the chain and represent a potential route for neurons to reach the brachial plexus or the cervical portion of the chain. An effort should be made during surgical procedures involving the sympathetic trunk to locate aberrant neuronal pathways within the first five intercostal spaces in order to manage their presence properly.

4.2.3. Unusual variants

Bifurcation of the intervening cords connecting sympathetic ganglia is another possible anatomical variation of the chain which might affect the outcomes of surgical procedures. For instance, as the ETS involves lifting the chain from the posterior thoracic wall in order to ensure its total resection, a bifurcating chain might decrease the structural integrity of the trunk and thus affect the process (Tarfusser, 2017). The chain might then be severed or simply partly resected and result in surgical failure (Tulay, 2015). Forceful manipulation of a bifurcating chain might also damage thoracic ganglia as one segment of the chain might stay firmly connected to the inner surface of the neck of the rib while lifting the chain away. A bifurcating chain was also described as a seldom morphology in one recent study (Tulay, 2015). Moreover, interganglionic neuro-compression might represent a challenging procedure in the presence of supernumerary rami communicantes. Albeit uncommon, this particular morphology of the rami connecting sympathetic ganglia to their respective intercostal nerves would impede normal surgical protocols as their frailty could lead to the procedure being impossible to be performed successfully. Surgeons should consequently bear in mind that discrete variations might affect the anatomy of the sympathetic trunk and may have important clinical implications as well as influence the way surgeries are and should be conducted.

4.3. Recommendations

The literature concerning anatomical variation of the sympathetic trunk is inconsistent in terms of its results and how data is measured and recorded. In order to minimise invalid identification of sympathetic structures, histological analyses of presumed neural structures should be considered as a primary validation technique. This microscopic verification of the presence of axonal structures could perhaps decrease the possibility of an over-representation of aberrant rami communicantes in the scientific literature. For instance, Ramsaroop et al. (2001) systematically verified their findings with histological investigations but only for the identification of the SG. Injection of intravascular color filling in formalin-treated cadavers should also be considered. Additionally, usage of standardized definitions and data collection protocols could help in recording the same structures in between studies, thus limiting the inconsistency of results. One should also bear in mind that such aberrant sympathetic nerve fibres are potentially subjected to nerve regeneration and could explain, at least in parts, symptoms recurrence following sympathetic surgeries where aberrant rami communicantes were successfully resected (Zheng et al., 2017).

5. Conclusion

Evidence displayed in the present study suggest that the anatomical variation of the sympathetic trunk is substantial and its clinical implications noteworthy. Underlying anatomical variants, such as the SG, the INK and aberrant rami communicantes, and their proximity with other neurovascular structures must indeed be acknowledged as they can potentially impede surgical outcomes. Consequential findings regarding those sympathetic structures and their interaction with biological sex disparity and laterality could increase clinical precision and accuracy and perhaps decrease surgical failure and recurrence of symptoms following sympathetic thoracic surgeries. Information concerning size, location and prevalence of anatomical variants in conjunction with both biological sex and side as well as significant positive associations between structures and their prevalence proportions should then be recognized and considered prior to conducting surgical procedures on patients.

Ethical statement

The anatomical examination undertaken as part of this study took place within the dissection room of the Centre for Anatomy and Human Identification (CAHID) at the University of Dundee. All dissection conducted on human remains was in compliance with the Human Tissue Act (Scotland) 2006 while being overseen by the Thiel Advisory Committee. Permission and informed consent were granted from both the latter as well as the bequeathing donors prior to their passing for medical education, training, and research through complete dissection and photographs before final disposal to their next of kin.

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Disclosure

The authors had no conflicts of interest to disclose.

References


