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Neuroanatomical studies

Anatomical variability of the relationship between the sympathetic trunk and the intercostal veins during thoracoscopic sympathectomy

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1. Introduction

Over the last decade, thoracoscopic sympathectomy (TS) has gained momentum in the treatment of palmar and axillary hyperhidrosis as well as skin blushing due to its high efficiency and minimized traumatic insult to the patient [1]. It has become the standard treatment for primary hyperhidrosis due to the use of minimally invasive single-port video-assisted techniques for accessing the sympathetic trunk (ST), which is located in a rather difficult anatomical area, namely the medial segments of the chest. Adequate endoscopic monoportal access ensures proper visualization of anatomical structures of the region and provides sufficient space to manipulate the tools. The insertion of a double-lumen endotracheal tube allows the ipsilateral lung to be collapsed, reducing invasion damage. It is equally crucial to preserve vascular and neurological structures during surgery, as it mostly affects the intercostal arteries, veins, and nerves, as well as the azygos vein, superior *vena cava*, etc. [1–3] The literature review revealed a lack of scientific research on the anatomical variations of veins and the relationship between the anatomical structures in the thoracic region. This necessitated the current study, which comprised the collection and evaluation of data obtained after TS was administered for hyperhidrosis and skin blushing.

2. Thoracic sympathetic trunk anatomy

The ST is a white cord that lies paravertebrally on the neck of the ribs near the joint between the head of each rib and the vertebra, visible beneath the parietal pleura. The ST contains preganglionic fibers running from the spinal cord as well as ascending and descending postganglionic fibers. It terminates at the level of the second lumbar vertebra. In general, the ST has a quite variable anatomical structure amongst patients and on the right and left sides of the chest. Multiple sympathetic trunks have been discovered on one side of the chest in various studies. Thus, three patients had two trunks and the other three had three trunks among the six patients who underwent TS [1]. Another anatomical research of 25 adult corpses found that 4 (16%) of them had identical anatomical characteristics, whereas the remainder had significant variances [2]. The T2, T3, and T4 ganglia, for example, were most typically found in the corresponding intercostal space as the ST descended, however with a noticeable ganglia displacement downward relative to the ribs. The T2 ganglion was located in the second intercostal space in 92% of corpses, while the T4 ganglion was found in the fourth intercostal space in 50% of cases, and it ran along the upper border of the fifth rib in 36% of cases.

The STS consensus is recommended for better ST verification [3]. The ribs represented by the ***R*** letter (R2 = interruption at the level of the second rib) serve as an anatomical reference point for exact interruption of the ST outflow level. The sympathetic thoracic ganglia (denoted by the ***G*** letter (***T*** in our article)) lie slightly farther distally to each respective rib at the intercostal space level, following the descending trajectory of the ST on either side. As the trunk descends, the lower ganglia tend to gradually shift downward. This means that the G2 ganglion is usually located in the second intercostal space, close to the

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bottom of the second rib, while the G4 ganglion tends to lie closer to the fifth rib than to the fourth.

The first rib, which reflects the *closed C ring trajectory*, is the best anatomical reference point above the operating field. A pulsating subclavian artery can easily be found just above its upper border. The stellate ganglion is the most cranial element of the intrathoracic sympathetic chain, and it should certainly be kept intact in all thoracic sympathectomies for hyperhidrosis. At the lower border of the ribs, where the intercostal neurovascular bundles join the sympathetic chain inferiorly, caution should be taken. Important vascular structures (superior *vena cava* on the right and aorta on the left) should be identified as you move medially to the mediastinum.

The tiny collateral fibers originating from the trunk are the *nerves of Kuntz* [2]. They may act as an alternative neural pathway through the ascending branches between the second and the first intercostal nerves to the brachial plexus, causing hyperhidrosis after TS. To avoid this, it is advisable to stretch the chain by ~ 2 cm more laterally above the inner surface of the ribs to expose the periosteum, so that these small nerves can be properly cut or coagulated. Despite the fact that the frequency of detection of the Kuntz nerves reported in clinical series ranges from 10% to 38%, anatomical investigations reveal the presence of these nerves at a distance of 1–2 cm laterally to the ST in 40% to 86% of cases [2–4].

Given the anatomical variations in the ST structure, the differences between the right and left sides, and the relationship with the surrounding structures, each patient should undergo a thorough preoperative CT scan of the thoracic cavity for proper treatment planning and a video-assisted surgical examination of the inner surface of the thoracic cavity.

3. Venous anatomy of the region

The upper right and left parts of the chest have different venous anatomy. On the right, at the level of the IV–V thoracic vertebrae, there is the azygos vein, *v. azygos*, which wraps around the root of the right lung posteriorly, runs forward and down, and enters the superior *vena cava*. The hemiazygos vein and veins of the posterior thoracic wall, such as the right superior intercostal vein and the IV–XI posterior intercostal veins, enter the azygos vein on their way to the superior *vena cava*. The right superior intercostal vein drains the three upper intercostal spaces (from the first to the third) and empties into the azygos vein near the point where the latter forms an arc that spreads over the right bronchus [5].

On the left, at the level of the VII–X thoracic vertebrae, there is a hemiazygos vein, which turns sharply to the right, crosses the anterior spine (located behind the aorta, esophagus, and thoracic duct), and drains into the azygos vein. An ascending *v. hemiazygos accessoria* enters the hemiazygos vein, which receives six to seven superior intercostal veins (I–VII). The *v. intercostalis superior sinistra*, or left superior intercostal vein, drains the first intercostal space and flows into the left brachiocephalic vein.

Venous collectors, which can be found on the way to the ST, also have a very variable anatomy. A study of 23 corpses confirmed that the superior intercostal vein crosses the ST in 22% of cases, with the most common location between the R4 and R5 (70%). On the right side of the chest, the superior intercostal vein blocks the T2 ganglion in 12% of cases, which increases the risk of bleeding during the ST autopsy or coagulation in this area [6]. Haam et al. identified anterior crossing-type intercostal veins in 12 (27.3%) and 7 cases (15.9%) in the third and fourth right intercostal spaces, respectively [7].

Unlike arteries, damage to the veins during TS may cause bleeding that is difficult to coagulate or coagulation itself may increase the risk of profuse bleeding. This may entail a thoracotomy, so this information may be important in determining an appropriate site for ST ganglia coagulation.

When performing TS, we found the following variations in venous anatomy: 1) the right superior intercostal vein and posterior intercostal veins do not come into contact with the ST or ganglia (Fig. 1**A**); 2) the right superior intercostal vein and posterior intercostal veins are posterior to the ST or ganglion (Fig. 1**B**); 3) the right superior intercostal vein or posterior intercostal vein of the respective level may overlap the ST or ganglion (Fig. 1**C**). The third variant is the most dangerous since

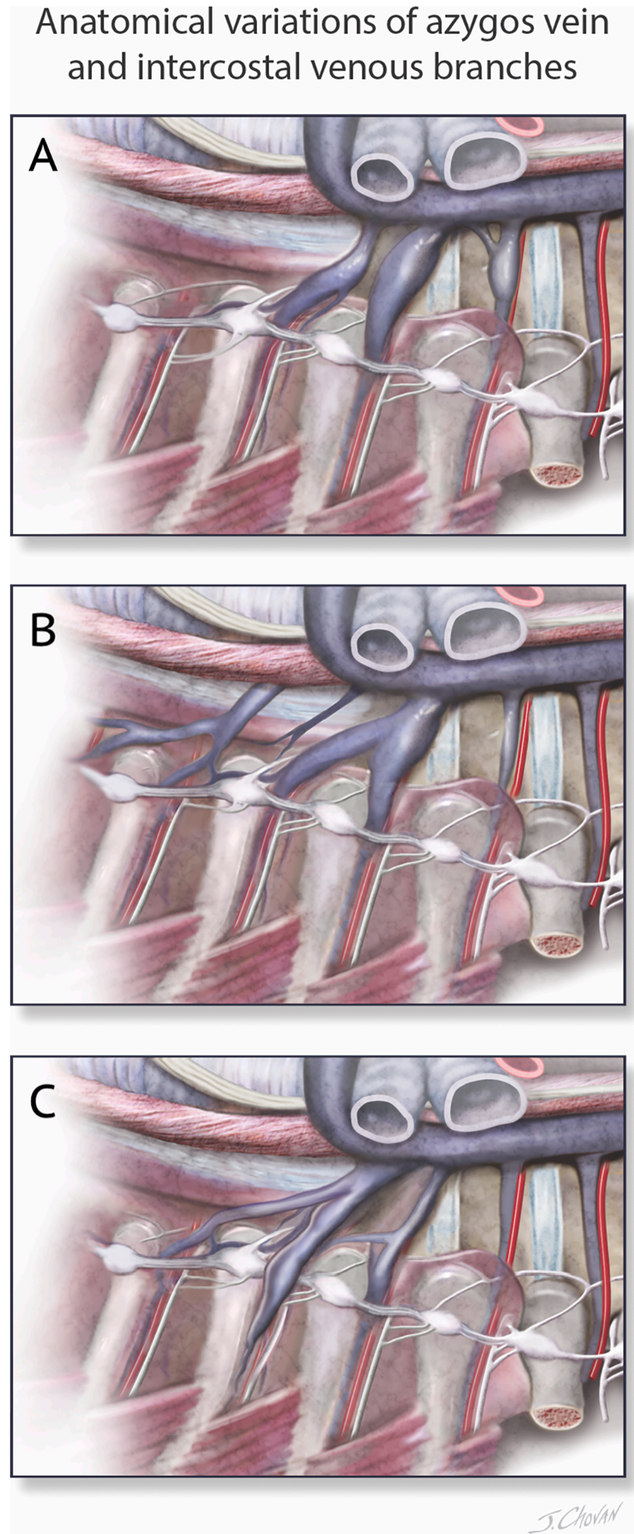

Fig. 1. Anatomical variations of the scattered type of draining of the intercostal veins into the azygos vein and their relationship with the ST; A = neutral type, no anatomical veins-trunk contact; B, C = direct contact type; B = posterior vein-ST crossing; C = anterior vein-ST crossing. The figure is original.

the vein closes the ganglion coagulation site, interfering with the surgery.

4. Material and methods

4.1. Study subject

Analysis of the anatomical variations in the ST structure and the anatomical relationship between the ST and the intercostal veins during TS.

4.2. Study design

A prospective randomized clinical and anatomical study was conducted. The following was analyzed: 1) anatomical variations in venous blood flow in the right and left thoracic regions; 2) the size of the intercostal veins: veins <1/4 of the width of the intercostal space were regarded as small, veins between 1/2 and 1/4 of the width were considered medium, and veins greater than 1/2 of the width were called large; 3) the trunk or scattered draining of the intercostal veins of the upper chest into the azygos vein; 4) The ST's anatomical relationship to the intercostal veins: 1) direct contact (direct crossing): posterior vein-ST crossing or anterior vein-ST crossing; 2) veins do not make direct contact (a neutral type).

Limitations of the study: insufficient classification of the size of the intercostal veins. Future studies may employ preoperative chest CT to more precisely assess the size of the veins.

4.3. Inclusion/exclusion criteria

The inclusion criteria of the study were: 1) males and females aged 16 to 60 years; 2) diagnosed with "primary focal hyperhidrosis of the extremities" and/or "skin blushing"; 3) ineffectiveness of conservative treatment; 4) performed surgical intervention - bilateral single-port TS (Table 1).

The exclusion criteria of the study were: 1) patients under the age of 16; 2) patients with secondary hyperhidrosis; and 3) patients with mental illnesses under the supervision of a psychiatrist.

4.4. Data analysis

Statistical data processing was performed using the EZR v. 1.54 (R statistical software version 4.03, R Foundation for Statistical Computing, Vienna, Austria) [8]. A critical level of significance of 0.05 was used to analyze the results of the study. Fisher's exact test was used in the analysis of contingency tables. The confidence interval (CI) was determined in the groups.

Table 1
Clinical characteristics of the patients.

	Group 1 (N = 11)	Group 2 (N = 34)	Group 3 (N = 35)
Age	33.27 ± 4.16	26.74 ± 1.10	28 (95% BI 27–30)
Sex			
male	3 (3.75%)	9 (11.25%)	23 (28.75%)
female	8 (10%)	25 (31.25%)	12 (15%)
BMI	20.35 ± 0.32	20.3 (95% BI 19.7–21.1)	20.53 ± 0.20
Severity of the disease:			
2nd degree	1(1.25%)	1 (1.25%)	6 (7.5%)
3rd degree	4 (5%)	9 (11.25%)	9 (11.25%)
4th degree	6 (7.5%)	24 (30%)	20 (25%)

4.5. Ethical considerations

All procedures involving human participants were carried out in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its subsequent revisions or comparable ethical standards.

The study was approved by the Ethics and Bioethics Committee of "MedClinic" Medical Center (Meeting Minutes No. 1 as of March 30, 2016).

4.6. Surgical technique

The patients were positioned on their backs on the operating table, with their upper extremities retracted by 90°. Individual lung intubation with a double-lumen tube was performed on the patients under general anesthesia. In the III–IV intercostal space, a 15 mm long skin incision was made along the anterior axillary line (Figs. 2, 3). A 10 mm trocar was inserted into the III–IV intercostal space and tissue was dissected from the skin to the parietal pleura, which was then perforated (pneumothorax). The lumen of the endotracheal tube, which ventilates the lungs, was exposed on the operated side. The ipsilateral lung collapse was caused by it. A 20-mm silicone trocar was introduced into the pleural cavity, through which a 30-degree thoracoscope was inserted. The anatomy of the ST and intercostal veins from the second to fifth intercostal spaces was video captured after the pleural cavity was investigated. The ST was then coagulated using a curved monopolar hook. The appropriate level of the ST was identified based on anatomical landmarks. The ST and a 4-cm-long section of the mediastinal pleura of the relevant rib were coagulated at that level between the two ribs (Figs. 4, 5). An 18-Fr drainage tube with a water valve was placed through the trocar into the thoracic cavity after the ST and its collateral innervation (the nerves of Kuntz) were coagulated to control lung straightening when the airway pressure was increased by artificial lung ventilation. The drainage device was removed when the lung was completely straightened and the wound was sutured in layers. A cosmetic suture and an aseptic bandage [9] were used to close the wound.

5. Results

Between 2015 and 2022, MedClinic conducted TS on 80 patients aged 17 to 42, with 35 men (44%) and 45 women (56%).

The patients underwent a single-port two-way VATS (video-assisted TS): 11 (14%) patients with palmar hyperhidrosis; 34 (42%) with palmar, axillary, and plantar hyperhidrosis; and 35 (44%) with blushing syndrome. The median age was 25 (17 to 42). The patients were divided into three groups depending on the ST coagulation level: the first group

Fig. 2. Intraoperative monoportal thoracoscopic sympathectomy image: trocar position for a single-port video-assisted thoracoscopic sympathectomy.

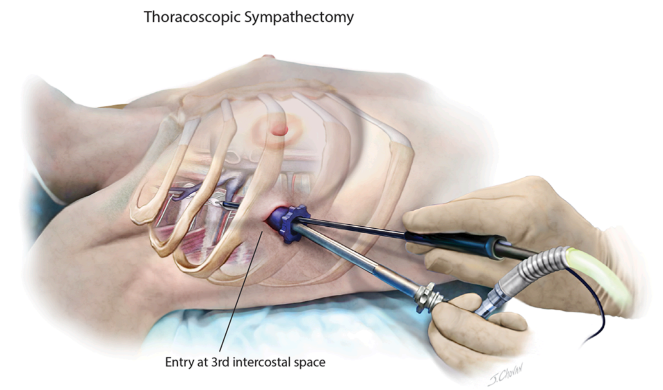

Fig. 3. Schematic representation of the sympathetic trunk and surrounding veins imaging in a single-port video-assisted thoracoscopic sympathectomy. The figure is original.

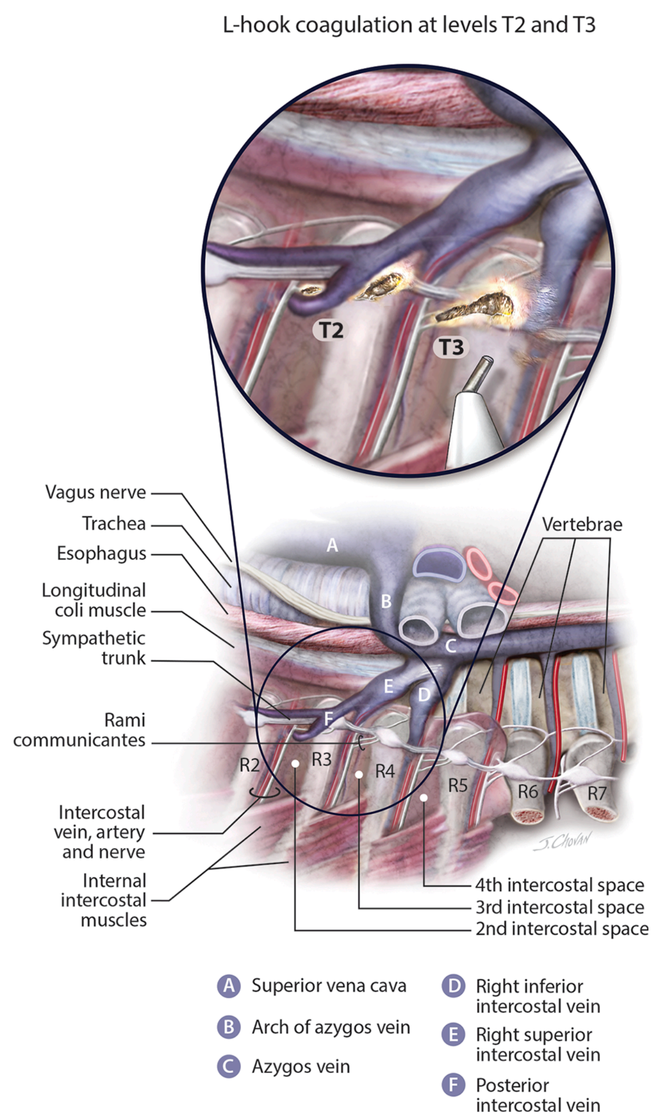

Fig. 4. Demonstration of the ST's relationship to surrounding anatomical structures (the trunk type of draining of the intercostal veins into the azygos vein); coagulation of the ganglia of the sympathetic trunk and the nerves of Kuntz. The figure is original.

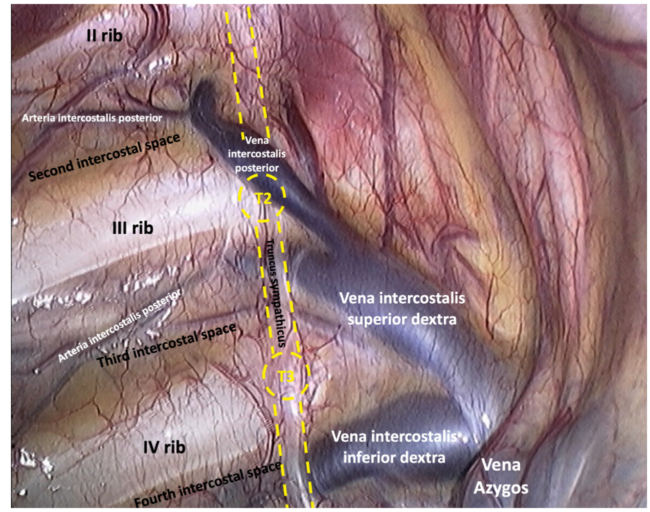

Fig. 5. Intraoperative image of the sympathetic trunk and surrounding anatomical structures (the trunk type of draining of the intercostal veins into the azygos vein).

(n = 11) underwent bilateral single-port sympathectomy at the level of R3 (isolated palmar hyperhidrosis), the second group (n = 34) at the level of R3–R4 (palmar and axillary hyperhidrosis), and the third group (n = 35) at the level of R2 (blushing syndrome).

All of the patients had a positive postoperative outcome. In all study groups, there were no postoperative complications, including Bernard-Horner syndrome, deaths, or VATS conversion to open surgery. No recurrences of the disease were reported during the entire follow-up period (one year). The length of hospital stays averaged 1.00 ± 0.41 days.

The results of surgery at various levels of the ST and its impact on quality of life were assessed using the DLQI questionnaire [10]. According to the questionnaire DLQI, in patients who underwent separation of the ST at the level of R3, quality of life improved from 21.5 (95% CI 17.6–24) to 1.0 (95% CI 1.0–2.3) score ($p = 0.0004$), at the level of R3 -R4 - from 25.0 (95% CI 21.4 – 26.0) to 2.0 (95% CI 2.3–2.5) score ($p < 0.0001$), at the level of R2 - from 18.0 (95% CI 15.5–20.0) to 2.0 (95%CI 1.0–2.7) score ($p < 0.0001$).

In general, much larger (in terms of length and diameter) (Fig. 6) and dilated intercostal veins were much more common on the right side (Table 2). Large veins were present in 46 (57.5%), 43 (53.7%), and 36 (45%) cases in the right second, third, and fourth intercostal spaces,

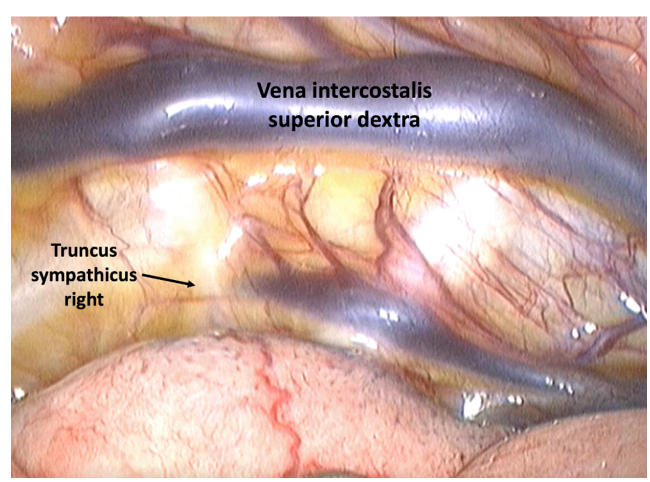

Fig. 6. Intraoperative image of the dilated right superior intercostal vein (direct contact type, anterior crossing).

Table 2
Breakdown of the posterior intercostal veins depending on the level of sympathectomy.

Vein diameter	Right	Left	P
The second intercostal space			
Small veins	11 (13.8% CI 7.0%–22.2%)	62 (77.5% CI 67.6%–86.0%)	p < 0.001*
Middle veins	23 (28.7% CI 19.3%–39.3%)	12 (15% CI 8.0%–23.7%)	p = 0.055
Large veins	46 (57.5% CI 46.4%–68.2%)	6 (7.5% CI 2.7%–14.4%)	p < 0.001*
The third intercostal space			
Small veins	13 (16.3% CI 8.9%–25.2%)	59 (73.8% CI 63.5%–82.9%)	p < 0.001*
Medium veins	24 (30% CI 20.4%-40.6%)	16 (20% CI 11.9%–29.6%)	p = 0.202
Large veins	43 (53.7% CI 42.7%–64.7%)	5 (6.3% CI 2.0%–12.7%)	p < 0.001*
The fourth intercostal space			
Small veins	18 (22.5 % CI 14.0%–32.4%)	70 (87.5 % CI 79.3%-93.9%)	p < 0.001*
Medium veins	26 (32.5 % CI 22.6%-43.3%)	6 (7.5 % CI 2.7%-14.4%)	p < 0.001*
Large veins	36 (45% CI 34.1%–56.1%)	4 (5% CI 1.3%-10.9%)	p < 0.001*

respectively, and only in 6 (7.5%), 5 (6.25%), and 4 (5%) cases on the left side. The incidence of large intercostal veins on the right was significantly higher than on the left ($P < 0.001$), while more than 85% of the left intercostal veins of the second, third, and fourth intercostal spaces were small. Anterior crossing veins were reported in 16 (20%) cases on the right and only in 4 (5%) cases on the left (Table 3). The incidence of anterior crossing veins was also statistically significantly higher on the right side ($P < 0.001$). The posterior intercostal veins, which ran parallel to the ST, were also included into the neutral type (Fig. 7).

On the right, the scattered type of draining of the posterior intercostal veins (PICV) and the right superior intercostal vein (RSICV) into the azygos vein (AV) was detected in 48 (60%) patients (Table 4). In 32 (41.25%) cases, the PICV and the RSICV coalesced into a common trunk and entered the AV. On the left, the scattered type was identified in 70 (87.5%) cases, while only 10 (12.5%) patients had the trunk type of draining. The accessory hemiazygos vein or the left brachiocephalic vein received blood from the left posterior intercostal veins or the left superior intercostal vein in most situations.

6. Discussion

Iatrogenic injury to the intercostal veins, azygos vein, superior *vena cava*, and other veins can cause severe bleeding and necessitate a thoracotomy. It should be noted that in some cases, the relative position of the veins around the ST is quite complicated in some cases, such as when the veins interfere with sufficient coagulation of the sympathetic ganglia due to their anatomical course, i.e., they overlap or displace the ganglia,

Table 3
The ST's anatomical relationship to the posterior intercostal veins.

Side	Neutral position	Rear crossing	Anterior crossing	P
Right	25 (31.25%)	39 (48.75%)	16 (20%)	p = 0.036; p < 0.001; p = 0.149.
Left	33 (41.25%)	43 (53.75%)	4 (5%)	p = 0.155; p < 0.001; p < 0.001.

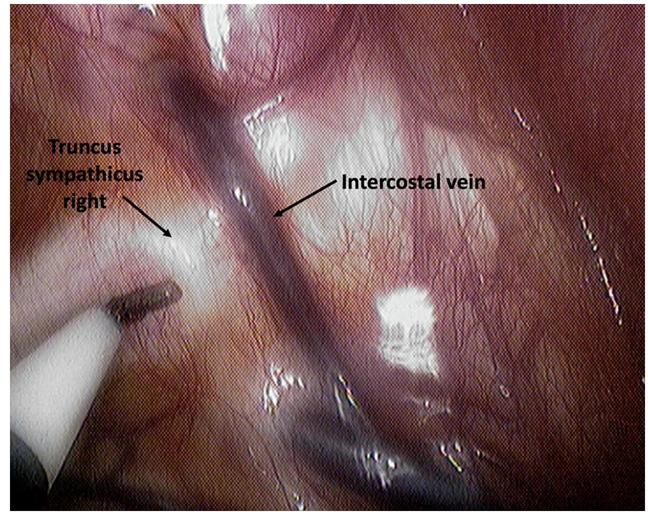

Fig. 7. Intraoperative image of the parallel course of the posterior intercostal vein relative to the ST, not anatomical vein to trunk contact (neutral type).

Table 4
Types of draining of the upper chest intercostal veins into the venous collectors.

Side	Scattered type	Trunk type	P
Right	48 (60% CI 48.9%–70.6%)	32 (40% CI 29.4%–51.1%)	p = 0.018*
Left	70 (87.5% CI 79.3%–93.9%)	10 (12.5% CI 6.1%–20.7%)	p < 0.001*

etc. In particular, the right-sided TR is more problematic since the ST is frequently crossed by dilated intercostal veins on the right.

According to the literature review, hemothorax is still a substantial concern after TS, despite being a rare post-TS complication. The most common cause is bleeding produced by a rupture of the intercostal veins. In some cases, bleeding may necessitate an open thoracotomy or careful hemostasis with pleural drainage. Gossot et al. reported 25 cases (5.3%) of severe bleeding (300–600 mL) during the ST dissection due to intercostal vein damage [11]. According to Rodriguez et al., TS complications occur in 5.6% of cases, and hemothorax requiring pleural drainage develops in 2.5% of cases [12].

As noted above, the right and left superior posterior intercostal veins have different outflow pathways. The veins of the second, third, and fourth intercostal spaces flow into the right superior intercostal vein or directly into the azygos vein on the right side. The superior intercostal vein becomes larger as it approaches the azygos vein (Fig. 8**A**). The left superior intercostal vein joins the left brachiocephalic vein and other left posterior intercostal veins to form the hemiazygos vein, which is drained by the azygos vein (Fig. 8**B**). The passage of the intercostal veins into the large full-blooded system of azygos veins causes their ectasia and pathological tortuosity, which makes their dissection during surgery substantially more difficult and increases the risk of bleeding.

In our study, 20% of patients had anterior crossing on the right side. In most cases, the intercostal veins flow either posteriorly to the ST or do not come into contact with it. However, if the ST is crossed anteriorly by an expanded full-blooded vein, there is a considerable risk of injury. In such cases, we recommend coagulation of the visible section of the ganglion or the ST without touching the veins and the point lateral to the vein — nerves of Kuntz, 1–2 cm laterally to the inner surface of the ribs at the appropriate level (Fig. 4).

7. Conclusions

The right-sided TS is more complex and presents greater risk due to the higher frequency of enlarged full-blooded intercostal veins crossing the ST anteriorly.

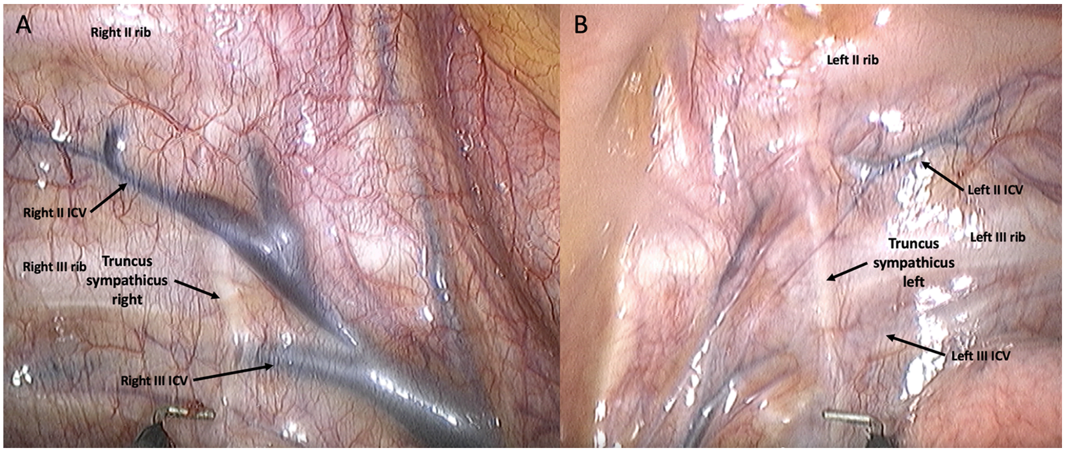

Fig. 8. Differences between the drainage veins of the right and left superior intercostal vein; (**A**) on the right side, the second, third, and fourth veins flow into the azygos vein, and the size of the vein at the head of the rib increases as the vein approaches the azygos vein; (**B**) on the left side, the superior intercostal vein diameter remains small on the head of the rib. *ICV = intercostal vein.

To avoid iatrogenic bleeding, comprehensive preoperative diagnostic planning and a thorough video-assisted surgical assessment of the inner surface of the thoracic cavity are required in each case prior to sympathetic trunk coagulation.

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Informed Consent

Informed consent was obtained from the patients included in the study. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and the Declaration of Helsinki (1964), as amended, or comparable ethical standards.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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