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Clinical Article

Morphometric Study of the Upper Thoracic Sympathetic Ganglia

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Objective : Morphometric data for the sympathetic ganglia (SG) of the upper thoracic spine was investigated to identify the exact location of the SG in order to reduce normal tissue injury in the thoracic cavity during thoracoscopic sympathectomy.
Methods : In 46 specimens from 23 formalin-fixed adult cadavers, the authors measured the shortest distance from the medial margin of the T1, T2 and T3 SG to the most prominent point and medial margin of the corresponding rib heads, and to the lateral margin of the longus colli muscle. In addition, the distance between the most prominent point of the rib head and the lateral margin of longus colli muscle and the width of each SG were measured.
Results : The shortest distance from the medial margin of the SG to the prominent point of corresponding rib head was on average 1.9 mm on T1, 4.2 mm, and 4.1 mm on T2, T3. The distance from the medial margin of the SG to the medial margin of the corresponding rib head was 4.2 mm on T1, 5.9 mm, and 6.3 mm on T2, T3. The mean distance from the medial margin of the SG to the lateral margin of the longus colli muscle was 6.7 mm on T1, 8.8 mm, 9.9 and mm on T2, T3. The mean distance between the prominent point of the rib head and the lateral margin of the longus colli muscle was 4.8 mm on T1, 4.6 mm, and 5.9 mm on T2, T3. The mean width of SG was 6.1 mm on T1, 4.1 mm, and 3.1 mm on T2, T3.
Conclusion : We present morphometric data to assist in surgical planning and the localization of the upper thoracic SG during thoracoscopic sympathectomy.

Key Words : Sympathetic ganglia · Thoracic vertebrae · Thoracoscopy · Sympathectomy.

INTRODUCTION

Essential palmar hyperhidrosis is an autonomic nervous system disorder associated with the hyperactivity of exocrine glands which are innervated by cholinergic neurons in the sympathetic ganglia (SG)[1,11,13]. Medications to treat this disorder are not curable[12,14] and may produce a variety of medication associated adverse reactions. On the contrary, the surgical removal of SG has been shown to be the most effective treatment for this medical condition[4,11]. The well-known anterior transthoracic approach or periaxillary transthoracic approach requires a large surgical incision in the chest and has a high risk for pleural injury[3]. The supraclavicular approach carries a higher risk of subclavian vessel injury or aortic injury and is also considered more likely to result in Horner's syndrome[2].

Kux[11] reported good results with the use of thoracoscopic sympathectomy, but the surgical procedure required the collapse of lungs by forcing air into the thorax, and drew little attention due to the technological limitations of video imaging at that time. However, with the development of double-lumen endotracheal tubes and the recent improvement in video imaging systems, minimally invasive procedures reduce the risk of lung injury and offer a wider surgical field of view. As a result, thoracoscopic sympathectomy is typically used as the surgical approach for essential hyperhidrosis of the palms or axillae[4,6]. In most cases, thoracoscopic surgery provides a good field of view, but since the SG and their chains should be detected in the state where they are covered by the parietal pleura, this surgical technique makes it difficult to confidently locate the SG. Thoracoscopic surgery may also cause injury to normal tissues if the surgeon lacks accurate anatomical knowledge or is unfamiliar with thoracoscopic procedures[20,29].

The authors used the location of the superior intercostal vein, which is first seen when thoracoscopic sympathectomy is performed around the first, second and third thoracic vertebral bodies, and the parts of the thoracic longus colli muscle and rib head as landmarks to measure their distances to the SG. Morphometric data for the SG of the upper thoracic spine was in-

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vestigated to identify the exact location of the SG in an effort to reduce normal tissue injury in the thoracic cavity during thoracoscopic sympathectomy.

MATERIALS AND METHODS

The authors used 23 adult cadavers (14 men and 9 women) perfused with a fixative solution containing formalin, phenol, alcohol and glycerin. The cadavers were aged between 38 and 85 years (mean=64 years). Each cadaver was placed in a supine position so that the first through third thoracic spines (T1-T3) could be observed, while the longus colli muscle, SG and rib heads in the lateral aspect of the thoracic vertebral body were exposed with the pleura removed (Fig. 1). In addition, the location of the posterior intercostal vein was identified and the crossing point between the superior intercostal vein and SG was determined (Fig. 2).

We measured the shortest distance from the medial margin of the T1, T2 and T3 ganglia to the most prominent point of the rib head, the medial margin of the rib head, and to the lateral margin of the longus colli muscle. We also measured the shortest distance from the most prominent point of the rib head to the lateral margin of the longus colli muscle and the widths of the first, second and third SG. All measured results were compared between the right and left sides, by thoracic segment and sex (Fig. 3).

A standard instrument was used for all measurements, and every measurement was performed by one operator in order to minimize possible errors. The Mann-Whitney test and t-test were conducted using SPSS software (version 11.0) to analyze the results. Values were considered statistically significance if they had a $p<0.05$.

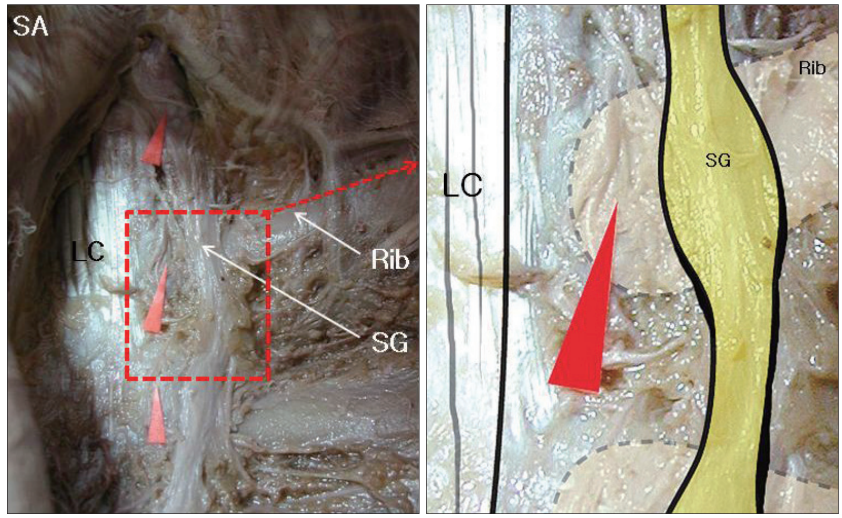

Fig. 1. Anatomical relationships and schematic view on the left upper thoracic area are shown after the removal of the parietal pleura. The red arrow-head markers indicate the prominent point of the 1st, 2nd, and 3rd rib heads. LC : longus coli muscle, SG : sympathetic ganglia, SA : subclavian artery.

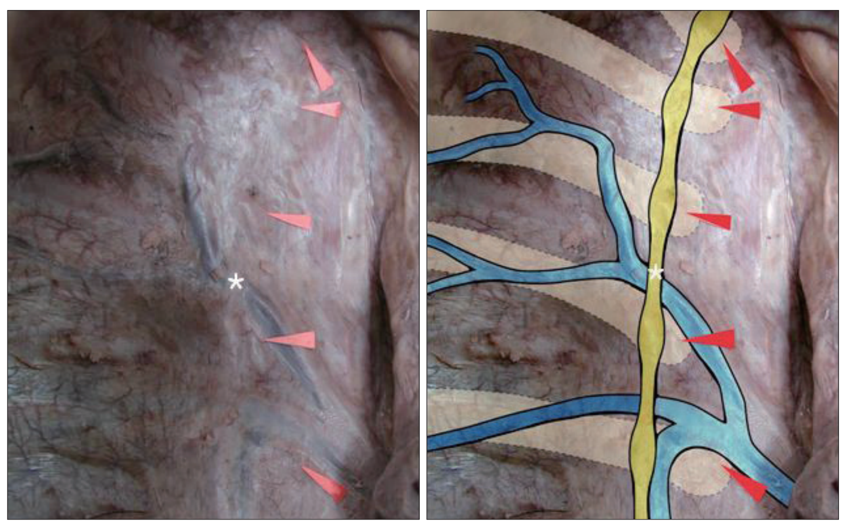

Fig. 2. Anatomical relationships in the right upper thoracic area before the parietal pleura removed. The red arrow-head markers indicate the prominent points of the 1st, 2nd, 3rd, 4th and 5th rib heads. The crossing point (*) between T3-4 sympathetic chain and superior intercostal vein is shown.

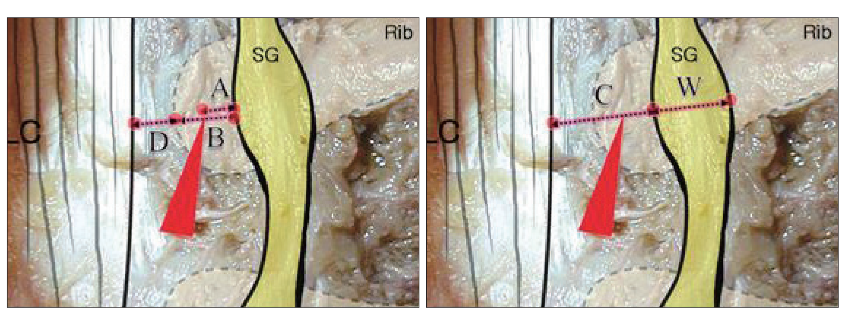

Fig. 3. The schematic image shows each anatomical landmark surrounding the left T2 sympathetic ganglia. Each of the measured variables is indicated as arrow-dotted lines. The red arrow-head marker indicates the prominent points of the rib head. A : The shortest distance from the medial margin of the SG to the most prominent rib head point. B : The shortest distance from the medial margin of the SG to the medial margin of the rib head. C : The shortest distance from the medial margin of the SG to the lateral margin of the longus colli muscle. D : The shortest distance from the most prominent point of rib head to the lateral margin of the longus colli muscle. W : The width of each SG. LC : longus coli muscle, SG : sympathetic ganglia.

RESULTS

The anatomical structures around the upper thoracic SG

In the anatomical position, T1, T2 and T3 ganglia are formed in the lateral as-

Table 1. Measured data at each vertebral level in 46 specimens from 23 cadavers

Data	Distance (mm) (mean±SD)					
	T1		T2		T3	
	Rt.	Lt.	Rt.	Lt.	Rt	Lt.
A	1.9±1.5	1.9±1.2	4.2±1.2	4.2±1.2	4.3±1.2	3.9±1.2
B	4.1±0.8	4.4±1.1	6.1±1.3	5.7±1.1	6.6±1.1	6.1±1.1
C	6.5±1.6	6.9±1.5	8.8±1.6	8.9±1.3	9.8±1.6	10.1±1.1
D	4.6±1.5	5.1±1.4	4.6±1.2	4.6±1.5	5.6±1.5	6.2±1.6
W	5.7±1.6	6.6±1.7	4.1±1.0	4.2±0.7	3.0±1.2	3.4±0.7

A : The shortest distance from the medial margin of the sympathetic ganglia to the most prominent rib head point. B : The shortest distance from the medial margin of the sympathetic ganglia to the medial margin of the rib head. C : The shortest distance from the medial margin of the sympathetic ganglia to the lateral margin of the longus colli muscle. D : The shortest distance from the most prominent point of rib head to the lateral margin of the longus colli muscle. W : The width of each sympathetic ganglia. Lt. : left, Rt. : right, SD : standard deviation

Table 2. Gender difference of the biometric at each vertebral level in 46 specimens from 23 cadavers

Level of vertebra	Measured data	Direction	Distance (mm) (mean±SD)		
			Male (14)	Female (9)	M-W test
T1	A	Rt.	2.8±1.1	0.6±1.0	0.000
		Lt.	2.4±0.7	1.0±1.2	0.003
	B	Rt.	4.4±0.8	3.5±0.3	0.004
		Lt.	4.4±1.1	4.4±1.1	0.829
	C	Rt.	6.9±1.6	5.8±1.3	0.179
		Lt.	7.0±1.6	6.6±1.3	0.557
	D	Rt.	4.2±1.6	5.2±1.3	0.062
		Lt.	4.7±1.5	5.6±1.3	0.096
	W	Rt.	6.2±1.7	5.0±1.2	0.720
		Lt.	6.8±1.9	6.4±1.2	0.781
T2	A	Rt.	4.6±1.0	3.5±1.2	0.053
		Lt.	4.4±1.3	4.0±1.1	0.403
	B	Rt.	6.5±1.2	5.5±1.2	0.096
		Lt.	5.8±1.1	5.6±1.1	0.781
	C	Rt.	9.2±1.4	8.3±1.9	0.201
		Lt.	8.8±1.4	9.0±1.2	0.643
	D	Rt.	4.5±1.3	4.7±1.0	0.557
		Lt.	4.4±1.7	5.1±1.3	0.224
	W	Rt.	4.4±1.1	3.5±0.5	0.023
		Lt.	4.4±0.6	3.8±0.8	0.096
T3	A	Rt.	4.5±1.3	3.9±1.0	0.224
		Lt.	4.3±1.3	3.2±0.6	0.019
	B	Rt.	6.8±1.2	6.1±0.9	0.250
		Lt.	6.3±1.1	5.6±0.9	0.159
	C	Rt.	9.8±1.9	9.9±1.0	0.336
		Lt.	10.2±1.1	10.0±1.0	0.877
	D	Rt.	5.4±1.8	6.0±1.1	0.369
		Lt.	5.9±1.6	6.8±1.4	0.179
	W	Rt.	3.2±1.4	2.5±0.6	0.179
		Lt.	3.6±0.8	3.1±0.6	0.159

A : The shortest distance from the medial margin of the sympathetic ganglia to the most prominent point of the rib head. B : The shortest distance from the medial margin of the sympathetic ganglia to the medial margin of the rib head. C : The shortest distance from the medial margin of the sympathetic ganglia to the lateral margin of the longus colli muscle. D : The shortest distance from the most prominent point of rib head to the lateral margin of the longus colli muscle. W : The width of each sympathetic ganglia. Lt. : left, Rt. : right, SD : standard deviation, M-W test : Mann-Whitney test

pects of the first, second and third thoracic vertebral bodies, respectively. They are located in the posterior part of the pleura, the anterior-medial aspect of the first through third rib head areas, and the anterior aspect of the intercostal nerves and vessels. The thoracic SG is connected through sympathetic trunks with the inferior cervical SG in the upper aspect and the lumbar or sacral SG in the lower aspect. The SG forms symmetrical chains on both sides, and in the medial aspect are connected with the anterior root of spinal nerves by gray and white rami (Fig. 1).

The second, third and fourth right posterior intercostal veins gather medially to form the superior intercostal vein which then cross SG to be connected to the azygos vein on the right side and hemiazygos vein on the left side. The superior intercostal vein and SG intersect with the fourth and fifth SG or their chains at the fourth and fifth intercostal spaces 70% of the time (Fig. 2).

The shortest distance from the medial margin of the SG to the most prominent point of the rib head (A)

If it is difficult to locate the SG covered by the parietal pleura upon use of the shortest distance from the medial margin of the SG to the most prominent point of the rib head, the operator can decipher the SG location by estimating the lateral distance using a probe to feel for the prominent bony ridge on the rib head. The shortest distance of the SG was 1.9±1.3 mm on T1, followed by 4.2±1.2 mm on T2 and 4.2±1.2 mm on T3 (Table 1). In a left-right comparison, we found no statistically significant difference (Table 3). A male-female comparison showed a statistically significant difference (p=0.003) with 2.4±0.7 mm for men and 1.0±1.2 mm for women on the left side of T1 (Table 2).

The shortest distance from the medial margin of the SG to the medial margin of the rib head (B)

If the prominent portion of the rib

head is not apparent to probe contact, the next best alternative is to use the shortest distance from the medial margin of the SG to the medial margin of the rib head. The length between the two points was shortest on T1 (4.3±1.0 mm), followed by T2 (5.9±1.2 mm) then T3 (6.4±1.1 mm), becoming shorter in the lower segments (Table 1). In comparison between the male and female groups on the right side of T1, there was a statistically significant difference (p=0.004) with 4.4±0.8 mm for men and 3.5±0.3 mm for women (Table 2).

Table 3. Left-right differences of the biometric at each vertebral level in 46 specimens from 23 cadavers

Level of vertebra	Data	Distance (mm) (mean±SD)		
		Rt.	Lt.	t-test
T1	A	1.9±1.5	1.9±1.2	0.278
	B	4.1±0.8	4.4±1.1	0.167
	C	6.5±1.6	6.9±1.5	0.640
	D	4.6±1.5	5.1±1.4	0.882
	W	5.7±1.6	6.6±1.7	0.998
T2	A	4.2±1.2	4.2±1.2	0.941
	B	6.1±1.3	5.7±1.1	0.502
	C	8.8±1.6	8.9±1.3	0.186
	D	4.6±1.2	4.6±1.5	0.289
	W	4.1±1.0	4.2±0.7	0.332
T3	A	4.3±1.2	3.9±1.2	0.846
	B	6.6±1.1	6.1±1.1	0.877
	C	9.8±1.6	10.1±1.1	0.522
	D	5.6±1.5	6.2±1.6	0.684
	W	3.0±1.2	3.4±0.7	0.402

A : The shortest distance from the medial margin of the SG to the most prominent point of the rib head. B : The shortest distance from the medial margin of the SG to the medial margin of the rib head. C : The shortest distance from the medial margin of the SG to the lateral margin of the longus colli muscle. D : The shortest distance from the most prominent point of rib head to the lateral margin of the longus colli muscle. W : The width of each SG. Lt. : left, Rt. : right, SD : standard deviation

The shortest distance from the medial margin of the SG to the lateral margin of the longus colli muscle (C)

The shortest distance from the medial margin of the SG to the lateral margin of the longus colli muscle is applicable when the border between the rib head and the SG is not seen due to atypical layers of fat and developed longus colli muscles. The mean interval between the two points was 6.7±1.6 mm on T1, 8.9±1.5 mm on T2 and 10.6±1.4 mm on T3 (Table 1). In a left-right comparison, the mean length was slightly longer on the left side with 0.4 mm on T1, 0.1 mm on T2 and 0.3 mm on T3, but there was no statistically significant difference between the two sides (Table 3). A male-female comparison also showed a statistically insignificant difference of approximately 1.1 mm on average with 6.9±1.6 mm for men and 5.8±1.3 mm for women on the right side of T1 (Table 2).

The shortest distance from the most prominent point of the rib head to the lateral margin of the longus colli muscle (D)

The shortest distance from the most prominent rib head point to the lateral margin of the longus colli muscle was 4.6 mm both on T1 and T2 and 5.9±1.5mm on T3 (Table 1). In a right-left comparison, both sides showed the same length of 4.6 mm on T2, while the left side was longer with lengths of 0.5 mm on T1 and 0.6 mm on T3 (Table 3). From a male-female comparison, we found a statistically significant difference with 4.4±0.8 mm for the male group and 3.5±0.3 mm for the female group on the right side of T1 (p=0.004) (Table 2).

The width of SG (W)

The width of SG was longest at 6.2±1.7 mm on T1, followed by 4.2±0.9 mm on T2 and 3.2±1.0 mm on T3. Those measured values can be used to estimate the height of the SG and to determine the extent of resection (Table 1). In a male-female comparison, the male group showed a longer width of 0.6-1.2 mm, but there was no statistically significant difference between men and women (Table 2).

The relative relationships between each landmark (Fig. 3)

The level of the SG could not be estimated by the appearance of rib heads alone, but we were able use relative ratios. The average relative ratio (A/C×100) of the shortest distance from the medial margin of the SG to the most prominent point of the rib head (A) to the shortest distance from the medial margin of the SG to the lateral margin of the longus colli muscle (C) was 28% on T1, 48% on T2, and 33% on T3; and for the width (W) of the SG, the average ratio percentages of T2 and T3 to T1 were 63% and 50%, respectively.

The location of a crossing point between the superior intercostal vein and the SG

In 46 SG specimens from 23 cadavers, we were able to locate a total of ten visible crossing points between SG and superior intercostal vein without distinction of right and left sides : 1 between the third and fourth ribs, 2 in the fourth rib, 4 on the lower border of the fourth rib, and 3 on the upper border of the fifth rib. As a result, 7 (70%) of the 10 crossing points were located between the fourth and fifth ribs. Therefore, in many cases, the upper and lower ribs are more likely to be number 4 and number 5, respectively (Table 4).

DISCUSSION

Since Kux[22] announcement of thoracoscopic sympathectomy for palmar hyperhidrosis in 1978, double-lumen endotracheal

Table 4. The crossing point between SG and the superior intercostal vein

Location of the crossing points	No. of cases (%)
3rd-4th intercostal space	1 (10)
Upper margin of 4th rib	2 (20)
Lower margin of 4th rib	4 (40)
Upper margin of 5th rib	3 (30)
Total	10

SG : sympathetic ganglia

tubes have been used[6)], and now the surgical procedure is attracting wide attention again with the advent of better thoracoscopic screens and devices. The thoracoscopic approach is a more effective way to reach the SG. It has provided an easier method to reach upper SG[20)]. Since it is less invasive than traditional surgical techniques, it has helped to reduce a length of hospital stays and morbidity.

In most cases, the upper thoracic SG can be reached with a wide field of view by temporarily collapsing the lungs artificially. However, in cases of pleural adhesion, the thoracoscopic entry itself can be difficult, while the ganglia, their chains and the anatomy are difficult to identify when the parietal pleura is closed[29)]. Moreover, it can be confusing to determine the level of SG and chains in the thorax. Actually, Kao[18)] reported that it was difficult to identify the SG exactly a third of the time and proposed a way to identify the SG by observing changes in finger skin temperature by electrostimulation. He also came up with a way to identify the SG by peeling off the parietal pleura with a probe after partial dissection[29)].

The success rate of sympathectomy is reported to be 93-100%[5,17,26,27)], but if the SG cannot be successfully located or if the second SG is connected to T1 and T2 ganglia by fibers due to a rare anatomical variation, it can lead to an incomplete resection and surgical failure[2,26)]. Therefore, it is absolutely necessary to understand correlations between the anatomical structures in the posterior mediastinum such as the subclavian vein, rib head, SG, longus colli muscle, and right superior intercostals vein.

When thoracoscopic resection of the second sympathetic ganglion is performed, the operator initially gets to observe a portion of the collapsed lung and subsequently will adjust the focus of the thoracoscope and advance towards the thoracic dome after identifying the direction of the apparatus in relation to the thoracic anatomy[15,27)]. In the dome of the thorax, the surgeon can find the subclavian artery and vein which lead to the extrathoracic space through the pleura on the upper border of the first rib. This helps to identify the location and order of ribs. Next, the operator needs to identify the first rib and the SG, but since they are mostly covered by the atypical layers of fat, it is difficult to do that in the field of thoracoscopy[15,24)]. In this case, the operator can view and identify the peripherally-running subclavian artery and vein[15,27)] and find the bony portion in contact with the surrounding artery and vein using a probe or a similar instrument[20,24)]. Another option is to make use of the fact that the second and third ribs run parallel to each other in a transverse plane, while the first rib is not parallel to them[27)]. Apparently, in the anatomical position, the jugular notch and sternal angle correspond to the height of T2 and the height of T3, respectively[18,28)]. In general, the second rib is below the intercostal muscle located uppermost in the field of thoracoscopy[24)], and there is a report that the superior intercostal artery is located 1 cm lateral to T2 ganglion 90% of the time[10)]. If all these fail, it is recommended to use radiography to locate the thoracic vertebrae and intercostals[24,29)]. In this study, the first rib was invisible due to fatty layers, so we had to remove them to see the rib. The second and third ribs ran parallel to each other but non-parallel to the first rib, and accordingly it seemed difficult to determine the exact location of the first rib in the thoracoscopic field. However, we could find the prominent point of the first rib head using a probe right below the subclavian artery and vein and then identify the medial margin of the first SG at an average of 1.9 mm lateral from the prominent point.

In many studies, it is recommended to surgically remove the SG of T2-T3 for palmar hyperhidrosis[21,29)], T2-T5 for axillary hyperhidrosis[9)], T2-T3 for facial hyperhidrosis[8)], and T1-T2 for facial flushing. The cause and mechanism of compensatory hyperhidrosis had been uncertain, but it seems to be closely associated with the extent of SG resection[7,19)]. There is a report that compensatory hyperhidrosis occurred in 24% after resection of T2 ganglion only and in 64% after resection of T2-T4 ganglia[16)]. Yoon et al.[29)] reported that the occurrence of compensatory hyperhidrosis was 33% after resection of the T2 ganglion only and to 51% after resection of the T2 and T3 ganglia. They indicated that if sweating only on the hands was the case, the removal of the second SG and its surrounding rami can reduce the operation time and lower the occurrence of compensatory hyperhidrosis. Since the eighth cervical ganglion and the first thoracic ganglion are associated with oculociliary pathways and ocular sympathetic innervations, Horner's syndrome may occur after the resection of T1 ganglion due to an intraoperative thermal injury. Accordingly, a procedure of limited T2 sympathectomy is recommended[23,25)]. In essential hyperhidrosis, it is important to find the T2 ganglion. The results of this study are significant in that they contribute to the easier identification of the T2 ganglion.

While performing thoracoscopic sympathectomy to identify the exact location of the upper thoracic SG, this study found that 70% of the superior intercostal vein can be easily observed thoracoscopy by crossed SG located between the fourth and fifth ribs. Therefore, this information is helpful in cases involving pleural adhesions making it difficult for a thoracoscope to reach the dome of the thorax. In addition, it will be possible to use the first-seen structure easily as the next best alternative if there are significant differences between individuals in the anatomical position.

If it is attempted to reduce unnecessary injury to normal tissues and quantify the extent of approach or resection by estimating an accurate distance between two points based on the absolute value measured in search of each landmark, it will help for intention of minimally invasive thoracoscopic sympathectomy. If, like in the study results, the relative length ratios for individual variables as necessary are determined and used, it will be considered to help make up for variations in the absolute values of measuring results with the body size of specimens.

CONCLUSION

A correct understanding of the structures surrounding the T2 ganglion can help to prevent compensatory hyperhidrosis and Horner's syndrome after surgery and to reduce injury to normal tissues in the thorax. The principal conclusions from this study are as follows:

1) Superior intercostal vein and SG cross each other between the fourth and fifth ribs 70% of the time.

2) The T2 SG can be found at an average of 4.2 mm lateral from the prominent portion of the second rib head and at an average of 8.8 mm lateral from the lateral margin of the longus colli muscle.

3) The relative ratio percentage of the shortest distance from the medial margin of the SG to the most prominent point of the rib head to the shortest distance from the medial margin of the SG to the lateral margin of the longus colli muscle is 28% on T1, 48% on T2 and 33% on T3, on average.

4) Regarding the width of SG (W), the ratio of the T2 SG to the longest T1 SG is 63% and the ratio of the T3 SG to the T1 SG is 50%, respectively, and the width becomes shorter in the lower segments.

5) In general, definite significant difference in length is not found from right-left and male-female comparisons.

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