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Anatomical variations of rami communicantes in the upper thoracic sympathetic trunk☆

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Abstract

Objective: The aim of this study was to clearly delineate the anatomical variations of the communicating rami in the upper thoracic sympathetic nervous system and to help develop better surgical method for essential palmar hyperhidrosis. **Methods**: Anatomical dissections of the upper thoracic sympathetic chains with sympathetic ganglia and communicating rami have been carried out in 42 adult Korean cadavers (male 26, female 16). The rami communicantes were classified into three types (Normal: transverse or oblique rami connected to the intercostal nerve of the same level; AR: ascending rami connected to the higher level; DR: descending rami to the lower level) based on the anatomical relationship of the thoracic sympathetic ganglia to the intercostal nerves. Both sides of the upper thoracic sympathetic nervous system were compared in the same individual. The number of the communicating rami was recorded in 32 cadavers (64 sides). The distance from the rami communicantes to the sympathetic trunk was measured in 26 cadavers (52 sides). **Results**: The incidence of AR (ascending rami) and DR (descending rami) arising from the second sympathetic ganglion was 53.6% (45/84), 46.4% (39/84). From the third thoracic sympathetic ganglion, the incidence of AR was 5.9% (5/84) and that of DR was 26.2% (22/84). And in the fourth thoracic sympathetic ganglion, the incidence of AR was 4.8% (4/84) and DR was 8.3% (7/84), respectively. When we compared anatomical structures of both sides among the 42 cadavers dissected, only 14.3% (6/42) had similar anatomy of the rami communicantes bilaterally. Among 32 cadavers (64 sides), the mean number of rami communicantes at the second thoracic sympathetic ganglion was 2.1/2.5 in the left and the right side. At the third and the fourth thoracic sympathetic ganglion, the mean number was 1.9/1.6 and 1.7/1.7 in each side. The mean distance from the thoracic sympathetic chain to the most distal communicating rami of the left and right side at the second intercostal nerve was 7.81/9.40 mm among 26 cadavers. The mean distance of each side was 6.81/7.94 mm at the level of the third intercostal nerve. And at the level of the fourth intercostal nerve, the mean distance was 7.48/10.92 mm, respectively. **Conclusion**: On the basis of this study, the anatomical variations of communicating rami could explain some surgical failures and recurrences. Moreover, in addition to the conventional surgical methods (sympathectomy, sympathicotomy, clipping of sympathetic chain and ramicotomy), dividing the inconstant sympathetic pathways (nerve of Kuntz, ascending or descending rami communicantes) on the second, the third and the fourth ribs will help to get better surgical effect.

Keywords: Hyperhidrosis; Rami communicantes; Anatomical variations

1. Introduction

Although such a video-assisted thoracoscopic surgery of sympathetic nerves as sympathicotomy (division of sympathetic chain) is now the most acceptable method to treat essential palmar hyperhidrosis [1–3], the anatomical structure of the upper thoracic sympathetic nervous system has not been fully described. Based on the anatomy of the thoracic sympathetic nervous system, the communicating rami of the upper thoracic sympathetic ganglia frequently become involved in essential palmar hyperhidrosis and a technique of dividing sympathetic rami communicantes with preserving thoracic sympathetic ganglia and nerve chain (ramicotomy) has been first introduced by Wittmoser [4] and later reported by Gossot [5]. However, the detailed anatomy of the rami communicates including anatomical variations have not been well documented. Clinically, ramicotomy, as it is usually carried out in the desired level only, fails to achieve acceptable surgical results (symmetrical decrease of sweating) and recurrence rates (less than 5%) [5–7] probably because not all the inconstant sympathetic conduction pathways that do not traverse the sympathetic trunk are interrupted. Therefore, the variations in the anatomy of rami communicantes through which they are

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connected with the spinal nerves have important clinical implication of the ramicotomy for essential palmar hyperhidrosis.

The purpose of this study was to investigate the anatomical variations of the rami communicantes in the upper thoracic sympathetic nervous system and to offer an important guide for the advanced techniques in treating essential palmar hyperhidrosis.

2. Materials and methods

Detailed dissections of the upper thoracic portions of 84 sympathetic chains with sympathetic ganglia and communicating rami have been carried out in 42 adult Korean cadavers (male 26, female 16). After removing the sternum and ribs from the first to the seventh levels including clavicles at bilateral midaxillary lines, the internal organs and parietal pleura were removed to expose the thoracic sympathetic chains. We focused our dissection on the anatomical variations of the rami communicantes from the second to the fourth thoracic sympathetic ganglia that have major components innervating to the hands (Fig. 1).

Diagrams of the upper thoracic sympathetic trunk, the rami communicates that connect it with the spinal nerves from the second to the fourth thoracic sympathetic ganglion level were made. The design of classifying the rami communicantes into three types (Normal, AR, DR) was based on the anatomical relationship of the thoracic sympathetic ganglia to the intercostal nerves. Consideration of its application for ramicotomy in patients with essential palmar hyperhidrosis was also a basis of the classification design. Normal: the transverse or oblique communicating rami connected to the intercostal nerve of same level; AR: the ascending rami to the intercostal nerve of the higher level; DR: the descending rami to the intercostal nerve of the lower level (Fig. 2).

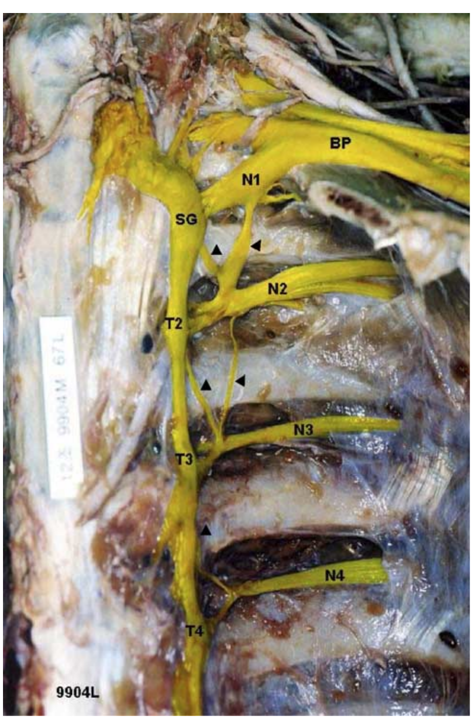

Fig. 1. The anatomical dissection of the rami communicantes of the thoracic sympathetic ganglia. BP, brachial plexus; SG, stellate ganglion; T2, the second sympathetic ganglion; T3, the third sympathetic ganglion; T4, the fourth sympathetic ganglion; N1, the first intercostal nerve; N2, the second intercostal nerve; N3, the third intercostal nerve; N4, the fourth intercostal nerve. *Arrowheads* indicate the rami communicantes.

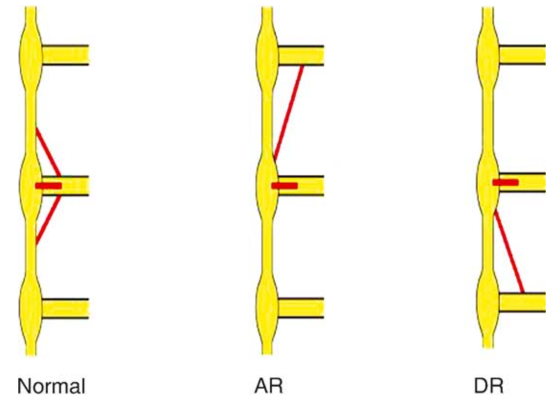

Fig. 2. The classification of the rami communicantes into three types according to the anatomical relationship between the upper thoracic ganglia and the intercostal nerves.

Both sides of the thorax were used to compare the anatomical variations of bilateral upper thoracic nervous system in the same individual. Among the anatomical variations of the rami communicantes, the components related to essential palmar hyperhidrosis were analyzed.

The number of branches of the communicating rami was counted at the respective thoracic sympathetic ganglia in 32 cadavers (64 sides). The distances from the most distal connecting point of rami communicantes at the second, third and fourth intercostal nerves to the sympathetic trunk were measured and recorded as mean$\pm$standard deviation with range in 26 cadavers (52 sides). All measurements were made with digital calipers (Mitutoyo) and the unmeasured values were calculated from the measured value into 5 mm intervals in photographs.

3. Results

Among the 84 thoracic sympathetic chains dissected, the communicating rami connected to the same level of intercostal nerve were observed in all thoracic sympathetic ganglia regardless of anatomical variations. The incidence of AR (ascending rami) or DR (descending rami) arising from the second thoracic sympathetic ganglion (T2) was 66.7% (56/84), moreover, 28 (33.3%) had both AR and DR. From the third thoracic sympathetic ganglion (T3), that of AR or DR was 32.1% (27/84). And in the fourth thoracic sympathetic ganglion (T4), AR or DR were found in 13.1% (11/84). The anatomical variation of T2 was much more stronger than that of the other two ganglia (T3, T4) and the variability became more and more similar at successive levels. The anatomical variations of the rami communicantes that may be concerned with essential palmar hyperhidrosis are intrathoracic nerve of Kuntz (59.5%, 50/84), the ascending

Table 1
Types of the communicating rami of the thoracic sympathetic ganglia ($n=84$)

Sympathetic ganglia	Normal	AR	DR	AR and DR
T2 ganglion	28 (33.3%)	45 (53.6%)	39 (46.4%)	28 (33.3%)
T3 ganglion	57 (67.9%)	5 (5.9%)	22 (26.2%)	0 (0.0%)
T4 ganglion	73 (86.9%)	4 (4.8%)	7 (8.3%)	0 (0.0%)

Normal, transverse or oblique rami connecting to the intercostal nerve of the same level; AR, ascending rami to the intercostal nerve of the higher level; DR, descending rami to the intercostal nerve of the lower level.

rami communicantes (AR) from the T3 or T4 (10.7%, 9/84), the descending rami (DR) from the T2 or T3 (72.6%, 61/84) (Table 1).

When we compared both sides of the upper thoracic sympathetic trunk from the second to the fourth sympathetic ganglia (T2-4), only 14.3% (6/42) had similar anatomy of the rami communicantes bilaterally (Table 2).

Among 32 cadavers (64 sides) in which the number of the communicating rami could be confirmed, the mean number of each side ranged between 1.6 and 2.5. As a result, the number of the communicating rami at the T2 level was larger than other levels due to greater variability in the anatomy determined as AR or DR (Table 3).

The farthest horizontal distance from the thoracic sympathetic chain to the most distal connecting point of the rami communicantes was 28.5 mm. Among 26 cadavers (52 sides), all the communicating rami of each side were within 3.0 cm in length from the sympathetic chain (Table 4).

4. Discussion

Patients with the essential hyperhidrosis usually have normal anatomical structures but show an overfunctioning of the sympathetic nervous system [8]. The sympathetic ganglion cells are activated mainly by stimuli received through afferent preganglionic neurons. The preganglionic neuron cells in the spinal cord are in the lateral portion of the intermediate zone of the gray matter. The preganglionic fibers, which come from the spinal cord in the thoracic nerves, traverse the ventral roots via the white communicating rami consisting of myelinated nerve fibers. After synapses at various levels in the paravertebral thoracic sympathetic ganglion, the postganglionic neurons connected to the thoracic nerves through the gray rami communicantes mainly composed of unmyelinated nerve fibers are distributed through different nerves to their end targets in blood vessels, sweat glands or hair follicles. The preganglionic fibers to the arm originate mostly from the third to the sixth spinal segments, and the postganglionic fibers to the arm originate from T2-T3 ganglia. Thus, preganglionic fibers to the hand ascend along the sympathetic chain to reach and synapse onto their target postgaglionic neurons [9]. The postganglionic neurons heading to the upper limb leave the sympathetic chain, join the spinal roots, enter the brachial plexus and later travel to the sweat glands of the hand. The autonomic innervation of the sweat glands of the palms is solely sympathetic, which comes mainly from T2-T3 or even T4. However, the data about the levels of the sympathetic innervation of the hand are inconclusive.

Table 2
Anatomical variations at both sides in the same individual ($n=42$)

Sympathetic ganglia	Similar[a]	Different
T2 sympathetic ganglion	18 (42.9%)	24 (57.1%)
T3 sympathetic ganglion	20 (47.6%)	22 (52.4%)
T4 sympathetic ganglion	31 (73.8%)	11 (26.2%)
T2-4 sympathetic ganglia	6 (14.3%)	36 (85.7%)

[a] Similar defined as the case that has the same type(s) of the communicating rami.

Table 3
Number of the communicating rami of the thoracic sympathetic ganglia

Sympathetic ganglia	Left side	Right side
T2 sympathetic ganglion	2.1±0.91 (1-4)	2.5±0.96 (1-4)
T3 sympathetic ganglion	1.9±0.83 (1-3)	1.6±0.76 (1-4)
T4 sympathetic ganglion	1.7±0.59 (1-3)	1.7±0.70 (1-3)

The basic anatomy of the sympathetic chain and neural connection between the sympathetic chain and the surrounding nerves was reported by some authors [10]. The anatomy of the upper thoracic sympathetic trunk with ganglia and its anatomical variations has also been previously studied in cadavers [11-13]. In 1942, Kirgis and Kuntz [14] reported that the incidence of bi- and uni-lateral intercostal rami arising from the T-2 and connected to the T-1 nerve in 44 cadavers was 59 and 31.8%, respectively. The incidence of those arising from the T3 ganglion and connected to the second thoracic nerve was reported to be 34.1 and 40.9%, respectively. In 1957, the intercostal ramus between the proximal intercostal nerves of T2 and T3 was demonstrated by Hoffman [15]. Pick [16] described that the upper thoracic sympathetic ganglia show a fairly regular pattern as far as to the eighth or ninth level in 1957, also. All thoracic spinal nerves are connected with the sympathetic trunk by white and gray rami. Fat, lymphatics and the intercostal blood vessels or branches arising separate white and gray rami from one another. This arrangement of the rami communicantes, typical for the upper thoracic region, includes usually the ninth thoracic segment. However, Kloot et al [17] reported that the variation in the anatomy of the upper thoracic sympathetic nervous system in relation to the spinal nervous system is much larger than had been described while preparing and studying the preparations in 1986.

From the surgical viewpoint of communicating rami, Wittmoser [4] described sympathetic T2-T4 or T2-T5 ramicotomy in treating the essential palmar hyperhidrosis in 1992. This technique was repeated and reported by Gossot in 1997 [5], who reported decreased rate of

Table 4
Distance from the thoracic sympathetic chain to the most distal communicating rami of the thoracic sympathetic ganglia

Sympathetic ganglia	Left side	Right side
T2 sympathetic ganglion	7.81±4.16 mm (2.5-17.0)	9.40±5.24 mm (2.5-28.5)
T3 sympathetic ganglion	6.81±2.82 mm (2.0-13.0)	7.94±3.35 mm (3.0-16.0)
T4 sympathetic ganglion	7.48±3.21 mm (3.0-15.0)	10.92±4.41 mm (3.5-23.5)

the compensatory sweating but higher recurrence rate (5%) in his 11-month follow-up. Furtheremore, Cheng et al. [18] recommended that all the rami communicantes of the ganglia and surrounding tissue of the sympathetic trunk should be cut down to pull the nerve chain high away from its base. Though ramicotomy is better surgical method for essential palmar hyperhidrosis than thoracic sympathectomy or sympathicotomy in decreasing the severity of compensatory hyperhidrosis [5,18], it has still some problems. Unfortunately, it has higher recurrence rates and difference of surgical results among patients and even between both sides of the same individual [6,7]. Surgical failure, recurrence of hyperhidrosis and asymmetrical sweating after operation probably resulted from the anatomical variations in the sympathetic chain. Aside from the nerve of Kuntz, multiple other aberrant pathways exist between the upper thoracic sympathetic ganglia and intercostal nerves. These anatomical variations are common and occur in some or another in more than half the population [19,20]. These anatomical variations are of great clinical importance, as they enable fibers to bypass the sympathetic chain, and thus are probably one of the main reasons for failures of surgical procedures [20,21]. For example, R3 sympathicotomy (sympathicotomy on the third rib) for palmar hyperhidrosis has excellent therapeutic results immediately after operation but therapeutic effectiveness is becoming to decrease 15 months after operation. The common causes of dissatisfaction are compensatory hyperhidrosis and recurrence of hyperhidrosis [22]. Therefore, the surgeon must be acquainted with the anatomy and physiology of the sympathetic system to achieve the desired clinical results and to minimize the adverse effects of upper thoracic sympathetic surgery [23].

As noted in this study, the anatomical variations of the upper thoracic sympathetic nervous system in relation to the intercostal nerves was striking, particularly the way in which the second sympathetic thoracic ganglion gives off its communicating rami. The numbers and anatomical variations of communicating rami connecting the intercostal nerves and the second sympathetic thoracic ganglion were much larger than lower levels. There was considerably less variability in the anatomy of the thoracic sympathetic ganglion at successive levels. The anatomical variations may be related to the essential palmar hyperhidrosis including the intrathoracic nerve of Kuntz (59.5%), the descending rami from the second thoracic sympathetic ganglion to the third intercostal nerve (46.4%), those from the third thoracic sympathetic ganglion to the fourth intercostal nerve (26.2%), the ascending rami from the third thoracic sympathetic ganglion to the second intercostal nerve (5.9%) and those from the fourth thoracic sympathetic ganglion to the third intercostal nerve (4.8%). Failure to interrupt these aberrant sympathetic conduction pathways that do not traverse the sympathetic trunk result in recurrence or different surgical results of both sides even in the same individual.

On the basis of the anatomical variations of the communicating rami in the upper thoracic sympathetic trunk from this study, the conventional surgical methods (sympathectomy, sympathicotomy, clipping of sympathetic chain and ramicotomy) confined to the desired level only would be incomplete for the treatment of essential palmar hyperhidrosis. From the viewpoint of clinical application, these anatomical variations could explain some surgical failure and help one develop a better surgical technique. To get a better effect when planning to perform the surgical treatment for essential palmar hyperhidrosis, it is helpful to divide the possible aberrant branches (nerve of Kuntz, ascending or descending rami communicantes) on the second, the third and the fourth ribs away from the sympathetic chain at least 3 cm.

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Appendix A. Conference discussion

Dr W. Weder (*Zurich, Switzerland*): The results you achieve by either coagulation of the ganglion or clipping the sympathetic chain are inferior than from those groups who resect the sympathetic chain. Could you imagine that this is because you don't interrupt the rami communicantes and the Kuntz nerve?

Dr Cho: I think the anatomical variation is also important in sympathectomy, sympathicotomy and clipping of sympathetic chains. I think surgeons should interrupt the aberrant pathways regardless of technique.

Dr Weder: Based on your study, what do you exactly expose during surgery to make sure that the sympathetic chain is resected completely?

Dr Cho: You mean for the palmar hyperhidrosis?

Dr Weder: Yes, for palmar hyperhidrosis, T2, T3.

Dr Cho: I think the key ganglion of the palmar hyperhidrosis is T3 ganglion. From the third thoracic sympathetic ganglion, the upper level is T2 and the lower level is T4. So I exposed from T2 to T4 level to divide all the anatomical variations completely. I think it's sufficient for palmar hyperhidrosis.

Dr Weder: Could you give the audience any hints how they don't miss the Kuntz nerve? It's easy to expose the main chain of the sympathetic trunk, but the Kuntz nerve is more difficult?

Dr Cho: I started the surgery with the lateral electrocoagulations on the second, third, and fourth ribs to divide the Kuntz fiber and other aberrant pathways.

Dr A. Alibrahim (*Amman, Jordan*): What do you do for hyperhidrosis of the face or flushed face?

Dr Cho: In facial hyperhidrosis, I think the best way to treat is clipping of the sympathetic chain. I performed the ramicotomy at the T2 level to treat facial hyperhidrosis, but the results were unsatisfactory.

Dr G. Friedel (*Gerlingen, Germany*): This confirms our results. For many years we have not resected the sympathetic chain itself. We resect those rami communicantes alone. I think it's not necessary to resect the sympathetic chain, and the more lateral you dissect the rami communicantes, the better your results are.