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ORIGINAL ARTICLE

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The sympathetic contributions to the cardiac plexus

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Abstract Cardiac sympathetic denervation for intractable angina pectoris in patients unsuitable for conventional revascularization is currently gaining popularity since this procedure may be performed via minimally invasive surgery. A thorough understanding of cardiac innervation and its variations is crucial to successfully effect cardiac denervation. This study aimed to demonstrate the cervical and thoracic sympathetic contributions to the cardiac plexus. The cervical and thoracic sympathetic trunks in 21 fetuses and eight adults were microdissected bilaterally and documented ($n = 58$ sides). The superior cervical cardiac ramus originated from the superior cervical ganglion (present in all specimens) in 53% of cases. The middle cervical ganglion (incidence 81%) gave rise to the middle cervical cardiac ramus in 88% of cases. The cervico-thoracic ganglion (incidence 85%) gave the cervico-thoracic cardiac ramus in 84%. In the thoracic region, four cardiac rami arose from the T2–T6 segment of the thoracic sympathetic trunk. All cervical and thoracic cardiac rami were traced consistently to the deep cardiac plexus. Khogali et al.'s (1999) success of limited T2–T4 sympathectomy in relieving pain at rest of patients with intractable angina pectoris appears to indicate that a significant afferent pain pathway from the heart is selectively interrupted. The variability in pattern of the cervical ganglia, cardiac rami and cervical contributions to the cardiac plexus does not appear to affect the outcome of limited sympathectomy. The complexity of cardiac pain pathways is not fully understood. The study is continuing and attempts to contribute to defining these cardiac neuronal pathways.

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Contribution sympathique au plexus cardiaque

Résumé La dénervation sympathique cardiaque pour angine de poitrine réfractaire chez les patients ne pouvant bénéficier d'une revascularisation conventionnelle est en train de connaître un regain de popularité depuis que cette technique peut être réalisée en chirurgie minimalement invasive. Une compréhension approfondie de l'innervation cardiaque et de ses variations est cruciale pour réaliser une dénervation cardiaque réussie. Cette étude avait pour but de démontrer les contributions sympathiques cervicale et thoracique au plexus cardiaque. Une microdissection bilatérale des troncs sympathiques cervico-thoraciques de 21 fœtus et de 8 adultes a été réalisée sous microscope et documentée (n = 58 côtés). Le rameau cardiaque cervical supérieur naissait du ganglion cervical supérieur (présent dans tous les cas) dans 53% des cas. Le ganglion cervical moyen (présent dans 81%) donnait naissance au rameau cardiaque cervical moyen dans 88% des cas. Le ganglion cervico-thoracique (fréquence 85%) donnait naissance au rameau cardiaque cervico-thoracique dans 84% des cas. Dans la région thoracique, 4 rameaux cardiaques naissaient du segment T2–T6 du tronc sympathique cervical. Tous les rameaux cardiaques cervicaux et thoraciques étaient suivis jusqu'au plexus cardiaque profond. Les succès enregistrés par Khogali et al. avec une sympathectomie limitée à T2–T4 pour la sédation de la douleur au repos des patients présentant une angine de poitrine réfractaire, semblent indiquer qu'une importante voie afférente de la douleur du cœur est interrompue de façon

sélective. La variabilité dans l'organisation des ganglions cervicaux, des rameaux cardiaques et des contributions du plexus cervical au plexus cardiaque ne semble pas avoir d'impact sur le résultat de la sympathectomie limitée. La complexité des voies de la douleur cardiaque n'est pas complètement comprise. L'étude est à poursuivre et vise à contribuer à définir les voies nerveuses du cœur.

Keywords Cardiac ramus · Cervical ganglia · Thoracic ganglia · Heart · Innervation

Introduction

The management of patients with intractable angina and coronary artery disease, unsuitable for conventional coronary revascularization, is increasingly appreciated by cardiologists as a serious and escalating problem. In addition, coronary artery bypass patients are living longer and beyond their vein graft life expectancy and develop angina due to graft blockage or disease [4]. These patients are refractory to current established treatment modalities and are markedly debilitated, require frequent hospitalization and consume significant amounts of economic resources. With the current advances in endoscopic surgical techniques, the success of surgical interruption of the sympathetic nervous system for the relief of anginal pain in these patients has been demonstrated in recent years [1, 4, 11].

Cardiac sympathetic denervation (CSD) performed via video-assisted thoracoscopic surgery (VATS) on patients with intractable angina and who are unsuitable for conventional revascularization was reported to be a safe and effective therapeutic option with good subjective as well as objective results. The left sympathectomy is always done first to avoid arrythmogenicity [11].

Angina of effort is similar in origin to intermittent claudication, just as the sympathetic nerves, which conduct pain impulses to the brain, are similar to the somatic sensory fibers [10]. They arise from periarterial and epicardial nerve endings in the heart and pass by way of the cardiac plexuses and the middle and inferior cervical nerves to the middle and inferior cervical ganglia through which they pass without interruption and continue down the ganglionated trunks to enter the spinal cord via the white rami communicantes of the upper four or five thoracic roots. It is probable that other routes exist, running directly from the deep plexus to the upper four or five thoracic ganglia, but little is known of these alternate pathways [10].

Selective, bilateral resection of the thoracic sympathetic trunk, from the second to the fourth ganglia, with the preservation of the stellate/cervico-thoracic ganglion (CTG), i.e. fused inferior cervical ganglion (ICG) and T1 ganglion, and cervical cardiac rami has been demonstrated to retain the warning signs of angina, viz. "an uncomfortable oppressive sensation" [4].

Literature reports cardiac sympathetic nerves to be highly variable in their topography [5, 7]. This complex and diverse arrangement may account for the morphological contradiction contained in the literature reviewed. Successful CSD for pain relief, a field often beset with failure, is dependent on adequate morphological knowledge of cervical and thoracic cardiac rami [2].

This study aimed to document the origin and incidence of the cervical and thoracic sympathetic contributions (CCR and TCR) to the cardiac plexuses.

Materials and methods

The cervical and thoracic portions of the sympathetic trunk in 21 formalized fetuses (gestational age range: 16 weeks to full term; 11 males, 10 females) and eight formalized adults (age range: 18–55 years; 4 males, 4 females), obtained from the Department of Anatomy at the University of Durban-Westville, were micro-dissected bilaterally using a magnifying loupe and documented (58 sides: 29 right, 29 left). A Sony Digicam 9 was used for the photodocumentation.

The sympathetic trunk was identified and the rami communicantes to each ventral ramus were exposed. The medial branches from the cervical and thoracic segments of the trunk were then dissected and traced to the cardiac plexus.

Fused ganglia, segments of cardiac rami and of the interganglionic segments between the ICG, T1 and T2, were biopsied and stained using hematoxylin and eosin (H and E), set in paraffin wax and sectioned at 0.1 μm before microscopic study. The authenticity of the biopsied structures was confirmed histologically.

Results

Incidence of cervical ganglia

The incidence of the cervical ganglia was:

- superior cervical ganglion (SCG): 100% (fetal, 100%; adult, 100%);
- middle cervical ganglion (MCG): 81% (fetal, 83%; adult, 75%);
- stellate or cervico-thoracic ganglion (CTG): 85% (fetal, 91%; adult, 69%).

In the absence of the CTG, a separate ICG and T1 ganglion was recorded in 16% of cases.

Histological examination of the interganglionic segment revealed absence of the ganglionic cell bodies and confirmed unfused ganglia.

Cardiac rami

Cardiac sympathetic rami were differentiated according to their origins from the cervical and thoracic parts of the sympathetic trunk into three groups: cervical cardiac sympathetic rami (CCR), cervico-thoracic cardiac rami (CTCR) and thoracic cardiac rami (TCR).

Cardiac rami were recorded bilaterally. These results are summarized in Table 1 and Fig. 1. The origin of the cardiac rami from the sympathetic trunk was found to

Table 1 Summary of the incidence and origin of CCR and TCR (*SCCR*, superior cervical cardiac rami; *MCCR*, middle cervical cardiac rami; *CTCR*, cervico-thoracic cardiac rami; *TCR*, thoracic cardiac rami)

Ramus	Incidence (%)	Origin (%)	
		Ganglionic	Interganglionic
SCCR	100	53	47
MCCR	88	71	17
CTCR	100	84	16
TCR2	85	50	35
TCR3	71	43	28
TCR4	83	54	29
TCR5	60	35	26

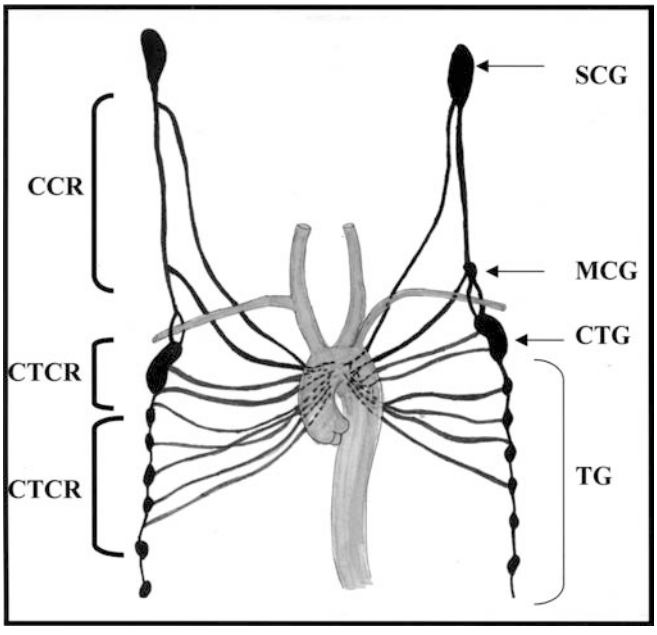

Fig. 1 Diagrammatic representation of the origin of the sympathetic contributions to the cardiac plexus from the cervical and thoracic sympathetic trunk. *SCG*, Superior cervical ganglion; *MCG*, middle cervical ganglion; *CTG*, cervico-thoracic ganglion; *TG*, thoracic ganglion; *CCR*, cervical cardiac ramus; *CTCR*, cervico-thoracic cardiac ramus

be highly variable and asymmetrical, i.e. in no specimen was the arrangement on the right side identical to that on the left side.

Cervical cardiac rami

The incidence of the superior cervical cardiac ramus (SCCR) was 100% and SCCR origin was from the SCG in 31 of 58 sides (53%; 16/29 on the right side, 55%; 15/29 on the left side, 52%) (Fig. 2) and from the interganglionic segment of the trunk, below the ganglion, in 27 of 58 sides (47%; 13/29 on the right side, 45%; 14/29 on the left side, 48%). In these, the distance from the lower pole of the SCG to the origin of the SCCR ranged from 4.8 to 19.3 mm (mean distance 17.3 mm).

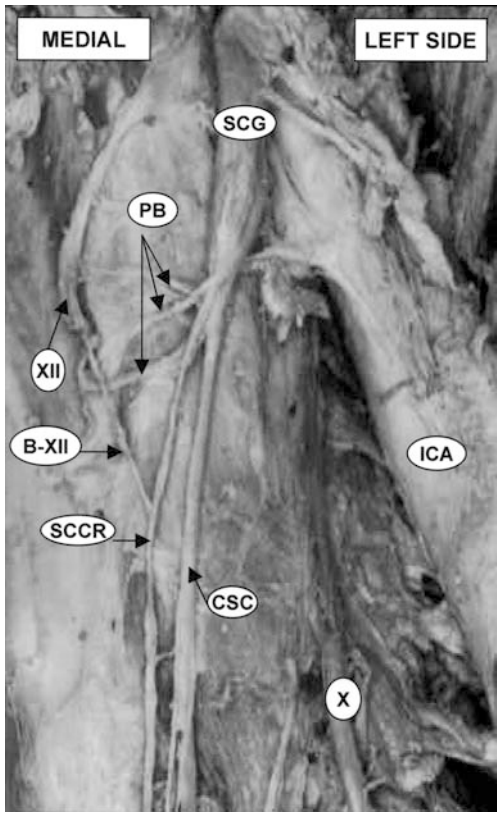

Fig. 2 Left superior oblique view demonstrating the ganglionic origin of the SCCR from the SCG in an adult specimen. *SCG*, Superior cervical ganglion; *CSC*, cervical sympathetic trunk; *ICA*, internal carotid artery; *SCCR*, superior cervical cardiac ramus; *PB*, pharyngeal branches; *X*, vagus nerve; *XII*, hypoglossal nerve

The middle cervical cardiac ramus (MCCR) was present in 51 of 58 sides (88%). The origin of the MCCR was from the MCG in 41 (71%) sides (Fig. 3) and from the interganglionic trunk in 10 of 58 sides (17%; 4/29 on the right side, 14%; 6/29 on the left side, 21%). The position of this origin ranged from 3.8 to 4.2 mm (mean distance 3.96 mm) below the lower pole of the ganglion. When the MCG was absent, the second cardiac ramus from the interganglionic trunk between the SCG and CTG was recorded as the MCCR. The MCCR was the thickest of all the cervical cardiac rami.

Cervico-thoracic cardiac rami

Cardiac rami issuing from the CTG or, in its absence, the ICG and T1 ganglion, were grouped together as CTCR and differentiated as CTCR "proper", inferior cervical cardiac ramus (ICCR) "proper" and thoracic cardiac ramus 1 (TCR1) "proper", respectively. ICCR "proper" and TCR1 "proper" could only be investigated in nine sides (5 right, 4 left) due the low incidence of ICG documented in this study (Fig. 4).

ICCR "proper" arose from the ICG in four of nine sides (45%; 3/5 on the right side, 60%; 1/4 on the left side, 25%) and TCR1 "proper" displayed a ganglionic

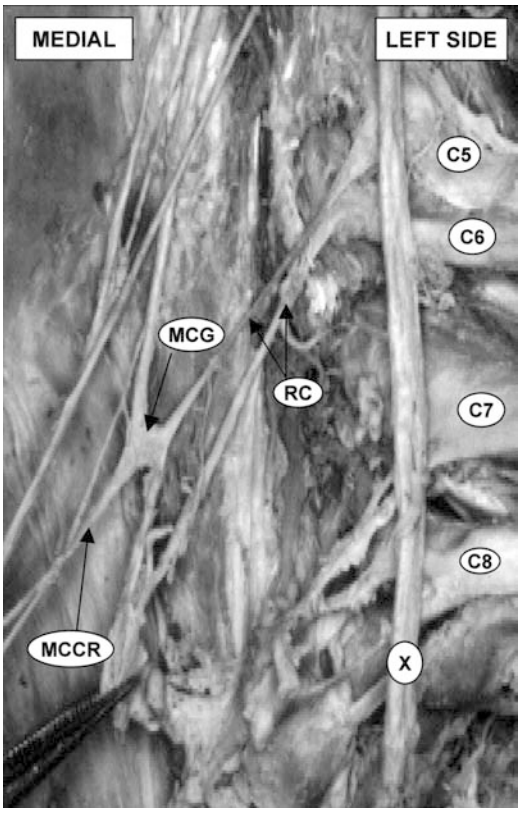

Fig. 3 Left superior oblique view of the MCG demonstrating the ganglionic origin of the MCCR in an adult specimen. *MCG*, middle cervical ganglion; *MCCR*, middle cervical cardiac ramus; *RC*, rami communicantes; *C5, 6, 7, 8,* C5, 6, 7, 8 ventral rami

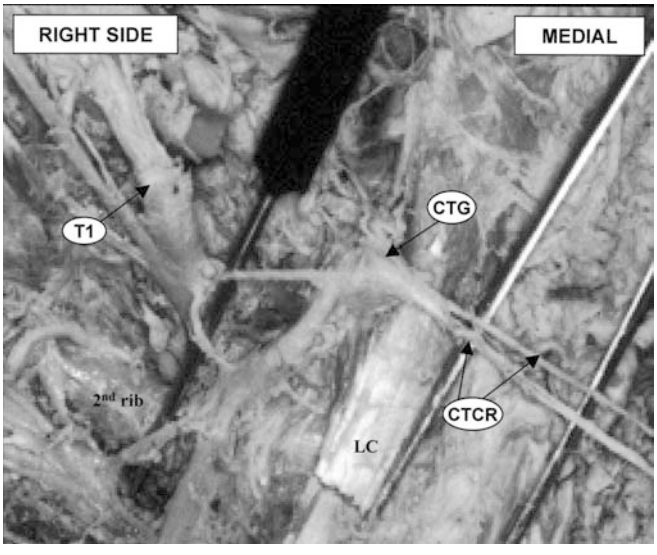

Fig. 4 Right superior oblique view demonstrating the origin of two CTCR from the CTG in an adult specimen. *CTG*, cervico-thoracic ganglion; *CTCR*, cervico-thoracic cardiac ramus; *T1*, T1 ventral rami; *LC*, tendon of longus colli

origin in six of nine sides (67%; 4/5 on the right side, 80%; 2/4 on the left side, 50%). In two of nine sides (22%) TCR1 ''proper'' arose from the upper half of the interganglionic segment of the trunk below T1G.

CTCR ''proper'' were investigated in all 49 of 58 sides that had a CTG. The incidence of CTCR was 100%. CTCR arose from the CTG in 41 of 49 sides (84%; 21/24 on the right side, 88%; 20/25 on the left side, 80%). In 37 cases (90.%) of this ganglionic origin two CTCR arose from the ganglion, while in four cases (10%) only one ramus was noted. In three of these cases a second ramus was found arising from the trunk below the CTG. In eight of 49 sides (16%) the CTCR arose from the interganglionic segment of the trunk below the ganglion. The position of this origin ranged from 1.2 to 2.6 mm (mean distance 2.1 mm) below the lower pole of the ganglion.

Thoracic cardiac rami

In the thoracic region, four TCR arose from the thoracic sympathetic trunk below the CTG or T1 ganglion (Fig. 5). The origin of these cardiac rami was both from the ganglion and from the interganglionic segment. TCR were named sequentially after identifying TCR1.

The incidence of a second thoracic cardiac ramus (TCR2) was 85% (ganglionic on 29/58 sides, 50%; interganglionic on 20/58 sides, 35%). The interganglionic origin was as follows: between T2G and T3G, 13 of 20 sides (65%; 5/8 on the right side, 63%; 8/12 on the left side, 67%); between CTG and T2G, five of 20 sides (25%; 3/8 on the right side, 38%; 2/12 on the left side, 17%); between T2G and fused T3–4G, two of 20 sides (10%; 0/8 on the right side; 2/12 on the left side, 17%).

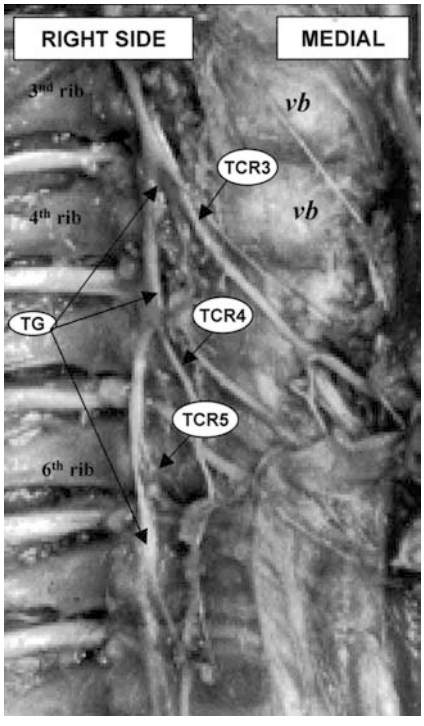

Fig. 5 Right supero-lateral view demonstrating the origins of TCR from the thoracic sympathetic trunk in a fetus. *TG*, thoracic ganglion; *TCR*, thoracic cardiac ramus; *vb*, vertebral body

A third cardiac ramus (TCR3) was present in 71% (ganglionic on 25/58 sides, 43%; interganglionic on 16/58 sides, 28%). The interganglionic origin was as follows: between T2G and T3G, 10 of 16 sides (63%; 4/7 on the right side, 57%; 6/9 on the left side, 67%); between T3G and T4G, six of 16 sides (38%; 3/7 on the right side, 43%; 3/9 on the left side, 33%).

The incidence of a fourth cardiac ramus (TCR4) was 83% (ganglionic on 31/58 sides, 54%; interganglionic on 17/58 sides, 29%). The interganglionic origin was as follows: between T3G and T4G, three of 17 sides (18%; 2/8 on the right side, 25%; 1/9 on the left side, 11%); between T4G and T5G, 11 of 17 sides (65%; 5/8 on the right side, 63%; 6/9 on the left side, 67%); between T4G and fused T5–6G ganglia, two of 17 sides (12%; 1/8 on the right side, 13%; 1/9 on the left side, 11%).

A fifth cardiac ramus (TCR5) was documented in 60% (ganglionic on 20/58 sides, 35%; interganglionic on 15/58 sides, 26%). The interganglionic origin was as follows: between T5G and T6G, 14 of 15 sides (93%; 7/7 on the right side, 100%; 7/8 on the left side, 88%); between T5G and fused T6–7G ganglia, one of 15 sides (7%; 0/7 on the right side; 1/8 on the left side, 13%).

Cardiac plexus

The cardiac plexus received both sympathetic and parasympathetic fibers. All sympathetic contributions from the cervical and thoracic sympathetic trunks were found to arborize directly in the deep cardiac plexus. This plexus is located posterior to the arch of the aorta and anterior to the left bronchus at the bifurcation of the pulmonary trunk. Fibers from the cardiac plexus were seen to pass forwards onto the anterior surface of the arch of the aorta and posterolaterally to the bronchi. Thus, the superficial cardiac plexus and the pulmonary plexus received indirect branches from the sympathetic trunk.

Discussion

The study permitted an overview of both fetal and adult specimens. The authors concur with Groen et al. [3] that the fetal study has the advantage of demonstrating, in a relatively small specimen, a unique overall view of the sympathetic nervous system from its origin in the spinal nerves to its termination in the cardiac plexus. A comparison between the fetal stage (from 15 mm) and the adult is feasible because the arrangement of the cardiac nerves does not change in further development [9]. Cardiac rami are generally named according to the ganglion nearest the point of origin of the ramus from the sympathetic trunk [2]. Fused ganglia were documented according to the method described by Pick [9], viz. by the distribution of rami communicantes to the segmental spinal nerves. Our study recorded a range from 8 to 11 thoracic ganglia, which corroborates earlier studies by Groen et al. [3] and Pick [9] of fused ganglia.

In the classical anatomical textbooks from 1772 to 1920, only the cervical cardiac nerves are shown as three distinct trunks arising from the corresponding ganglia descending downwards to the deep cardiac plexus: The important anatomical discovery of the thoracic cardiac nerves which form direct connections between the upper four or five thoracic ganglia to the heart was made coincidentally by Braeucker in 1927 and Jonnesco and Enarchesco in 1927 [12]. Subsequent reports on the extent of the origin of TCR vary amongst authors, from SCG: toT2 [8]; to T3 [5] and to T4/5 [7]. This study reports the origin of TCR from the thoracic sympathetic trunk up to the interganglionic segment between T5 and T6 ganglia. Although this interganglionic origin of TCR5 is present in only a small percentage of cases (4%), it should be noted that this interganglionic origin occurred between T5 ganglion and a fused T6–T7 ganglion.

The results of this pilot study corroborate the inter- and intra-individual variability in the origin of cardiac sympathetic nerves documented by Ellison and Williams [2]. The study confirms the great variability in the origin of CCR as demonstrated by Mizeres [7]. Variability in the origin of the cardiac nerves was also seen in the thoracic region.

Furthermore, CCR and TCR were also noted to arborize in the deep cardiac plexus. The superficial plexus was not clearly distinguishable from the deep plexus, concurring with the results of independent studies by Mitchell [6] and Mizeres [7], who suggest that the superficial and deep cardiac plexuses are created by artificial dissection. No direct branches from the sympathetic trunk were traced to the pulmonary plexus. The branches traced to the bronchi from the cardiac plexus appear to support the view that these TCR should be more accurately named cardiopulmonary nerves. These cardiopulmonary nerves are currently under investigation.

The success of limited T2–T4 sympathectomy in relieving pain at rest of patients with intractable angina pectoris, appears to indicate that a significant afferent pain pathway from the heart is selectively interrupted [4]. CSD via VATS is reported to be successful, with increased exercise tolerance time, ECG improvement, some degree of anti-ischemic effect, reduction in angina symptoms, decreased incidence of tachy-arrhythmias, unaffected left ventricular function and an improved quality of life with a 1 year follow-up [11]. Importantly, the patients do not lose their warning signal of an angina attack and were able take the necessary pharmacological action [4]. It is interesting to note that the variability in pattern of the cervical ganglia, CCR and cardiac plexus does not appear to affect the outcome of limited thoracic sympathectomy for pain relief.

However, the complexity of cardiac pain pathways is not fully understood. This study is being expanded with a collaborative clinical series and is designed to con-

tribute to defining the afferent and efferent cardiac pathways, particularly the contributions of the stellate and first thoracic ganglion to the cardiac plexus. The wide discrepancy of these variations warrants further anatomical analysis.

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