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A comparative study of structures comprising the thoracic outlet in 250 human cadavers and 72 surgical cases of thoracic outlet syndrome[1]

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Abstract

Objective: We have hypothesized that variations in fibrous, muscular and osseous structures with the potential to entrap the brachial plexus occur within the thoracic outlet of the normal population; and that these variations are different in pattern and frequency from those in patients presenting with thoracic outlet syndrome (TOS). **Methods:** Structural anomalies with potential for entrapping elements of the brachial plexus were examined following dissections of the posterior triangle of the neck in 250 human cadavers ($N = 500$ thoracic outlet dissections) and catalogued jointly by an anatomist and a thoracic surgeon. The pattern and frequency of anomalies in the 250 cadavers was compared to that encountered in 72 surgical cases of removal of the first rib for relief of symptomatic TOS ($N = 72$ procedures, 55 patients). **Results:** Relevant structural variations were encountered in 46% of cadavers, exhibiting no left–right or gender preference overall. When compared with the surgical group in which 100% exhibited structurally relevant anomalies, significant differences in pattern of anomalous structures and gender distribution were revealed. Anomalies posterior to the brachial plexus, ranging from fibrous bands to cervical ribs in both groups, were prevalent in the surgical group. A 'scissors-like' pattern, with neural entrapment by anterior and posterior anomalies was frequently encountered in females. **Conclusions:** Based on these data and embryological considerations, we propose a revised and simplified classification of impingement mechanisms within the anatomic thoracic outlet. Comparing these data to radiological imaging and observations at surgery, we offer a new perspective for the investigation and management of patients with TOS. © 1998 Elsevier Science B.V. All rights reserved.

Keywords: Thoracic outlet syndrome; First rib resection; Anatomy; Brachial plexus

1. Introduction

Both true neurogenic and symptomatic thoracic outlet syndrome are thought to result from compression of the brachial plexus within the thoracic outlet [1]. Patients with the symptomatic or disputed form of TOS present with cervico-brachial neuralgia and hand paraesthesiae, aggravated by arm elevation, reaching or lifting. These subjective symptoms are often intense in nature. They are usually unaccompanied by objective signs. This is frustrating to those that attempt to treat these patients and is devastating for patients whose pain is given little credence, sending them to seek help from multiple practitioners and often relegating them to the downward spiral of physical, functional and socio-economic hardship that accompanies chronic pain [2]. It has been claimed for a long time that structural anomalies neighbouring the thoracic outlet are associated with the neural and vascular compression of TOS [3], however, their significance and surgical removal in

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the treatment of TOS remains controversial [4–6]. This report is the first phase of a five phase study to revisit the mechanism of impingement, develop standardized outcome measures for both surgical and conservative treatment, provide an evidence base for confident patient-centred treatment selection and ultimately to provide clinical practice guidelines for TOS. This anatomical study reconsiders the anatomical mechanism of compression of the brachial plexus in a clinical context.

We hypothesize that: symptomatic TOS results from compression of the brachial plexus by a subset of anatomical variations in normal myofascial structures neighbouring the thoracic outlet. This gives rise to the prediction that (1) if the myofascial bands represent anatomical variations in degree and distribution in structures normally present within or bordering the outlet, evidence of these bands will occur in human subjects non-selected for thoracic outlet syndrome; and (2) the frequency and extent of the bands will be different in patients that present with symptomatic thoracic outlet syndrome than in the non selected population. To test these predictions, we examined 500 thoracic outlets in 250 human cadavers for the presence of fibrous or muscular structures and devised a simplified classification of structural variation consistent with our observations. Using this classification, we then compared the frequency of these structures with a series of patients undergoing first rib resection for thoracic outlet syndrome (72 procedures, 55 patients). As a result of these findings, based on our observations of what may be a thoracic outlet specific anomaly pattern, we propose a new perspective which may contribute to the assessment and treatment of TOS. These include an understanding that the population of patients presenting with TOS present with variations in normal structures surrounding the outlet that are different in distribution and pattern from those in the non-selected population and evidence to support a diagnostic tool using CT scan to assist in verifying the presence of posterior fibro-osseous anomalies. Normal CT scans do not exclude the diagnosis of thoracic outlet syndrome but point towards the presence of anterior non-imagable anomalies in appropriately symptomatic patients.

2. Materials and methods

Access to cadaver material for the anatomical component of this study was made available through the generous co-operation of the anatomy departments in the University of British Columbia, Vancouver BC, Canada, Brown University, Providence RI, Harvard University, Boston MA and University of Nebraska, Omaha NB, USA. To provide a source of subjects non-selected for TOS, all cadavers in this study were examined without knowledge of any medical history. Dissections were extended to expose the posterior triangle of the neck and all of the structures within and neighbouring the thoracic outlet from their exit from their respective intervertebral foramen. The same anatomist examined the left and right sides of all 250 cadavers described, jointly classifying the majority of cases with the thoracic surgeon that treated the entire surgical group. Findings at surgery were always confirmed by one other surgeon.

The walls and contents of the posterior triangle of the neck and the course of the brachial plexus beyond the first rib were examined bilaterally in each cadaver. The presence and nature of fibrous bands, Sibson's fascia, muscular or tendonous portions of scalenus anterior or scalenus medius muscles within and neighbouring the thoracic outlet were recorded in detail and from that information, a simplified classification constructed (see Section 3).

The data was organized to reveal (1) whether the compression was anterior or posterior to the plexus (anterior or posterior anomaly); (2) which elements of the plexus were being compressed (T1, C8T1, C78T1 or greater); and (3) whether the anomalous structure was a connective tissue band or a muscular slip. Demographic information of gender and side were recorded and multiple combinations of anomalies were grouped for frequency. Observations which did not fall within the classification were recorded separately for discussion.

Each cadaver examination consisted of an evaluation of the structures surrounding the entire course of the nerve roots of C5, C6, C7 and C8. T1 was followed from where the root exited the inter-vertebral foramina (from within the thoracic cavity) to the point at which the brachial plexus crosses the first rib. All borders of the scalenius anterior and scalenius medius muscles were palpated and examined visually. Sibson's fascia, was defined as fascia extending over the parietal pleura within in the confines of the first rib, extending toward, but not inserting into the first rib. Any structures associated with the Sibson's fascia were examined from above and again from within the thoracic cavity and recorded. Similarly, the walls of the pleural deficit through which the root of T1 leaves the confines of the thorax were examined for a thickened band (first rib to first rib band). Any bands of fibrous tissue, positioned in a way to provide potential impingement of the brachial plexus, were designated as 'slips' if they contained muscles fibres or 'bands' if the fibrous component could be seen to extend from origin to insertion. Their nature, course and attachments were recorded. Small arterial branches arising directly from the subclavian artery observed to course through or around the brachial plexus were noted. Subclavian arteries that coursed through the body of any portion of the Scalene

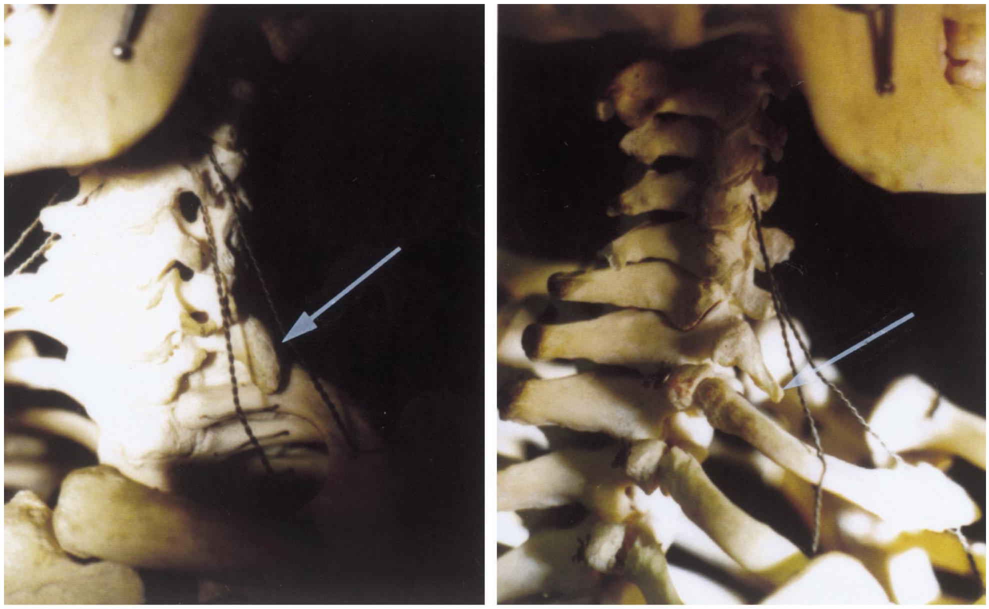

Fig. 1

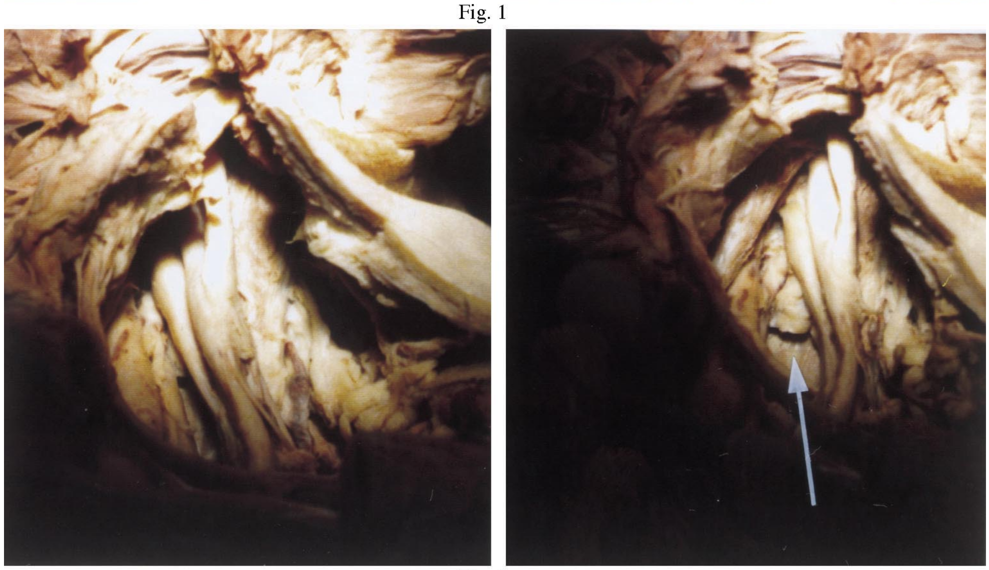

Fig. 2

Fig. 1. Elongated C7 transverse processes. Examples of blunt (left) and pointed (right) elongated transverse processes of the seventh cervical vertebrae are illustrated from a bony skeleton.

Fig. 2. Elongated transverse process of the seventh cervical vertebra alters the course of the brachial plexus in a cadaver subject. Its relationship to the brachial plexus is shown (left). In the right figure, the C8T1 nerve roots are drawn aside to the left of the process and the C567 roots are drawn to the right to reveal the elongated process. The connective tissue band from the transverse process to the first rib has been severed to reveal the tip of the elongated process (arrow).

mass were noted. Selected photographic examples of the structures encountered in this study were made from subjects at Brown University and Harvard University.

All patients had a diagnosis of TOS established by the surgeon and by either a neurologist or a physiatrist or both. All had failed to respond to conservative treatments before being considered as surgical candidates. As part of the pre-operative evaluation for surgical cases, CT scan images of the lower cervical vertebra were scored for the presence of cervical ribs, elongated transverse processes or other structures situated where they could potentially impinge on the brachial plexus. All patients selected for surgical exploration and treatment of symptomatic thoracic outlet syndrome from December 1995 to May 1997 (72 surgical procedures, 55 patients) were examined during surgery for the presence of anomalous fibrous bands or muscular slips and scored as to the presence (positive) or absence (negative) of these bands according to the marking scheme developed from the cadaver study. Those patients with identified cervical ribs underwent supra-

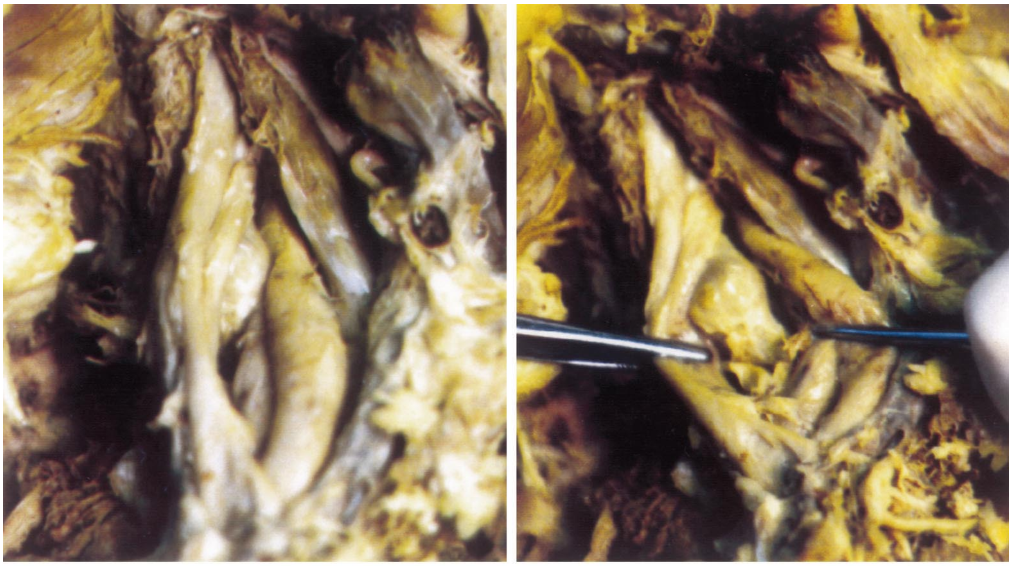

Fig. 3

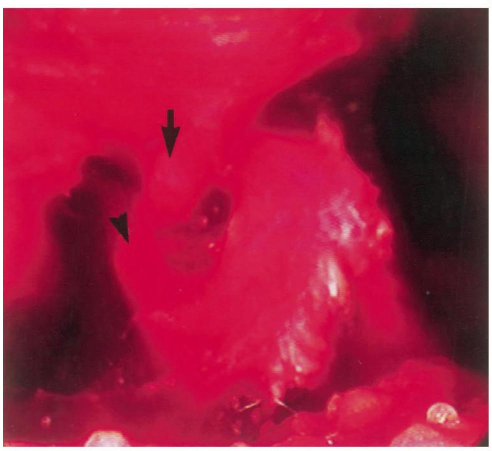

Fig. 4

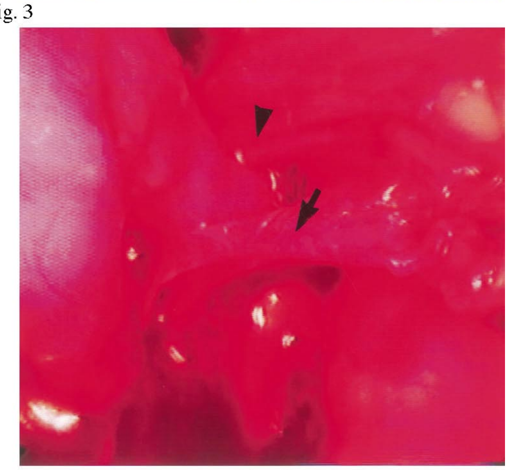

Fig. 5

Fig. 3. Marked distortion of the path of the subclavian artery and brachial plexus by a cervical rib. The brachial plexus is lifted anteriorly and the subclavian artery indented by the cervical rib (left). These structures are drawn aside to reveal the underlying cervical rib (right).
Fig. 4. Transaxillary view of a left first rib in preparation for removal. The anterior scalene muscles lies to the left of the upwardly reflected subclavian artery (arrow).
Fig. 5. The 'scissors-like' band pattern frequently observed in thoracic outlet syndrome. This is a later view of the surgical case shown in Fig. 4 in which the subclavian artery is moved medially to reveal an anterior band (arrow). In this 'scissors-like' pattern, the anterior band and the posterior band (arrowhead) create a vice-like compression of the nerve root.

clavicular cervical rib resection without first rib resection. Those with normal radiology and those with elongated transverse processes of C7 underwent transaxiallary first rib resection along with the removal of significant bands. At surgery, each subject was classified by two surgeons for the presence of anomalies.

Table 1
Distribution of anomalies in cadavers

	Total	#Anomalies	Unilateral	Bilateral
Male	133	65	30	35
Female	117	67	21	29
Total subjects	250	115	51	64

There is no preference for gender ($P = 0.60$).
There is no preference for left versus right ($P = 0.84$).
Bilateral and unilateral were equally likely and not different in males versus females.
Pearson's χ^2 Test of Independence.

2.1. Statistical analysis

Groups were compared by Pearson's χ^2 Test of Independence. Patterns were analyzed by Fisher Goodness of Fit. (significance $= P < 0.05$)

3. Results

In cadaver subjects, we observed that the individual roots of the brachial plexus demonstrated considerable

Table 2
Anterior anomalies in cadavers

		Trap T1				Trap C8,T1		Trap C78,T1	
		Sibson's fascia		1st rib to 1st rib					
		Right	Left	Right	Left	Right	Left	Right	Left
Male	266	6	5	29	25	23	22	5	1
Female	234	5	3	23	20	14	18	3	2
Total outlets	500	19		97		74		11	

No gender preference.
No side preference.

variation in their relative thickness (post-fixed and pre-fixed brachial plexus) as did the total thickness of the plexus between cadavers. A small branch of the subclavian artery coursed between the C5 and T1 roots of the brachial plexus in approximately 50% of cases, with no apparent deformation of the plexus (data not shown). The muscle fibres of the scalene mass taking origin from the anterior and posterior aspect of the transverse processes of C5–C8 and the course to their insertion was more variable than suggested by traditional text-book accounts. In general, the scalene muscle mass is subdivided into two groups by the vascular and neural components as they pass through the presumptive Scalene muscles during development. The differentiating muscles, flanking the neuro-vascular, bundle take attachment to the anterior and posterior aspects of the transverse processes of the cervical vertebra variably from C2 to C7. They are enveloped by connective tissue elements subdividing them into anterior and middle scalene muscles respectively. The connective tissue often leaves one or more additional muscular slips or fibrous bands separate intervening slips have been described as a separate 'minimus' muscle and may insert between the brachial plexus and the subclavian artery. In our study, the anterior scalene muscles were observed to arise from an anterior tubercle of the transverse processes, generally from C3 or C4 to C6. Frequently, accessory muscular slips were observed to separate high in the muscle belly and to insert posterior to the plexus, divide the plexus itself or insert between the subclavian artery and the brachial plexus. These slips presented in the form of broad muscular sheets rejoining the main muscle bulk for insertion, small discrete muscles with separate tendonous attachments or fibrous bands lacking any muscular component. These structures appeared to represent numerous variations in which the fascial sheaths surrounding the scalene muscle served to divide the muscle group into individual scalene muscles during development.

Occasionally, anomalous structures extended from a prolonged, pointed and anteriorly directed transverse process of C7 in a manner consistent with tethering the transverse process to the first rib (Fig. 1). These were documented as a 'prolonged transverse process of C7' (Fig. 2) when an enlarged process the size of a rib was encountered, it was scored as a 'cervical rib' (Fig. 3). A prolonged transverse process, its attached band, or a cervical rib were observed to distort the path of the brachial plexus and occasionally the subclavian artery.

The details of the complex nature of the distribution of the fibrous and muscular slips are likely less important than three important, clinically relevant factors: (1) whether the compression is anterior or posterior to the plexus (anterior or posterior anomaly); (2) which elements of the plexus were being compressed (T1, C8T1, C78T1 or greater); and (3) whether the anomalous structure is a non-extensible connective tissue band

Table 3
Anterior anomalies in cadavers fibrous bands versus muscle slips

	Total	C8, T1 Fibrous band	C78, T1 Muscle slip
T1	116	103	13
	67	23	44
	11	2	9
Total	194		

Short anomalies trapping T1 are usually fibrous (bands).
Long anomalies trapping greater than T1 are usually muscle (slips).

Table 4
Posterior anomalies in cadevers

Sex	Outlets	Prolonged C7	Cervical rib
Male	266	13	2
Female	234	11	2
Total	500	24	4

No gender preference.
82% were bilateral.
'Prolonged C7 transverse processes' were slender, pointed and had an associated band attached to the 1st rib. Cervical ribs were large, blunt and bound to the 1st rib.

Table 5
Distribution of anomalies in TOS patients

	Total patients	Unilateral	Bilateral	Onset Gradual	Trauma
Male	15 17 resections	13	2	2	13*
Female	45 55 resections	35	10	27	18

Patients presenting with TOS, significantly more were female.
Males present more frequently due to trauma*.
There is no preference for bilateral/unilateral or side.
Pearson' χ^2 Test of Independence.

(band) or a muscular slip (slip) capable of being induced to lengthen by the addition of sarcomeres, a clinically important consideration. Demographic information of gender and side were recorded and multiple combinations of anomalies were grouped for frequency. Observations which did not fall within the classification were recorded separately for discussion.

3.1. Data from cadaver group

Table 1 Indicates the frequency of anomalies in 250 cadaver subjects. Table 2 documents the distribution of anomalies encountered anterior to the brachial plexus in the cadaver group. Analysis of the pattern of anomalies with respect to fibrous bands or muscle slips using a Fisher test of goodness of fit, indicates there is a significant change in pattern with fibrous bands more prevalent in structures entrapping T1 and a change to muscle slips in the longer anomalies that entrap C8T1 or C78T1 (Table 3). Posterior anomalies were much less frequent and, unlike the anterior anomalies were significantly more likely to be bilateral (Table 4).

3.2. Data from the surgical cases

Significantly more females underwent surgery for TOS in our practice (Table 5),. Male patients more frequently reported onset of symptoms following trauma (Table 5). All anomalies described in cadavers, were significantly more prevalent in TOS patients. Importantly, the pattern of presentation was different as revealed by the test of goodness of fit (Table 6). A reversal of the pattern of anomalies was observed, with the frequency of posterior anomalies a prominent feature in surgical cases, compared to a prevalence of anterior anomalies in cadaver subjects. Observations at surgery suggested that there may be a relationship between the combined pattern of posterior anomaly and anterior anomaly on the same side, resulting in a 'scissors-like' impingement of the roots of the plexus. Although the incidence of posterior anomalies was low in both male and female cadavers and associated anterior anomalies were not seen in male cadavers, 73% of posterior anomalies had associated anterior anomalies in female cadavers. Fig. 4 shows overall appearance of a case presenting with combined anterior and posterior anomalies. Fig. 5 shows the compressing scissor-like bands. One case of this type was observed in a male TOS patient, but occurred in almost 65% of the female TOS patients. In the CT scans from these 72 surgical cases, only three patients were under-estimated (failed to identify a prolonged transverse process when a prolonged transverse process was observed at surgery) (Tables 7 and 8). No false positive results were reported.

Table 6
Comparison of patients/cadavers anomaly pattern

	TOS resections (%)	Cadaver outlets (%)
Anterior	41 (57)	194 (39)
Posterior	37 (51)	24 (5)
Cervical rib	17 (24)	4 (0.8)
Number of cases	72	500

The frequency of each anomaly is significantly greater in surgical cases.
Anterior, $P = 0.02$; posterior, $P < 0.001$; cervical rib, $P < 0.0001$.
The pattern of anomalies is significantly different in cadavers compared with surgical cases: $P < 0.002$.

4. Discussion

The complex nature of the distribution of annomalous structures encountered in the thoracic outlet has been described previously [1]. We have chosen to present the results of this study guided by three important, clinically relevant factors: (1) whether the compression was anterior or posterior to the plexus; (2) which elements of the plexus were being compressed; and (3) whether the anomalous structure was a non-extensible connective tissue band (band) or a muscular slip (slip) capable of being induced to lengthen by the

Table 7
Comparison of patients/cadavers TOS pattern

Sex	Surgical resection		Outlets in cadavers	
	Post anomaly	Associated with anterior anomaly	Post anomaly/500	Associated with anterior anomaly
Male	8	1	13	0
Female	29	13 (13)	11	8 (8)

addition of sarcomeres, a clinically important consideration.

All 'anomalous' structures could be accounted for by the variable division of the scalene muscle mass by the brachial plexus and subclavian artery as they extend into the arm during development. While there is a division of the scalene mass into three general muscle groups by the intervening fascia during the later stages of development of the neck muscles, occasionally small slips of muscles become separated from the parent group, giving rise to a range of muscle fibres forming sheets or discrete muscle slips. The term 'scalenus minimus' has been used to describe the more discrete of these muscle bundles. When they are exclusively comprised of connective tissue, they have been called bands. It is reasonable to assume that those containing muscle fibres and in which connective tissue does not extend the full length may be capable of the addition of sarcomeres in response to persistent lengthening. In addition to variations of the scalene mass, fibrous structures arising as a thickened Sibson's fascia or a pronounced edge of the defect through which the T1 nerve root exits the thorax are a potential source of compression.

Our observations suggest that while the anomalies encountered in cadavers are variations on normal structures, those encountered in patients represent a special population and present in a different pattern than in the general population. It is clear that the presence of structures capable of compressing the outlet are essential but not sufficient to produce symptoms of TOS. Cases ultimately selected for surgical intervention may form a specific sub group of those anatomical deviations. What is not known is whether they are anatomically different from those who respond to conservative modalities. With the possible exception of CT scanning for prolonged C7 transverse process [7], there are few objective measures that suggest nerve compression within the thoracic outlet. In TOS, resolution by conservative means must be given full opportunity before considering surgery. However, this approach must also be exercised with caution because the concept that there is no urgency to resolve TOS ignores three possibilities: (1) if compression is the result of non-extensible bands, increase in activity may result in repeated trauma to the trapped neural elements; (2) withholding surgical intervention in favour of conservative treatment, without improvement, increases the possible consequences of chronic pain [8]; and (3) that surgical and conservative treatments are not mutually exclusive.

The data from our study comparing the anatomical anomalies in cadavers not selected for TOS and surgical cases selected for TOS indicate that the population of patients presenting with TOS present with variations in normal structures surrounding the outlet that are different in distribution and pattern from those in the non-selected population. Furthermore, these anomalies may be associated with abnormal findings on CT scan, providing evidence to support a diagnostic tool using CT scan to assist in verifying the presence of posterior fibro-osseous anomalies. Negative findings on CT scans do not exclude the diagnosis of thoracic outlet syndrome, but point towards the presence of anterior non-imagable anomalies in appropriately symptomatic patients. In consideration of the intense suffering of patients with TOS and the unique physical, emotional and social impact of chronic pain, we are currently developing a comprehensive, objective profile of outcome measures to establish an evidence base from which to design individualized, integrated treatment program selecting from psycho-social, physical and surgical treatment modalities.

Table 8
Comparison of observations CT scan versus surgery

	Negative finding		Prolonged C7 transverse process		Cervical rib	
	CT scan	Surgery	CT scan	Surgery	CT scan	Surgery
Surgical cases	23	20	33	36	16	16
Error			Three were under-estimated			

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Appendix A. Discussion

Dr G.S. Kobinia (*Klagenfurt*, *Austria*): I had the privilege to host David Roos some 15 years ago when he came to Austria, so I got all of his teaching and I wondered how the classification that you presented compared to the type 1, type 2 bands that he described.

Dr Redenbach: What we are trying to do is relate our classification a little bit more to clinical findings so that you think in terms of an anterior or a posterior anomaly, of which posterior anomalies appear to be more important. His is a very thorough classification, but we felt that ours relates a little more to the combination of bands in patients that present with TOS syndrome and identifies which roots are being trapped. What we are hoping that we can do, is to continue with the collection of surgical data and see if we can find if there are any other combinations that would also be important.

Dr J. Thorpe (*Sheffield*, *UK*): I think this is a very important area for the surgeon and I would like to ask, because you have mentioned CT scanning, do you think that MRI scanning of the area would give you additional information about the particular bands? Also, is it going to influence our surgical approach because in the past we have just removed a cervical rib. I tend to do the Urschel or transaxillary approach, which I found is very useful at visualizing the artery and the trunks, but what makes me concerned is that I'm missing some of those small bands that you actually identified and this may account for failure of the operation.

Dr Redenbach: I am not the surgeon in this case, but I will try to answer the question. I know this question has been asked of Dr Bill Nelems, many times. First, his approach has always been that he prefers to do the complete first rib resection because he had occasion to re-operate on a case where he had previously done a partial rib resection, only to find a band attached to what was left of the rib. In terms of just cutting the bands, which I think is another approach, his finding is that they will sometimes reattach to connective tissue. In view of the fact that the surgery is already a reasonably major intervention, his position has always been to proceed with the whole first rib resection. In spite of our experience and we have now seen a tremendous variety of bands, that continues to be his approach.

Dr Thorpe: And the MRI scan, have you utilized that at all?

Dr Redenbach: Again, I can't really speak to this from my experience, but I do know that Bill Nelems has found that MRI is not nearly as helpful to him as the CT scans. As for the CT scans, the radiologists that do them for Bill have become quite accustomed to looking for these anomalies and I think there is an element of learning time in identifying them.

Dr Thorpe: Thank you.

Dr J.-M. Wihlm (*Strasbourg*, *France*): I have three short questions. First, do you have any idea about screening on chest X-ray for bone abnormalities? In France we used to have an X-ray every year. Would you have an idea of the percentage of abnormalities you can find just on a normal chest X-ray in a population?

Dr Redenbach: I think one of the most striking elements about anomalies in the thoracic outlet is that the degree of, if you like, pathology is not directly related to the severity of the symptoms. Certainly a lot of patients are referred with a cervical rib, which would be the most striking anomaly, but are without symptoms. There is no reason for these patients to be referred. So, I think we would find anomalies that we do not need to find by screening. In other words, it is the patient's pain that is the issue.

Dr Wihlm: That leads to the second question. Of course on the cadaver you didn't have the dynamic way of seeing things. Don't you think that there should be more clinical cases with less abnormality but with dynamic problems?

Dr Redenbach: Yes, I think so. One of the things that is really very important, I think, is to realise that some of these anomalies are going to be muscle slips and may be amenable to stretching. It is important to deal with the situation so continuing injury doesn't occur when there are connective tissue bands present. We have a five-phase study which involves developing standardized outcomes measures which can be equally applied to the surgical and conservative treatments. We are trying to develop a way of reducing the number of patients coming to surgery. We also feel very strongly that other elements of chronic pain are important here, psychological counseling and various therapies that treat the entire patient rather than using only the surgical approach. What we would like to do is to, again, look more carefully at the conservative treatment methods that have been used by other caregivers that provide relief and then write a Clinical Practice Guidelines so that our colleagues can help patients make the choice.

Dr Wihlm: Thank you very much.