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Bilateral Cervical Ribs with Asymmetric Morphology: Anatomy, Embryology and a 30-Year Follow-up Case Report

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ABSTRACT

Introduction: cervical ribs are anatomical variations resulting from the persistence of the costal primordium of the C VII vertebra and may be of clinical relevance when associated with compression of neurovascular structures at the cervicothoracic outlet. This anatomical case report describes bilateral cervical ribs with asymmetric morphology in a female patient followed for approximately 30 years, emphasizing morphological aspects and their long-term clinical implications. The left cervical rib presented an incomplete, two-segment pattern, whereas the right rib showed a markedly curved morphology, potentially narrowing the interscalene space and predisposing to compression of the lower brachial plexus. The patient underwent left-side decompressive surgery at the age of 20, with transient postoperative neuropraxia and satisfactory functional recovery after early-onset physiotherapy, remaining asymptomatic for about 15 years. In contrast, right-side decompressive surgery at the age of 32 was followed by severe neurogenic thoracic outlet syndrome, with chronic neuropathic pain and complete peripheral neuropathy of the right upper limb, partially controlled with pharmacological management. This long-term case underscores how bilateral cervical ribs with asymmetric morphology can lead to markedly different clinical outcomes and highlights the importance of detailed anatomical knowledge, careful surgical planning, and structured rehabilitation in the management of such anatomical variations.

Keywords: Cervical rib; Anatomical variation; Thoracic outlet syndrome; Brachial plexus.

Introduction

Cervical ribs (CRs) represent a classic example of how subtle embryological deviations can significantly affect adult functional anatomy. They result from the anomalous persistence of the costal primordium of the C VII vertebra, a process related to altered expression of HOX genes, which are crucial for axial skeletal patterning[1]. When the cervical costal element fails to regress, it may give rise to bony structures ranging from small tubercles to complete ribs.

The reported prevalence of cervical ribs varies widely among populations. Imaging-based studies describe rates from 0.2% to 6%, depending on the sample and methodology[2]. A meta-analysis comprising 141 studies found a mean prevalence of approximately 1.1%[1]. Brazilian clinical and radiological series suggest values between 0.5% and 1%, with a predominance in females[3].

The clinical interest in cervical ribs stands from their intimate relationship with the structures of the cervicothoracic outlet, particularly the brachial plexus and subclavian vessels. Even minor changes in the shape, thickness, or orientation of these ribs can reduce the available space to the nearby neurovascular structures, leading to mechanical compression. Such compression may present clinically as transient paresthesia, chronic neuropathic pain, or, less frequently, vascular symptoms[4,5].

Most individuals with cervical ribs remain asymptomatic throughout life[1,5]. However, specific morphological patterns such as elongated, thick, sharply curved, or incomplete ribs, and associated findings (fibrous bands, scalene muscle alterations, first-rib anomalies) increase the risk of neurovascular compression[4-7]. In bilateral cases, asymmetric morphology between sides may create distinct "risk architectures" within the same individual.

Despite being widely described in the international literature, there are few long-term follow-up reports focusing on bilateral cervical ribs with asymmetric morphology and detailed anatomical interpretation, particularly in Brazilian patients. In this context, the present study reports a 30-year follow-up of a female patient with bilateral cervical ribs, highlighting the morphological asymmetry and correlating it with divergent clinical outcomes.

This study has been approved by the local Institutional Ethics Committee (CAAE: 95719226.3.0000.5060 / Decision number: 8.332.757).

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Anatomical and Embryological Features

Anatomy of the brachial plexus and neurovascular structures in the cervicothoracic outlet

The brachial plexus is formed by the ventral rami of spinal nerves C5 to T1, which emerge through the cervical intervertebral foramina, being initially organized into roots, trunks, divisions, and cords, before giving rise to the main peripheral nerves of the upper limb[8,9]. Proximally, C5 and C6 unite to form the upper trunk, C7 continues as the middle trunk, and C8 and T1 join to form the lower trunk. These trunks traverse the interscalene space, delimited anteromedially by the anterior scalene muscle and posterolaterally by the middle scalene muscle, in close relationship with the subclavian artery[8].

Within the cervicothoracic outlet, the roots and trunks of the brachial plexus, the subclavian artery, and, to a lesser extent, the subclavian vein pass through a relatively narrow osteomyofascial corridor. Superiorly, this space is bounded by the transverse processes of the lower cervical vertebrae; inferiorly, by the first rib; anteriorly, by the anterior scalene muscle and the clavicle; and posteriorly, by the middle scalene muscle and deep paravertebral muscles[8]. Small changes in the size or shape of any of these structures may reduce the functional space and create abnormal contact between neurovascular elements and bony or fibrous components[4,5].

The presence of a cervical rib markedly alters this architectural arrangement. Anatomically, the rib usually arises from the costal element of the C VII transverse process and projects anterolaterally above the first rib[6,8]. Depending on its length, orientation, thickness, and degree of fusion with the first rib, it may form an additional bony "roof" over the brachial plexus and subclavian artery, reducing both vertical and horizontal diameters of the interscalene space[5,6]. In incomplete variants, bony or fibrocartilaginous segments can create bridges or bands acting as abnormal points of muscular traction and neurovascular compression[5,6].

Functionally, the lower roots (C8–T1) and the inferior trunk of the brachial plexus are particularly vulnerable in cervicothoracic outlet narrowing, given their caudal and medial position adjacent to the first rib and the cervicothoracic junction[4,8]. Movements involving sustained elevation of the upper limb, abduction above 90°, or neck rotation may exacerbate compression, especially in the presence of elongated or sharply curved cervical ribs[4,7]. Secondary muscular adaptations such as hypertrophy, shortening, or fibrosis of the scalene muscles, can further amplify the compressive effect imposed by the bony variation[4,7].

In the present case, bilateral cervical ribs with asymmetric morphology represent two distinct patterns of interference with the cervicothoracic outlet. On the left side, the cervical rib was incomplete, with a larger proximal segment originating from C VII and a smaller distal segment fused to the first rib, both segments connected by an intervening band of connective tissue; this segmented configuration may have created multiple potential contact points between brachial plexus trunks and the bony framework[5,6]. On the right side, the cervical rib formed a complete bony arch fused to the first rib, with a markedly curved course that probably reduced the interscalene space more critically, predisposing to dynamic compression of C8–T1 during specific upper-limb movements. Understanding these detailed relationships is essential for surgical planning, choice of approach, and postoperative rehabilitation strategies[4,7], and is schematically illustrated in the anatomical drawing of this case (Figure 1).

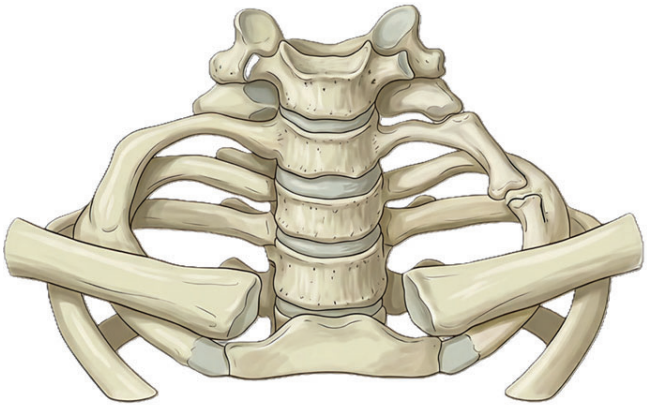


Figure 1. Bilateral cervical ribs with asymmetric morphology.
On the left side, the cervical rib is incomplete, with a larger proximal segment arising from C VII and a smaller distal segment fused to the first rib, both segments connected by an intervening band of connective tissue. On the right side, the cervical rib forms a complete, markedly curved osseous arch fused to the first rib, potentially narrowing the interscalene space. The sternal ends of the clavicles are shown disarticulated. This is an anatomical drawing created by the authors.

Embryological development and pathophysiology of cervical ribs

The axial skeleton develops from the differentiation of paraxial somites into sclerotomes, which give rise to vertebrae and thoracic ribs. In each vertebral segment, a costal primordium arises from the embryonic costal process; in cervical, lumbar, and sacral regions, these primordia normally regress through programmed apoptosis, whereas in the thoracic region they persist and develop as typical ribs[10] This process is tightly controlled by axial patterning genes, especially members of the HOX family, which determine the regional identity of vertebral and costal elements[1,10].

Cervical ribs result from partial or complete persistence of the costal primordium of C VII. Altered spatial or temporal expression of HOX genes may lead to partial "thoracization" of cervical segments, allowing the cervical costal element to escape the normal regression program[1,10]. The broad phenotypic spectrum, from small osseous tubercles to complete ribs fused to the first rib, reflects different degrees

of development and ossification of this persistent primordium[5,6,11]. Unilateral or bilateral occurrence and asymmetry between sides suggest that these alterations may arise in a multifocal and non-synchronous fashion during embryogenesis[6].

From a pathophysiological standpoint, the mere presence of a cervical rib does not necessarily imply clinical symptoms. Population-based studies show that most individuals with cervical ribs remain asymptomatic[1,5]. However, when the rib morphology is unfavorable - long, thick, sharply curved, or incomplete - or when additional factors such as fibrous bands, scalene hypertrophy, or first-rib variations coexist, the risk of neurovascular compression increases substantially[4,5,7]. The cervical rib thus becomes a structural component of thoracic outlet syndrome rather than an innocuous variant[4,7].

Chronic compression of the brachial plexus leads to neuropathy through combined mechanical and ischemic mechanisms. Narrowing of the interscalene space and repetitive contact between roots or trunks and bony or fibrous surfaces promote microtrauma, intraneural edema, and, in more advanced stages, segmental demyelination and axonal degeneration[4,7]. Clinically, patients may present with paresthesia, neuropathic pain, muscle weakness, and eventual atrophy. When surgical manipulation is extensive or when exuberant postoperative scar fibrosis develops, neural hyperexcitability and chronic peripheral neuropathy may become even more pronounced, as observed in the right upper limb of our patient[7].

Arterial involvement may occur through subclavian artery compression, resulting in hemodynamic turbulence, endothelial injury, and, in severe cases, thrombosis and distal embolization with limb ischemia[3,4]. Although the present case manifested predominantly with neurogenic symptoms, the morphology of the cervical ribs and their relationship to subclavian vessels must be carefully evaluated preoperatively, particularly in patients with mixed or vascular symptoms[3,4].

In our patient, bilateral ribs with asymmetric morphology and divergent clinical evolution illustrate how subtle differences in embryological patterning can generate distinct anatomical risk scenarios within the same individual[5,6,11]. The incomplete, two-segment left rib and the markedly curved right rib, combined with different surgical and rehabilitation contexts, contributed to contrasting neurological outcomes.

Case Report

A female patient noticed, at the age of 12, a firm prominence in the lower cervical region during personal hygiene. During clinical investigation, bilateral cervical ribs were found, with the left cervical rib presenting an incomplete, two-segment pattern, whereas on the right side, the cervical rib formed a complete, markedly curved arch fused to the first rib, suggesting potential narrowing of the interscalene space (Figure 1).

Because of the proximity to neurovascular structures, a conservative approach was initially adopted, with clinical follow-up through adolescence. However, due to persistent local discomfort, the patient was submitted to partial resection of the left cervical rib at the age of 20 at a tertiary orthopedic center. Surgery lasted approximately nine hours. In the immediate postoperative period, she presented transient loss of movement in the left upper limb, consistent with neuropraxia of the brachial plexus. Functional recovery occurred within about three weeks, aided by early-onset physiotherapy, and the patient remained asymptomatic for nearly 15 years.

In 2007, at age of 32, she developed progressive numbness in the right upper limb, predominantly in the C8–T1 dermatome, associated with intense neuropathic pain and symptoms exacerbation upon arm elevation. Electroneuromyography suggested dynamic brachial plexus compression, and she underwent exploratory and decompressive surgery on the right side, in December 2007.

Unlike the first procedure, the postoperative course of this second approach was unfavorable, with early onset of severe neuropathic pain refractory to initial pharmacological management. In January 2008, at 33 years, she was diagnosed with neurogenic thoracic outlet syndrome, probably related to neural hyperexcitability induced by extensive surgical manipulation. Over time, deep scar fibrosis and complete peripheral neuropathy of the right upper limb have developed, with sensory loss in the first three digits. Since 2013, at 38 years, she has been using pregabalin with partial control of painful crises, now mainly triggered by isometric contractions or sustained postures. At present (50 years), she remains under outpatient follow-up with stable but persistent neurological deficits.

Discussion

Cervical ribs, often regarded as mere anatomical variants, can produce relevant biomechanical alterations of the neck and the cervicothoracic outlet. Even small bony projections may modify muscular and neurovascular trajectories, creating functional compression points[5]. Population studies show that most individuals with cervical ribs are asymptomatic, but the occurrence of symptoms is strongly associated with additional factors such as bilateral presence, unfavorable morphology, and coexisting fibrous bands or muscular changes[1,5,6].

From an embryological perspective, HOX gene involvement in cervical rib formation helps explain the wide phenotypic variability observed[1,10]. Subtle alterations in HOX expression can lead to partial or

complete persistence of the C VII costal primordium, resulting in structures that range from rudimentary tubercles to complete ribs fused with the first rib. In this case, morphological asymmetry (incomplete, two-patter rib on the left and markedly curved rib on the right) suggests distinct axial developmental patterns during embryogenesis, translating into different risk architectures within the cervicothoracic outlet.

Bilateral cervical ribs have been described as an additional risk factor for symptom development, especially when associated with potentially compressive morphologies[1,3,5]. Henry *et al.*[1], in a meta-analysis of 141 studies, demonstrated a significant association between cervical ribs and thoracic outlet syndrome, particularly in symptomatic patients. In the present report, the patient had a long asymptomatic period after the left side decompressive surgery, followed by progressive neuropathic pain on the right side, illustrating how the interaction between bony morphology, brachial plexus dynamics, and surgical factors may lead to divergent outcomes in the same individual.

The patient's symptom pattern is compatible with predominant involvement of C8–T1 roots and the inferior trunk of the brachial plexus, which are recognized as vulnerable structures in cervicothoracic compression[4,8]. The literature describes that sustained abduction of the upper limb, elevation above 90°, and cervical rotation can exacerbate compression in these segments, particularly when cervical ribs are elongated or sharply curved[4,7,11]. In the present case, the markedly curved right rib likely contributed to more critical narrowing of the interscalene space, favoring dynamic compression and the onset of intense neuropathic pain.

Surgical management and rehabilitation aspects also deserve emphasis. Several case series suggest that resection of cervical ribs and the first rib can yield substantial symptom relief in patients with cervicothoracic outlet syndrome, especially when combined with careful preoperative planning and a multidisciplinary approach[4,7,11]. However, neurological complications, such as neurapraxia, chronic pain, and persistent motor or sensory deficits, are not uncommon, particularly when there is extensive manipulation of the brachial plexus[7]. In this case, the favorable outcome after the first surgery contrasts with the unfavorable evolution after the second, suggesting that differences in surgical technique, degree of neural manipulation, and extent of bony and soft-tissue resection may have contributed to neural hyperexcitability and chronic peripheral neuropathy.

This report also reinforces the central role of physiotherapy in postoperative management. The literature highlights the importance of early rehabilitation in preventing scar fibrosis, promoting muscular reorganization, and modulating pain, with a direct impact on upper-limb function[4,7]. While the patient experienced satisfactory functional recovery of the left upper limb with early-onset physiotherapy, the lack of a structured protocol after the second surgery may have favored the development of deep fibrosis and stiffness, contributing to chronic neuropathy of the right upper limb. This contrast underscores how inadequate rehabilitation can transform a potentially correctable anatomical condition into a persistent neuropathic pain syndrome.

From a morphological standpoint, this case illustrates the progression from a seemingly simple anatomical variation to a complex clinical scenario. The combination of bilateral presence, asymmetric morphology, outlet narrowing, and differences in surgical and rehabilitative management resulted in distinct outcomes on each side. Integrated analysis of anatomy, embryology, and clinical evolution contributes not only to understanding the individual pathophysiology of this case but also to refining diagnostic and therapeutic strategies in patients with cervical ribs and cervicothoracic outlet syndrome.

Conclusion

This anatomical case report demonstrates that cervical ribs, although simple in structural terms, can have significant clinical repercussions when associated with bilateral presentation, asymmetric morphology, and suboptimal management. The long-term follow-up of this patient shows how different morphological patterns on each side may lead to markedly distinct neurological outcomes. The case highlights the importance of detailed anatomical knowledge, careful surgical indication and technique, structured physiotherapeutic rehabilitation, and long-term follow-up. In the Brazilian context, it also underscores the need for clearer clinical guidelines and multidisciplinary approaches to the management of cervical ribs and related cervicothoracic outlet syndromes.

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Mini Curriculum and Author's Contribution

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