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Morphofunctional study of the cervical ribs and thoracic outlet syndrome: a review.

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ABSTRACT
The cervical rib (CR) is a supernumerary rib that has been described since the beginning of the 20th century. It can originate from the costal element of the C7 vertebra or from a prolongation of its transverse process. Its presence may be associated with neurovascular manifestations, especially thoracic outlet syndrome (TOS). This study aimed to summarize the scientific evidence on the morphological, clinical, and functional aspects of CRs in TOS from 2004 to 2024, based on the PRISMA-ScR guidelines. CRs typically consist of a head, neck and tubercle. They are more prevalence in women during the fertile period. There is no significant difference between the left or right side when this structure only appears on one side. Genetically, it exhibits an autosomal dominant inheritance pattern, resulting from a genetic mutation. In the context of TOS, the dimensions of the CR can impact how the condition manifests itself. For early diagnosis and assessment, X-rays and advanced imaging methods are essential. In cases of neurogenic TOS, CRs often compress the lower primary trunk of the brachial plexus, resulting in nerve lesions that cause pain, sensitivity changes and muscle weakness in the ipsilateral upper limb. In arterial TOS, vascular compression can lead to claudication, muscle weakness, decreased temperature, tissue alterations and retrograde embolism in the subclavian artery.

Keywords: Anatomical variation, Brachial plexus, Cervical rib, Thoracic outlet syndrome, Subclavian Artery.

RESUMEN
La costilla cervical (CC) es una costilla supernumeraria descrita desde principios del siglo XX. Puede originarse en el elemento costal de la vértebra C7 o en una prolongación de su apófisis transversa. Su presencia puede asociarse a manifestaciones neurovasculares, especialmente al síndrome de la salida torácica (SST). Este estudio pretende resumir la evidencia científica sobre los aspectos morfológicos, clínicos y funcionales de los CC en el SST desde 2004 hasta 2024, basándose en las directrices PRISMA-ScR. Los CC suelen constar de cabeza, cuello y tubérculo. Son más prevalentes en mujeres durante el periodo fértil. No hay diferencias significativas entre el lado izquierdo o derecho cuando esta estructura sólo aparece en un lado. Genéticamente, presenta un patrón de herencia autosómico dominante, resultado de una mutación genética. En el contexto del SST, las dimensiones del CC pueden influir en la forma en que se manifiesta la afección. Para un diagnóstico y una evaluación precoces, son esenciales las radiografías y los métodos avanzados de diagnóstico por imagen. En los casos de SST neurogénico, los CC suelen comprimir el tronco primario inferior del plexo braquial, lo que provoca lesiones nerviosas que causan dolor, cambios de sensibilidad y debilidad muscular en la extremidad superior ipsilateral. En el SST arterial, la compresión vascular

puede provocar claudicación, debilidad muscular, disminución de la temperatura, alteraciones tisulares y embolia retrógrada en la arteria subclavia.

Palabras clave: Arteria subclavia, Costilla cervical**,** Plexo braquial**,** Síndrome de salida torácica**,** Variación anatómica.

INTRODUCTION

In the field of anatomy, the term “normal” is characterized by structures most frequently observed in a sample of individuals **(Di Dio, 2002)**. Anatomical variation refers to the study of morphological differences that arise in the structures of the human body, which do not normally affect functionality and, as a result, do not present themselves as pathological nosological entities **(Kachlík *et al.*, 2020)**. It is worth noting that the definition of anatomical variation is totally distinct from the context of congenital anomaly, since anomaly is about structural or functional defects in organs that are present at birth and can affect the viability of life, thus increasing the individual's morbidity and mortality rates **(Pereira *et al.*, 2019)**. However, anatomical variants under any altered condition can go unnoticed both functionally and clinically, or they can aggravate an existing condition or even trigger a new one **(Kachlík *et al.*, 2020)**. Characteristics that escape from the normal anatomical pattern require a great deal of knowledge, thus offering valuable insights for making more accurate diagnoses and facilitating improved therapeutic interventions **(Sañudo *et al.*, 2003)**.

Throughout evolutionary history, the number of ribs and vertebrae in mammals has remained remarkably consistent **(Schut *et al.*, 2020)**. In this context, morphological changes in the cervical spine have occurred during phylogeny, coinciding with changes to an orthograde body posture and bipedal movement **(Karapetian, 2017)**. The cervical ribs (CR), a structure already mentioned in the studies of Galen in the 2nd century A.D. and in the 16th century by Andreas Vesalius, are defined as supernumerary ribs, of a congenital character, in relation to the twelve standard thoracic ribs. They usually arise from the cervical vertebra or may result from an increase in its transverse process **(Adson *et al.*, 1927; Spadliński *et al.*, 2016)**. CRs are frequently observed in reptiles and are rarely seen in humans due to the faster development of the vertebral column compared to the upper limbs. This disparity leads to an oblique angulation of the spinal nerves in the limb bud, which interrupts the formation of CRs **(Abimbola *et al.*, 2014)**. In the general population, the occurrence of this additional anatomical feature ranges from approximately 0.2% to 1.2% **(Nwadinigwe *et al.*, 2018)**.

In the past, CRs were considered an asymptomatic condition with no clinical relevance **(Chang *et al.*, 2013)**. However, its significance became apparent after the detailed description and understanding of the anatomy of the thoracic outlet **(Bokhari *et al.*, 2012)**. Although the term thoracic outlet may be etymologically inaccurate, it designates the funnel-shaped virtual space that guides nerve and vascular structures on their way to the upper limbs **(Kuhn *et al.*, 2015)**. Its broad base is formed by the interscalene emergence of the brachial plexus and the upper thoracic opening, with its apex extending to below the pectoralis minor muscle **(Campo, 2012)**. The presence of CR in this anatomically crowded region of important structures can contribute up to 30% in the development of thoracic outlet syndrome (TOS) **(Bokhari *et al.*, 2012; Masocatto *et al.*, 2019)**.

The natural progression of TOS is slow, and the variety of symptoms contributes to the difficulty in diagnosis **(Alemán-Iñiguez *et al.*, 2021)**. In this sense, factors such as a lack of clinical consensus regarding diagnosis, poor awareness on the part of the medical team of the presence and anatomical-functional characteristics of the cervical ribs, the subjective nature of the pathology, the wide range of symptoms indicative of other diseases, mean that there is an average delay of 4 years in deriving a diagnosis of the disease after the initial presentation, severely affecting the individual's quality of life **(Illig *et al.*, 2021)**.
The aim of this study was to summarize the scientific evidence from the last 20 years on the morphological, anatomical and functional aspects of CR and its impact on TOS.

MATERIALS AND METHODS

This study is a scoping review of anatomo-clinical evidence on CR in the context of TOS, covering publications from 2004 to 2024. It was guided by the following research question: What is the current anatomo-clinical evidence on cervical ribs in the context of TOS? The study selection and screening process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines and was summarized using a flowchat. The screening process was carried out using the Rayyan® platform (http://rayyan.qcri.org), and included all studies identified through the predefined search strategy.
A literature search was performed in September 2024 across the following electronic databases: PubMed, LILACS, Cochrane Library, SciELO, and ScienceDirect. The search strategy included the following descriptors combined with Boolean operators: “Cervical Rib” OR “Cervical Rib Syndrome” AND “Congenital Abnormalities” AND “Thoracic Outlet Syndrome”. The initial screening was based on title and abstract content. Eligible studies were those published between 2004 and 2024, in any language. Inclusion criteria comprised original research, review articles, case reports, and case series that addressed the research question. Exclusion criteria included duplicates, incomplete entries in databases, and any content that did not qualify as a scientific article.

RESULTS

Selection and profile of studies

During the literature search, of the 581 articles retrieved, 42 were duplicates. 216 were excluded after screening the title and abstract and a further 88 were excluded after reviewing the full text because they did not meet the guiding question. Thus, 44 articles were included in this review **(Figure 1)**.
After a thorough analysis of the selected studies, the data were compiled descriptively, including information on the main author, year of publication, country of origin, study methodology, and the findings obtained **(Table 1)**.
The geographical distribution of the studies showed that India contributed the most, accounting for approximately 30,2% of the included articles, followed by the United States with 21,8% and Brazil with 14,9%. Studies from India reported a notably high incidence of CRs, particularly among women, along with evidence of a genetic predisposition. In contrast, most studies from the United States focused on therapeutic methods, especially the effectiveness of surgical resections. Contributions from Brazil were primarily in the form of anatomical studies, case reports, and systematic reviews.

Among the 44 selected studies, case reports and cross-sectional studies were the most prevalent, comprising approximately 59% of the overall sample. Case reports were the most frequent, representing 36,3% of the analyzed articles. These studies highlighted documented morphological variations of CR and novel therapeutic approaches associated with TOS. Cross-sectional studies made up about 22,7% and played a crucial role in evaluating the prevalence of CR through radiographs and CT scans.

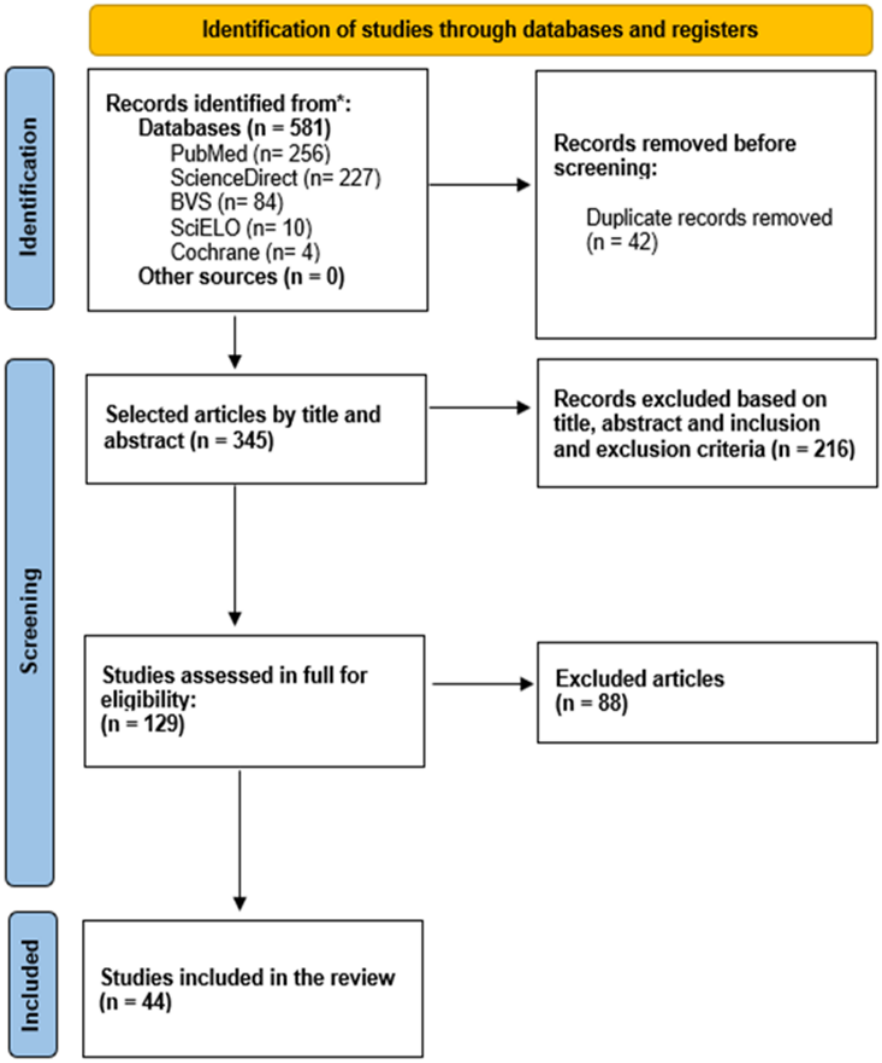

Figure 1. PRISMA flowchart representing the inclusion and exclusion of the studies selected for this review.

Review articles accounted for 18,1%, playing an important role in the embryological and morphological contextualization of CR, as well as in presenting clinical discussions regarding the neurovascular impact of this anatomical variation. Retrospective observational studies represented 13,6%, contributing to the understanding of clinical and radiological data of patients over time, without direct intervention.

Table 1. Data extraction table of the studies eligible for the review.

Author / Year	Study design	Country	Methodology	Results obtained
Abimbola et al., 2014	Cross-sectional study	Nigeria	Analysis of 500 cervical radiographs in adult patients from Nigerian hospitals with identification of CR by specific anatomical criteria.	Prevalence of 0,6%, with a higher incidence in women (0,78%). CR can cause neurovascular compression in the thoracic outlet, resulting in pain, tingling and weakness in the upper limb.
Agarwal et al., 2018	Retrospective observational study	India	Evaluation of 8.000 chest X-rays to identify CR. Data analyzed included gender, age and laterality of the anatomical variation.	Prevalence of 0,79%, predominantly in women. Bilaterality was observed in 69,84% of cases. Evidence shows a relationship with neurovascular compression, especially in women during childbearing.
Aignătoaei et al., 2018	Case study	Romania	Review of 11.853 imaging exams in adults. Classification based on developmental defects.	Three cases of bilateral CR were identified. Reports suggest that 10% of patients with this condition may develop TOS, highlighting the importance of early detection.
Al Subshi et al., 2022	Cross-sectional study	Oman	Analysis of 1.165 CT scans of the cervical spine performed between January 2016 and December 2020 at a tertiary hospital in Oman.	The prevalence of cervical ribs was 0,94%, with females predominating. The majority of cervical ribs were unilateral (54%). Elongated transverse processes of C7 were observed in 18,45% of patients, with a higher prevalence in men. The prevalence of elongated transverse processes was comparable to that of the Saudi population.
Alemán-Iniguez; Hermida-Córdova, 2021	Case study	Ecuador	He describes the history of a young patient with bilateral CR, who underwent a detailed clinical evaluation, CT studies and electrophysiological tests to determine BP compression, and surgery to excise the right CR with neurolysis and neural transposition.	Symptoms improved post-surgery, with progressive recovery of strength in the right hand. Post-operative electrophysiological tests showed persistent reduced recruitment in the distal muscles, indicating a slow recovery process. The left CR did not cause compression and remained asymptomatic. The study highlights that CR can be an asymptomatic anatomical variation or lead to neurovascular compression, requiring individualized assessment for therapeutic decisions.
Bhat et al., 2015	Cross-sectional study	India	Analysis of 2.000 chest X-rays with clear diagnostic criteria for CR and elongated transverse processes.	Prevalence of 2,67%, with a higher incidence in women (3,1%). In 66% of cases, the ribs were unilateral. The findings reinforce the association with vascular and neurological alterations in TOS.
Bokhari et al., 2012	Cross-sectional study	Saudi Arabia	Review of 1,000 chest X-rays with standardized criteria for identifying CRs.	Prevalence of 3,4%, predominantly in women and bilateral in 41% of cases. The presence of CR is associated with compression of the BP and SA, contributing to TOS.
Bots et al., 2011	Descriptive observational study	Netherlands, Finland	He investigated 199 fetuses from elective abortions, using alizarin staining to analyze bone anomalies.	A 40% prevalence of CR, associated with a higher risk of fetal mortality. Studies suggest a relationship with alterations in the development and expression of Hox genes, which are essential for the morphology of the axial skeleton.
Braga, et al., 2013	Case study	Portugal	He described the case of a young man with bilateral CR, aTOS and surgical success after resection.	Bilateral CR caused compression of the right SA, generating stenosis and post-stenotic dilatation. Surgery was effective in restoring functionality.
Brewin et al., 2009	Cross-sectional study	United Kingdom	It examined 1,352 chest X-rays of adults to determine the prevalence of CR.	Overall prevalence of 0,74% in the London population; higher frequency in women. Less than 10% had symptoms, such as nTOS and vascular compression.
Campo, 2012	Case study	Mexico	Review of nTOS, analyzing 53 surgical cases after failure of conservative treatments.	Partial or complete CR or apophyseal transversomegaly of C7, often associated with compressive symptoms of nerve and vascular structures. Predominantly in women.

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Table 1. Data extraction table of the studies eligible for the review.

Chang et al., 2013	Retrospective observational study	USA	Analysis of 23 CR resections in 20 patients with TOS. Methods included clinical examinations, duplex ultrasound, and surgery (transaxillary or supraclavicular approach).	CRs cause significant neurovascular compression, often fused to the first rib. Patients with TOS present with neurogenic, arterial or venous symptoms. Combined resection of the CR and first thoracic rib has been effective in relieving symptoms, especially in cases of bone fusion and arterial complications (aneurysms or thrombosis).
Connolly et al., 2021	Narrative review	USA	Discussion on the embryology, anatomical variants and clinical implications of thoracic outlet anomalies, with a focus on CR.	CRs result from a failure in the embryological regression of the C7 costal process, often associated with compression of the BP and SA. Predisposition to TOS increases in cases of pre-fixed or post-fixed BP, which alter the anatomical relationship in the canyon space.
Dharmshaktu et al., 2016	Retrospective observational study	India	Analysis of 1,500 cervical and thoracic radiographs to assess the prevalence of CR and other vertebral anomalies.	Prevalence of 0,8%, predominantly in women. The CRs were bilateral in all cases. Although mostly asymptomatic, the cases show potential for neurovascular improvement, especially in symptomatic presentations of TOS.
Farina et al., 2019	Case study	Italy	Detailed study of a case with bilateral RC and anterior scalene muscle hypertrophy, using Doppler ultrasound, Adson's test and imaging tests for diagnosis.	The patient presented VS alterations in the interscalene triangle, with pain, cyanosis and paresthesia. The association of CR and scalene hypertrophy contributed to the development of TOS. Conservative management with physiotherapy for the symptoms.
Farzam et al., 2023	Case study	Afghanistan	Case report of a 32-year-old man with severe pain in his right arm, who underwent CT angiography which revealed bilateral CR (more prominent on the right), with pseudoaneurysm and arterial thromboembolism.	This study highlighted the direct relationship between CR and aTOS, emphasizing that pseudoaneurysms and thromboses often result from vascular compression. The images showed bone fusion between the CR and the first thoracic rib, implying serious complications for the vascular system.
Fliegel et al., 2023	Narrative review	USA	Narrative review on anatomy, anatomical variants, clinical complications and diagnostic methods related to CRs.	The prevalence of CRs ranges from 0.5 to 1%, most of which are asymptomatic. When symptomatic, they often cause compression of the BP or SA. Vascular compression can lead to severe distal ischemia. In addition, diagnostic methods such as CT and MRI are recommended for accurate assessment of anatomy and structural compression.
Gelabert et al., 2018	Retrospective cohort study	USA	Analysis of 70 transaxillary surgical procedures for resection of the CR and first ribs in patients with nTOS and aTOS.	CR resection, when indicated, showed a significant improvement in symptoms in 92,8% of patients. Its presence was associated with compression of neurovascular structures, especially in cases of aTOS , where aneurysms and subclavian thrombosis were prevalent. The study also highlighted that the transaxillary approach is effective and associated with low morbidity and complications.
Gupta et al., 2012	Cross-sectional study	India	Analysis of 12,950 chest X-rays of individuals, covering both sexes, to estimate the prevalence of CR in Lucknow.	Overall prevalence of 0,6%; higher incidence in women (0,73%) compared to men (0,49%). Bilaterally symmetrical CRs were the most frequent.
Henry et al., 2018	Systematic review with meta-analysis	Poland, USA, Norway, Italy	Analysis of 141 studies with data on the prevalence of CR in healthy individuals and patients with TOS.	Prevalence in healthy individuals (1,1%) and patients with TOS (29,5%). Evidence suggests that CR significantly increases the risk of TOS, especially neurogenic and vascular TOS.
Jiang et al., 2019	Case study	China	Description of a 32-year-old patient diagnosed with aTOS associated with thrombosis in the axillary and brachial arteries caused by CR.	Confirmation of the causal relationship between CR and vascular compression, leading to thrombosis. Early diagnosis and surgical management are crucial to avoid serious complications.

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Table 1. Data extraction table of the studies eligible for the review.

Kaderi et al., 2021	Case study	India	Report of a rare variant of CR that fused to the transverse process of C6, causing aTOS, documented with Doppler and angiotomography.	Clinical evidence of significant arterial compression associated with rare anatomical variants, with ischemia and gangrene in the upper limbs; highly relevant in differential diagnoses of TOS.
Karapetian, 2017	Descriptive observational study	Russia	Analysis of five osteological samples to map patterns of morphological variation of cervical vertebrae in different populations.	CR is more frequent in women and is linked to genetic and epigenetic factors; prevalence varies globally from 0,58% to 6,2%; possible link with systemic malformations.
Köksal, 2019	Narrative review with case study	Türkiye	One case of a large complete CR, simulating a thoracic rib. Severe TOS symptoms assessed clinically and with imaging tests.	Impacted CR morphometry was directly associated with severe neurovascular compression. Supraclavicular surgery proved effective in treating the patient.
Lalchan et al., 2016	Cross-sectional study	Nepal	3.600 cervical and thoracic X-rays were analyzed to determine the prevalence of CR and associated symptoms.	The prevalence of CR was 1.1%, more frequent in women. 10.25% of patients had symptoms compatible with TOS, such as arm pain and cervical inflammation. The majority of ribs were bilateral (46.2%), and unilateral presence was more common on the right (38.5%).
Maślanka et al., 2023	Narrative review	Poland	Analysis of multiple studies to determine congenital, acquired and traumatic factors associated with TOS, with an emphasis on CR as a predisposing factor.	CRs are present in 1.1% of the general population, but in 29.5% of patients with TOS. They are mainly associated with aTOS, causing embolism and ischemia. Studies suggest that CRs alone are not enough to trigger TOS, but significantly increase the risk when combined with other anatomical or traumatic factors.
Marciano et al., 2023	Narrative review	Brazil	A review of 17 articles addressing TOS from an anatomo-clinical perspective, highlighting etiology, diagnosis and treatment.	TOS can occur in three main locations: the interscalene triangle, the costoclavicular space and the pectoralis minor space, leading to variation in the neurovascular bundle. CRs are present in up to 85% of surgical cases of TOS, and are a determining factor for vascular or neurological specification. Early diagnosis improves therapeutic results.
Martins et al., 2007	Case study	Brazil	Clinical case of a 9-year-old child with nTOS secondary to a VC fracture. Diagnosis by radiography and electrophysiology, with a surgical approach.	The fracture of the RC led to distension of the BP, resulting in progressive pain, paresthesia and motor deficit. Surgical resection was effective, relieving symptoms and highlighting the relationship between CR and TOS. The study highlights the rarity of childhood TOS and the importance of differential diagnosis.
Navandhar et al., 2024	Case study	India	Incidental discovery of a CR in a 53-year-old patient during investigation of acute cholecystitis.	Although the patient was asymptomatic for TOS, the study highlights that CRs can be detected incidentally, alerting us to the need for additional clinical assessments to avoid future symptoms of neurovascular compression.
Nwadinigwe et al., 2018	Case study	Nigeria	Study of a patient with bilateral TOS caused by CR. It included imaging tests, a surgical approach and post-operative follow-up.	In bilateral cases, RC can cause irradiated pain, paresthesia, sensory loss and muscle weakness in the upper limbs. It has been observed that bone fusion and fibrous bands contribute to neurovascular compression. Surgical resection of the ribs resulted in complete relief of symptoms.
Morel et al., 2019	Retrospective cohort study	France	It reviewed 33 patients who underwent CR resection between 2004 and 2016, analyzing the impact on professional life and functional recovery. It evaluated pre- and post-operative symptoms, as well as clinical tests.	The surgery resulted in significant functional improvement, allowing 64% of patients to return to work. The study identified a strong association between CR and AS compression, with 9 cases of aneurysms and 2 of arterial thrombosis. It indicates that the presence of CR is strongly related to aTOS and nTOS, and that surgical resection offers important benefits.
Oliveira et al., 2024	Case study	Brasil	Detailed analysis of a rare case of CR fused to the first thoracic rib in an osteological specimen.	Fusion of the CR with the first thoracic rib can increase the risk of neurovascular compression, aggravating TOS symptoms. Synostosis can lead to more severe compression of the SA and BP, suggesting a greater risk of vascular and neurological compromise.

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Table 1. Data extraction table of the studies eligible for the review.

Patrone et al., 2019	Integrative review	Brazil	Review of 26 national and international articles on the etiology, pathophysiology, diagnosis and treatment of TOS. It included theoretical, quantitative and qualitative studies.	The review highlights that CR is one of the main anatomical causes of TOS, especially in the neurogenic form. Patients with CR are at greater risk of BP compression, resulting in chronic pain, paresthesia and muscle weakness. The diagnosis must be confirmed by imaging tests such as X-rays, CT and MRI.
Sabapathy et al., 2010	Case study	India	Clinical case of a 14-year-old girl with TOS secondary to pseudoarthrosis of the CR. Diagnosis by magnetic resonance imaging and computerized tomography.	The patient developed severe BP wear due to a pseudoarthrosis of the CR, resulting in intense pain, paresthesia and severe functional limitations. Surgical resection completely relieved the symptoms, highlighting the direct relationship between cervical anomalies and TOS.
Sharma et al, 2014	Cross-sectional study	India	Analysis of 5000 chest X-rays of Central Indian patients to determine the prevalence of TOS and its association with gender, laterality, manual dominance and other bone anomalies.	Prevalence of 1,22%, with a unilateral predominance (0,78%) and a slight male predominance. Non-significant associations with thoracic scoliosis and elongated transverse processes of C7. Less than 10% of sufferers develop TOS, suggesting that the presence of CR alone is not enough to cause the clinical condition.
Schut et al., 2020	Retrospective cohort study	Netherlands	Analysis of 374 deceased fetuses and neonates, evaluating vertebral anomalies and genetic variants associated with CR.	CR were present in 50.3% of cases, and were more common in stillbirths (53.9%). The study suggests that cervical ribs may be a marker of abnormal development, often associated with vascular and neurological abnormalities that may predispose to TOS.
Silva Filho et al., 2021	Case study	Brazil	Two cases surgically treated for aTOS associated with CR, using angiotomography and supraclavicular approach for resection.	SA participation is involved in microembolization and aneurysms. Resection of the CRs restored arterial flow and relieved symptoms. The evidence highlights the importance of the surgical approach to prevent serious complications of TOS.
Spadliński et al., 2016	Narrative review	Poland	Literature review and population analysis on the morphology, embryology and clinical manifestations of CR.	The CR can compress the BP and SA, resulting in neurological symptoms (paresthesia, muscle weakness) and vascular symptoms (ischemia, thrombosis). Prevalence varies between 0,58% and 6,2% in the populations analyzed.
Venkatesan et al, 2014	Retrospective observational study	India	Analysis of 1500 chest and cervical spine X-rays of patients seen in Chennai hospitals to determine the incidence of CR.	The incidence was 1,16%, predominantly in men. 90% of cases were unilateral. The study suggests that vascular compression was more prevalent than neurogenic compression, contradicting previous studies which pointed to nerve compression as predominant in TOS. The presence of a CR reduced the costoclavicular space, favoring neurovascular compression.
Viertel et al., 2012	Retrospective observational study	USA	Review of 3404 CT scans of the cervical spine to determine the incidence of CR and the rate of reporting by radiologists.	The incidence was 2%, with a predominance of 2.8% in women and 1.4% in men. 40.3% of cases were bilateral. The study highlighted that the presence of CR increases the risk of developing TOS 10-fold, and compression of the BP or SA was observed in up to 10% of those affected. There was underreporting in 74.6% of cases, suggesting that the condition is often overlooked in clinical practice.
Walden et al., 2013	Retrospective observational study	USA	Review of 2083 MRI scans of the cervical spine to identify CR and assess their clinical relevance. Comparison with CT scan when available.	The prevalence found was 1.2%, lower than in CT studies. 22.9% of RCs came into contact with the BP, but few cases showed clear symptoms of plexopathy. MRI was less sensitive than CT in identifying bone structure. Only one confirmed case of TOS was reported, in which compression of the AS was evidenced by MRI angiography.
Yadav et al., 2021	Case Study	Nepal	Report of five cases of female patients with symptoms such as neck pain, tingling and weakness, treated surgically with resection of the CR.	TOS can manifest in adolescence due to disproportionate growth between the neck and shoulders, leading to neurovascular compression. The surgery resulted in a significant recovery of symptoms in an average period of 9 weeks.

aTOS= Arterial thoracic outlet syndrome; **BP**= Brachial Plexus; **CR**= Cervical rib; **CT**= Computed Tomography; **nTOS**= Neurological Thoracic Outlet Syndrome; **MRI**= Magnetic Resonance Imaging; **SA**= Subclavian Artery; **SV**= Subclavium Artery; **TOS**= Thoracic outlet syndrome; **USA**= United States.

Morphological and Embryological Aspects of CRs

Based on the articles presented in **Table 1**, CRs are defined as congenital supernumerary ribs that exceed the typical count of twelve thoracic ribs. These ribs usually develop from the seventh cervical vertebra or can arise from an overgrowth of their transverse process, a condition called transverse apophysomegaly. Some studies have reported CRs arising from the fourth to sixth cervical vertebrae. They commonly consist of a head, neck, and tubercle, although in certain cases, the presence of a diaphysis has also been observed. The prevalence of CR in the general population varies and is influenced by factors such as ethnicity and geographic region. Most studies suggest a female predominance, with a female-to-male ratio of approximately 2:1, most often seen in individuals aged 20 to 50 years. In terms of laterality, CRs may be unilateral or bilateral, frequently presenting asymmetrically. While no significant difference is observed between left and right-sided cases when unilateral, the right side is slightly more common than the left, both in the general population (51,6% vs. 48,4%) and among patients with TOS (51,1% vs. 48,9%, respectively).

For many years, the scientific community viewed this anatomical variation as indicative of a pathological genotype, a notion that remains controversial today. CRs are thought to arise due to mutations in the HOX-4 and HOX-5 genes, along with inactivation of growth differentiation factor 11 (GDF11) during the fourth week of embryonic development. This condition exhibits an autosomal dominant inheritance pattern with variable phenotypic expression and possible incomplete penetrance, meaning approximately 50% of offspring may inherit the trait.

The paraxial mesoderm, which surrounds the neural tube and the notochord, as well as the somatopleuric mesoderm laterally, is responsible for the formation of the vertebral column and its associated musculature. During the process of craniocaudal segmentation of this paraxial mesoderm, a set of cells is generated, organized into 42 to 44 pairs, called somites, occurring between the 19th and 32nd day of neural tube development.

Subsequently, the somites undergo further subdivision into a ventral component known as the sclerotome and a dorsal component called the dermatome. The sclerotome originates from the ventromedial edge of the epithelial somite and is subsequently divided into cranial and caudal sections. The cells within the sclerotome differentiate into mesenchymal cells, which eventually develop into the entire axial skeleton, particularly the ribs. The proper localization of these mesenchymal cells is directed by the HOX and GDF11 genes. Mutations occurring in these genes can lead to the development of CRs from the costal elements associated with the vertebral arches in formation.

In the early stages of development, the costal component of misplaced mesenchymal cells often undergoes atrophy. However, if atrophy does not occur, it can ossify, resulting in an elongated transverse process or a fully formed rib. In certain cases, this structure may be of insufficient size to connect to the sternum, leading to anterior fusion with T1 below the first rib.

It was previously proposed that, during embryonic development, the costal element of the CRs was initially separated, but later regressed and fused with the transverse process, thus creating the anterolateral boundary of the transverse foramen. It is believed that this structure does not persist into adulthood, as any adverse health effects were considered minimal. However, a growing body of recent research indicates that the CRs do not disappear during the development process. The main limiting factor in the

formation of a CR is the neurovascular structures. Some studies classify CRs as either complete—fully articulated with the sternum or the first thoracic rib—or incomplete, which are attached via a fibrous band or a pseudoarthrosis, typically located posterior to the scalene tubercle, where the anterior scalene muscle inserts. Regardless of classification, cervical ribs have no known physiological function.

Clinical implications of CR in the context of TOS

In the context of TOS, rib dimensions can impact how the condition manifests itself. Generally, vascular problems are linked to longer ribs, while shorter ribs are more likely to lead to neurological symptoms. These symptoms arise from the compression of neurovascular structures by the CR, usually by putting pressure on the scalene muscles. For early diagnosis and thorough assessment of this bony structure, X-rays and advanced imaging methods such as Computerized Tomography and Magnetic Resonance Imaging are crucial.

In cases of neurogenic TOS, the cervical ribs often compress the lower primary trunk of the brachial plexus, resulting in a neuropraxia-type injury that presents with symptoms including occipital headaches and neck pain radiating from the medial aspect of the arm to the ulnar border of the hand. This condition can also lead to burning and tingling sensations and includes muscle atrophy in the distal region, causing a clawed hand appearance in the middle, ring and little fingers of the arm on the same side as the plexus lesion.

In vascular TOS, compression of the subclavian artery leads to arterial predominance, manifesting as intermittent and migratory claudication in the arm, absent radial pulse, prolonged capillary refill time, pallor, audible murmurs, reduced temperature in the distal upper extremity, weakness, fatigue in the affected limb and a pulsatile mass in the supraclavicular area. In more severe cases, gangrenous changes can occur in the fingertips and ischemia of the upper limb, which can occur with or without neurological impairment and stroke due to embolism through the retrograde flow of the artery. To check whether the subclavian artery is compressed by the CR, the Adson provocative test can be a good indicator of whether the vessel has been damaged by the bone structure in question. The test consists of hyperabduction of the patient's shoulder and extension of the elbow and palpation of the patient's radial pulse while they inhale deeply and turn their head to the side being tested and is considered positive when this ipsilateral pulse is reduced or absent.

DISCUSSION

This study aimed to synthesize the morphological and clinical aspects of CR and their association with TOS, based on current scientific evidence from the 21st century. CRs are present in less than 1% of the global population and are responsible for up to 10% of TOS cases due to the compression of neurovascular structures in the cervical region **(Navandhar *et al.*, 2024; Morel *et al.*, 2019)**. The clinical manifestations of TOS vary depending on the affected structure, with neurological involvement being the most frequent, characterized by pain, muscle weakness, and paresthesia. Vascular involvement, particularly arterial, may include stenosis, thrombosis, microembolization, and aneurysm **(Farzam *et al.*, 2013; Lalchan *et al.*, 2016; Gelabert *et al.*, 2018)**. Surgical resection of the bone anomaly is indicated only when conservative treatment—comprising physical therapy, pharmacological therapy, and local infiltrations—fails to alleviate symptoms **(Martins *et al.*, 2007; Köksal, 2019)**. A major finding of this review was the

predominance of CRs in females, particularly during the reproductive period, although incidental diagnoses at birth during unrelated examinations have also been reported **(Farina *et al.*, 2021)**. This may be partly attributed to postural changes linked to breast hypertrophy, loss of muscle tone, and decreased upper body strength with aging, which contribute to depression of the shoulders and mechanical traction on the neurovascular structures within the interscalene triangle **(Sharma *et al.*, 2014)**. In males, symptoms tend to appear early in adulthood, particularly in those engaged in manual labor or sports involving repetitive overhead movements **(Alemán-Iñiguez *et al.*, 2021)**.

Experimental studies suggest that CRs and hypertrophic transverse processes of cervical vertebrae follow an autosomal dominant inheritance pattern with variable phenotypic expression. This occurrence may be even higher in populations with consanguineous unions. Given that a significant portion of the studies were conducted in regions such as India, Africa, and the Middle East - where intrafamilial marriages remain culturally prevalent - this genetic predisposition is relevant. Such unions account for up to 50% of marriages in some populations, depending on ethnicity, religion, and local traditions **(Tadmouri *et al.*, 2009; Acharya *et al.*, 2021)**. Mutations in HOX genes and deactivation of GDF11 disrupt the regulatory mechanisms of axial skeleton patterning along the craniocaudal axis, leading to the misplacement of rib-forming cells in the cervical region **(Bots *et al.*, 2011; Mallo *et al.*, 2009)**.

CRs may resemble thoracic ribs or represent an overgrowth of the cervical transverse process. Their development is influenced by the surrounding musculature and neurovascular structures of the lower neck **(Partiot *et al.*, 2020)**. When they extend anterolaterally, they can fuse with the sternum or the first thoracic rib, constituting a complete CR, or end in the soft tissues of the neck without this fusion, incomplete CR **(Erken *et al.*, 2002; Spadliński *et al.*, 2016)**.

Given their lack of physiological function, CRs can be considered pathological variants, especially when contributing to neurovascular compression syndromes such as TOS. Incomplete CRs typically affect the C8–T1 roots of the brachial plexus, while complete CRs may compress the subclavian artery. Diagnosis involves a detailed clinical history, physical examination, and confirmatory imaging studies such as X-ray, MRI, ultrasound, and complementary electrophysiological and neurographic assessments **(Alemán-Iñiguez *et al.*, 2021)**. Differential diagnoses include atherosclerosis, vasculitis, vasospastic disorders, Raynaud's syndrome, acute coronary syndrome, shoulder impingement syndrome, rotator cuff syndrome, adhesive capsulitis, cervical radiculopathy, ulnar neuropathy, carpal tunnel syndrome, brachial plexitis, multiple sclerosis, Pancoast tumor, trigger points, fibromyalgia, and complex regional pain syndrome **(Daniels *et al.*, 2014)**.

Neurogenic TOS is marked by both motor and sensory deficits, ranging from radiating pain and paresthesia to severe hand muscle atrophy, resulting in weakness and impaired motor coordination, particularly during overhead arm elevation **(Campo, 2012)**. Arterial complications follow a progressive course of vascular insufficiency, with symptoms such as intermittent arm claudication, pallor, reduced temperature, and in rare cases, digital gangrene and embolization **(Spadliński *et al.*, 2016; Morel *et al.*, 2018; Yadav *et al.*, 2012)**.

Regarding treatment, most studies advocate for conservative management through physical therapy to strengthen the shoulder girdle, improve posture, and reduce fibromuscular tension on neurovascular structures. Pharmacological support and decompressive surgery may be added if necessary. A meta-

analysis involving 141 studies assessed the prevalence of surgical approaches for TOS associated with CR, with supraclavicular and transaxillary techniques, accounting for 60% and 40% of cases, respectively. Surgical approach selection depends on the anatomical involvement and surgeon expertise **(Henry *et al.*, 2018; Masocatto *et al.*, 2019)**.

CR represents an anatomical abnormality that can arise from congenital, functional or traumatic origins. This secular condition can simulate various local and systemic diseases, mainly due to neurovascular involvement in the neck root. In-depth anatomical knowledge of the topographical relationships of CR at the base of the neck is fundamental for screening, diagnosis and the clinical management of each patient, mitigating late diagnosis and possible complications of TOS, in order to generate new diagnostic and treatment perspectives.

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