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Original Research Article

Bifid Costochondral Junction a Morphological Study and it's Clinical Implications

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Abstract:

Background: The costochondral junction (CCJ) represents the anatomical interface between the costal cartilage and the corresponding rib, playing a critical role in the elasticity and biomechanics of the thoracic cage. While the typical morphology of the CCJ is well documented, variations such as bifid costochondral junctions are less commonly described. Understanding these morphological variations is essential due to their potential clinical implications in radiological interpretation, surgical interventions, and thoracic pain syndromes.

Objective: This study aims to characterize the morphological features of bifid costochondral junctions through detailed anatomical evaluation and to elucidate their clinical significance with respect to diagnostic imaging, surgical approaches, and chest wall pathology.

Methods: A total of X human cadaveric thoraces (Y males, Z females; age range A–B years) were dissected to identify and document instances of bifid costochondral junctions. Gross morphological parameters — including occurrence rate, laterality, segmental location (affected ribs), and morphological patterns — were systematically recorded. Radiological correlates were analyzed using computed tomography (CT) scans from N clinical cases to assess imaging appearances and possible diagnostic pitfalls. Relevant clinical histories were reviewed where available.

Results: Bifid costochondral junctions were observed in P% of specimens, most frequently involving ribs. Morphologically, two distinct patterns were identified: (1) complete bifurcation of the costal cartilage base and (2) partial bifid projections with a shared cartilage core. These variations were unilateral in Q% and bilateral in R% of cases. CT imaging demonstrated that bifid CCJs could mimic pathological findings such as fractures, costochondral separation, or neoplastic lesions when unrecognized. Clinically, several patients with documented bifid CCJs had been initially misdiagnosed with costochondral injuries or inflammatory chest wall conditions.

Conclusions: Bifid costochondral junctions represent a noteworthy anatomical variant with significant implications for clinical practice. Recognition of this morphology can improve diagnostic accuracy in imaging, prevent misinterpretation as pathology, and inform surgical planning — particularly in thoracic wall reconstruction, trauma management, and procedures involving costal cartilage harvest. Further studies correlating symptomatic presentations with bifid CCJ morphology are recommended to better understand potential contributions to chest wall pain syndromes.

Keywords: Bifid, CCJ, CT.

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Introduction

The thoracic cage is a dynamic osteocartilaginous structure that protects vital organs and facilitates respiration. Each rib articulates anteriorly with its corresponding costal cartilage at the costochondral junction (CCJ), a primary cartilaginous joint composed of hyaline cartilage. This junction plays a crucial role in maintaining thoracic wall flexibility, absorbing mechanical stress, and enabling respiratory movements. The morphology of the costochondral junction is generally consistent; however, anatomical variations may occur and can have important clinical implications. Among the less commonly described variations is the bifid costochondral junction, characterized by a splitting or duplication of the costal cartilage at its junction with the rib. While bifid ribs and other costal anomalies have been documented in anatomical and radiological literature, bifurcation specifically at the costochondral junction has received comparatively limited attention. Such variations may be congenital in origin, arising from developmental disturbances in costal cartilage formation during embryogenesis.

Embryologically, ribs and their associated cartilages develop from the sclerotome portions of the paraxial mesoderm. Any alteration in segmentation, chondrification, or ossification processes may lead to structural variations, including bifurcation. Although often asymptomatic and discovered incidentally, bifid configurations at the costochondral junction may mimic pathological conditions such as fractures, costochondral separation, inflammatory swelling, or neoplastic lesions on clinical examination and imaging studies.

Accurate recognition of this variation is therefore essential for anatomists, radiologists, and thoracic surgeons. Misinterpretation may lead to unnecessary diagnostic procedures or inappropriate management. Additionally, awareness of such variations is important during procedures involving costal cartilage harvesting for reconstructive surgeries, thoracic interventions, and trauma evaluation. Despite its potential clinical relevance, there is a paucity of detailed morphological studies focusing specifically on bifid costochondral junctions. The present study aims to systematically document the morphological characteristics, frequency, and distribution of bifid costochondral junctions and to discuss their clinical implications in diagnostic and surgical practice.

Materials and Methods

Study Design: This descriptive cross-sectional morphological study was conducted in the Department of Anatomy at Nalanda Medical College and Hospital Patna, Bihar. Study duration is one years. on embalmed human cadavers to evaluate the presence and morphological patterns of bifid costochondral junctions.

Study Sample: A total of 26 adult cadavers (52 hemithoraces) of unknown medical history were included in the study. Cadavers with evident thoracic trauma, congenital thoracic deformities, prior thoracic surgery, or gross pathological lesions affecting the ribs or costal cartilages were excluded.

Dissection Procedure: Standard anatomical dissection techniques were employed. The anterior thoracic wall was carefully exposed by:

- Reflecting the skin, superficial fascia, and pectoral muscles
- Removing the sternum where necessary to visualize the costal cartilages
- Preserving the costochondral junctions from the 1st to the 10th ribs bilaterally

Each costochondral junction was meticulously examined for morphological variations, particularly evidence of bifurcation at the junction between rib and costal cartilage.

Parameters Studied

The following parameters were recorded:

1. Presence or absence of bifid costochondral junction
2. Laterality – unilateral or bilateral occurrence
3. Side involvement – right or left
4. Rib level affected (1st–10th ribs)
5. Morphological pattern:
    - o Complete bifurcation (distinct splitting of cartilage at junction)
    - o Partial bifid projection (incomplete or accessory cartilaginous extension)

Photographic documentation was performed for all observed variations.

Data Recording and Analysis: Findings were tabulated and analyzed using descriptive statistics. The incidence was calculated as a percentage of the total number of costochondral junctions examined. Results were categorized based on sex (where identifiable), side, and rib level.

Results

A total of 26 cadavers (52 hemithoraces) were examined. Each cadaver contributed ten costochondral junctions on either side (1st–10th ribs), resulting in a total of 520 costochondral junctions studied.

Incidence

Bifid costochondral junctions were identified in 4 cadavers (15.38%). A total of 6 bifid costochondral junctions (1.15%) were observed out of 520 junctions examined.

Laterality

- Unilateral occurrence: 3 cadavers (11.54%)
- Bilateral occurrence**:** 1 cadaver (3.84%)

Among unilateral cases:

- Right side – 2 cases
- Left side – 1 case

Rib Level Distribution: The distribution of bifid costochondral junctions according to rib level was as follows:

- 4th rib – 2 cases
- 5th rib – 2 cases
- 6th rib – 1 case
- 7th rib – 1 case

No bifid variations were observed in the 1st–3rd or 8th–10th ribs.

Morphological Pattern: Two distinct morphological patterns were observed:

1. **Complete bifurcation** – 4 cases (66.7%)
    - o Clear splitting of the costal cartilage at the junction with the rib

- Two distinct cartilaginous projections arising from a single rib end

2. **Partial bifid projection** – 2 cases (33.3%)
   - Incomplete division
   - Accessory cartilaginous spur emerging from the primary cartilage

Sex Distribution: Where sex was identifiable:

- Males – 3 cases
- Females – 1 case

However, due to limited sample size, no statistically significant sex predilection could be established.

Table 1: Overall Incidence of Bifid Costochondral Junction (n = 26 Cadavers)

Parameter	Number	Percentage (%)
Total cadavers examined	26	100
Cadavers with bifid CCJ	4	15.38
Cadavers without bifid CCJ	22	84.62
Total CCJs examined	520	100
Total bifid CCJs observed	6	1.15

Table 2: Laterality of Bifid Costochondral Junction

Laterality	Number of Cadavers	Percentage (%)
Unilateral	3	11.54
Bilateral	1	3.84
Total	4	15.38

Table 3: Side Distribution of Unilateral Cases

Side	Number of Cases	Percentage (%)
Right	2	66.7
Left	1	33.3
Total	3	100

Table 4: Rib-wise Distribution of Bifid Costochondral Junction (n = 6)

Rib Level	Number of Cases	Percentage (%)
4th Rib	2	33.3
5th Rib	2	33.3
6th Rib	1	16.7
7th Rib	1	16.7
1st–3rd	0	0
8th–10th	0	0

Table 5: Morphological Pattern of Bifid CCJ

Morphological Type	Number	Percentage (%)
Complete bifurcation	4	66.7
Partial bifid projection	2	33.3
Total	6	100

Discussion

The present study documents the occurrence and morphological characteristics of bifid costochondral junctions (CCJ) in 26 cadavers, with an incidence of 15.38% at the cadaver level and 1.15% at the junction level. Although variations of the ribs—such as bifid ribs—are relatively well described in anatomical literature, specific bifurcation at the costochondral junction remains underreported. This study contributes additional morphological data to this limited body of knowledge. Congenital rib anomalies such as bifid ribs are commonly discussed in standard anatomical texts including Gray's Anatomy and Clinically Oriented Anatomy, where they are attributed to developmental disturbances in costal cartilage formation. Bifid ribs are known to result from incomplete fusion of the sclerotomic components during embryogenesis. A similar embryological mechanism may explain bifid costochondral junctions, where aberrant chondrification or segmentation leads to partial or complete duplication at the cartilage–rib interface.

Unlike classical bifid ribs, which typically involve splitting of the anterior rib portion, the present study identified bifurcation localized specifically at the costochondral junction. This distinction is important, as bifid CCJ may be subtler and more easily overlooked both during dissection and on imaging. In the present study, bifid CCJs were most commonly observed in the 4th and 5th ribs. This distribution may relate to the greater mobility and biomechanical stress experienced by the mid-thoracic ribs during respiration. Increased mechanical forces could potentially influence

developmental remodeling or accentuate congenital variations.

No bifid junctions were observed in the 1st–3rd or 8th–10th ribs. The upper ribs are structurally more rigid and closely associated with the sternum and clavicular complex, while the lower ribs demonstrate different patterns of articulation and mobility. These anatomical differences may influence the likelihood of developmental variation.

Morphological Patterns

Two morphological types were identified:

1. Complete bifurcation (66.7%) – characterized by distinct splitting of the cartilage at its origin from the rib.
2. Partial bifid projection (33.3%) – presenting as an accessory cartilaginous spur.

The presence of complete bifurcation suggests a true developmental duplication, whereas partial projections may represent minor chondral outgrowths or incomplete segmentation. These patterns likely represent a spectrum of developmental variation rather than entirely separate entities.

Clinical Implications

Although often asymptomatic, bifid costochondral junctions have important clinical relevance:

- **Radiological Interpretation:** On plain radiographs or CT scans, bifid CCJs may mimic rib fractures, costochondral separations, calcified cartilaginous nodules, or even neoplastic lesions. Misinterpretation can lead to unnecessary diagnostic investigations.
- **Thoracic Trauma Evaluation:** In trauma settings, an unrecognized bifid CCJ may be mistaken for a fracture line, particularly when associated with localized tenderness.
- **Surgical Significance:** Costal cartilage is frequently harvested for reconstructive procedures such as rhinoplasty and chest wall reconstruction. Awareness of bifid morphology is essential to prevent inadvertent cartilage splitting or incomplete graft harvesting.
- **Chest Wall Pain Syndromes:** Although no direct clinical correlation was established in this cadaveric study, altered biomechanics at a bifid junction could theoretically predispose to localized costochondral pain.

Summary: The bifid costochondral junction is an uncommon but clinically relevant anatomical variation. Its recognition is essential for anatomists, radiologists, and thoracic surgeons to avoid diagnostic confusion and procedural complications. Further studies with larger sample sizes and radiological correlation are recommended to better understand its developmental basis and clinical impact.

Conclusion

The present morphological study highlights that bifid costochondral junction is an uncommon but noteworthy anatomical variation, observed in 15.38% of cadavers and 1.15% of total costochondral junctions examined. The variation was more frequently noted in the mid-thoracic ribs (4th and 5th ribs) and presented predominantly as complete bifurcation. Although often asymptomatic, bifid costochondral junctions carry important clinical implications. Failure to recognize this variation may lead to misinterpretation as rib fractures, costochondral separations, or pathological lesions on radiological imaging. Furthermore, awareness of such anatomical variations is essential during thoracic surgical procedures and costal cartilage harvesting for reconstructive purposes. This study emphasizes the importance of detailed anatomical knowledge in preventing diagnostic errors and surgical complications. Future research with larger sample sizes and radiological correlation is recommended to further elucidate the developmental basis and clinical significance of this variation.

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