Anatomy of the interchondral joints and the effects on mobility of ribs

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BACKGROUND: Variations in the anatomy of the anterior rib cage and costal margin have been observed. We sought to evaluate the location of interchondral joints and evaluate their effect on mobility of the rib cage.

METHODS: Cadaveric dissections were performed to evaluate the anatomy of the anterior ribs and the composition of the costal margin. Experienced chest wall surgeons and anatomists evaluated this anatomy through a standardized dissection and assessment. The presence of interchondral joints, and morphology and mobility of ribs were quantified. In addition, the movement and interactions of the ribs with upward pressure on the costal margin at the tip of the 10th rib were assessed.

RESULTS: Twenty-eight cadavers were evaluated bilaterally. In all patients, the first rib attached to the manubrium, the second rib attached to the sternal/manubrial junction, and ribs 3 to 6 attached directly to the sternum. Interchondral joints were present between ribs 4/5 in 0%, 5/6 in 35%, 6/7 in 96%, and 7/8 in 96%. The eighth/ninth ribs had free tips in 58% and 92%, respectively, and 10th rib was floating in 46%. Upward pressure on the costal margin resulted in compression of the ribs up to, on average, the 5.7 ± 0.6 rib with no compression above this level. This level corresponded to the rib interspace just above the most superior interchondral joint in 98% of evaluation. The transmission of these upward forces demonstrated an articulation of the ribs at the costal cartilage-sternal junction in the lower ribs.

CONCLUSION: Bridging interchondral joints are common between ribs 5 to 8 and participate in distributing forces from the costal margin across the chest wall. Upward forces at the costal margin are transmitted across the lower rib cage and result in increased mobility of the lower half of the ribs. The eighth/ninth ribs often have mobile tips, and the 10th is often a floating rib. (*J Trauma Acute Care Surg.* 2024;00: 00–00. Copyright © 2024 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Diagnostic Test; Level II.

KEY WORDS: Costal margin; intracondral joint; hypermobile rib; floating rib; anatomy.

Although costal cartilage rupture was first described by Roland as early as 1499, there has recently been an increased focus on the anatomy of the anterior chest wall.[1] Over time, various approaches to managing benign and traumatic chest wall pathologies, such as costal margin disruption and flail chest, have been described.[2,3] Specific focus has been placed on recognizing and classifying costochondral injuries through case studies and imaging.[4–7] A comprehensive grasp of chest wall anatomy and thorax variability is imperative for effectively addressing pathologies involving costochondral junctions and the costal margin.

The literature distinguishes the initial seven ribs as true ribs, linked to the manubrium/sternum by costal cartilage, followed by three false ribs attached to the cartilage above and two floating ribs without sternal attachments.[5,8,9] The conventional definition of the costal margin encompasses ribs 7 to 10, serving as the lower thoracic wall's foundation and offering an insertion point for the diaphragm and abdominal muscles.[8]

Although Sir Charlton Briscoe documented costochondral anatomy in 1925, detailing interchondral joints between ribs 5 and 9, subsequent exploration of variations in costal margin anatomy and anterior chest wall attachments has been limited.[10] With the rising trend of surgical interventions on the anterior chest wall, a thorough understanding of its anatomical composition becomes increasingly crucial. Thus, our study aims to assess interchondral joint location and its impact on rib cage mobility.

PATIENTS AND METHODS

Institutional review board approval was obtained, as the study design solely involved cadaver-based subjects, which met "Not Human" research criteria by the Code of Federal Regulations (45CFR46). A prospective cadaveric study was performed with a procedural design related to our prior institutional study designs.[11] To ensure appropriate reporting methods, results, and discussion, the STROBE guideline was used (Supplemental Digital Content, Supplementary Data 1, http://links.lww.com/TA/E4).

Cadavers are perfused with an aqueous-based embalming solution that allows for optimal fixation while also maintaining pliability of tissue for cadaveric educational dissection. All tissues are equally perfused with embalming solution such that relative mobility of tissues, including rib cage mobility, is maintained during extended dissection

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procedures. An anatomical evaluation was performed on bilateral anterior chest walls of cadaveric subjects by experienced chest wall surgeons. Superficial structures overlying the chest wall were dissected and reflected, including the skin, subcutaneous tissue, pectoralis major/minor, serratus anterior, and the rectus abdominis muscle. Full exposure of the sternum, anterior ribs, sternal attachments, and interchondral joints was obtained. The dissection was carried out to the inferior aspect of the costal margin to expose the costochondral costal margin attachments. The lower extent of the dissection comprised the 10th rib. An analysis of the anterior rib anatomy was then performed. Each rib was inspected to determine attachment type to the manubrium/sternum, individual or combined chondral attachment with adjacent ribs. The costal margin was evaluated, and the presence of costochondral attachments combining via cartilaginous unions forming the margin was recorded. Our definition of interchondral joints was a side-to-side articulation between adjacent costal cartilages with intercostal musculature lateral to the joint with an interchondral space or additional intercostal muscle medial to the articulation. Fibrous junctions were described as ligamentous attachments between adjacent ribs that formed a common rib or a chondral attachment between two adjacent ribs at their costal margin insertion. A rib was categorized as a "floating rib" if it rested independently within soft tissue, devoid of connections to and distinctly separated from the superior adjacent rib, as conventionally described for ribs 11 and 12. A rib was deemed to possess a "free tip" if it extended toward the superior rib closely but terminated within the anterior chest wall tissue without any attachment. An analysis was then performed on the stability and mobility of each rib at its costal margin insertion. To perform this evaluation, pressure was applied to the rib of interest at its costal attachment. Mobility was categorized as none, minimal, or hypermobile. We also assessed each rib for internal and external subluxation with cranial pressure. In addition to assessing mobility of each individual rib at its costal margin insertion, we assessed compression and articulation of each rib when upward pressure was applied along the costal margin at the 10th rib. The anatomic assessments were recorded and standardized based on the definitions outlined previously. These assessments were led by a board-certified trauma and critical-care surgeon with high-volume chest wall reconstruction experience. Consensus among the surgeons as to the grading of anatomy was determined at the time of anatomic assessment.

The age, sex, and body mass index were recorded for each cadaver specimen. Microsoft Excel (Redmond, WA) was used to record data obtained from the video recordings. The data were analyzed using Statistical Package for the Social Sciences version 25 (SPSS, Chicago, IL). Normal distributed data are represented as mean ± SD, whereas nonnormally distributed data are represented as a median with interquartile range.

RESULTS

Bilateral chest wall anatomy of 28 cadavers (n = 56 hemithoraces) was evaluated (14 males, 14 females). The average age was 81.4 ± 9.5 years. All specimens were White. The average body mass index was 22.7 ± 4.1 kg/m^2.

In every instance (56 of 56), the first rib was consistently observed to attach to the manubrium, while the second rib was found to attach to the manubriosternal junction (56 of 56). Similarly, the third through sixth ribs were consistently observed to attach directly to the sternum in every case (56 of 56). Interchondral joints were observed between ribs 4/5 in 0% (0 of 56), 5/6 in 35% (20 of 56), 6/7 in 96% (54 of 56), and 7/8 in 96% (54 of 56). The eighth rib had a free tip in 58% of evaluations (32 of 56), while the ninth rib displayed this feature in 92% of evaluations (51 of 56). In 44% of cases (25 of 56), the 10th rib exhibited a hooked tip, while, in 46% of cases (26 of 56), it was identified as a floating rib, detached from the ninth rib. The mobility of the ribs showed increasing degrees of mobility of the tips of the ribs from 8 to 9 to 10 (Table 1).

Mobility analysis demonstrated that application of upward pressure on the costal margin resulted in rib compression, affecting ribs up to on average of 5.7 ± 0.6 rib with no compression noted above this level. This level consistently coincided with the rib interspace just above the most superior interchondral joint in 98% of evaluations. In the one instance where this alignment was not observed, examination revealed a fractured interchondral joint between ribs 6 and 7, leading to an unstable interchondral joint and consequent loss of force transmission to the sixth rib. Furthermore, the transmission of these upward forces illustrated rib articulation at the costal cartilage-sternal junction in the lower ribs. A video of this mobility can be viewed in the Supplementary Digital Content (Supplementary Data 2, http://links.lww.com/TA/E5). In this video, anatomic flags have been placed in the intercostal muscles of the midclavicular line in the interspaces of ribs 4/5, 5/6, and 6/7. The video shows the transmission of the upward force on the distal aspect of the 10th rib through the coastal margin attachments and continued transmission through the interchondral joints of ribs 5/6 and 6/7. The white flag in the 4/5 inner space does not move, while the orange and black flags in the 5/6 and 6/7 intercostal inner spaces move with upward pressure on the coastal margin.

DISCUSSION

Diagnosing and treating conditions related to the costal margin and costochondral region remain a persistent challenge for health care providers. Various interventions have been proposed for specific anterior chest wall pathologies, necessitating a thorough understanding of relevant anatomical features. In this study, we build upon previous research centered on the costal margin and chondral attachments to investigate the location of interchondral joints and their impact on rib cage mobility. Our findings offer anatomical insights that are essential for health care providers managing chest wall pathology. In all 28 cadavers, there were consistent findings of rib 1 attaching directly to the manubrium, rib 2 to the manubriosternal junction, and ribs 3 to 6 to the sternum. This provides health care providers with a reliable framework when addressing rib pathology in these areas. It is also crucial to understand that variability in costal attachment becomes apparent around

TABLE 1. Rib Tip Mobility Analysis

	No Mobility	Moderate Mobility	Hypermobility
8th Rib	20 (35%)	21 (38%)	15 (27%)
9th Rib	5 (9%)	26 (46%)	25 (45%)
10th Rib	0 (0%)	3 (5%)	53 (95%)

Description: Mobility analysis for ribs 8 to 10 (n = 56 hemithoraces) defined as no mobility, moderate mobility, and hypermobility at the rib tip.

rib 6, which can affect both chondral attachments and interchondral joints. As previously described, interchondral joints, which are composed primarily of synovial cartilage, facilitate thoracic movement by enabling anteroposterior motion, which alters the thoracic cavity's shape and facilitates a gliding motion that affects its transverse diameter.[10,12] It has been described that these joints decrease with age, which could lead to calcification of the chondral attachments and predispose these patients to fractures.[4,10] Disruptions in these joints can compromise normal anatomy, leading to hypermobility and subluxation of the rib causing impingement of the intercostal nerves, potentially resulting in anterior chest pain that may necessitate surgical intervention to alleviate symptoms.[2,6,13]

Health care providers face persistent challenge in identifying syndromes related to the costochondral and costal margin. Even in acute scenarios, such pathology is frequently overlooked or may not be evident on radiographic or computed tomography scans. According to Nummela et al.,[5] costochondral injuries were reported in 7.8% of all blunt trauma patients and 19.9% of those with thoracic trauma. Notably, this pathology most commonly affects ribs 6 and 8.[4,5]

The standard teaching described ribs 7 to 10 attaching to the cartilage of the rib above with no mobility of the rib. Our study found a significant number of specimens with mobile ribs, alternative costal margin anatomy, and a high number of floating 10th ribs. Our findings are similar to the costal margin anatomic studies of Laswi et al.[8] and Patel et al.[11] where they also found significant variability of the costal margin. This information is essential for proper surgical fixation, which requires an appropriate understanding of the anatomy.

The clinical significance of the mobility of ribs 8, 9, and 10 and the transmitted forces through interchondral joints and articulation of the ribs at the sternal junction is just beginning to be understood. This transmission of forces seems to divide the thoracic chest into two regions. There is an upper region above the interchondral joints, which is minimally affected by forces to the coastal margin. There is a second region along the ribs that make up the coastal margin and ribs connected by interchondral joints that have multidirectional forces affecting their movement through both the respiratory cycle and movement of the abdominal wall musculature and the diaphragm. The authors theorize that this increased mobility may impair fracture healing by increasing motion at the fracture site. Also, the increased articulation at the level of the sternum, as well as mobility of the attachments of the lower ribs, could result in a pseudo flail type physiology in the lower chest region. This increased motion may predispose patients to increased pain, increased respiratory insufficiency, and increased mobility of fractured ribs resulting in nonunion/malunion rib fractures. Ongoing investigations are continuing to outline these interactions and their clinical ramifications.

Limitations in this study parallel those found in comparable cadaveric anatomy investigations. The preservation process could have had unanticipated effects on the mobility of the rib cage. The specimens assessed lacked a documented history of chest trauma. The average age was 81.4 years, which is much older than average trauma patients and the effects of aging on the flexibility and mobility of the chest wall. It can be theorized that, with increased calcium deposition in the costal cartilage, the degree of flexibility and mobility will decrease over time. There remains a scarcity of data regarding how age influences the integrity of interchondral joints and chest wall mobility. In addition, the cadavers exhibited minimal diversity in ethnicity and race, potentially limiting the applicability of our findings. Furthermore, the dissection process could have modified the native anatomy, hindering joint identification. In addition, the pressure applied to the 10th rib was not standardized, which may over- or underestimate the mobility assessment. Future studies may benefit from incorporating imaging techniques to enhance internal validity.

CONCLUSION

Our study reveals a prevalent occurrence of bridging interchondral joints among ribs 5 to 8, which can play a role in dispersing forces along the chest wall. While this insight is valuable for health care providers managing costal margin pathology, the clinical significance of the articulation of the costal cartilage sternal junction remains uncertain. To enhance patient outcomes, further research into the significance of interchondral joints and the mobility of the lower rib cage is required.

AUTHORSHIP

E.E., A.H., and S.W.K. contributed in the design. A.H., E.E., W.G., C.M., J.H., and S.W.K. contributed in the data acquisition. A.H., E.A.E., S.W.K., A.P., A.R.P., and D.A. contributed in the data analysis. A.H., W.G., C.M., J.H., D.A., A.P., A.R.P., S.W.K., and E.A.E. contributed in the interpretation of data. D.A., A.H., A.P., A.R.P., and E.A.E. contributed in the preparation of manuscript. All authors contributed in the approval of final manuscript.

DISCLOSURE

Conflicts of Interest: Author Disclosure forms have been supplied and are provided as Supplemental Digital Content (http://links.lww.com/TA/E6).

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