Redefining the costal margin: A pilot study

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BACKGROUND: Classical teaching of rib anatomy contends that the false ribs (7th to 10th) fuse anteriorly to form the costal margin of the chest. Slipped rib syndrome consists of false rib subluxation into the thorax with symptomatic impingement of the intercostal nerve. We sought to determine the incidence of this anatomic finding through anatomic study of the costal margin.

METHODS: Cadavers were evaluated for mobility and attachment of the ninth and tenth ribs. Experienced anatomists and chest wall surgeons conducted a standardized dissection and assessed rib tip mobility using predefined criteria. Videos of dissections were submitted to a single investigator who reviewed the findings.

RESULTS: Costal margins of 40 cadavers (45% male) were evaluated bilaterally. The average age was 83 years ± 11 years. The ninth rib was found to be attached to the eighth rib 100% of the time by an interchondral cartilaginous attachment along the body of the eighth and ninth ribs. Internal subluxation was noted in 19% (15 of 80), and the tip of the rib was mobile in 86% (69 of 80) evaluations. The tenth rib was attached to the ninth rib in 18%(14/80). A "floating" 10th rib was noted in 59% (47 of 80) of specimens. Subluxation was noted in 33% (26 of 60). Half of the ribs that subluxed moved medially to the ninth rib and half moved externally. An upwardly hooked tip was noted in 10% (8 of 80). Ribs with a hooked tip subluxed in 63% (5 of 8), and all of these ribs (5 of 5) moved to the interior of the chest ($p = 0.020$).

CONCLUSION: The ninth rib is commonly attached to the eighth rib, but the tenth rib is often not attached to the ninth rib. Most commonly, the tenth rib is a "floating" rib. Internal subluxation of the tenth rib as well as the presence of a hooked tip may predispose individuals to the development of "slipped rib syndrome." (*J Trauma Acute Care Surg.* 2022;93: 762–766.

LEVEL OF EVIDENCE: Diagnostic Tests or Criteria; Level III.

KEY WORDS: Costal margin; slipped rib; hypermobile rib; floating rib; anatomy.

The costal margin has been described consistently in classical anatomy teaching.[1,2] Ribs 1 to 7 have direct cartilaginous attachments to the sternum. The 8th to 10th ribs have been described as each having cartilaginous attachments to the rib above it. These interchondral joints fuse to form the costal margin and costal arch, which attaches to the lower sternum. Ribs 11 and 12 are floating ribs and have no attachments to the costal margin. Disruption of the interchondral attachments between ribs 8 through 10 can result in weakness and rib separation at the costal margin.[3,4] This laxity results in hypermobility and subluxation of the rib in relation to the ribs above and/or below the mobile rib.

One clinical consequence of these hypermobile ribs is slipped rib syndrome. Slipped rib syndrome (sometimes referred to as "slipping rib syndrome") is the constellation of symptoms that results from impingement of intercostal nerves between slipping rib tips.[5,6] The tip of the hypermobile rib can impinge on the intercostal nerve of the rib above causing a complex pain response. This interaction between the rib tip and the intercostal nerve results in pain with activity and movement, which can lead to limitations in quality of life especially for the active individual. The diagnosis requires a high index of suspicion and is mainly diagnosed clinically by thorough palpation of the costal margin. One physical exam maneuver that can be used to reproduce the pain in clinic is to perform a hooking maneuver. This maneuver can be used to determine if the hypermobile rib is causing the symptoms the patient is experiencing.[7,8] A hooking maneuver is performed by placing the patient in a supine position. The examiner places their fingers under the inferior margin of the ribs and distracts the ribs in a cranial direction to determine if the maneuver reproduces the pain or rib movement can be appreciated.

This condition has been described in multiple case reports, but a true incidence has never been identified.[3,9–13] Moreover, variability in attachments of ribs 8 to 10 between different individuals was not assessed. The goal of this study is to identify variances in the anatomy of the costal margin and to define an incidence for slipped rib syndrome.

METHODS

Institutional review board (IRB) applications were submitted by each investigator. The IRBs confirmed that the project met Not Human Research criteria set forth by the Code of Federal Regulations (45CFR46), as the research was using only cadaver specimens. Approval to videotape the evaluations was also obtained from the collaborating anatomy laboratories. The STROBE

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This study will be presented at the Chest Wall Injury Society meeting in April 2022.

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guideline was used to ensure proper reporting of methods, results, and discussion (SDC 1, http://links.lww.com/TA/C695).

A prospective pilot study evaluation of the cadavers was undertaken by the investigators. The evaluation was limited to the costal margin, consisting of the 8th, 9th, and 10th ribs bilaterally. This was carried out by experienced anatomists and chest wall surgeons in a standardized fashion. Incisions were made overlying the costal margin. The subcutaneous tissue and external oblique muscle were incised and dissected to completely expose the lower ribs and the costochondral attachments. The variances in the attachments of ribs 8, 9, and 10 were identified. The stability, attachments, and mobility of the ribs were assessed using a hooking maneuver. Ribs that were mobile were also assessed to determine if they subluxed into or outside the chest wall. Pressure was applied to the 9th and 10th ribs sequentially, in a cranial direction, to determine if they were mobile and to demonstrate if the ribs subluxed inside or outside of the chest. If no movement was observed the ribs were considered stable. If there was mild movement but not free movement the rib was classified as moderately mobile. If the rib was freely mobile and able to move around the edge of the costal margin, it was felt to be highly mobile. In the situation where the 10th rib was free from attachments to the 9th rib and did not displace up to the 9th rib with the hooking maneuver it was characterized as a floating rib. The shape and consistency of the tip of the ribs were also evaluated. In the experience of the authors caring for patients with slipped rib syndrome, many of these patients have a "hook" tip of the 10th rib. A "hook" tip on the 10th rib is a cartilaginous tapering to the rib that curves up towards the 9th rib at an acute angle compared with the normal curvature of the 10th rib. The presence of a "hook" tip on the 10th rib was evaluated. The examinations of bilateral costal margins were recorded using a high-definition camera. The video recordings were submitted to a single investigator for evaluation of the costal margins in order to eliminate interobserver variability. The age, height, weight, and gender of the specimens were recorded.

The data from the video recordings were then compiled using Microsoft Excel (Redmond, WA). Data were analyzed utilizing the Statistical Package for the Social Sciences (SPSS) version 25 (SPSS, Chicago, IL). The Shapiro-Wilk test was used to determine normality for continuous variables. Normally distributed data are presented as mean ± standard deviation and non-normally distributed data are presented as median (interquartile range). A p value of 0.05 was considered statistically significant. All tests were performed as two-sided evaluations. For continuous data, normally distributed data was analyzed using Student t test and nonnormally

Figure 1. Floating 10th rib tip.

distributed data analyzed using Mann-Whitney *U* test. For categorical data, frequencies and values were compared using χ^2 or Fisher's exact test as applicable.

RESULTS

Forty cadavers (45% male) were evaluated bilaterally. All of the cadavers except one were white ethnicity. The average age, height, and weight was 83 ± 11 years, 66 ± 4 inches, and 150 ± 50 pounds respectively. The 9th rib was found to be attached to the 8th rib 100% of the time. The 9th rib was found to form a stable costal margin with no mobility in 33% (26 of 80) examinations. Moderate mobility was found in 37% (30 of 80) and high mobility in 30% (24 of 80) of patients (Video 1, http://links.lww.com/TA/C696). Subluxation of the 9th rib was present in 19% (15 of 80) of patients and the subluxation was into the chest 100% of the time (Video 2, http://links.lww.com/TA/C697). A mobile discrete tip of the 9th rib was present in 79% (63 of 80) examinations.

The 10th rib was attached to the 9th rib in 18% (14 of 80). The 10th rib was found to be highly mobile in most examinations: no mobility 4% (3 of 80), moderate mobility 10% (8 of 80), and highly mobile 86% (69 of 80). A "floating" 10th rib was noted in 59% (47 of 80) of specimens (Fig. 1). Subluxation was noted in 33% (26 of 60). Half of the ribs that had subluxation moved medially into the chest under the 9th rib (13 of 26) and half went external to the 9th rib (13 of 26) (Video 3, http://links.lww.com/TA/C698). An upwardly pointed hooked tip was noted in 10% (8/80). Ribs with a hooked tip (Fig. 2) had subluxation present in 63% (5 of 8) and in all of these the ribs (5 of 5) moved to the interior of the chest ($p = 0.020$) (Video 4, http://links.lww.com/TA/C699). There was not a significant difference in specimens with subluxation of the 10th rib with respect to side (28% right vs 38% left [$p = 0.474$]), gender (34% vs 30% [$p = 0.737$]),

Figure 2. "Hook" tip on the distal 10th rib to the right of the finger.

height (65.9 ± 4.4 vs. 65.8 ± 3.3 inches [$p = 0.944$]), or weight (152 ± 51 vs. 143 ± 47 pounds [$p = 0.484$]).

DISCUSSION

Slipped rib syndrome has been described in the literature since 1919.[14,15] It results in severe and debilitating pain at the costal margin due to impingement of an intercostal nerve by the slipping of the rib beneath the rib superior to it. The primary mechanism is due to a defect in the costal margin and loss of the interchondral attachments, in the 8th to 10th ribs. As described in classic teaching, ribs 8 to 10 are attached to the sternum via costochondral attachments forming a combined common costal margin. Loss of integrity of the costal margin may lead to the symptoms associated with slipped rib syndrome.

In our study, we demonstrated that hypermobility of the costal margin is common. Significant mobility of the 9th and 10th ribs was present. This may predispose patients to slipped rib syndrome. We did not observe the same anatomic attachments traditionally described in anatomy textbooks and diagrams.

The majority of 9th ribs were found to be moderate to highly mobile. In addition, 19% of all examinations revealed subluxation with a hooking maneuver into the chest. There was also a discrete mobile tip of the 9th rib present in the majority of examinations. This mobility of the 9th rib may be sufficient to impinge the 8th intercostal nerve as it passes deep to the 9th rib at its insertion on the 8th rib before coursing between the internal oblique and transversalis muscles.

The 10th rib was found to be even more mobile and rarely attached to the 9th rib. The majority of the ribs were floating ribs, similar to the traditional anatomic description of the 11th and 12th ribs.[2] Theoretically, these ribs pose less risk to impingement of the 9th intercostal nerve. One third of the examinations revealed a 10th rib that subluxed either medially or laterally to the 9th rib revealing considerable costal margin instability. One half of these ribs subluxed internally, placing the tip of the 10th rib in close approximation to the 9th intercostal nerve as it transitions from the inferior side of the rib to its position within the oblique musculature. There was a significant association between the hooked tip and internal subluxation of the 10th rib. This is consistent with the clinical findings of the authors when surgically repairing the 9th and 10th ribs for patients with slipped rib syndrome.[3,5,6,8,16,17] There was no difference in these anatomic findings with respect to side, gender, height, or weight.

In addition, a connection between the anatomic findings and a clinical significance needs to be discerned. The current treatment of patients with slipped rib syndrome consists of rib excision or surgery to reform the costal margin and limit the hypermobility of the lower ribs. Performing this surgery requires a careful inspection of the costal margin and determining each rib. Given the findings of this evaluation, it would be possible to misinterpret a 10th rib for an 11th rib resulting possibly in an incorrect site surgery. This could result in the 10th rib not being resected or repaired with continued symptoms for the patient. Continuing to work on establishing a connection between anatomic findings on specimens and findings on clinical examinations will be important. The study team has plans to continue to expand our understanding of the costal margin and evaluating additional cadaveric and live anatomic evaluations to further understand this pathology.

This study has several limitations. The cadavers evaluated had an average age of 83 years. The effect of aging on the integrity of the costal margin is unknown. In addition, the past medical history of the cadavers including trauma to the chest wall was unknown. Almost all of the specimens were White, of presumed European ancestry, and it is unclear if these findings would be applicable to other ethnicities. While all of the videotaped examinations were reviewed by a single reviewer, examinations were performed by multiple providers. This may result in inter-observer variability and possible bias as all were reviewed by a single reviewer. The performance of the dissection may have changed the mobility of the ribs as the skin, adipose, and external oblique muscle were dissected away from the costal margin. The effect on the hooking maneuver of this dissection is unknown. A more diverse group of cadavers of varying ages, heights, weights, and ethnicities may result in different examination and anatomic findings.

CONCLUSION

An anatomic predisposition to slipped rib syndrome may be more common that previously documented in the medical literature. Our study demonstrates that the 9th and 10th ribs are not invariably attached to the costal margin as described in anatomy books. In this study the 10th rib was commonly a floating rib. Further study is needed to determine additional clinical significance of these anatomic variations.

AUTHORSHIP

E.E., A.H., A.K. participated in the literature search. E.E., R.L., A.K., Z.B., A.H. participated in the study design. E.E., A.K., R.L., Z.B., A.H., J.A., S.K., M.L. participated in data collection. E.E. performed the data analysis. E.E., A.K., R.L., Z.B., A.H., J.A., S.K., M.L. participated in data interpretation. E.E., M.L. drafted the article. E.E., A.K., R.L., Z.B., A.H., J.A., S.K., M.L. participated in critical revisions. All authors approved the final article version for submission.

DISCLOSURE

E.E. is a speaker for DePuy Synthes. A.K. is a speaker for Zimmer/Biomet, and Atricure. Z.B.is a speaker for Zimmer/Biomet, KLS-Martin, and Atricure. The remaining authors declare no conflicts of interest.

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