Anatomy of the intercostal nerves of ribs in the lower rib cage: A pilot study

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BACKGROUND: Traditional intercostal nerve anatomy teaching describes nerves crossing directly across the costal margin. Significant variability in costal margin bony anatomy has been described. Our cadaveric study evaluated variability, branching, and coursing patterns of intercostal nerves at the costal margin.

METHODS: Cadaveric dissections were performed evaluating the branching anatomy and course of intercostal nerves, specifically of ribs 7 to 9, at the costal margin because of the highly variable rib anatomy and neural innervation of abdominal wall musculature in this region. Experienced chest wall surgeons evaluated this anatomy using a standardized dissection and assessment to quantify the location and branches of the nerves.

RESULTS: The intercostal nerves and costal margins of 12 hemithoraces were dissected (n = 12). All seventh, eighth, and ninth nerve gave rise to a diaphragmatic branch. The seventh nerve arborized at the costochondral junction in 25% of hemithoraces. The eighth nerve arborized at the costochondral junction in 42% of hemithoraces and continued arborizing at the ninth rib tip in 33%. The ninth nerve arborized at the costochondral junction in 60% of hemithoraces and continued arborizing at the ninth rib tip in 90%. When the eighth rib directly attached to the sternum (42%), the seventh nerve entered the 7/8 interchondral groove, and the eighth nerve directly crossed then ascended along the costal margin giving off abdominal wall musculature branches. When the seventh rib directly attached to the sternum with the eighth rib joining to form the costal margin (58%), the seventh nerve directly crossed then ascended along the costal margin with similar branching.

CONCLUSION: The seventh, eighth, and ninth intercostal nerves arborize at the costal margin (costochondral junction) to provide branches into the diaphragm and abdominal wall musculature with additional arborization at the lower rib tips. The seventh and eighth intercostal nerve location is variable based on their associated bony anatomy at the costal margin. (*J Trauma Acute Care Surg.* 2025;00: 00–00.

LEVEL OF EVIDENCE: Diagnostic Test; Level II.

KEY WORDS: Intercostal nerve; costal margin; diaphragm innervation; abdominal wall innervation; anatomy.

Traumatic rib fractures have long been known to place trauma patients at increased risk of morbidity and mortality with complications including pneumothorax, hemothorax, and pulmonary contusion in addition to prolonged ventilator support and intensive care.[1,2] Increased focus over the last decade has been placed on identification of additional complications including costal margin disruption and intercostal hernias.[3–7] Even pseudohernia development, while traditionally linked to injury from thoracic surgical intervention,[8–10] has been noted in the setting of rib fractures because of denervation of the abdominal wall.[11,12]

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With the number of complications related to rib fractures, heightened emphasis has been placed on surgical stabilization of rib fractures internationally over the last 10 years with exponentially increasing research volume and clinical application.[13] Multiple consensus guidelines have been published, most recently by the World Journal of Emergency Surgery, detailing indications, timing, operative planning, approaches, and techniques.[13,14] With the increased utilization of surgical stabilization of rib fractures, it is essential for surgeons to have a detailed and accurate understanding of the bony and cartilaginous makeup of the chest wall in addition to the supporting musculature and nervous innervation.

Previously, significant variability has been described in the anterior chest wall, especially pertaining to the costal margin, which strays from the traditional chest wall teaching of this anatomy.[15–18] Similar to the anterior chest wall and costal margin, a traditional description of the intercostal nerve exists, described as a segmental nerve lying in the subcostal groove adjacent to the intercostal artery and vein with those of 7 to 12 innervating the abdominal wall.[8,19] Other groups have attempted to understand the anatomy of the intercostal nerves and have identified variability in the nerve position and cutaneous branching patterns, but these studies have focused either on the proximal nerve or ribs 10 to 12.[19–22] To the best of our knowledge, no study has elucidated the branching pattern and trajectory of the intercostal nerves at the costal margin, a region which we have identified as already

having significant variability from traditional described anatomy. The goal of our cadaveric study was to evaluate the variability, branching pattern, and course of the intercostal nerves at the costal margin as well as further detail the costal margin bony anatomy and determine if the intercostal nerves can be adequately traced across the costal margin.

PATIENTS AND METHODS

Using previously described procedural design created at our institution,[15–17] we developed a prospective cadaveric based study with dissection focused on anterior chest wall and costal margin anatomy with the addition of a heightened detail to intercostal nerve course and branching pattern as well as the feasibility of dissecting the nerves across the costal margin. The STROBE guidelines were used for proper reporting of methods, results, and discussion (Supplemental Digital Content, Supplementary Data 1, http://links.lww.com/TA/E710). This study was solely a cadaveric-based project, which was approved by the institutional review board having met "Not Human" research criteria established by the Code of Federal Regulations (45CFR46).

Anterior thoracic chest plates including abdominal musculature were obtained, and dissection and anatomic identification were performed bilaterally on the cadaveric specimens. The age, height, weight, body mass index, and sex of the specimens were recorded using precollected cadaveric data. Dissection was conducted by experienced chest wall surgeons who first dissected the superficial structures of the chest to allow visualization of the sternum, anterior ribs, and costal margin prior to removal of the chest plates. Each chest plate was removed from the thorax along the mid axillary line, leaving 1 cm of abdominal wall muscle and diaphragm attached. The chest plates were removed by graduate studies students as part of their anatomy class. Specimens were excluded from study if the specimen was too desiccated from cadaveric processing, not enough muscular tissue remained on the chest plate, or the nerve was transected at the costal margin during removal. The chest plates allowed visualization of the anatomy down to the rib and associated costal margin segment of rib 9 and abdominal wall musculature at this level. We specifically focused on ribs 7, 8, and 9 as previous research has noted variability in the costal margin and the clinical importance of denervation injuries to the abdominal wall musculature.[16] Tenth rib data were not collected, as it was not part of the chest plate per the anatomic dissection guidelines of the course.

After the student's intrathoracic module was completed, the thoracic chest plates were evaluated, and the intrathoracic dissection was undertaken. This primarily involved the identification of each intercostal bundle for ribs 7, 8, and 9 on the inferior aspect of each rib proximally followed by careful dissection of each intercostal nerve. Each intercostal nerve was then traced out in length as it coursed anteriorly along the underside of the rib. The path of each nerve was recorded in relation to if and where the nerve crossed the costal margin and how it ascended along either its associated interchondral groove or the costal margin. The branching pattern was also recorded with careful focus on where the nerves arborize and on the specific branching patterns of each nerve. Particular attention was focused on the location of branching and its relationship to the tips of adjacent ribs. The findings of these dissections were recorded and reviewed by a board-certified trauma and critical care surgeon with extensive chest wall surgery experience. Upon complete review, the video recording data were compiled using Microsoft Excel (Redmond, WA). Normally distributed data are presented as mean ± SD.

RESULTS

Fifteen chest walls were evaluated, and 12 hemithoraces were found to have adequate preservation of the neural anatomy and muscular anatomy of the diaphragm and chest wall. The average age was 82 ± 10 years. All specimens were White, 50% were male, and 50% were female. The average height, weight, and body mass index were 172 ± 12 cm, 63 ± 12 kg, and 12 ± 4 kg/m^2, respectively. Nerve data were available for 100% (12/12) of the seventh and eighth intercostal nerves; however, data for two of the ninth intercostal nerves (2/12) required exclusion for a total of 10 specimens because of inadequate muscular tissue around the rib at the costal margin. In the specimens examined, the nerves could be traced along the anterior rib cage and followed across the costal margin.

Upon inspection of the bony anatomy and costal margin makeup, eighth rib inserted directly into the sternum in 42% (5/12), and the seventh rib inserted directly into the sternum in 58% (7/12) of cases. Of these cases, the eighth rib (7/12) combined with the seventh rib to form the costal margin via interchondral joints. When inspecting the specific branches of each nerve, every nerve examined, whether it was associated with rib 7, 8, or 9, diaphragmatic and abdominal wall branches were observed; however, variation was noted in the location of branching (Figs. 1 and 2).

When inspecting the arborization pattern of each rib (Table 1), the seventh, eighth, and ninth intercostal nerves began to arborize at the costochondral junction in 25% (3/12), 42% (5/12), and 60% (6/10) cases, respectively. The nerves traversed the costal margin under the insertion of the diaphragm and gave rise to diaphragmatic branches in 100% of evaluations. The seventh nerve then came back together as a common bundle and ascended the inferior boarder of the seventh rib at the costal margin before giving rise to abdominal wall branches. The eighth intercostal nerve showed more variability in how it crossed the costal margin. If the eighth rib had a direct attachment to the sternum (5/12), the nerves crossed the costal margin then ascending the costal margin along the inferior aspect of the eighth rib (100% [5/5]). If the eighth rib did not attach directly to the sternum (7/12), it was noted to arborize after crossing the costal margin at the level of the tip of the ninth rib in 57% (4/7) of cases and ascended the costal margin along the eighth rib in the remainder of cases (43%, 3/7). The ninth intercostal nerve began to arborize at the costochondral junction in 60% (6/10) of specimens and with arborization at the tip of the 9th rib in 90% (9/10) of cases and at the tip of the 10th rib in 60% (3/5). No significant differences were noted in the bony or neural anatomy based on the sex of the specimen.

DISCUSSION

Workup, diagnosis, and management of chest wall pathologies have significantly evolved in recent years. Despite research of the anterior chest wall and the costal margin dating back decades, the previous work by our group has identified

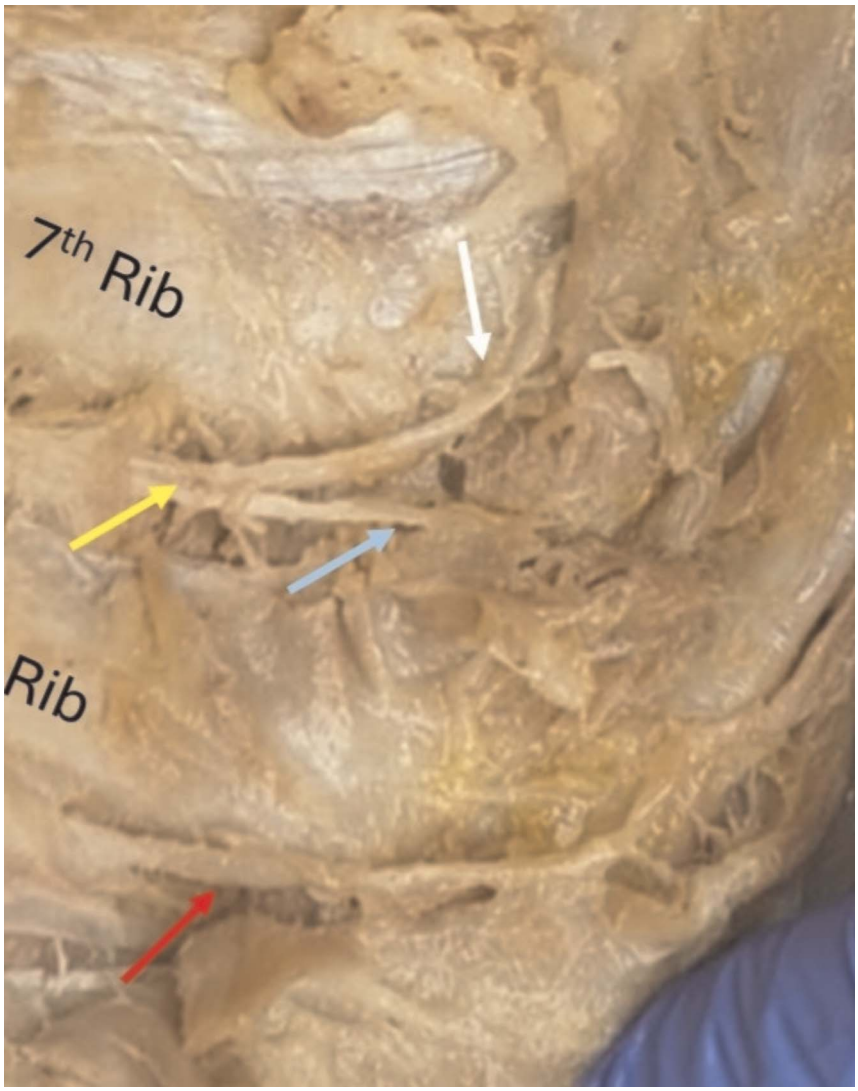

Figure 1. Seventh and eighth rib branching. Legend: Seventh and eighth ribs labeled in white lettering. Seventh intercostal nerve (yellow arrow) arborizes to form a diaphragmatic branch (light blue arrow) and abdominal wall muscular branch that courses between the seventh and eighth cartilage (white arrow). Eighth intercostal nerve (red arrow) crossing the costal margin and progressing up the costal margin of the eighth rib.

variations in the chest wall anatomy that strays from the traditionally described anatomy.[15–17] This study continues to add to the field of knowledge as we have further delved into an understanding of the intercostal nerve anatomy in relation to the costal margin. Our study confirmed the ability to dissect the intercostal nerves and identify the branches to the nerves as well as observe their course as they cross the costal margin. Additionally, we successfully identified the distal branching patterns of the intercostal nerves into diaphragmatic and abdominal wall branches for intercostal nerves for ribs 7 through 9 with additional notation of the location of these branches at the costochondral junction and rib tips. Lastly, we have been able to identify a pattern of the nerve trajectories based on the sternal attachments of the ribs.

A thorough understanding of the intercostal nerve anatomy when combined with additional bony and costal margin anatomical knowledge is of utmost importance for surgeons. The location of the intercostal nerve in relation to the rib was studied decades ago in 1988 by Hardy,[19] identifying the nerves that ran in the classically described subcostal space only 16.6% of the time and were more often located in the midzone (73%). Rendina and Ciccone[23] further deconstructed the intercostal space, describing the origin from the ventral rami of the thoracic spinal nerves and describing how anterior branches from the intercostal nerves 7 to 11 innervate the abdominal wall with additional proximal lateral cutaneous branches. These findings correlate with more recent research by Talsma et al.[21] focusing on the location of the lateral cutaneous branching pattern with findings of cutaneous branching anterior to the midaxillary line in 78.3%. Our study adds to this body of knowledge as we redefine the branching at the costal margin into both abdominal wall and diaphragmatic branches and have elucidated the location of these branches.

Clinically, these findings have significant ramifications as we continue to understand costal margin and rib cage pathologies

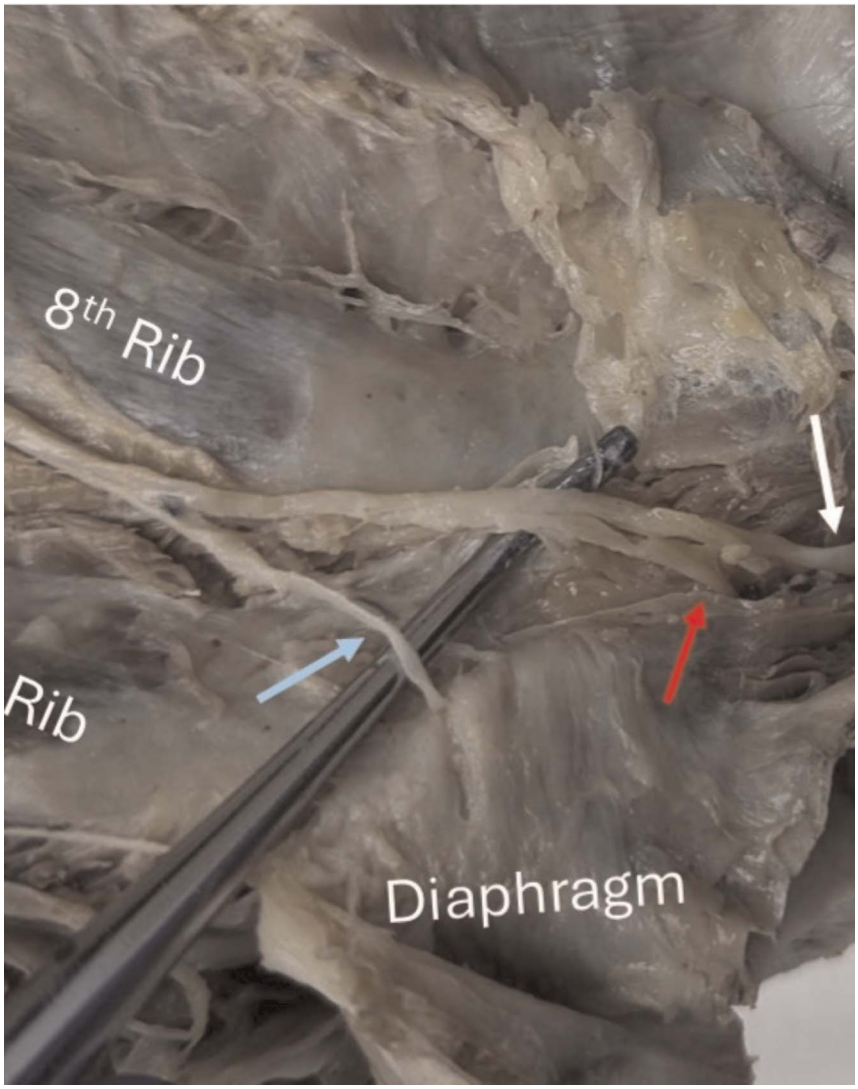

Figure 2. Eighth rib arborization at the costochondral junction. Legend: Eighth and ninth ribs labeled in white lettering. Eighth intercostal nerve (yellow arrow) arborizes to form a diaphragmatic branch (light blue arrow), as well as a common nerve that further arborizes into a branch directly to the abdomen (red arrow) and a branch crossing the costal margin and progressing up the costal margin of the eighth rib.

related to rib fractures. Previous literature extensively describes costal margin fractures and disruptions, intercostal hernias, and diaphragmatic hernias[3,5,6,24,25] as resulting pathologies related to costal margin injury; however, further complications of injury to the intercostal nerve are continuing to be noted. Described primarily in the thoracic surgery and plastic surgery literature, abdominal wall denervation can be noted after thoracotomies/thoracoscopy or deep inferior epigastic artery perforator flaps.[8,9,12] More recently, these findings are being identified after rib fractures.[11,12] As the intercostal nerves play a known important role in innervation of the abdominal wall, an understanding of the intercostal nerve trajectory and branching pattern is essential to predict and develop interventions for nerve injury. This is especially important as the recognition of prevalence and imaging identification of costochondral injury, a once underrecognized diagnosis, continues to evolve.[6,24,25] Anatomical understanding of the intercostal nerves may allow us to further understand and predict denervation injuries to both the abdominal wall and diaphragm. The bulging of a denervation injury to the abdomen takes months to become clinically evident. The changes in forces applied to the costal margin over time from the loss of muscular contraction of the abdominal wall change the vectors

TABLE 1. Intercostal Nerve Arborization Patterns

	Costochondral Junction	Associated Rib Tip	Rib Tip Below
7th ICN	25% (3/12)	0%	0%
8th ICN	42% (5/12)	0%	33% (4/12)
9th ICN	60% (6/10)	90% (9/10)	60% (3/5)

Description: Arborization patterns identified for each ICN at the costochondral junction, associated rib tip (i.e., seventh ICN, seventh rib tip), and the rib tip below (i.e., seventh ICN, eighth rib tip).
ICN, intercostal nerve.

of forces. These changes in force vectors at the costal margin likely will affect healing rates of injuries of the costal margin managed operatively and nonoperatively. It may also lead to unexpected hardware failures for costal margin repairs.

As a cadaveric anatomical investigation, the study has limitations primarily related to the preservation process and acquired specimens. In this study, we were forced to exclude some specimens if the chest plates provided had too little diaphragm and/or abdominal musculature remaining to allow proper nerve identification. Similarly, we were unable to evaluate the course of the 10th to 12th ribs to comprehensively evaluate the anatomy of the lower ribcage. In addition, the preservation process causes tissue desiccation resulting in tissue destruction or difficulty in anatomic identification. With the small number of hemithoraces evaluated, the generalizability of these findings is limited. Lastly, any differences in anatomy between men and women may not be evident but will be evaluated in future projects.

CONCLUSION

Our study identifies the feasibility of tracing the distal branches of intercostal nerves associated with ribs 7 through 9 in addition to detailing their arborization patterns. When comparing to the costal margin, we also have identified patterns of intercostal nerve course as they cross the costal margin and enter abdominal wall musculature. While this study helps to define anatomical patterns of the intercostal nerves, further work must be done to develop modalities and techniques for both diagnosis of nerve injury and options for intervention to continue to enhance patient care and surgical outcomes.

AUTHORSHIP

A.N.P., S.W.K., and E.A.E. contributed to the design. A.N.P., G.T.S., and E. A.E. contributed to the data acquisition. A.N.P., G.T.S., M.C.S., D.N.D., S.W.K., and E.A.E. contributed to the data analysis. A.N.P., G.T.S., M.C.S., D.N.D., S.W.K., and E.A.E. contributed to the interpretation of data. A.N.P. and E.E. in the preparation of manuscript. All authors contributed to 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/E711).

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