Radiology

Incidence and Imaging Findings of Costal Cartilage Fractures in Patients with Blunt Chest Trauma: A Retrospective Review of 1461 Consecutive Whole-Body CT Examinations for Trauma[1]

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Purpose: To assess the incidence of costal cartilage (CC) fractures in whole-body computed tomographic (CT) examinations for blunt trauma and to evaluate distribution of CC fractures, concomitant injuries, mechanism of injury, accuracy of reporting, and the effect on 30-day mortality.

Materials and Methods: Institutional review board approval was obtained for this retrospective study. All whole-body CT examinations for blunt trauma over 36 months were reviewed retrospectively and chest trauma CT studies were evaluated by a second reader. Of 1461 patients who underwent a whole-body CT examination, 39% (574 of 1461) had signs of thoracic injuries (men, 74.0% [425 of 574]; mean age, 46.6 years; women, 26.0% [149 of 574]; mean age, 48.9 years). χ^2 and odds ratios (ORs) with 95% confidence intervals (CIs) were calculated. Interobserver agreement was calculated by using Cohen kappa values.

Results: A total of 114 patients (men, 86.8% [99 of 114]; mean age, 48.6 years; women, 13.2% [15 of 114]; mean age, 45.1 years) had 221 CC fractures. The incidence was 7.8% (114 of 1461) in all whole-body CT examinations and 19.9% (114 of 574) in patients with thoracic trauma. Cartilage of rib 7 (21.3%, 47 of 221) was most commonly injured. Bilateral multiple consecutive rib fractures occurred in 36% (41 of 114) versus 14% (64 of 460) in other patients with chest trauma (OR, 3.48; 95% CI: 2.18, 5.53; $P < .0001$). Hepatic injuries were more common in patients with chest trauma with CC fractures (13%, 15 of 114) versus patients with chest trauma without CC fractures (4%, 18 of 460) (OR, 3.72; 95% CI: 1.81, 7.64; $P = .0001$), as well as aortic injuries ($n = 4$ vs $n = 0$; $P = .0015$; OR, unavailable). Kappa value for interobserver agreement in detecting CC fractures was 0.65 (substantial agreement). CC fractures were documented in 39.5% (45 of 114) of primary reports. The 30-day mortality of patients with CC fractures was 7.02% (eight of 114) versus 4.78% (22 of 460) of other patients with chest trauma (OR, 1.50; 95% CI: 0.65, 3.47; $P = .3371$).

Conclusion: CC fractures are common in high-energy blunt chest trauma and often occur with multiple consecutive rib fractures. Aortic and hepatic injuries were more common in patients with CC fractures than in patients without CC fractures.

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After head injuries, blunt chest trauma is the second leading cause of morbidity and mortality in patients with trauma (1). Although radiologic findings of chest trauma and chest wall disorders have been widely described in the literature (2–9), costal cartilage (CC) fractures are rarely mentioned (10–14). Contact sports–related costochondral injuries are well known and usually discovered at magnetic resonance (MR) imaging (15–20). As of today, the true incidence, clinical significance, and long-term effects of these injuries in patients with blunt polytrauma remain unknown. CC fractures contribute to rib cage instability and may manifest clinically as late as weeks or months after the acute trauma (16). The data on the healing process of CC fractures remains sparse (21).

Conventional radiography cannot reveal CC fractures, but computed tomography (CT), MR imaging, and ultrasonography have proven to be useful in their depiction (10–12,22,23). Previous publications of CC injuries have focused on posttraumatic evaluation weeks or months after the initial trauma (10,11). Imaging has been used to help determine severe posttraumatic parasternal pain unexplained by radiographic findings, or because of a painful parasternal mass with clinical suspicion of tumor in patients without obvious recent trauma (10). Several case reports of contact sports–related costochondral injuries in rugby and American football players have also been published (15–20). Recent retrospective research over a period of 10 years found a total of 44 patients with CC injuries seen at CT. However, this review was based on a retrospective keyword search in the written reports, thereby excluding any missed injuries, and no incidence was reported (24).

Because patients with polytrauma have multiple severe and potentially life-threatening concomitant injuries by definition, CC fractures add to the trauma burden by increasing thoracic instability. Thus, it is important to pay attention to these injuries. To our knowledge, there are no previously published reports of the incidence of CC fractures in a large cohort of patients with blunt polytrauma. The purpose of our study was to assess the incidence of CC fractures in whole-body CT examinations for blunt trauma and to evaluate distribution of CC fractures, concomitant injuries, mechanism of injury, accuracy of reporting, and the effect on 30-day mortality.

Advances in Knowledge

- Costal cartilage fractures are common in blunt chest trauma with an incidence of 19.9% (114 of 574) in this study cohort.
- Costochondral fractures are commonly missed; the initial detection rate in this study was 39.5% (45 of 114).
- Costal cartilages of rib 7 (21.3%, 47 of 221), rib 1 (17.2%, 38 of 221), and rib 6 (14.9%, 33 of 221) were most commonly injured; bilateral multiple consecutive rib fractures, sternal fractures, and injuries to the liver were more frequent in the costochondral fracture group than in patients with chest trauma without costochondral fractures.

Materials and Methods

Patients

Institutional review board approval for this retrospective study was obtained from the ethics committee of the Department of Surgery. All acute-phase whole-body CT examinations for blunt trauma (1461) from the emergency unit of a single large level I trauma center during a period of 36 months (January 1, 2013–December 31, 2015) were consecutively included in the study. All patients aged 18 years and older with a history of blunt trauma and who underwent a contrast material–enhanced chest and abdominopelvic CT examination for trauma were included regardless of their injury severity score. Patients for whom emergency imaging indication was other than blunt trauma—search for primary malignancy, metastatic disease, source of fever, or focus of infection—were excluded from our study (6.7%, 105 of 1566). Patients with penetrating trauma of the torso are referred and transferred to another departmental unit in this catchment area and are not treated in the level I trauma center in question.

At the time of imaging, all examinations were primarily reviewed by either an on-call resident or specialist of radiology, followed by a second reading on the following day by an attending board-certified trauma radiologist with more than 5 years of experience.

Implications for Patient Care

- Costal cartilage fractures occur with multiple consecutive rib fractures and contribute to rib cage instability, thus impairing the patient's respiratory function.
- Pneumothorax, hemothorax, and aortic injury were significantly more common in the costochondral fracture group than in patients with chest trauma without costochondral fractures.

CT Imaging and Image Analysis

Imaging was performed by using a 64-section CT scanner (Discovery CT750 HD; GE Medical Systems, Milwaukee, Wis) with the following

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Content codes: CH CT

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Abbreviations:
CC = costal cartilage
CI = confidence interval
OR = odds ratio

Author contributions:
Guarantors of integrity of entire study, M.T.N., F.V.B.; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; approval of final version of submitted manuscript, all authors; agrees to ensure any questions related to the work are appropriately resolved, all authors; literature research, all authors; clinical studies, T.T.P., S.K.K.; statistical analysis, M.T.N., F.V.B., S.K.K.; and manuscript editing, all authors

Conflicts of interest are listed at the end of this article.

Figure 1

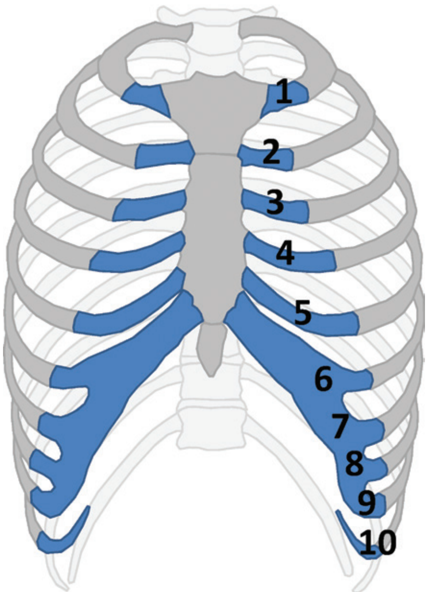


Figure 1: Illustration shows anatomy of CCs (blue) and their numbering. CCs of ribs 1 to 7 attach directly to sternum; ribs 8 and 9 (and in some patients, rib 10) attach to adjacent cartilage. Ribs 11 and 12 have no osseous or cartilaginous attachment anteriorly (ie, floating ribs).

image sets available in picture archiving and communication systems (IMPAX 6.0; Agfa HealthCare, Mortsel, Belgium) and used for review: axial section thickness of 2.5 mm and standard reformatted images at 2 mm sagittal, 4 mm coronal, and (starting from May 2015) 3 mm in both sagittal and coronal reformatted images. A board-certified radiologist (M.N., with 5 years of experience) was blinded to the initial reports and reviewed all whole-body CT examinations by using picture archiving and communication systems. In the first phase of this retrospective reading, all whole-body CT examinations were classified by reader 1 (M.N.) into subgroups of chest trauma, nonchest trauma, and no signs of trauma based on the findings. Special attention was paid to the CCs (Fig 1) and ribs. In the second phase of our study, all whole-body CT examinations with signs of chest trauma were independently reviewed by a second reader (F.B., a board-certified trauma radiologist with 12 years of experience) to determine the interobserver agreement for cartilage fracture detection. Reader 2 was blinded to initial reports and to the opinion of reader 1. Any disagreements (9.9%, 57 of 574) between readers 1 and 2 were subsequently resolved by consensus. Interobserver agreement was calculated with weighted kappa values.

Patients with signs of chest trauma (any of the following: CC fracture, rib fracture, sternal fracture, pneumothorax, hemothorax, pulmonary contusions, pulmonary lacerations, mediastinal hematoma, pneumomediastinum, aortic injury, chest wall hematoma) as categorized by reader 1 were further categorized by both readers 1 and 2 into two subgroups: patients with CC fractures and patients without CC fractures. Any isolated fracture of the thoracic spine, clavicle, or scapula was not included in the chest trauma group.

A nondisplaced CC fracture was identified as a hypoattenuating fracture line across the cartilage seen in more than one image and most commonly oriented perpendicular to the rib margins. Cartilages were assessed on axial and coronal images. A step-off on the even surface of the cartilage and often overlapping cartilage fragments reveal the dislocated fracture on axial images. Also, hematoma surrounding the dislocated costochondral fracture can facilitate detection.

Variables

Cartilage fracture location, cartilage calcification, and the presence of concomitant intrathoracic, skeletal, and intra-abdominal injuries were recorded. Depending on their location, CC fractures were categorized as costochondral, midchondral, or chondrosternal. Costochondral separation (ie, costosternal dissociation) was categorized as chondrosternal fracture. Costochondral fractures that were agreed on in the consensus reading were subsequently compared with the original report to determine the initial detection rate of CC fractures.

Measuring the detection rate of other variables was beyond the main focus of this article. However, reporting of intrathoracic injuries, sternal fractures, and rib fractures was screened by reader 1. Overall, the presence of concomitant intrathoracic, skeletal, and intra-abdominal injuries were recorded on the basis of the original reports and the reading of all whole-body CT examinations by reader 1.

The mechanism of injury and additional clinical information, along with the 30-day mortality rate, were obtained from patients' medical records. Any available follow-up CT study covering the area of injured cartilages was also reviewed by readers 1 and 2 to evaluate posttraumatic changes at the fracture site. All of these follow-up examinations were performed for different indications than CC fractures—for example, for the evaluation of pulmonary infection (pneumonia, empyema), size of pneumothorax or hemothorax, retained pleural fluid, pulmonary embolism, abdominal emergency, follow-up after blunt cerebrovascular injury, or a successive event of blunt trauma.

Statistical Analysis

χ^2 test and odds ratios (ORs) with 95% confidence intervals (CIs) of different mechanisms of trauma, associated injuries, and 30-day mortality between patients with and patients without CC fractures were calculated. Two-tailed t test for independent samples was used to assess the age difference between sexes. Logistic regression models for dichotomous outcome variable were used to find out whether costochondral fractures are an independent predictor for 30-day mortality. Statistical significance was set at .05. Interobserver agreement was calculated with linearly weighted kappa values. Magnitude for interobserver agreement was interpreted as follows: values less than 0, no agreement; 0–0.20, slight agreement; 0.21–0.40, fair agreement; 0.41–0.60, moderate agreement; 0.61–0.80, substantial agreement; and 0.81–1, almost perfect agreement (25). We used a commercial software package

(SAS/STAT, version 9.3; SAS Institute, Cary, NC).

Results

Over a period of 36 months, a total of 1461 consecutive whole-body CT examinations met the inclusion criteria. Radiologic signs of chest trauma were found in 574 of 1461 (39%) examinations (mean age, 47.2 years; range, 18–97 years; men, 74.0% [425 of 574]; mean age, 46.6 years; range, 18–91 years; women, 26.0% [149 of 574]; mean age, 48.9 years; range, 18–97 years). The age difference between men and women was not statistically significant (*P* = .213).

Among the 574 patients with chest trauma, a total of 114 patients had 221 CC fractures (mean age, 48.2 years; range, 18–84 years; men, 86.8% [99 of 114]; mean age, 48.6 years; range, 18–84 years; women, 13.2% [15 of 114]; mean age, 45.1 years; range, 20–74 years). The male-to-female OR for having a CC fracture was 2.71 (95% CI: 1.52, 4.84; *P* = .0005).

Incidence

The incidence of CC fractures was 7.8% (114 of 1461) in all whole-body CT examinations and 19.9% (114 of 574) in patients with chest trauma. Altogether, 221 CC fractures were found in 114 patients and categorized as either midchondral (52.9%, 117 of 221), costochondral (41.2%, 91 of 221), or chondrosternal (5.9%, 13 of 221) (Figs 2–4). The CCs of rib 7 (21.3%, 47 of 221), rib 6 (14.9%, 33 of 221) (Fig 2), and rib 1 (17.2%, 38 of 221) (Fig 3) were most commonly injured (Table 1).

Fourteen patients of 114 (12.3%) had a CC fracture without osseous rib fractures. Multiple CC fractures were found in 60 of 114 patients (52.6%) (Figs 2a, 5a) and 17 of 114 patients (14.9%) had bilateral fractures (Fig 5a). Only two of 114 patients (1.8%) had an isolated CC fracture without any concomitant injuries. Pseudoarthrosis-type calcifications and the cleftlike appearance of the first rib costochondral joint were occasionally mistaken for signs of fracture (Fig 6). In one patient, posterior dislocation of the second costosternal joint was associated with cardiac contusion (Fig 4). Available follow-up CT examinations of 17 patients showed posttraumatic calcifications adjacent to or inside the fracture cleft (Fig 5b) starting from 27 days after trauma. The average length of duration to first follow-up CT (for

Figure 2

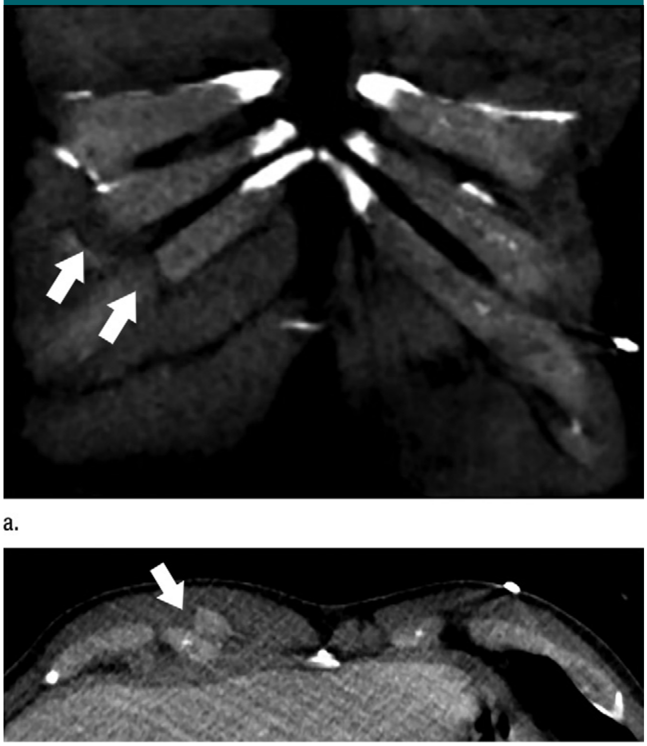


Figure 2: CT images in a 52-year-old man who drove his car off the road at 60 miles per hour (96.5 kph) into a barn. **(a)** Coronal CT image shows two consecutive midchondral fractures of right sixth and seventh rib cartilage (arrows). **(b)** Axial CT image shows seventh cartilage fracture (arrow).

Figure 3

Figure 3: Axial CT image in a 27-year-old woman who was the driver in a motor vehicle crash shows dislocated costochondral fracture of first rib synchondrosis on right (arrow).

Figure 4

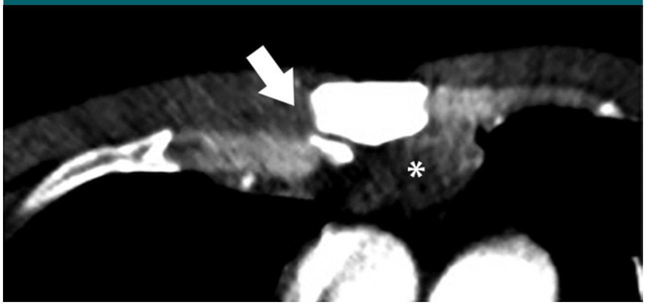


Figure 4: Axial CT image in a 35-year-old man who was ejected during a motor vehicle crash shows posterior sternocostal dislocation of right second rib (arrow) and retrosternal hematoma (*). No vascular injury was detected, but patient sustained cardiac contusion.

Table 1

Distribution of CC Fractures by Location per Rib

Variable	Costochondral	Midchondral	Chondrosternal	Right	Left	Total
Rib 1	25 (27.5)	7 (6.0)	6 (46.2)	21	17	38 (17.2)
Rib 2	5 (5.5)	8 (6.8)	1 (7.7)	9	5	14 (6.3)
Rib 3	3 (3.3)	10 (8.5)	4 (30.8)	7	10	17 (7.7)
Rib 4	8 (8.8)	20 (17.1)	1 (7.7)	14	15	29 (13.1)
Rib 5	8 (8.8)	10 (8.5)	0 (0)	9	9	18 (8.1)
Rib 6	14 (15.4)	18 (15.4)	1 (7.7)	19	14	33 (14.9)
Rib 7	11 (12.1)	36 (30.8)	0 (0)	21	26	47 (21.3)
Rib 8	11 (12.1)	7 (6.0)	…	6	12	18 (8.1)
Rib 9	5 (5.5)	1 (0.9)	…	2	4	6 (2.7)
Rib 10	1 (1.1)	0 (0)	…	1	0	1 (0.5)
Rib 11	0 (0)	…	…	0	0	0 (0.0)
Rib 12	0 (0)	…	…	0	0	0 (0.0)
Total	91	117	13	109	112	221

Note.—Unless otherwise indicated, data are the number of fractures; data in parentheses are percentages.

any indication) that showed the calcifications was 160 days (range, 27–595 days).

Concomitant Injuries

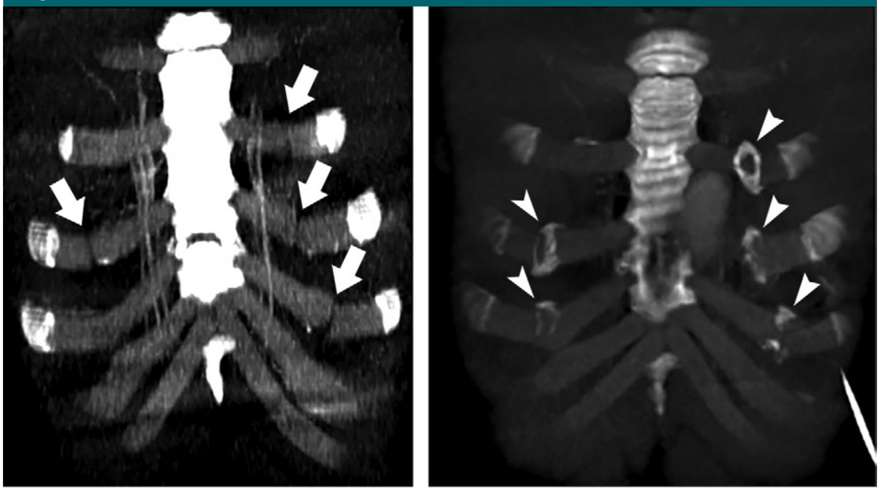
Associated intrathoracic injuries were pneumothorax (65.8%, 75 of 114), pulmonary contusions (52.6%, 60 of 114), hemothorax (51.8%, 59 of 114), and pulmonary lacerations (17.5%, 20 of 114). Pneumomediastinum was found in 7.9% (nine of 114) (Table 2). No internal mammary or subclavian artery injuries were observed (Figs 3, 5a). Blunt traumatic aortic injury was rare (3.5%, four of 114). Associated osseous injuries were fractures of the thoracic spine (24.6%, 28 of 114), sternum (24.6%, 28 of 114), clavicle (21.9%, 25 of 114), and scapula (10.5%, 12 of 114). A four-column fracture of the thoracic spine, including fractured sternum and associated rib and costochondral fractures, was found in 9.6% (11 of 114). Multiple consecutive rib fractures occurred in 92 of 114 patients (80.7%), of which 41 fractures were bilateral. Intra-abdominal injuries were seen in 22.8% of patients (26 of 114), including the liver (n = 15), kidneys (n = 11), and spleen (n = 7) (Table 2).

Pneumothorax (OR, 2.88; 95% CI: 1.88, 4.43), hemothorax (OR, 3.37; 95% CI: 2.21, 5.16), and aortic injury (n = 4 vs n = 0; OR, unavailable) were significantly more common in patients with CC fractures than in patients without CC fractures ($P < .0001$). The same finding applied to bilateral multiple consecutive rib fractures (OR, 3.48; 95% CI: 2.18, 5.53; $P < .0001$), sternal fractures (OR, 2.50; 95% CI: 1.50, 4.18; $P = .0003$), clavicle fractures (OR, 2.03; 95% CI: 1.20, 3.42; $P = .0074$), and thoracic spine fractures (OR, 1.75; 95% CI: 1.07, 2.88; $P = .0248$). Injuries to the liver (OR, 3.72; 95% CI: 1.81, 7.64; $P = .0001$) were also more frequent in the CC fracture group, but splenic injuries were equally common in both groups (OR, 1.01; 95% CI: 0.43, 2.37; $P = .9830$) (Table 2).

Mechanism of Injury, Detection Rate, and Effect on Mortality

Most common trauma mechanisms were motor vehicle crashes (34.2%, 39 of 114) and falls (28.1%, 32 of 114) (Table 3). Isolated CC fractures were caused by either direct blunt impact or momentary compression force to the upper abdomen and/or lower thorax area. No significant difference was found in the prevalence of different mechanisms of injury between the two chest trauma groups, although fall was a less common trauma mechanism in patients with costochondral fractures than in patients with chest trauma without costochondral fractures. Costochondral fractures were documented in 39.5% (45 of 114) of initial reports, when the result of the consensus reading was compared with the initial reports. Nondislocated fractures were most commonly missed. Nondislocated osseous rib fractures were either missed or only partially mentioned in 45 of 413 (10.9%) patients with multiple rib fractures, and sternum fracture were missed in nine cases of 81 (11.1%). Only one small-sized pneumothorax was left undetected (0.04%, 1 of 259). Calculated with χ^2 test, no statistically significant difference was found in the 30-day mortality in patients with CC fractures (7.02%, 8 of 114) compared with patients without CC fractures (4.78%, 22 of 460) (OR, 1.50; 95% CI: 0.65, 3.47; $P = .3371$), and CC fracture was not an independent predictor for 30-day mortality (logistic regression analysis; $P = .3886$).

Figure 5



a. b.

Figure 5: Coronal oblique maximum intensity projection (10 mm) images in a 27-year-old man with mental illness who attempted a backflip from fourth-floor window. Fourteen weeks after initial trauma, patient jumped from height of 20 m and whole-body CT was repeated. **(a)** Multiple bilateral CC fractures (arrows) in ribs 3–5 on left and rib 4 on right are shown. **(b)** Fracture of right fifth rib cartilage is revealed by posttraumatic calcifications at fracture sites (arrowheads) because it is not visible in primary CT study (**a**).

Figure 6

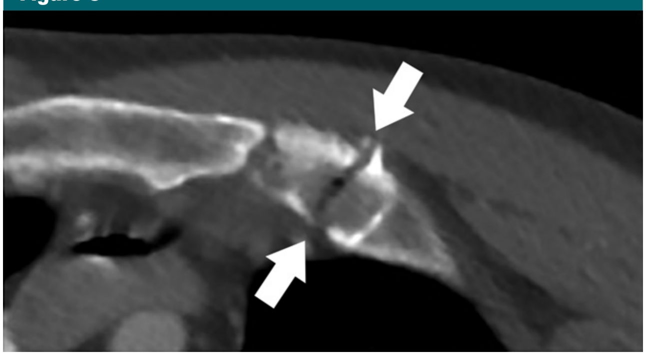


Figure 6: Axial CT image in a 42-year-old man after a motorcycle crash. Injury to left first rib synchondrosis was suspected. Air inside cleftlike costochondral junction (arrows) and pseudoarthrosis-type calcifications are seen on edges of cleft. No fracture line or air outside the junction is seen. In follow-up study 23 days later, the finding was exactly similar to the primary images.

Interobserver Agreement

All chest trauma examinations (574) that were categorized by reader 1 were reviewed by a second reader (reader 2) to determine interobserver agreement on detection of CC injuries. All differences were reassessed and settled by using consensus. Both reviewers initially agreed on 517 of 574 examinations (90.1%); these included 436 of 460 (94.8%) negative findings and 81 of 114 (71.1%) positive findings for CC fractures. These detection rates were not separately compared with initial reports; only the final result of the consensus reading was compared with the initial reports. Linearly weighted kappa value for interobserver agreement was 0.56 (95% CI: 0.48, 0.64; moderate agreement). Evidence of a learning curve was observed in detecting costochondral fractures, because frequency of disagreement between the two readers decreased from the early to the late phase of the study. Nondislocated fractures were more difficult to both detect and assess in the acute phase of injury. Some of the fractures were more easily identified at follow-up imaging as a result of increased dislocation. Streak artifact from intravenous contrast agents or dense cortical bone and subtle hypodense irregularities inside the cartilage can mimic a nondislocated fracture. Also, the large variance in the appearance of the first rib synchondrosis makes the detection of nondislocated fractures in this particular area challenging.

Discussion

CC fractures are common in blunt chest trauma. However, the incidence of CC fractures in patients with blunt trauma has not been previously reported. Most commonly fractured cartilages in our study cohort were in ribs 1, 6, and 7, located at the upper and lower margins of the anterior chest wall.

Fracture of the first rib costochondral junction was commonly associated with posterior first rib fractures. The first rib differs anatomically from the others by having a short radius and by forming a synchondrosis with the manubrium of the sternum. Different stages of calcification and/or ossification in the first rib synchondrosis and the often cleftlike appearance of the costosternal joint complicates the evaluation of acute signs of trauma in this location (5,8,26–28). Fractures of the first rib have been reported to indicate high trauma energy (6,29,30), a finding that our study cohort confirms, and which we suggest to be applicable also to the CC fracture of the first rib.

The absence of vascular injuries to the subclavian vessels or the internal mammary arteries in our study implies that these structures are not at immediate risk. Fractures of the third and fourth CCs and/or ribs were associated with traumatic aortic injury, all of which originated at the most common site for these injuries, the aortic isthmus (31). In one patient, posterior dislocation of

Table 2

Additional Injuries

Variable	CC Fractures (*n* = 114)	No CC Fractures (*n* = 460)*	OR†	*P* Value
Pneumothorax	75 (66)	184 (40)	2.88 (1.88, 4.43)	<.0001
Hemothorax	59 (52)	111 (24)	3.37 (2.21, 5.16)	<.0001
Pulmonary contusions	60 (53)	171 (37)	1.88 (1.24, 2.84)	.0026
Pulmonary lacerations	20 (18)	41 (9)	2.17 (1.22, 3.88)	.0074
Pneumomediastinum	9 (8)	11 (2)	3.50 (1.41, 8.66)	.0063
Aortic injury	4 (4)	0 (0)	…	.0015
Liver	15 (13)	18 (4)	3.72 (1.81, 7.64)	.0001
Spleen	7 (6)	28 (6)	1.01 (0.43, 2.37)	.9830
Kidney	11 (10)	19 (4)	2.48 (1.14, 5.37)	.0178
Adrenal	3 (3)	8 (2)	1.53 (0.40, 5.85)	.4634
Pancreas	2 (2)	1 (0)	8.20 (0.74, 91.20)	.1022
Bowel	2 (2)	5 (1)	1.63 (0.31, 8.49)	.6303
Multiple rib fractures	92 (81)	321 (70)	1.81 (1.10, 3.00)	.0202
Bilateral multiple rib fractures	41 (36)	64 (14)	3.48 (2.18, 5.53)	<.0001
Thoracic spine fracture	28 (25)	72 (16)	1.75 (1.07, 2.88)	.0248
Sternum fracture	28 (25)	53 (12)	2.50 (1.50, 4.18)	.0003
Clavicle fracture	25 (22)	56 (12)	2.03 (1.20, 3.42)	.0074
Scapular fracture	12 (11)	45 (10)	1.09 (0.55, 2.13)	.8121

Note.—Unless otherwise indicated, data are the number of patients, with percentages in parentheses.

* Patients with radiologic signs of chest trauma but no CC fractures.

† Data in parentheses are 95% CIs.

Table 3

Mechanism of Injury

Mechanism of Injury	CC Fractures (*n* = 114)	No CC Fractures (*n* = 460)	OR*	*P* Value
Motor vehicle crash	39 (34)	118 (26)	1.50 (0.97, 2.34)	.0665
Fall	32 (28)	175 (38)	0.64 (0.41, 1.00)	.0471
Motorcycle crash	18 (16)	56 (12)	1.35 (0.76, 2.41)	.3024
Bicycle crash	11 (10)	47 (10)	0.94 (0.47, 1.87)	.8570
Pedestrian	8 (7)	21 (5)	1.58 (0.68, 3.66)	.2845
Compression	5 (4)	16 (3)	1.27 (0.46, 3.55)	.6440
Assault	1 (1)	15 (3)	0.26 (0.03, 2.01)	.1663
Other	0 (0)	10 (2)	…	.2237
Unknown	0 (0)	2 (0)	…	…

Note.—Unless otherwise indicated, data are the number of patients, with percentages in parentheses.

* Patients with radiologic signs of chest trauma but no CC fractures.

† Data in parentheses are 95% CIs.

the second costosternal joint was associated with cardiac contusion (32). These vascular injuries most likely indicate thoracic deformation during the initial trauma that far exceeds the extent of deformation seen at the time of imaging.

Midchondral fractures of CCs 6 and 7 were associated with cases of multiple consecutive rib fractures and concomitant abdominal injuries. On CT images, abdominal parenchymal injuries may indicate a CC injury and vice versa. Injuries to the subcostal angle (cartilages of ribs 6 and 7) were overall most common and sometimes presented as isolated injuries as a result of momentary local compression force to the lower thorax.

In general, CC fractures are highly associated with multiple consecutive rib fractures and severe intrathoracic injuries such as pneumothorax, hemothorax, and pulmonary contusions. Half of all patients had multiple cartilage fractures. Multiple consecutive posterior rib fractures together with CC fractures increase thoracic instability and may form a large

flail chest segment, thus impairing the patient's respiratory function. Fractures of the sternum, as an adjacent structure, were significantly more common in the costochondral fracture group than in patients without cartilage injuries. Also, unstable hyperflexion fractures of the thoracic spine were accompanied with anterior chest wall (ie, costochondral and sternal) fractures in this cohort, further emphasizing that the thoracic cage—with all of its components—should be viewed as a single functional unit.

CC fractures commonly occur in high-energy trauma, with the most common mechanisms of injury being motor vehicle crashes and falls. Trauma mechanisms did not differ significantly between patients with chest trauma with or without costochondral injuries. However, the higher incidence of concomitant injuries in patients with CC fractures indicates its connection to higher trauma energies.

Fractures of the first rib synchondrosis were accurately identified in most of the on-call reports, whereas CC fractures in the lower parts of the anterior chest wall often remained undetected. The radiologic signs of CC fractures may not be as familiar as the imaging findings of osseous rib fractures. Thus, noticing these injuries seems to be more of a matter of perception than detection. Because fractured cartilage ends are usually smooth and well delineated, it is difficult to detect the fracture. Also, the abundance of other injuries in patients with polytrauma may cause satisfaction of search, whereby the finding of one abnormality on an image results in a second abnormality being overlooked (33). We found coronal reformatted images to be useful in the detection of CC fractures. This finding is in accordance with a study on evaluating missed rib fractures in multidetector CT examinations, in which the use of coronal reformatted images was recommended for detecting the commonly missed buckled anterior rib fractures (34).

Even though the majority of thoracic injuries are treated conservatively, the knowledge of CC injuries may explain persistent pain in patients with chest trauma and may guide pain relief protocol and ventilation support analogous to the management of flail chest and multiple consecutive rib fractures. Whether these fractures truly heal to form a stable union is not entirely known, although dense calcifications are frequently seen at the fracture site in follow-up CT examinations, which suggests a solid union. Particularly concerning dislocated fractures, cartilage healing process and the restoration of chest wall stability over time still call for further investigation (21).

Limitations of our study include that it was a retrospective review. The data were collected over a 3-year period at a single large level I trauma center covering a population of 1.6 million people, providing a cohesive and representative sample. Patients were not selected based on injury severity score; all patients older than age 18 years who were assigned to and underwent a whole-body CT examination for blunt trauma were included in our study. The effect of CC fracture on 30-day mortality would require a more comprehensive analysis of other injuries to calculate the well-known prognostic indexes of Trauma and Injury Severity Score and Revised Injury Severity Score. All whole-body CT examinations were reviewed twice during the acute phase; first by an on-call resident or a board-certified radiologist in the acute phase, and reread by an experienced trauma radiologist within 24 hours.

Another limitation was the prescreening of the whole-body CT examinations that was performed by reader 1. Reader 2 was given a prescreened subset of 574 chest trauma examinations, from the cohort of all 1461 whole-body CTs, to determine the interobserver agreement on costochondral fracture detection. This setting might create a somewhat biased assessment for the detection of CC fractures; however, this method was chosen because the main purpose of our study was to focus on the incidence of CC fractures (not on all signs of chest trauma, which are generally well known). Overall, this retrospective study constitutes the third reading of all whole-body CTs and the fourth reading of the whole-body CTs with findings of chest trauma.

In conclusion, CC fractures are common in high-energy blunt chest trauma and often occur with multiple consecutive rib fractures. Patients with costochondral fractures are at higher risk of associated intrathoracic and liver injuries. CC fractures often remain overlooked. In the presence of multiple rib fractures, cartilage fractures should be suspected and actively searched for when evaluating chest wall instability.

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References

1. German Trauma Registry 2015 annual report. http://www.traumaregister-dgu.de/fileadmin/user_upload/traumaregister-dgu.de/docs/Downloads/TR-DGU-Jahresbericht_2015.pdf. Published 2015. Accessed May 12, 2016.
2. Peters S, Nicolas V, Heyer CM. Multidetector computed tomography-spectrum of blunt chest wall and lung injuries in polytraumatized patients. Clin Radiol 2010;65(4):333–338.
3. Miller LA. Chest wall, lung, and pleural space trauma. Radiol Clin North Am 2006;44(2):213–224, viii.
4. Lomoschitz FM, Eisenhuber E, Linnau KF, Peloschek P, Schoder M, Bankier AA. Imaging of chest trauma: radiological patterns of injury and diagnostic algorithms. Eur J Radiol 2003;48(1):61–70.
5. Mirvis SE. Diagnostic imaging of acute thoracic injury. Semin Ultrasound CT MR 2004;25(2):156–179.
6. Mirvis SE, Harris JH Jr. Chest: trauma. In: Harris JH Jr, Pope TL Jr, eds. Harris & Harris' radiology of emergency medicine. 5th ed. Philadelphia, Pa: Lippincott Williams & Wilkins, Wolters Kluwer, 2012; 489–572.
7. Levine BD, Motamedi K, Chow K, Gold RH, Seeger LL. CT of rib lesions. AJR Am J Roentgenol 2009;193(1):5–13.
8. Guttentag AR, Salwen JK. Keep your eyes on the ribs: the spectrum of normal variants and diseases that involve the ribs. RadioGraphics 1999;19(5):1125–1142.

9. Jeung M-Y, Gangi A, Gasser B, et al. Imaging of chest wall disorders. RadioGraphics 1999;19(3):617–637.
10. Malghem J, Vande Berg B, Lecouvet F, Maldague B. Costal cartilage fractures as revealed on CT and sonography. AJR Am J Roentgenol 2001;176(2):429–432.
11. Subhas N, Kline MJ, Moskal MJ, White LM, Recht MP. MRI evaluation of costal cartilage injuries. AJR Am J Roentgenol 2008;191(1):129–132.
12. Ontell FK, Moore EH, Shepard JA, Shelton DK. The costal cartilages in health and disease. RadioGraphics 1997;17(3):571–577.
13. Lee TJ, Collins J. MR imaging evaluation of disorders of the chest wall. Magn Reson Imaging Clin N Am 2008;16(2):355–379, x.
14. Sangster GP, González-Beicos A, Carbo AI, et al. Blunt traumatic injuries of the lung parenchyma, pleura, thoracic wall, and intrathoracic airways: multidetector computer tomography imaging findings. Emerg Radiol 2007;14(5):297–310.
15. Lopez V Jr, Ma R, Li X, Steele J, Allen AA. Costal cartilage fractures and disruptions in a rugby football player. Clin J Sport Med 2013;23(3):232–234.
16. Peterson LL, Cavanaugh DG. Two years of debilitating pain in a football spearing victim: slipping rib syndrome. Med Sci Sports Exerc 2003;35(10):1634–1637.
17. Willis-Owen C, Kemp SP, Thomas RD. Hepatic injury after costochondral separation in a rugby football player. Clin J Sport Med 2009;19(1):70–71.
18. Hayashi D, Roemer FW, Kohler R, Guermazi A, Gebers C, De Villiers R. Thoracic injuries in professional rugby players: mechanisms of injury and imaging characteristics. Br J Sports Med 2014;48(14):1097–1101.
19. Kemp SP, Targett SG. Injury to the first rib synchondrosis in a rugby footballer. Br J Sports Med 1999;33(2):131–132.
20. McAdams TR, Deimel JF, Ferguson J, Beamer BS, Beaulieu CF. Chondral rib fractures in professional American football: two cases and current practice patterns among NFL team physicians. Orthop J Sports Med 2016;4(2):2325967115627623.
21. Piao Z, Takahara M, Harada M, et al. The response of costal cartilage to mechanical injury in mice. Plast Reconstr Surg 2007;119(3):830–836.
22. Mattox R, Reckelhoff KE, Welk AB, Kettner NW. Sonography of occult rib and costal cartilage fractures: a case series. J Chiropr Med 2014;13(2):139–143.
23. Lee WS, Kim YH, Chee HK, Lee SA. Ultrasonographic evaluation of costal cartilage fractures unnoticed by the conventional radiographic study and multidetector computed tomography. Eur J Trauma Emerg Surg 2012;38(1):37–42.
24. OBrien M, Myers D, Spizarny D. Costal cartilage injuries in acute trauma: an overlooked injury (digital poster). Presented at the Radiological Society of North America 2014 Scientific Assembly and Annual Meeting, Chicago, IL. http://archive.rsna.org/2014/14005162.html.
25. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977;33(1):159–174.
26. Gossner J. Pseudarthrosis of the cartilaginous part of the first rib is a common incidental finding on chest CT. Diagn Interv Imaging 2016;97(1):53–56.
27. Brower AC, Woodlief RM. Pseudarthrosis at the first sternocostal synchondrosis. AJR Am J Roentgenol 1980;135(6):1276–1277.
28. Takeuchi M, Goto T, Yukata K, et al. Nonunion of the first sternocostal synchondrosis accompanied by sternoclavicular joint synovitis. Case Rep Orthop 2014;2014:798329.
29. Gupta A, Jamshidi M, Rubin JR. Traumatic first rib fracture: is angiography necessary? A review of 730 cases. Cardiovasc Surg 1997;5(1):48–53.
30. Woodring JH, Fried AM, Hatfield DR, Stevens RK, Todd EP. Fractures of first and second ribs: predictive value for arterial and bronchial injury. AJR Am J Roentgenol 1982;138(2):211–215.
31. Steenburg SD, Ravenel JG, Ikonomidis JS, Schönholz C, Reeves S. Acute traumatic aortic injury: imaging evaluation and management. Radiology 2008;248(3):748–762.
32. Oikonomou A, Prassopoulos P. CT imaging of blunt chest trauma. Insights Imaging 2011;2(3):281–295.
33. Bruno MA, Walker EA, Abujudeh HH. Understanding and confronting our mistakes: the epidemiology of error in radiology and strategies for error reduction. RadioGraphics 2015;35(6):1668–1676.
34. Cho SH, Sung YM, Kim MS. Missed rib fractures on evaluation of initial chest CT for trauma patients: pattern analysis and diagnostic value of coronal multiplanar reconstruction images with multidetector row CT. Br J Radiol 2012;85(1018):e845–e850.