

Disruption Junction: A Chest Wall Injury Society Survey on Costal Margin Rupture, Intercostal, Diaphragmatic, And Abdominal Wall Hernia Diagnosis and Management

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Abstract

Background: Costal margin rupture (CMR), intercostal hernia (IH), diaphragm rupture (DR) non-union fracture (NURF) are poorly described and management remains unclear. CT analysis is recognized as essential for identifying CMR/IH/DR/NURFs. We hypothesized 1) CT recognition of these injuries is variable and, 2) debate exists regarding the non-operative and operative management.

Methods: We utilized the Chest Wall Injury Society (CWIS) Thoracic Injury Correlation Collaboration (TICC) to survey surgeons. Practice demographics were collected; 9 cases, all with standard 3-view CT were shown. Diagnoses were determined by surgical treatment and defined the gold standard. Participants were asked to 1.) identify the presence of CMR, IH, DR, or NURF and, 2.) select combined surgical/nonsurgical approaches.

Results: The TICC survey was sent to 493 individual surgeons with 36 responses. Surgeons characterized as trauma 61%, thoracic 56%, orthopedic 6%, and general 17%. They represented 15 countries. They treated the following number of patients with CMR per year: 0 – 11%, 1-2 39%, 3-5 31%, 6-10 8%, >10 11%. Agreement in diagnosis was made for CMR 80%, DR 66%, IH 84%, and NURF 81%. Agreement in identification of all components was a median of

43%. Comparing surgeon agreement to the number of CMR repairs per year 0 vs 1-2 vs 3-5 vs 6-10 vs >10 revealed the following results: 25% vs 83% vs 100% vs 89% vs 89%, $p = 0.027$. Favored techniques for repair are: CMR- titanium plates, 67 – 84%; DH- mesh 50 – 86% and suture 57 – 83%; IH- double layer mesh 12 – 61%; NURF-titanium plates 93 – 100%.

Conclusion: Identification and treatment of CMR, IH, DR, and NUF remains variable and detecting all 4 components of these injuries is uncommon. Experience with CMR seems to relate to ability to recognize injuries on CT scan. Further evaluation of methods to detect, characterize, and treat these injuries are warranted.

Keywords: Costal Margin Rupture, Non-Union Rib Fractures, Intercostal Hernia, Diaphragm Rupture

1. Introduction

The costal margin is a series of interconnected hyaline cartilage bars originating from the anterior ribs associated with the sternum, the bony chest wall, anterolateral abdominal wall, and the diaphragm. In some circumstances, when left untreated, acute injury to the costal margin may result in chronic disruption of the costal margin, ongoing pain, non-united rib fractures, intercostal hernia (IH), abdominal wall hernia, and diaphragm rupture (DR). A classification of injuries around the costal margin has been proposed, relying on “sequential analysis” of the presence or absence of costal margin rupture (CMR), IH and DR to give distinct radiologic entities [1]. These injuries are perceived to be rare and are frequently under-recognized, although larger cohort series have been published recently. Even in the case reports describing “thoraco-abdominal hernia”, the presence of CMR and its central role in the pathogenesis of these injuries is frequently overlooked [2]. An enhanced knowledge of costal margin anatomy has facilitated a better understanding of the patterns of injury [3,4]. The category of CMR and IH occurs most frequently with injury to the 9th costal cartilage, either a fracture of the costal cartilage with separation or a rupture of the interchondral joint ligaments causing separation of an intact costal cartilage from its cephalad neighbor. A range of different aetiologies has been described, with IH associated with chronic presentation [5].

The variable reporting of the presence of CMR in the literature suggests that there are challenges in the accurate radiology assessment of injury, which relies on the analysis of computed tomography (CT) scans. One aim of this study was to determine the inter-observer variability of CT assessment of a spectrum of CMR injuries. With regards to the clinical management of CMR associated with IH, there is no consensus regarding the optimal timing or techniques of surgical repair, with a variety of techniques described [6-8]. Hence, we also aimed to determine the most common surgical strategy regarding the indications for repair.

2. Methods

2.1. Study Design

This survey was performed by the Thoracic Injury Correlation Collaboration (TICC) by CWIS, an online collaboration. The protocol was exempted from medical ethical approval. In this study, the TICC by CWIS assesses the agreement in interpretation of diagnoses between surgeons with regards to the presence and extent of CMR and associated lesions. Furthermore, the

agreement on treatment is analyzed. The TICC by CWIS is an international collaboration of healthcare professionals interested in chest wall injury, with various backgrounds and different levels of experience. The survey was designed and distributed with an online survey tool to the CWIS surgeon members. For this survey, 493 CWIS surgeon members were invited of whom 36 (7.3%) completed the survey. In order to ensure we were obtaining data from the majority of experienced surgeons in CMR, a second brief survey regarding experience alone was sent to the same group of surgeons and cross-referenced with the more extensive TICC survey respondents. Invitations were sent via email in October 2024. The CWIS members participate voluntarily and do not receive (financial) incentives to participate.

2.2. Case Selection

For the CMR injuries 9 cases, all with standard 3 view computed tomography (CT) chest imaging with cartilage 3-dimensional reconstruction were shown, anonymized. These patients were all operated on by two of the senior authors. The operative findings were analyzed in the operative reports and defined the gold standard for the presence or absence of various injuries.

2.3. Survey Design

Each participant viewed the 9 CMR cases. The CT scans were given in YouTube format. After each case presentation the participants were asked to 1.) identify the presence of CMR, IH, DR, or NURF (yes/no) and, 2.) select combined surgical or nonsurgical approaches (sutures, plates, mesh, non-operative and/or referral to another center) to any injuries that were recognized. Of the participants the following variables were collected: subspecialty (trauma, thoracic, orthopedic and/or general surgery), country of practice, number of treated CMR patients per year.

2.4. Statistical Analysis

Descriptive statistics of all observer characteristics were performed. Correct diagnoses will be presented stratified for background and number of treated CMR lesions annually. Data were analyzed utilizing the Statistical Package for the Social Sciences (SPSS) version 30 (SPSS, Chicago, IL, USA). Normally distributed data is presented as mean $\pm$ standard deviation and non-normally distributed data is presented as median (minimum - maximum range). A p -value <0.05 was considered statistically significant. All tests were performed as two-sided evaluations. For continuous data, non-normally distributed data was analyzed using

Mann-Whitney U-test and Kruskal-Wallis Test if the comparison was dichotomous or multiple groups respectively.

3. Results

The TICC survey was performed by 36 international surgeons. The continent where they resided is represented in Figure 1.

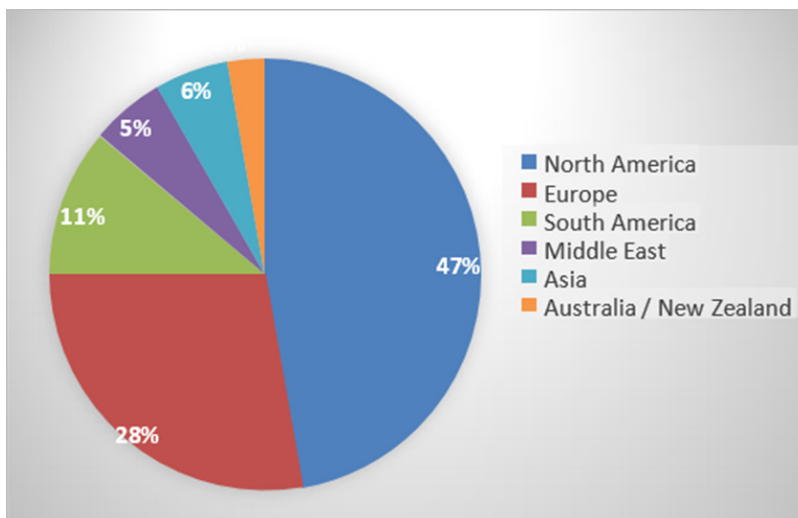


Figure 1: Residence of Respondents

Respondents self-identified as trauma surgeons 61% (22/36), thoracic surgeons 56% (20/36), general surgeons 17% (6/36) and orthopedic surgeons 6% (2/36). Many of the respondents identified with more than one surgeon type 36% (11/36). The average number of rib fracture patients treated at their institution was 0-100 per year (31%), 101 – 200 per year (28%), and > 200 per year (41%). They had been in practice 0-5 years (11%), 6-10 years (25%), 11-20 years (33%), and > 20 years (31%). SSRF had been a part of their practice for 0-5 years (20%), 6-10 years (42%), 11-20 years (36%), > 20 years (3%). They performed SSRF at their institution 0-5 times per year (0%), 6-10 times per year (20%), 11-20 times per year (36%), and > 20 times per year (44%). They had been aware of a pathology referred to as “costal margin rupture” for < 1 year (22%), 2-4 years (36%), 5-10 years (28%), > 10 years (14%).

Patients were surgically managed for costal margin rupture or intercostal hernia by the surgeons 0 times per year (11%), 1-2

times per year (39%), 3-5 times per year (31%), 6-10 times per year (8%), > 10 times per year (11%). The second short survey was performed by 136 surgeons, 49% of respondents repair costal margins (66/136). Of the respondents they repaired # last 12 months 0 (10% (10)), 1-2 (58% (37)), 3-5 (19% (12)), 6-10 (6% (4)), >10 (2% (1)) No response (2). They repaired # last 36 months 0 (3), 1-2 (23), 3-5 (18), 6-10 (13), >10 (7) No response (2). They repaired this many in their career 0 (0), 1-2 (14), 3-5 (16), 6-10 (16), >10 (16), no response (4).

Injuries were in agreement and identified on CT scan imaging by the reviewers for costal margin rupture (80 +/- 12%, diaphragm rupture 66 +/- 26%, intercostal muscle rupture 85 +/- 17%, and non-union fractures 18 +/- 21%. Overall, the presence or absence of these injuries were agreed upon in only 43 +/- 27% of evaluations. Identification correlation with the presence of absence of injury is summarized in Table 1.

Scenario	Costal Margin Rupture	Diaphragm Rupture	Intercostal muscle rupture	Non-union Fractures	All injuries identified correctly
1	Yes 86% (31/36)	Yes 17% (6/36)	Yes 78% (28/36)	Yes 81% (29/36)	6% (2/36)
2	Yes 94% (29/31)	No 74% (23/31)	Yes 87% (27/31)	Yes 90% (28/31)	55% (17/31)
3	Yes 83% (25/30)	No 77% (23/30)	Yes 93% (28/30)	Yes 90% (27/30)	57% (17/30)
4	Yes 85% (22/26)	Yes 81% (21/26)	Yes 100% (26/26)	Yes 88% (23/26)	72% (18/26)
5	Yes 78% (18/23)	Yes 61% (14/23)	Yes 100% (23/23)	No 65% (15/23)	21% (5/23)
6	Yes 55% (12/22)	Yes 32% (7/22)	No 45% (10/22)	No 31% (7/22)	0% (0/22)
7	Yes 68% (15/22)	No (86% (19/22)	Yes 77% (17/22)	Yes 95% (21/22)	45% (10/22)
8	Yes 86% (19/22)	No 72% (16/22)	Yes 95% (21/22)	Yes 100% (22/22)	59% (13/22)
9	No 81% (18/22)	No 95% (21/22)	Yes 86% (19/22)	No 91% (20/22)	68% (15/22)
Overall	80 +/- 12%	66 +/- 26%	85 +/- 17%	81 +/- 21%	43 +/- 27%

Table 1: Correct identification of the injuries on radiograph compared to intraoperative findings

Comparing participants that identified as trauma surgeons to non-trauma surgeons no significant differences were identified in the diagnosis of the following injuries on CT scan: costal margin rupture (89% (0-100) vs 89% (0-100), $p = 0.253$), diaphragm injury (67% (20-100) vs 78% (0-100), $p = 0.116$), intercostal muscle injury (89% (0-100) vs 89% (0-100), $p = 0.377$), or nonunion injury (83% (0-100) vs 89% (0-100), $p = 0.451$). Comparing participants that identified as thoracic surgeons to non-thoracic surgeons no significant differences were identified in the diagnosis of the following injuries on CT scan: costal margin rupture (89% (0-100) vs 89% (0-100), $p = 0.765$), diaphragm injury (72% (0-100) vs 71% (44-100), $p = 0.912$), intercostal muscle injury (89% (0-100) vs 89% (25-100), $p = 0.386$), or nonunion injury (83% (0-100) vs 89% (0-100), $p = 0.582$).

Comparing participants that identified as general surgeons to non-general surgeons no significant differences were identified in the diagnosis of the following injuries on CT scan: costal margin rupture (63% (0-100) vs 89% (0-100), $p = 0.327$), diaphragm injury (72% (50-89) vs 71% (0-100), $p = 0.852$), intercostal muscle injury (82% (0-100) vs 89% (0-100), $p = 0.394$), or nonunion injury (77% (50-100) vs 89% (0-100), $p = 0.467$). Comparing participants' ability to injuries based on time in practice 0-5 vs 6-10 vs 11-20 vs > 20 years revealed the following results: costal margin (89% (67-100) vs 89% (0-100) vs 89 (0-100) vs 78% (0-100) vs, $p = 0.891$), Diaphragm injury (72 % (67 – 89) vs 78% (20-89) vs 67% (0-100) vs 75% (33-100), $p = 0.868$), intercostal injury (100% (78 – 100) vs 89% (0-100) vs 89% (0-100) vs 89% (25-100), $p = 0.374$), nonunion injury (89% (89-100) vs 89% (50-100) vs 72% (0-100 vs 89% (0-100), $p = 0.366$).

Comparing participants' ability to injuries based on years performing SSRF 0-5 vs 6-10 vs 11-20 vs > 20 years revealed the following results: costal margin (89% (0-100) vs 89% (0-100) vs 89% (0-100) vs 78% (78-78) vs, $p = 0.851$), Diaphragm injury (78 % (50 – 100) vs 67% (0-89) vs 67% (33-100) vs 78% (78-78), $p = 0.638$), intercostal injury (100% (25 – 100) vs 89% (0-100) vs 89% (50-89) vs 89% (89-89), $p = 0.509$), nonunion injury (89% (75-100) vs 89% (50-100) vs 67% (0-100) vs 89% (89-89), $p = 0.134$). Comparing participants' ability to injuries based on SSRF performed per year 6-10 vs 11-20 vs > 20 years revealed the following results: costal margin (50% (0-100) vs 89% (0-100) vs 89% (0-100) vs, $p = 0.242$), Diaphragm injury (50% (0-100) vs 78% (20-100) vs 78% (20-100), $p = 0.384$), intercostal injury (89% (0-100) vs 89% (25-100) vs 89% (25-100), $p = 0.978$), nonunion injury (89% (50-100) vs 89% (0-100) vs 89% (0-100), $p = 0.905$). Comparing participants' ability to injuries based on number of costal margin repairs per year 0 vs 1-2 vs 3-5 vs 6-10 vs >10 revealed the following results: costal margin (25% (0-50) vs 83% (0-100) vs 100% (67-100) vs 89% (38-100) vs 89% (89-89), $p = 0.027$), Diaphragm injury (75 % (50 – 100) vs 78% (20-100) vs 67% (56-78) vs 63% (0-89) vs 72% (56-78%), $p = 0.968$), intercoastal injury (38% (0 – 100) vs 89% (0-100) vs 89% (25-100) vs 89% (75-100) vs 89% (89-100), $p = 0.434$), nonunion injury (63% (0-100) vs 89% (0-89) vs 89% (56-100) vs 88% (67-100) vs 89 (67-100), $p = 0.401$).

Techniques to repair the costal margin rupture differed with each case. The majority of surgeons favored using plates in 67 – 84%, mesh in 33 – 74%, and sutures in 13 – 46% of cases (Table 2).

Scenario	Sutures	Plates	Mesh	Suture + Plate	Plate + Mesh	Suture + Mesh	Suture + Plate + Mesh	Non-operative	Refer to another facility
1	29% (9/31)	71% (22/31)	74% (23/31)	19% (6/31)	55% (17/31)	19% (6/31)	16% (5/31)	3% (1/31)	0%
2	21% (6/29)	79% (23/29)	62% (18/29)	17% (5/29)	41% (12/29)	10% (3/29)	7% (2/29)	0%	0%
3	32% (8/25)	72% (18/25)	68% (17/25)	16% (4/25)	48% (12/25)	20% (5/25)	12% (3/25)	0%	0%
4	36% (8/22)	68% (15/22)	55% (12/22)	18% (4/22)	36% (8/22)	14% (3/22)	9% (2/22)	0%	0%
5	22% (12/18)	67% (12/18)	56% (10/18)	6% (1/18)	28% (5/18)	11% (2/18)	0%	0%	0%
6	42% (5/12)	67% (8/12)	33% (4/12)	17% (2/12)	25% (3/12)	8% (1/12)	8% (1/12)	0%	0%
7	13% (2/15)	73% (11/15)	40% (6/15)	7% (1/15)	33% (5/15)	0%	0%	0%	0%
8	26% (5/19)	84% (16/19)	47% (9/19)	21% (4/19)	32% (6/19)	5% (1/19)	0%	0%	0%
9	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 2: Costal Margin Repair Technique

A combination of these repair techniques were the preferred repair method: sutures + plate 6 – 12%, plate + mesh 25 – 55%, suture + mesh 0 – 20%, and suture + plate + mesh 0 – 16% of cases.

Diaphragm ruptures were treated in the majority of facilities however 5% would transfer to another facility. Only four of the scenarios had a diaphragm rupture but when it was identified it was always justified repair. The repair would consist of mesh 50 – 86% of the time and suture 57 – 83% of the time (Table 3).

Scenario	Mesh	Suture	Suture + Mesh	Non-operative	Refer to another facility
1	50% (3/6)	83% (5/6)	33% (2/6)	0%	0%
2	NA	NA	NA	NA	NA
3	NA	NA	NA	NA	NA
4	81% (17/21)	66% (14/21)	52% (11/21)	0%	5% (1/21)
5	86% (12/14)	71% (10/14)	57% (8/14)	0%	0%
6	71% (5/7)	57% (4/7)	29% (2/7)	0%	0%
7	NA	NA	NA	NA	NA
8	NA	NA	NA	NA	NA
9	NA	NA	NA	NA	NA

Table 3: Diaphragm Rupture Repair Technique

A combination of mesh and suture was planned to be used in 29 mesh 9 - 42%, double-layer mesh 12 – 61% in these scenarios – 57% of cases. The proposed method of repairing the intercostal (Table 4). hernia included sutures 5-37%, internal mesh 30 – 44%, external

Scenario	Sutures	Internal Mesh	External Mesh	Double-Layer Mesh	Suture + Internal Mesh	Suture + external Mesh	Suture + Double-Layer Mesh	Non-Operative	Refer to Another Facility
1	36% (10/28)	43% (12/28)	14% (4/28)	10% (10/28)	21% (6/28)	4% (1/28)	4% (1/28)	0%	0%
2	33% (9/27)	44% (12/27)	11% (3/27)	44% (12/27)	15% (4/27)	4% (3/27)	11% (3/27)	0%	0%
3	32% (9/28)	43% (12/28)	14% (4/28)	43% (12/28)	11% (3/28)	4% (1/28)	11% (3/28)	0%	0%
4	5% (1/26)	35% (9/26)	38% (10/26)	12% (3/26)	12% (3/26)	4% (1/26)	12% (3/26)	0%	8% (2/26)
5	35% (8/23)	30% (7/23)	9% (2/23)	61% (14/23)	13% (3/23)	4% (1/23)	13% (3/23)	0%	0%
6	NA	NA	NA	NA	NA	NA	NA	NA	NA
7	35% (6/17)	35% (6/17)	35% (6/17)	29% (5/17)	18% (3/17)	12% (2/17)	12% (2/17)	6% (1/17)	0%
8	29% (6/21)	33% (7/21)	14% (3/21)	57% (12/21)	14% (3/21)	5% (1/21)	10% (2/21)	0%	0%
9	37% (7/19)	42% (8/19)	42% (8/19)	21% (4/19)	11% (2/19)	11% (2/19)	11% (2/19)	0%	0%

Table 4: Intercostal Hernia Repair Technique

Multiple repair techniques were proposed in the scenarios: suture + internal mesh 11 – 21%, suture + external mesh 4 – 12%, suture + double-layer mesh 4-13%. When non-united rib fractures were identified, the proposed repair was planned with sutures 3-10% and plates 93 – 100% of the time. (Table 5) Sutures and plates were the planned repair in 3-10%. Non-operative management was planned in 0-7% of scenarios.

Scenario	Sutures	Plates	Suture + Plates	Non-Operative	Refer to Another Facility
1	3% (1/29)	93% (27/29)	3% (1/28)	7% (2/29)	0%
2	0%	96% (27/28)	0%	4% (1/29)	0%
3	4% (1/27)	100% (27/27)	4% (1/27)	0%	0%
4	9% (2/23)	96% (22/23)	4% (1/23)	0%	0%
5	NA	NA	NA	NA	NA
6	NA	NA	NA	NA	NA
7	10% (2/21)	95% (20/21)	10% (2/21)	5% (1/21)	0%
8	9% (2/22)	95% (21/22)	5% (1/22)	0%	0%
9	NA	NA		NA	NA

Table 5: Non-Union Repair Technique

4. Discussion

The ability of experienced chest wall surgeons to recognize and agree on CMR, DR, IH, and NURF remains variable. Intra-observer agreement was common for these injuries when taken independently (80%, 66%, 85%, 81% respectively) but was rare amongst surgeons agreeing on all 4 components of these injuries (43% agreement). As previously reported, there are challenges in the accurate radiologic assessment of the injury, which relies on the analysis of CT scans, but these challenges seem to be more related to diagnosing the full extent of all injuries rather than the individual and more obvious pathologies (ie large IH or easily visible NURF) [1,2,5]. The question remains, are surgeons not agreeing on these injuries because they aren't visible on CT? It is the authors' belief that the majority (if not all) of these injuries are visible on CT when compared to the operative findings, however capturing their entirety is often overlooked and difficult for even the most trained surgeon. It is our opinion that CT scan should be the gold standard radiographic modality to recognize this pathology and that appropriate education regarding recognition of CMR, DR, IH, and NURF on CT is needed across medical disciplines.

Comparing surgeon CMR repair experience in volume/year did create a statistically significant difference in injury recognition and prompts the discussion as to whether or not CMR, IH, DR, and NURF should be best evaluated and treated in high-volume centers. Understanding differences in ability to detect injuries and subsequently treat said injuries and how they relate to patient outcomes is unknown and warrants further study. Lastly, intra-observer agreement was common for these injuries when taken independently but diminished when considering all 4 components of these injuries. It may be beneficial to conduct a multi-disciplinary/multi-surgeon review of these cases in order to enhance the detection of the full extent of CMR and subsequently increase agreement in treatment strategy.

Preoperative recognition of CMR injury patterns likely relates to operative management/intervention [5]. We found the operative management of each of these injuries to be variable and may be related to the aforementioned differing CT interpretations amongst surgeons. However, regional repairs were favored. Most commonly CMR was repaired with titanium plates, DR with suture and/or mesh, IH with a double-layer mesh (intra and extrathoracic), and NURF with titanium plates. More research is needed to ascertain which repair/technique is most efficacious for individual injuries.

This study has several limitations; most notably the potential for our low response rates (36/493 surgeons) impacting data validity. The second short survey was sent to the same 493 individual surgeons with 136 responses. Of those, we identified a total of 66 surgeons who had experience with CMR. The second brief survey yielded more surgeons but less experienced surgeons (per year) compared to the TICC survey, 1-2 cases/yr (58% vs 39%), 3-5 (19% vs 31%), 6-10 (6% vs 8%), and >10 (2% vs 11%) respectively. Though the TICC survey response rate was low from the general membership we believe 1) response rate was low simply because there are not many chest wall surgeons practicing CMR repair, and 2) more

experienced surgeons did complete the TICC survey and hence represent a more valid sample of surgeon expertise in CMR.

Other limitations include difficulty accurately representing the whole spectrum of injuries within the realm of CMR. We did ensure that all possible combinations of injuries were represented as described by the Sheffield Classification, but the delivery method, utilizing pre-recorded, short YouTube video clips to view the CT and 3D reconstructions, may have led to increased misinterpretations, as these are much different than "scrolling" through a CT at one's leisure. Another limitation is of course respondent fatigue due to the length of the survey, as this survey took a minimum of 45 min to complete; it was understood by the authors that this may lead to a potential decrease in recognition of the injury patterns. Lastly, in this form, the questions and cases lack the full ability to capture complex nuances of patient presentation/symptomatology, injury recognition, and repair plans with simple questions and videos.

5. Conclusion

Identification of CMR, IH, DR, and NUF remains variable and detecting all 4 components of these injuries is uncommon. Experience in CMR repair may relate to one's ability to recognize injuries on CT scan. The operative management of each of these injuries is variable but amongst experienced surgeons tends to be titanium plates with CMR/NURF and double-layer mesh repair for IH. Further education amongst chest wall surgeons and evaluation of methods to better detect, characterize, and subsequently treat these injuries is warranted.

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