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Chest Wall Injuries in Athletes

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Abstract

Purpose of Review Musculoskeletal injuries of the chest wall are underrecognized by sports medicine clinicians. The purpose of this review is to highlight key elements of the presentation and management of chest wall injuries seen in an athletic population.

Recent Findings Chest wall injuries may arise from the bony or cartilaginous structures, joints, or myofascial structures of the trunk. Injury can occur in the setting of trauma during sport or may occur due to overuse. Many chest wall injuries can be successfully rehabilitated, allowing return to the athlete's prior level of play. However, some injuries carry a risk of complications and should be monitored closely.

Summary Chest wall pain is common in athletes and can arise from a variety of musculoskeletal structures. Timely recognition and treatment helps to minimize lost fitness and hasten return to play. Further research is needed to identify modifiable risk factors and optimize rehabilitation outcomes.

Keywords Chest wall injuries · Musculoskeletal injuries in athletes · Athletic injuries · Thoracic trauma

Introduction

Chest pain is a common presenting complaint that can arise from musculoskeletal, visceral, or referred sources. Musculoskeletal injuries of the chest wall are underrecognized by sports medicine clinicians and are underrepresented in the literature, leading to delays in diagnosis and costly evaluations for visceral pathology. This review focuses on injuries of the chest wall in athletes, with an emphasis on conditions arising from the ribs, sternum, joints of the thoracic cage, and myofascial structures of the anterior and lateral trunk (Fig. 1). Injuries of traumatic and nontraumatic etiology are included. Injuries to the pectoralis major and minor muscles have been covered previously and are not presented here [1].

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Rib Injuries

Rib Bone Stress Injury

Bone stress injury (BSI) of the ribs has been observed in a number of sports, particularly those involving twisting motions of the torso or repetitive strain on the upper extremity. Rowers, golfers, throwers, swimmers, and overhead athletes are most commonly affected [2, 3]. In an elite rowing cohort, the 4-year period prevalence of at least one rib stress injury was 9.9%, with a median 10 weeks of lost training time [4•]. Risk factors include female sex, decreased bone mineral density, lack of strength or flexibility, training errors, poor technique, or changes in equipment [4, 5].

As the ribs are a non-weight-bearing location, stress injury is due to repetitive tensile muscle forces and is uncommon outside of sport. The bone of the first rib is subject to upward traction by the anterior scalene muscle and downward traction by the intercostal muscle, generating a bending force at the subclavian sulcus, which is the typical site of fracture [3, 6]. In ribs 4–9, simultaneous contraction of the serratus anterior and external obliques creates a bending force at the posterolateral angle [2, 7].

BSI of the rib presents as insidious onset of vague thoracic wall pain corresponding to the site of injury which

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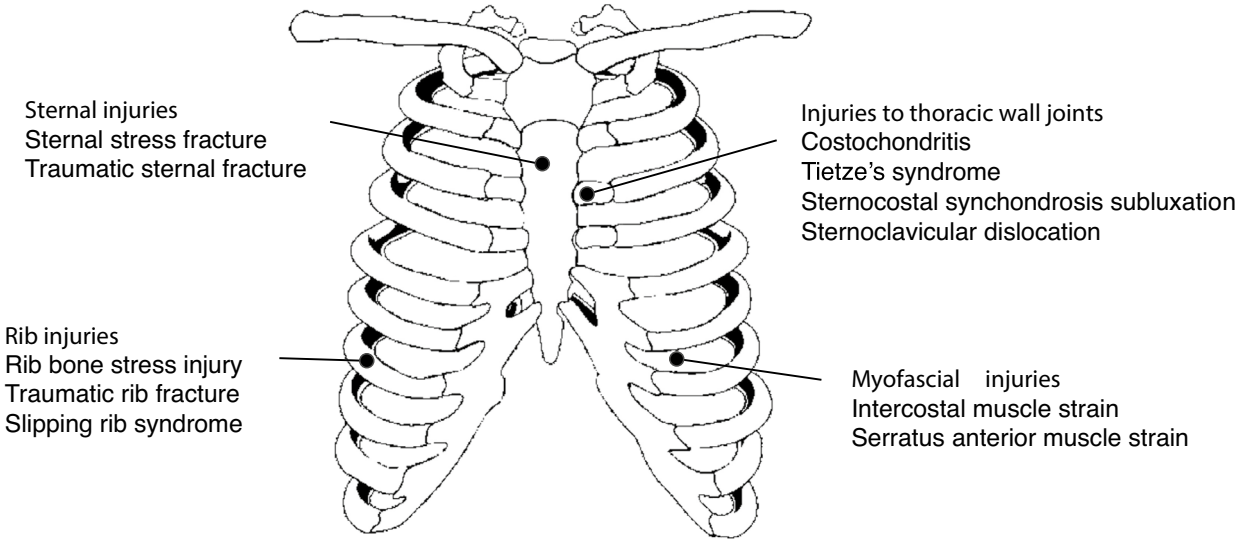

Fig. 1 Diagram showing injuries arising from the various anatomic structures of the chest wall

may progress to sharp pain sufficient to limit activity [8]. The pain may radiate along the distribution of the intercostal nerve [9]. First rib BSI may be felt in the region of the shoulder, anterior cervical triangle, clavicle, or deep in the axilla and may radiate to the sternum or pectoral region [8]. Eleventh and twelfth rib pain may be felt in the lumbosacral region [10]. Pain is often worse with deep inspiration. Exam may demonstrate local tenderness to palpation and pain with rib spring, though bony tenderness is not always present [3, 4, 8, 11]. Plain radiographs may show subtle evidence of stress fracture as early as 2 weeks after onset of pain, though more obvious findings such as callous formation may not be present until several weeks after injury [11]. Chest radiographs are appropriate for detection of lower rib injuries, while the first rib is more clearly visualized on radiographs of the shoulder or cervical spine [12]. First rib nonunion may be an incidental finding [8]. CT, MRI, or triple phase bone scan can be utilized in cases where there is strong clinical suspicion with negative radiographs. Additionally, ultrasound has increasingly been used for diagnosis of radiographically occult rib stress fractures [13, 14].

For injuries of the first rib, treatment involves analgesia and immobilization of the shoulder girdle of the affected side in a sling [8]. If movements are painful, a soft collar can be used to limit pull on the rib from the scalene muscles [8]. Serial radiographs should be obtained for 6 months to assess for late complications. Most athletes are able to return to sport in 4–8 weeks. However, delayed union is not unusual, and some BSI may take 4–5 months to heal. Fibrous nonunion is usually nonpainful and requires no treatment if asymptomatic [8]. Painful nonunion has been successfully treated with transaxillary total or partial rib resection [12]. Operative treatment can also be considered for excessive callous formation resulting in thoracic outlet syndrome or brachial plexus palsy [15].

BSI of other ribs has a good prognosis for uncomplicated healing. Relative rest is recommended for 4–6 weeks, though light training and cardiovascular training are acceptable [8]. As with BSI of other sites, activity should be reintroduced gradually at a reduced intensity. Most athletes return to full training or competition by 8–10 weeks [4•]. Exercises to strengthen the serratus anterior are hypothesized to reduce the risk of repeat injury. Changes to equipment or technique to reduce the work done by the serratus and the consequent force exerted on the ribs may reduce reinjury risk, as well. In rowers, smaller blades require less serratus activity to provide scapular stability [7]. Rowing with the scapulae in a less protracted position as the oars enter the water or using less scapular retraction at the end of pull-through likewise reduces the force on the rib from the serratus anterior [3].

Traumatic Rib Fractures

Rib fractures can occur with blunt trauma to the chest and most commonly affect the middle and lower ribs [16]. The most common mechanism is a direct force to the chest wall in the anteroposterior plane resulting in injury to the posterior angle of the fifth through ninth ribs. Fracture can also occur directly beneath a point of focal impact or may rarely occur as a result of a forceful muscle contraction [16]. Flail chest and serious internal injuries such as pneumothorax, hemothorax, cardiac contusion, or cardiac

tamponade can occur but are more likely to be seen with rib fractures due to high-energy trauma such as motor vehicle collisions than with athletic injury [16].

Two types of rib fracture are more commonly seen in athletes than with other types of trauma: first rib fractures and floating rib fractures [16]. The latter type are avulsion fractures of the external oblique muscle attachments resulting from sudden, vigorous, multi-directional contraction and have been reported in baseball pitchers and batters as well as a javelin thrower [8, 17]. Radiographs can differentiate this type of fracture from the more common external oblique muscle strain [16]. First rib fractures have been reported in a number of sports, with American football being the most common culprit [18–22]. Neurovascular injury is theoretically possible due to the proximity of the first rib to the subclavian vessels, brachial plexus, and aortic arch; however, the risk appears to be low [18, 19].

Patients with rib fracture present with a history of chest trauma with onset of localized pain which may be exacerbated by deep breathing. Pain may be localized to the shoulder girdle with first rib fractures [18]. Exam reveals point tenderness over the affected rib or focal tenderness with compression of the rib cage at a distant site. Bony crepitus or a palpable step-off may be present. Lung exam may show decreased breath sounds as the patient limits their depth of inspiration due to pain. All patients with suspicion for rib fracture should have chest radiographs taken to rule out associated intrathoracic injury such as pneumothorax or hemothorax, and confirm the presence of fracture; however, the sensitivity of chest x-ray for detection of nondisplaced rib fractures is generally believed to be low. In a trauma population receiving both chest radiograph and chest CT, two-thirds of rib fractures were observed on CT only [23]. However, in a series of 14 athletes in whom a first rib fracture was identified, the fracture was identified in plain radiographs in all cases [18]. CT scan or MRI is recommended if there is strong clinical suspicion for fracture and radiographs are negative, particularly in athletes as continued sporting activity may delay healing of an undiagnosed injury [18].

Treatment of isolated solitary rib fractures involves primarily pain control with ice and analgesics [16]. A rib belt or rib taping for middle and lower rib injuries or a sling for first rib injuries can be used for comfort [16, 18]. Some sources recommend allowing for a period of bony healing before returning to contact sport given the risk of pneumothorax or damage to mediastinal structures should the fractured rib displace [16, 19]. However, there are no clear guidelines governing return to sport. Among athletes with acute first rib fracture, many athletes were pain-free after 2–3 weeks and nearly all had returned to play by 12 weeks with no documented complications [18].

Slipping Rib Syndrome

Slipping rib syndrome is defined by three features: (1) pain in the lower chest or upper abdomen, (2) a tender spot on the lower costal margin, and (3) reproduction of the pain with palpation of that spot [24]. Hypermobility of the false rib costal cartilages may be a causative factor, with rupture or inadequacy of the medial fibrous attachments allowing superior subluxation of the affected cartilage and potential for intercostal nerve impingement [25]. Additionally, intercostal muscle strain can result from excessive rib mobility [26].

Presentation is often insidious, with running, rowing, swimming, field hockey, and lacrosse the most implicated sports [27–29]. Chest wall trauma may precede onset of pain in a minority of patients [27, 28, 30, 31]. A retrospective study of 54 athletes with slipping rib syndrome revealed that 70.4% of patients were female, with a mean age of 19.1 years [27]. The vast majority (90.7%) had unilateral symptoms, and ribs 8–10 were the most commonly affected. Nearly one-fifth of patients were hypermobile [27].

Slipping rib syndrome presents as transient sharp pain felt in the lower rib cage or upper abdomen which may be followed by a persistent dull ache [8, 25, 26]. The pain ranges in severity but can be debilitating [24]. Mechanical symptoms such as a slipping or popping sensation or a clicking sound may be present [8, 28]. Deep breathing or certain repetitive trunk movements may trigger symptoms. On exam, symptoms may be reproduced by applying pressure to certain points along the costal margin. A "hooking maneuver" test has been described, in which the clinician hooks their fingers beneath the lower costal margin and pulls anteriorly [32]. Reproduction of pain and mechanical symptoms constitutes a positive test. Diagnosis is clinical, though imaging is often undertaken unnecessarily to exclude other pathology due to the potential for visceral referred pain. Dynamic ultrasound can be used as a diagnostic aid and can confirm the presence of subluxation [33, 34].

Initial treatment is reassurance along with ice, NSAIDs, and activity modification. Physical therapy and osteopathic manipulation techniques can be utilized [27]. Intercostal nerve block anteriorly and posteriorly as well as of adjacent nerves or injection of steroid and local anesthetic at the costochondral junction may have diagnostic and therapeutic value for persistent symptoms [27]. Temporary improvement has been seen with trigger point and botulinum toxin injections [35]. In refractory cases, good outcomes including full return to sport have been reported following surgical excision of the affected rib and costal cartilage with preservation of the intercostal nerve to prevent neuropathic pain [27, 28]. Rib stabilization using bioabsorbable plating is an emerging treatment option [28, 36].

Sternal Injuries

Sternal Stress Fractures

Stress fractures of the sternum are exceedingly rare, though some authors postulate that the condition may be underdiagnosed [37]. Repetitive contraction of the muscles attached to the sternum, including the sternocleidomastoid and pectoralis major anteriorly, sternohyoid and sternothyroid posteriorly, and rectus abdominis distally, can generate torque that over time exceeds the remodeling capacity of the bone [8]. The injury has been reported in association with extreme upper body stresses, as in wrestlers, or with repetitive hyperflexion of the torso, such as with golf or exercises like sit-ups and triceps dips [37–43].

Patients present with anterior chest pain exacerbated by movement or deep breathing and may report a recent increase in volume or intensity of upper body or abdominal strength training. Onset may be gradual or sudden. The sternum is tender to palpation on exam, and localized swelling may be present [40]. Radiographs may be normal or may show periostitis or a fracture line. The earlier literature describes bone scans for improved detection of stress injury, but MRI is increasingly preferred [38].

Management consists of analgesia if necessary and rest from the inciting activity followed by progressive return to sport. Most athletes are symptom-free and able to resume their normal activities within 2–4 months, though residual symptoms at 15 months have been reported [37–43].

Traumatic Sternal Fractures

Traumatic sternal fractures are rare, owing to the large amount of force needed to overcome the elastic recoil of the ribs [43]. Seventy percent are sternal body fractures, of which transverse fractures through the mid-body of the sternum are most common, and 17.6% occur at the manubriosternal joint [43]. Physeal injury should be considered in the pediatric athlete as the sternal physis does not ossify until age 18 [44, 45]. The most common cause of traumatic sternal fracture is motor vehicle collision, though fractures can also be seen following a high-energy direct blow to the anterior chest wall during contact sports [46]. Sport-associated sternal fractures involve significantly lower force and therefore have a lower incidence of concomitant internal injury [44].

Athletes presenting with sternal fracture describe a history of direct trauma with moderate to severe pain over the sternum which may be pleuritic. Exam reveals tenderness to palpation and possible ecchymosis, crepitus, or deformity. Associated injuries, though less common in the sporting context, may include cranial injury, rib fracture, pulmonary or cardiac contusion, spinal fracture, retrosternal hematoma, pneumothorax, hemothorax, and extremity injury [46].

Initial imaging with AP and lateral radiographs should be obtained for suspected sternal fracture. Ultrasound may be more sensitive and specific for sternal fracture than plain radiographs and can evaluate for retrosternal hematoma and other associated injuries [47]. CT with contrast to identify injury of internal structures should be obtained in cases where sternal fracture is identified on radiographs or ultrasound in the setting of polytrauma but may not be necessary for nondisplaced isolated sternal fractures. EKG should be obtained to assess for myocardial injury [48, 49].

Isolated sternal fractures tend to respond well to conservative management with rest and analgesics [50]. For displaced fractures or those with cardiopulmonary complications, open reduction with sternal wires or plating is indicated [49]. Athletes should be withheld from sport pending resolution of symptoms and radiographic healing. Unrestricted return to play was reported in a female collegiate hockey player 3 months after an acute traumatic sternal fracture [44]. Bardos et al. reported on a series of five elite athletes with symptomatic nonunion of a vertical sternal fracture who achieved fracture healing following ORIF, with four athletes able to return to sport at their preinjury level [51].

Conditions Affecting Thoracic Wall Joints

Costochondritis

Costochondritis is a common condition characterized by pain and tenderness over the costochondral or chondrosternal joints without associated swelling, typically involving multiple sites and most commonly occurring at the second through fifth costal cartilages. It accounts for a high proportion of medical visits for chest pain and is associated with female gender, Hispanic and Afro-Caribbean origin, and lower socioeconomic status. While the etiology is unknown, inflammation is thought to play a role as evidenced by the raised erythrocyte sedimentation rate, presence of morning stiffness, and positive gallium scan observed in a proportion of patients. Hypermobility of the thoracic spine was hypothesized to be a contributing factor in a report of a female collegiate rower with costochondritis [52]. The incidence of costochondritis in athletes has not been reported; however, its high incidence in the general population, including young adults, makes it an important diagnostic consideration in athletes presenting with chest pain.

Diagnosis is clinical and based on a history of anterior chest wall pain which is reproducible with palpation over the costochondral junctions or chondrosternal joints on exam. The presence of swelling, warmth, or erythema suggests an alternative diagnosis of Tietze's syndrome. Compression of

the affected joints via ipsilateral arm adduction with head rotation to the same side may reproduce pain. Routine imaging is unnecessary, though cardiopulmonary or neoplastic disease should be ruled out in patients with risk factors. If obtained, radiographs are typically normal but may show soft-tissue swelling or chondral calcification.

Treatment is with analgesics and reassurance. Athletes may continue sporting activity as tolerated, though a period of activity restriction may provide symptom relief. Most cases resolve within weeks to months, but refractory cases may demonstrate persistent or recurrent symptoms for a year or more. Anesthetic or corticosteroid injections can be considered if symptoms fail to respond to stretching exercises, heat, and ice. A female collegiate volleyball player experienced improvement with manipulation of hypokinetic joints, soft-tissue mobilization, and taping [53].

Tietze's Syndrome

Tietze's syndrome is a benign but painful inflammation of the costosternal, sternoclavicular, or costochondral joints which, by definition, is accompanied by localized swelling [8, 54]. It is rare and usually occurs in young adults [54]. Aside from early reports in the Russian literature, the condition has not been well studied in athletes. In contrast to the more diffuse inflammation of costochondritis, the inflammation in Tietze's syndrome is focal and typically involves a single site, most commonly the second or third rib [8]. The onset is insidious and the cause is unknown, though it may be related to repetitive movements, thoracic trauma, or antecedent cough. Some have proposed a systemic inflammatory etiology and suggested the syndrome may overlap with seronegative spondyloarthritides with chest wall involvement [55, 56].

Radiographs are often normal [8]. MRI can be considered for refractory cases and may show cartilage or subchondral edema or cartilage thickening [57]. The course is usually self-limited but may be characterized by waxing and waning symptoms. NSAIDs are generally effective for pain control, though the swelling may persist [6]. Refractory symptoms may benefit from local infiltration with corticosteroid or anesthetic [58]. Surgical resection has been performed in rare cases with good results [59].

Sternocostal Synchondrosis Subluxation

Fracture-subluxation of the second sternocostal synchondrosis has been reported in an 18-year-old wrestler who experienced a combination of leverage and twisting forces across the sternocostal joint [60]. The patient described a popping sensation and severe pain over the left upper chest as he twisted his torso in an attempt to extricate himself from a hold. Examination revealed a tender swelling over the second sternocostal junction which became more prominent with shoulder abduction and extension, though shoulder range of motion was preserved. Radiographs were normal, but bony fragments and subluxation at the sternocostal joint were seen on CT. The injury was initially treated with anti-inflammatories and rest. The wrestler underwent surgical exploration and debridement due to persistent symptoms and was symptom-free at 3-month follow-up [60].

Sternoclavicular Dislocation

The sternoclavicular joint is a saddle-shaped synovial joint which derives most of its stability from the posterior capsule and the sternoclavicular, costoclavicular, and intraarticular disc ligaments anteriorly [61••]. Dislocation most commonly occurs in high-impact sports such as football and rugby and can result from a direct blow to the medial clavicle or from medially directed compression of the shoulder girdle (e.g., with a tackle during contact sport) [62, 63]. It has also been reported in a baseball player during the acceleration phase of throwing [64]. The joint can dislocate anteriorly, typically due to a lateral compressive force causing rupture of the anterior capsule and often the costoclavicular ligament, or posteriorly, by a direct force to the medial clavicle or indirect force to the posterolateral shoulder [63]. Posterior subluxations are more rare but have the potential to cause life-threatening injury to mediastinal structures [61, 63, 65].

Patients present with anterior chest and shoulder pain which is worse with arm movement. Dyspnea, dysphagia, or arm paresthesias may signal internal injury [63, 66, 67]. A prominence of the sternoclavicular joint may be palpable with anterior dislocation. Swelling and reduced upper extremity range of motion may be observed [63]. Plain radiographs have low sensitivity for detection of malalignment but are useful for ruling out associated injury such as pneumothorax, pneumomediastinum, or hemopneumothorax [61, 63, 63]. CT is the preferred imaging modality for diagnosis and characterization of sternoclavicular joint dislocations, and intravenous contrast should be added in cases of posterior dislocation to evaluate for vascular injury [61••]. Ultrasound has increasingly played a role in diagnosis of sternoclavicular dislocation [68, 69].

Anterior dislocations should ideally be reduced within 24 h, as closed reduction becomes more difficult after 48 h. However, closed reduction can be attempted within the first 7–10 days. Traction is applied with the affected arm in 90° of abduction while direct pressure is applied over the medial clavicle with the patient in a supine position with a bolster between their shoulders. Patients should then be placed in a sling for 4 weeks [63]. Persistent anterior instability, though common after non-operative treatment, is generally well tolerated and can be managed conservatively [63]. Some patients go on to require surgical stabilization [70, 71]. Posterior dislocations require urgent reduction and typically require consultation with cardiovascular

surgery if vascular injury is present. A traction-abduction technique has been described, with the shoulder abducted to 90° and placed in traction while an extension force is applied to the shoulder [72]. A method utilizing a percutaneous towel clip to grasp the medial clavicle and pull it anteriorly has also been used. Numerous surgical techniques have been used with success to achieve reduction of injuries resistant to closed reduction or to address persistent sternoclavicular joint instability [73–76].

Injury to Myofascial Structures

Muscle injury may occur due to either contusion in the setting of direct trauma or strain associated with excessive load. Contusion results from crush injury to muscle fibers due to blunt trauma from the striking object or compression against underlying tissues. Acute muscular strain usually occurs during eccentric muscle contraction due to the combined forces of active contraction and passive stretch during muscle lengthening [77]. It is more often seen when an athlete returns to heavy training after a period of rest. Injury is often localized to the myotendinous junction as this is the weakest point of the muscle-tendon-bone unit. Radiographs are typically normal following soft-tissue trauma but may be obtained to look for tendon avulsion injury. MRI findings range from mild interstitial edema for minor injuries to complete fiber disruption in setting of high-grade tear [61••].

Intercostal Muscle Strain

The intercostal muscles consist of three layers that run between the ribs and function to elevate and depress the ribs during inspiration and expiration. They may also be recruited with the obliques for twisting and flexing movements of the torso [61••]. The external and internal intercostals are continuous with the external and internal obliques, respectively, and insert on the lower (external) or upper (internal) rib of each intercostal space. The neurovascular bundle runs along the posteroinferior border of each rib between the internal and innermost intercostal layers.

Intercostal muscle injury may result from unaccustomed or excessive muscular activity and may or may not have a specific inciting event [6]. The intercostal muscles can be strained during the high-velocity thoracic torque generated by baseball batting or rowing [78]. Respiratory infections with forceful or persistent cough may result in muscle strain [8].

Clinically, intercostal strains present as pain between adjacent ribs that is worse with movement, inspiration, or cough, with associated tenderness to palpation. Radiographs are normal, though imaging is rarely necessary as most injuries are low grade. Anti-inflammatories and rest are the mainstays of treatment. If pain persists, imaging should be considered to assess for stress reaction of an adjacent rib [61••].

Serratus Anterior Muscle Strain

The serratus anterior muscle originates on the lateral aspects of the first through eighth or ninth ribs and inserts onto the medial scapular border, functioning to rotate the scapula upward during arm elevation and stabilize the scapula against the ribcage. It is known as the "boxer's muscle" due to its role in scapular protraction and is also involved in the mechanics of throwing. Serratus anterior muscle strain can occur with repetitive, forceful contraction, most commonly in sports involving trunk rotation (rowing, golf) or overhead movements (weightlifting) [79]. Avulsion injuries at the costal attachment are rare but have been reported in rowers, pitchers, and golfers [79–82].

Strains of the serratus anterior muscle present as lateral chest wall pain that is worse with rotational movements, cough/sneeze, or scapular activation [6]. A palpable mass may be present with avulsion injuries. Most patients do well with conservative management including avoidance of painful activity followed by strengthening exercises to target the serratus anterior and a gradual return to sport [79]. Avulsion injuries have been treated successfully using both surgical and nonsurgical management [80].

Conclusions

Chest wall pain is common in athletes and often arises from a musculoskeletal source. Early and accurate diagnosis is important in order to provide appropriate management and minimize lost fitness and playing time. Recognizing the anatomy and biomechanics relevant to these injuries can aid in diagnosis and inform management and rehabilitation strategies. Further research into chest wall injuries as they relate to an athletic population can help minimize modifiable risk factors and optimize treatment outcomes.

Declarations

Conflict of Interest The authors declare no competing interests.

Human and Animal Right and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance

1. Liem BC, Olafsen N. Pectoralis major injuries: return to play potential. Curr Phys Med Rehab Rep. 2017;5:91–7.

2. Warden SJ, Gutschlag FR, Wajswelner H, Crossley KM. Aetiology of rib stress fractures in rowers. Sports Med. 2002;32(13):819–36.
3. Karlson KA. Thoracic region pain in athletes. Curr Sports Med Rep. 2004;3(1):53–7.
4.• Harris R, Trease L, Wilkie K, Drew M. Rib stress injuries in the 2012-2016 (Rio) Olympiad: a cohort study of 151 Australian Rowing Team athletes for 88 773 athlete days. Br J Sports Med. 2020;54(16):991–6. **This reference describes the rib injuries seen in a large cohort of elite rowers followed for a 4-year period of training and competition and observes greater time lost to injury than previous reports.**
5. Miller TL, Harris JD, Kaeding CC. Stress fractures of the ribs and upper extremities: causation, evaluation, and management. Sports Med. 2013;43(8):665–74.
6. Gundersen A, Borgstrom H, McInnis KC. Trunk injuries in athletes. Curr Sports Med Rep. 2021;20(3):150–6.
7. McDonnell LK, Hume PA, Nolte V. Rib stress fractures among rowers: definition, epidemiology, mechanisms, risk factors and effectiveness of injury prevention strategies. Sports Med. 2011;41(11):883–901.
8. Gregory PL, Biswas AC, Batt ME. Musculoskeletal problems of the chest wall in athletes. Sports Med. 2002;32(4):235–50.
9. Lin HC, Chou CS, Hsu TC. Stress fractures of the ribs in amateur golf players. Zhonghua Yi Xue Za Zhi (Taipei). 1994;54(1):33–7.
10. Horner DB. Lumbar back pain arising from stress fractures of the lower ribs: report of four cases. J Bone Joint Surg Am. 1964;46:1553–6.
11. Schowalter S, Le B, Creps J, McInnis KC. Rib fractures in professional baseball pitchers: mechanics, epidemiology, and management. Open Access J Sports Med. 2022;13:89–105.
12. Funakoshi T, Furushima K, Kusano H, Itoh Y, Miyamoto A, Horiuchi Y, et al. First-rib stress fracture in overhead throwing athletes. J Bone Joint Surg Am. 2019;101(10):896–903.
13. Sheng DL, Burnham K, Boutin RD, Ray JW. Ultrasound identifies first rib stress fractures: a case series in division I athletes. J Athl Train. 2022. https://doi.org/10.4085/1062-6050-0375.21.
14. Roston AT, Wilkinson M, Forster BB. Imaging of rib stress fractures in elite rowers: the promise of ultrasound? Br J Sports Med. 2017;51(14):1093–7.
15. Chaudhury S, Hobart SJ, Rodeo SA. Bilateral first rib stress fractures in a female swimmer: a case report. J Shoulder Elbow Surg. 2012;21(3):e6–10.
16. Miles JW, Barrett GR. Rib fractures in athletes. Sports Med. 1991;12(1):66–9.
17. Tullos HS, Erwin WD, Woods GW, Wukasch DC, Cooley DA, King JW. Unusual lesions of the pitching arm. Clin Orthop Relat Res. 1972;88:169–82.
18. Marcussen B, Negaard M, Hosey RG, Smoot MK. A case series and literature review: isolated traumatic first rib fracture in athletes. Clin J Sport Med. 2020;30(3):257–66.
19. Colosimo AJ, Byrne E, Heidt RS Jr, Carlonas RL, Wyatt H. Acute traumatic first-rib fracture in the contact athlete: a case report. Am J Sports Med. 2004;32(5):1310–2.
20. Sakellaridis T, Stamatelopoulos A, Andrianopoulos E, Kormas P. Isolated first rib fracture in athletes. Br J Sports Med. 2004;38(3):e5.
21. Sclafani MP, Amin NH, Delehanty E, Figler R, Williams J. Rehabilitation following an acute traumatic first rib fracture in a collegiate football player: a case report and literature review. Int J Sports Phys Ther. 2014;9(7):1021–9.
22. Tekyol D, Akman G, Dogruyol S, Akbas I. Injuries in recreational footballers and the severe consequences of player-to-player contact: a prospective observational study. Cureus. 2022;14(1):e21758.
23. Westcott J, Davis SD, Fleishon H, Gefter WB, Henschke CI, McLoud TC, et al. Rib fractures. American College of Radiology. ACR Appropriateness Criteria. Radiology. 2000;215(Suppl):637–9.
24. Scott EM, Scott BB. Painful rib syndrome--a review of 76 cases. Gut. 1993;34(7):1006–8.
25. Copeland GP, Machin DG, Shennan JM. Surgical treatment of the 'slipping rib syndrome'. Br J Surg. 1984;71(7):522–3.
26. Arroyo JF, Vine R, Reynaud C, Michel JP. Slipping rib syndrome: don't be fooled. Geriatrics. 1995;50(3):46–9.
27. Foley CM, Sugimoto D, Mooney DP, Meehan WP 3rd, Stracciolini A. Diagnosis and treatment of slipping rib syndrome. Clin J Sport Med. 2019;29(1):18–23.
28. McMahon LE. Slipping rib syndrome: a review of evaluation, diagnosis and treatment. Semin Pediatr Surg. 2018;27(3):183–8.
29. Udermann BE, Cavanaugh DG, Gibson MH, Doberstein ST, Mayer JM, Murray SR. Slipping rib syndrome in a collegiate swimmer: a case report. J Athl Train. 2005;40(2):120–2.
30. Peterson LL, Cavanaugh DG. Two years of debilitating pain in a football spearing victim: slipping rib syndrome. Med Sci Sports Exerc. 2003;35(10):1634–7.
31. Chhipa I, Cheesman Q. Slipping rib syndrome in an adolescent wrestler. BMJ Case Rep. 2020;13(1):e232514.
32. Heinz GJ, Zavala DC. Slipping rib syndrome. JAMA. 1977;237(8):794–5.
33. Girbau A, Alvarez-Rey G, Cano-Herrera CL, Balius R. Slipping rib syndrome: a clinical and dynamic-sonographic entity. A serial cases report. J Back Musculoskelet Rehabil. 2022;35(2):253–9.
34. Van Tassel D, McMahon LE, Riemann M, Wong K, Barnes CE. Dynamic ultrasound in the evaluation of patients with suspected slipping rib syndrome. Skeletal Radiol. 2019;48(5):741–51.
35. Migliore M, Signorelli M, Caltabiano R, Aguglia E. Flank pain caused by slipping rib syndrome. Lancet. 2014;383(9919):844.
36. McMahon LE. Recurrent slipping rib syndrome: initial experience with vertical rib stabilization using bioabsorbable plating. J Laparoendosc Adv Surg Tech A. 2020;30(3):334–7.
37. Hill PF, Chatterji S, DeMello WF, Gibbons JR. Stress fracture of the sternum: an unusual injury? Injury. 1997;28(5-6):359–61.
38. Baker JC, Demertzis JL. Manubrial stress fractures diagnosed on MRI: report of two cases and review of the literature. Skeletal Radiol. 2016;45(6):833–7.
39. Barbaix EJ. Stress fracture of the sternum in a golf player. Int J Sports Med. 1996;17(4):303–4.
40. Keating TM. Stress fracture of the sternum in a wrestler. Am J Sports Med. 1987;15(1):92–3.
41. Lee J, Fields KB. Sternal stress fracture in a middle-aged woman. BMJ Case Rep. 2017;2017:bcr2016218203.
42. McCurdie I, Etherington J, Buchanan N. Sternal fracture in a female army officer cadet. Br J Sports Med. 1997;31(2):164.
43. Robertsen K, Kristensen O, Vejen L. Manubrium sterni stress fracture: an unusual complication of non-contact sport. Br J Sports Med. 1996;30(2):176–7.
44. Culp B, Hurbanek JG, Novak J, McCamey KL, Flanigan DC. Acute traumatic sternum fracture in a female college hockey player. Orthopedics. 2010;33(9):683.
45. Larson CM, Fischer DA. Injury to the developing sternum in an adolescent football player: a case report and literature review. Am J Orthop (Belle Mead NJ). 2003;32(11):559–61.
46. Odell DD, Peleg K, Givon A, Radomislensky I, Makey I, Decamp MM, et al. Sternal fracture: isolated lesion versus polytrauma from associated extrasternal injuries--analysis of 1,867 cases. J Trauma Acute Care Surg. 2013;75(3):448–52.

47. Rainer TH, Griffith JF, Lam E, Lam PK, Metreweli C. Comparison of thoracic ultrasound, clinical acumen, and radiography in patients with minor chest injury. J Trauma. 2004;56(6):1211–3.
48. Uluşan A, Karakurt Ö. Cardiac findings of sternal fractures due to the thoracic trauma: A five-year retrospective study. Turkish J Trauma Emerg Surg. 2018;24(3):249–54.
49. Khoriati AA, Rajakulasingam R, Shah R. Sternal fractures and their management. J Emerg Trauma Shock. 2013;6(2):113–6.
50. Alent J, Narducci DM, Moran B, Coris E. Sternal injuries in sport: a review of the literature. Sports Med. 2018;48(12):2715–24.
51. Bardos A, Sabhrawal S, Tytherleigh-Strong G. Management of vertical sternal fracture nonunion in elite-level athletes. Orthop J Sports Med. 2021;9(6):23259671211010804.
52. Grindstaff TL, Beazell JR, Saliba EN, Ingersoll CD. Treatment of a female collegiate rower with costochondritis: a case report. J Man Manip Ther. 2010;18(2):64–8.
53. Aspegren D, Hyde T, Miller M. Conservative treatment of a female collegiate volleyball player with costochondritis. J Manipulative Physiol Ther. 2007;30(4):321–5.
54. Proulx AM, Zryd TW. Costochondritis: diagnosis and treatment. Am Fam Physician. 2009;80(6):617–20.
55. Gill GV. Epidemic of Tietze's syndrome. Br Med J. 1977;2(6085):499.
56. Aeschlimann A, Kahn MF. Tietze's syndrome: a critical review. Clin Exp Rheumatol. 1990;8(4):407–12.
57. Volterrani L, Mazzei MA, Giordano N, Nuti R, Galeazzi M, Fioravanti A. Magnetic resonance imaging in Tietze's syndrome. Clin Exp Rheumatol. 2008;26(5):848–53.
58. Kamel M, Kotob H. Ultrasonographic assessment of local steroid injection in Tietze's syndrome. Br J Rheumatol. 1997;36(5):547–50.
59. Gologorsky R, Hornik B, Velotta J. Surgical management of medically refractory Tietze syndrome. Ann Thorac Surg. 2017;104(6):e443–e5.
60. Mudgal C, Waters PM. Isolated fracture-subluxation of the second sternocostal synchondrosis. A case report. Am J Sports Med. 1998;26(5):729–30.
61. •• Varada SL, Popkin CA, Hecht EM, Ahmad CS, Levine WN, Brown M, et al. Athletic injuries of the thoracic cage. Radiographics. 2021;41(2):E20–39. **This reference outlines the indications for imaging as well as important imaging correlates of chest wall injuries in athletes.**
62. Cruz MF, Erdeljac J, Williams R, Brown M, Bolgla L. Posterior sternoclavicular joint dislocation in a division I football player: a case report. Int J Sports Phys Ther. 2015;10(5):700–11.
63. Morell DJ, Thyagarajan DS. Sternoclavicular joint dislocation and its management: a review of the literature. World J Orthop. 2016;7(4):244–50.
64. Ogawa T, Masuya M, Onishi S, Iwabuchi S, Yoshii Y, Hirano A, et al. Positional anterior sternoclavicular joint dislocation in the acceleration phase of throwing: a case report. JSES Int. 2020;4(3):532–5.
65. Fournier MN, Sinclair MR, Zheng ET, Spiegel DA, Johnson AL, Shah AS, et al. The frequency of mediastinal injury in acute posterior sternoclavicular dislocations: a multicenter study. J Pediatr Orthop. 2020;40(10):e927–e31.
66. Calderazzi F, Menozzi M, Valenti P, Colacicco A, Bastia P, Pogliacomi F, et al. A rare case of complicated pure posterior sternoclavicular dislocation in a young athlete. Acta Biomed. 2020;91(14-S):e2020015.
67. Albors LM, Lee RJ. Chronic posterior sternoclavicular dislocation in a contact athlete: a case report. JBJS Case Connect. 2020;10(1):e0032.
68. Blakeley CJ, Harrison HL, Siow S, Hashemi K. The use of bedside ultrasound to diagnose posterior sterno-clavicular dislocation. Emerg Med J. 2011;28(6):542.
69. Bengtzen RR, Petering RC. Point-of-care ultrasound diagnosis of posterior sternoclavicular joint dislocation. J Emerg Med. 2017;52(4):513–5.
70. Singer G, Ferlic P, Kraus T, Eberl R. Reconstruction of the sternoclavicular joint in active patients with the figure-of-eight technique using hamstrings. J Shoulder Elbow Surg. 2013;22(1):64–9.
71. Garcia JA, Arguello AM, Momaya AM, Ponce BA. Sternoclavicular joint instability: symptoms, diagnosis and management. Orthop Res Rev. 2020;12:75–87.
72. Wirth MA, Rockwood CA Jr. Acute and chronic traumatic injuries of the sternoclavicular joint. J Am Acad Orthop Surg. 1996;4(5):268–78.
73. Damschen J, Nowak M, Murphy A, Park S, Li X, Galvin J. Return to sports after closed reduction of acute traumatic posterior sternoclavicular joint dislocations: a systematic review. Am J Sports Med. 2022;51(11). https://doi.org/10.1177/03635465221131900.
74. Tytherleigh-Strong G, Sabharwal S, Peryt A. Clinical outcomes and return to sports after open reduction and hamstring tendon autograft reconstruction in patients with acute traumatic first-time posterior dislocation of the sternoclavicular joint. Am J Sports Med. 2022;50(13):3635–42.
75. Lacheta L, Dekker TJ, Goldenberg BT, Horan MP, Rosenberg SI, Pogorzelski J, et al. Minimum 5-year clinical outcomes, survivorship, and return to sports after hamstring tendon autograft reconstruction for sternoclavicular joint instability. Am J Sports Med. 2020;48(4):939–46.
76. Gowd AK, Liu JN, Garcia GH, Cabarcas BC, Agarwalla A, Nicholson GP, et al. Figure-of-eight reconstruction of the sternoclavicular joint: outcomes of sport and work. Orthopedics. 2019;42(4):205–10.
77. LaStayo PC, Woolf JM, Lewek MD, Snyder-Mackler L, Reich T, Lindstedt SL. Eccentric muscle contractions: their contribution to injury, prevention, rehabilitation, and sport. J Orthop Sports Phys Ther. 2003;33(10):557–71.
78. O'Neal ML, McCown K, Poulis GC. Complex strain injury involving an intercostal hematoma in a professional baseball player. Clin J Sport Med. 2008;18(4):372–3.
79. Carr JB 2nd, John QE, Rajadhyaksha E, Carson EW, Turney KL. Traumatic avulsion of the serratus anterior muscle in a collegiate rower: a case report. Sports Health. 2017;9(1):80–3.
80. Gaffney KM. Avulsion injury of the serratus anterior: a case history. Clin J Sport Med. 1997;7(2):134–6.
81. Otoshi K, Itoh Y, Tsujino A, Hasegawa M, Kikuchi S. Avulsion injury of the serratus anterior muscle in a high-school underhand pitcher: a case report. J Shoulder Elbow Surg. 2007;16(6):e45–7.
82. Winther AK, Ohlenschlaeger TF. Avulsion fracture of the serratus anterior muscle in a golfer. Ugeskr Laeger. 2015;177(2A):56–7.