Management of Vertical Sternal Fracture Nonunion in Elite-Level Athletes

Andrea Bardos,* MD, Sanjeeve Sabhrawal,* FRCS (Orth & Tr), and Graham Tytherleigh-Strong,*† FRCS (Orth & Tr)

Investigation performed at Addenbrooke's Hospital, Cambridge, UK

Background: Sternal fractures are rare, and they can be treated nonoperatively. Vertical sternal fractures have rarely been reported.

Purpose: To describe the management and surgical treatment of a series of elite-level athletes who presented with symptomatic nonunions of a vertical sternal fracture.

Study Design: Case series; Level of evidence, 4.

Methods: Patients with an established symptomatic nonunion of a vertical sternal fracture, as diagnosed by computed tomography (CT) or magnetic resonance imaging (MRI), underwent open reduction and internal fixation using autologous bone graft and cannulated lag screws. The patients were assessed preoperatively and at the final follow-up using the Rockwood sternoclavicular joint (SCJ) score; Constant score; and shortened version of the Disabilities of the Arm, Shoulder and Hand (QuickDASH) scores. Bony union was confirmed on postoperative CT scan.

Results: Five patients (4 men and 1 woman) were included; all were national- or international-level athletes (rugby, judo, showjumping, and MotoGP). The mean age at surgery was 23.4 years (range, 19-27 years), the mean time from injury to referral was 13.6 months (range, 10-17 months), and the mean time from injury to surgery was 15.8 months (range, 11-20 months). The mean follow-up was 99.4 months (range, 25-168 months). There was a significant improvement after surgery in the mean Rockwood SCJ score (from 12.6 to 14.8 [$P < .05$]), Constant score (from 84 to 96.4 [$P < .05$]; 80% met the minimal clinically important difference [MCID] of 10.4 points), and QuickDASH (from 6.8 to 0.98 [$P < .05$]; 0% met the MCID of 15.9 points). Four of the patients were able to return to sport at their preinjury level, and 1 patient retired for nonmedical reasons. All of the fractures had united on the postoperative CT scan. There were no postoperative complications.

Conclusion: Vertical fractures of the sternum are very rare and tend to behave clinically like an avulsion fracture injury to the capsuloligamentous structure of the inferior SCJ. The requirement of advanced imaging to diagnose this injury means that the actual incidence and natural history are not known. For high-demand athletes, early identification, surgical reduction, and fixation are likely to achieve the best outcome.

Keywords: sternal fracture; nonunion; sternoclavicular joint; avulsion fracture

Although more than a third of sports injuries involve the upper extremity, injuries to the sternum account for less than 1%.[9] The most common mechanism of injury is a direct blunt force to the anterior chest wall that results, almost exclusively, in a transverse fracture configuration. The vast majority of these fractures can be successfully treated nonoperatively.[1,4,6,21] Nonunion of a traumatic transverse sternal fracture is extremely rare.[4,8,19,25]

Vertical sternal fractures are even less common and likely to be the result of an indirect force onto the shoulder, passing down to the medial end of the clavicle and directed into the base of the sternal articular facet of the sternoclavicular joint (SCJ).[13] The force then passes inferiorly, propagating a fracture into the body of the manubrium.

Because of the indirect nature of the injury and the difficulty in visualizing a vertical sternal fracture on plain radiograph, an initial diagnosis is often not made.

†Address correspondence to Graham Tytherleigh-Strong, Division of Orthopaedics, Addenbrooke's Hospital, Cambridge University Hospitals Trust, Hills Road, Cambridge CB2 2QQ, UK (email: graham.tytherleigh-strong@addenbrookes.nhs.uk).

*Division of Orthopaedics, Addenbrooke's Hospital, Cambridge University Hospitals Trust, Cambridge, UK.

Final revision submitted December 20, 2020; accepted February 9, 2021.

The authors declared that there are no conflicts of interest in the authorship and publication of this contribution. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

Ethical approval for this study was obtained from Cambridge University Hospitals NHS Foundation Trust.

The Orthopaedic Journal of Sports Medicine, 9(6), 23259671211010804
DOI: 10.1177/23259671211010804

As a result of extravasation of synovial fluid and the ligamentous forces of the SCJ and chondral-manubrial joints distracting the fracture, there is a tendency for these fractures to progress to a symptomatic delayed nonunion.

We report the results of a consecutive series of elite-level athletes on whom we undertook surgical fixation and bone grafting of a symptomatic nonunion of a vertical intra-articular fracture of the sternum. All of the fractures were sustained by indirect force and initially presented as a more global shoulder injury. The initial focus of investigation and management was focused on the glenohumeral and acromioclavicular joints. As a result, the diagnosis of the sternal fracture was delayed in all cases. We hypothesized that the nonunion would be successfully treated by bone grafting and surgical fixation.

METHODS

We searched the senior author's surgical database for patients with symptomatic sternal fracture nonunions who had undergone an open reduction and internal fixation with bone grafting between January 2006 and November 2017 and who had a minimum follow-up of 2 years. Exclusion criteria included any associated SCJ injury, medial clavicle fracture, and neurological injury or infection. Institutional board approval was obtained for the study, and informed consent was obtained from all patients. All of the procedures were undertaken by the senior author.

Patients were asked a thorough history, including the date and exact mechanism of their original injury as well as any associated injuries and previous treatment, and underwent a clinical examination of both shoulders. All patients were tertiary referrals and had undergone varying investigations before presentation. In some, the diagnosis of a sternal fracture nonunion had been made before referral on a computed tomography (CT) or magnetic resonance imaging (MRI) scan, and for others, a CT or an MRI scan was used to confirm the diagnosis.

All patients included in this study were professional or semiprofessional athletes who had undergone extensive rehabilitation programs before referral to our unit. For those who had sustained them, there had been a full recovery of all other associated shoulder girdle injuries. However, although there had been an improvement in their symptoms of sternal pain and weakness, their recoveries had plateaued, and none of them had been able to return to the level of sporting activities they desired. Based on this, the option of undertaking an open reduction and internal fixation using bone graft with the associated risks and benefits was discussed and offered to the patients.

Surgical Technique

Before performing the procedures, informed consent was obtained. The patients were anesthetized using a general anesthetic, and prophylactic antibiotics were administered before the commencement of surgery. All of the procedures were undertaken by the senior author with a cardiothoracic surgeon in attendance.

The patients were positioned supine with the anesthetic tubing directed upward over the patient's face. A sandbag was positioned between the patient's scapulae to retract the shoulder blades and open the fracture nonunion. The chest wall was square draped from the lower neck to the xiphisternum and out to the midclavicular line on both sides. The ipsilateral iliac crest was also draped.

An incision was made from the medial end of the clavicle curving medially and inferiorly over the SCJ and along the medial edge of the manubrium. The fibers of platysma, at the upper end of the incision, were divided, and the medial edge of the sternal insertion of pectoralis major elevated off of the sternum and reflected medially. The anterior sternum was exposed, and the fracture nonunion was then identified running vertically down the manubrium from the base of the sternal articular surface. The dissection was then taken more medially to expose the chondral cartilage insertions of the upper ribs as well as the lateral edge of the sternum between them. This fracture nonunion was then curetted, removing any fibrous tissue, to create bleeding bone edges. The area was then covered with a moist swab.

The anterior superior iliac spine was then exposed; a 1.5-cm cortical "lid" was created using osteotomes and then elevated to reveal cancellous bone within the vault. A 7.5-mm Arthrodax bone grafting tube was then used to extract two 7.5 mm–diameter by 15 mm—long cores of cancellous bone. The cortical lid was sutured back into position and the wound closed in layers.

Attention was then returned to the sternal fracture. The cores of cancellous bone graft were broken up, and the smaller particles of graft were pushed into the exposed fracture gap and tamped down with a punch. The sandbag that had been positioned between the scapulae was then removed, allowing the shoulder blades to protract, putting compression across the fracture. A 2.5-mm drill was used to make a unicortical hole in the midline of the anterior cortex of the sternum. A large reduction bone forceps was then positioned and tightened across the fracture, between the hole and the lateral edge of the sternum, applying further compression across the fracture site.

The distance from the lateral edge of the sternum/chondral cartilage to the midline of the sternum was then measured. A 1-mm guide wire was then drilled medially from the lateral edge of the sternum/chondral cartilage in a direction to cross the fracture perpendicularly, to just beyond this distance. The guide wire was then overdrilled with a 2.7-mm cannulated drill to the measured distance, and a 3.5-mm partially threaded cannulated titanium cancellous screw, 2 mm shorter than this distance, was inserted over the guide wire. In all of the cases, the bone was of good quality, and a good hold and compression of the fracture was obtained. The number of compression screws required depended on the length of the fracture and ranged from 1 to 2. Hemostasis was achieved, and the wound was then closed in layers (Figures 1 and 2) .

Postoperatively, the arm of the affected side was kept in a sling for 4 weeks, and the patients were encouraged to undertake passive movements of the glenohumeral joint. At 4 weeks, the patients began a structured passive or assisted movement to active rehabilitation program of the

SCJ, glenohumeral joints, and scapulothoracic joints. At 4 months, the patients underwent a CT and MRI scan to check that the fracture had healed. At that point, they could commence a sport-specific rehabilitation and training program with no restrictions.

Clinical and Radiographic Assessment

Patients were examined at 1 and 4 months and underwent a telephone consultation at a final postoperative follow-up.

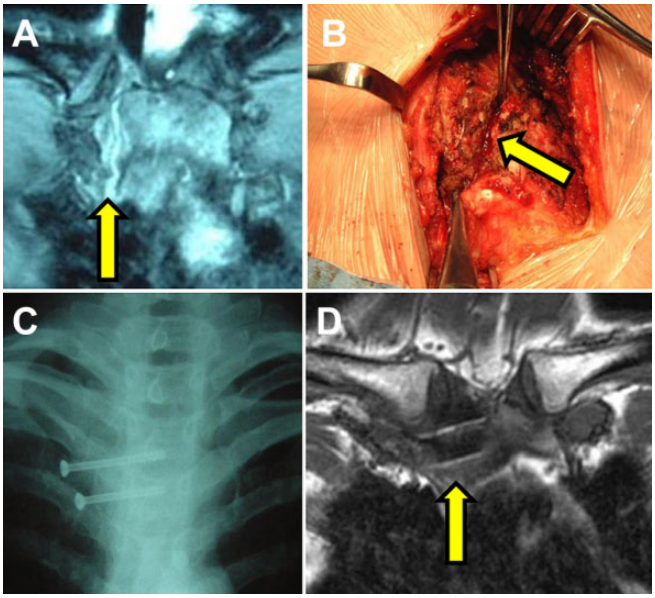

Figure 1. Right vertical sternal fracture nonunion. (A) Preoperative T-2 coronal MRI scan demonstrating a vertical fracture nonunion of the sternum (yellow arrow). (B) Intraoperative photograph. The pec major has been retracted laterally and the anterior surface of the sternum exposed. Forceps have been positioned at either end of the fracture nonunion (yellow arrow). (C) Postoperative chest radiograph demonstrating 2 partially threaded lag screws crossing the fracture site. (D) Postoperative T-1 coronal MRI scans demonstrating the 2 screws and the united fracture (yellow arrow). MRI, magnetic resonance imaging.

Outcome scores were assessed using the Rockwood SCJ score; the modified Constant shoulder score; and the shortened version of the Disabilities of the Arm, Shoulder and Hand (QuickDASH) score.[7,12,18,23] At the final follow-up, patients were asked whether they had returned to their desired or preinjury level of sport.

A CT scan was obtained for each patient at the 4-month follow-up assessment. Bony union was confirmed by the presence of bridging bone across the fracture.[24]

Statistical Analysis

The statistical analysis was performed using the unpaired Student t test between pre- and postoperative functional scores (SPSS Statistics for Windows, Version 25.0; SPSS). $P < .05$ was considered statistically significant.

RESULTS

Five patients were identified who had undergone an open reduction and internal fixation with bone grafting for a nonunion of a vertical sternal fracture over the study period. There was 1 female and 4 male patients. All patients described their mechanism of injury as falling slightly backward from a height with their arm elevated and then landing on their shoulder. At the time of the precipitating incident, 4 had sustained an associated ipsilateral injury. Initially, this was the main focus of concern and treatment, and it was only as they began to recover from these injuries that the symptoms of their sternal injury became more evident. In 4 of the patients, the diagnosis of a vertical sternal fracture had been made on MRI or CT scan before referral. There was no evidence of a soft tissue SCJ capsular injury on the MRI scans of any of the patients.[2] All of these patients had previously undergone an SCJ soft tissue injury rehabilitation program.[15]

Upon presentation to our institution, all of the patients had completely recovered from their associated injuries and had also made a sufficient recovery from their sternal injury to return to their chosen sport. However, none of them had been able to return to their preinjury or desired level of competition. Clinically, all of the patients had pain on palpation over their sternum with pain on protraction

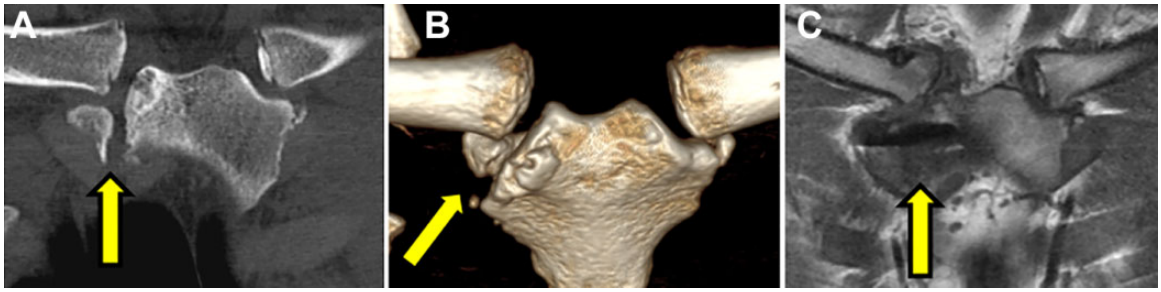

Figure 2. Right vertical sternal fracture nonunion. (A) Preoperative coronal CT scan demonstrating a vertical fracture nonunion of the sternum (yellow arrow). (B) Preoperative reformatted CT scan demonstrating the fracture (yellow arrow). (C) Postoperative T-1 coronal MRI scan demonstrating a single lag screw fixation and the united fracture (yellow arrow). CT, computed tomography; MRI, magnetic resonance imaging.

TABLE 1
Patient Characteristics[a]

Patient	Age, y	Sex	Side	Sport	Associated Injury (Treatment)	Time to Referral, mo	Diagnosis	Time to Surgery, mo
1	29	F	R	International show jumping	Pubic rami fracture (nonop)	15	MRI	18
2	23	M	R	MotoGP	Distal radius fracture (surgery)	17	MRI	20
3	24	M	L	International judo	Type 2 ACJ (nonop)	10	CT, MRI	11
4	25	M	R	Professional rugby	Anterior GH dislocation (arthroscopic stabilization)	10	CT	12
5	21	M	R	International judo	None	16	CT, MRI	18

[a]ACJ, acromioclavicular Joint, CT, computed tomography; F, female; GH, glenohumeral joint; L, left; M, male; MRI, magnetic resonance imaging; nonop, nonoperative; R, right.

TABLE 2
Results[a]

	Rockwood Score		Constant Score		QuickDASH Score			
Patient	Preop	FFU	Preop	FFU	Preop	FFU	Postop CT 4 mo	Return to Preinjury Level of Sport FFU
1	12	15	80	95	11.4	2.3	United	Yes/retired
2	13	15	85	98	6.8	0	United	Yes
3	13	15	83	96	6.8	0	United	Yes
4	12	15	87	100	4.5	0	United	Yes
5	13	14	85	93	4.5	2.3	United	Yes
Mean ± SD	12.6 ± 1.1	14.8 ± 0.54	84 ± 2.37	96.4 ± 1.9	6.8 ± 2.51	0.98 ± 1.74		
P value (preop vs FFU)	<.05		<.05		<.05			

[a]CT, computed tomography; QuickDASH, shortened version of Disabilities of the Arm, Shoulder and Hand; FFU, final follow-up; postop, postoperative; preop, preoperative.

and retraction of the scapula. None of the patients appeared to have any SCJ instability.

The characteristics of all of the patients are summarized in Table 1. The mean age of the patients at the time of their surgery was 24.4 years (range, 21-29 years), the time from the index injury to referral to our unit was 13.6 months (range, 10-17 months), and the mean time from injury to definitive treatment was 15.8 months (range, 11-20 months). The mean time to the final follow-up was 99.4 months (range, 25-168 months).

The functional outcome scores for all of the patients are summarized in Table 2. At the final follow-up, there was a significant improvement in the mean Rockwood SCJ score (12.6-14.8; $P < .05$), Constant score (84-96.4; $P < .05$) (minimal clinically important difference [MCID] of 10.4 points; 80%) and QuickDASH Score (6.8-0.98; $P < .05$) (MCID of 15.91 points; 0%).[11,17] After their recovery from surgery, 4 of the patients were able to return to their sport at their preinjury level of competition. The fifth patient felt that her sternal fracture had completely recovered but decided for nonmedical reasons not to return to her sport at a competitive level. All of the patients said that they were satisfied with the results of their surgery and that they would be happy to undergo the procedure again.

Bony union was present for all of the patients on the postoperative CT scans taken at 4 months postoperatively. There were no intra- or postoperative complications, and at the time of final follow-up, none of the patients had required removal of their hardware.

DISCUSSION

The main findings of this study are that vertical fractures of the sternum are caused by an indirect mechanism of injury, they do not initially tend to result in severe mediastinal clinical symptoms, and if they do go onto a nonunion, they seem to cause symptoms only during higher functional demand activities. An open reduction and internal fixation, using autologous bone graft, for a symptomatic nonunion provides a successful outcome in terms of bony union and improved function.

Thoracic injuries incurred during sport are unusual, with contact sports being the major cause. Because of minimal thoracic protective gear, rugby has the highest reported incidence with 8.3/1000 player-hours lost from match injuries involving the upper back, sternum, or ribs at the 2007 Rugby World Cup.[14] Two mechanism of injury have been described for sternal fractures and dislocations of the manubriosternal junction, which are either a direct blunt impact to the front of the chest or a flexion-compression force through the thoracic and cervical spine.[10,20]

Figure 3. Diagram of mechanism of injury. A force is transferred longitudinally down the clavicle (black arrow) and transferred into the base of the manubrial facet creating a vertical fracture line.

The vast majority of transverse sternal fractures are isolated injuries and can be successfully treated; they will heal, with conservative management.[1,4,6,21] The main indication for surgical intervention after an acute sternal fracture is fracture displacement, fracture instability, associated chest trauma, and associated polytrauma injuries.[16] In a systematic review of 191 patients with sternal fractures by Klei et al,[16] 89% were treated with surgical fixation. However, only 22% of the whole group had an isolated injury. The main methods of fixation were with plates and locking plates. Bone graft was used in only 16% of the operative cases.

Fracture nonunion after a transverse sternal fracture is rare, with an incidence of $<1\%$ reported in the literature.[25] Successful treatment using a standard and multidirectional locking plates has been described.[22,25]

The vertical fractures in all of the patients in our series appeared to have originated at the junction where the horizontal part of the sternal SCJ articular facet joins the body of the manubrium. The fracture had then propagated inferiorly and exited where the lateral manubrial flare blends into the body. We suspect that, unlike transverse fractures, the mechanism of injury was due to the patient's landing on an elevated shoulder with the force of the injury being directed longitudinally down the length of the clavicle. The force was then transmitted through the medial end of the clavicle, in its elevated position, into the base of the manubrial facet. The focused vertical shear force then created a fracture failure point that propagated inferiorly, leading to a vertical fracture failure (Figure 3).

Despite a protracted time of nonoperative management, none of the vertical fractures in our series healed. The probable reason for these fractures going on to a nonunion is because of continued excessive micromovement at the fracture site. Although the fractures were not grossly unstable, it is likely that the strong ligamentous soft tissue attachments around the inferior SCJ, between the clavicle and the sternum, created a constant distracting force across the vertical fracture line. The situation may have been further compounded by the communication between the proximal end of the fracture with the SCJ leading to extravasation of synovial fluid into the fracture site.

Because of the vertical orientation of the fracture line, we were able to address the nonunions by compressing the fracture using partially threaded lag screws inserted from the lateral edge of the manubrium across the fracture site. This construct was able to achieve a rigid fixation, so we did not require a plate to bridge and compress the fracture. An advantage to this is that unlike the case for transverse sternal fractures, we did not need to subsequently remove any metalwork from our patients.[16]

Although there has been increasing awareness of thoracic injuries in sport and recommendations with regard to both prevention and early detection, the presentation of all of the patients on our series was delayed as a fracture nonunion.[5,9,14] This is probably because of the fact that the apparent mechanism of injury for a vertical sternal fracture is different from a transverse fracture. The mechanism of injury described by all of the patients, of falling slightly backward from a height with their arm elevated and landing on their shoulder, is much more akin to the indirect mechanism of injury resulting in an SCJ injury or dislocation.[3] Describing these vertical sternal fractures as behaving clinically like a large, minimally displaced bony avulsion fracture of the sternal insertion of the inferior SCJ ligamentous-capsular structure might be a more instructive way to help explain and understand their mechanism of injury, presentation, and behavior.

Using the grade 1 to 3 classification of SCJ injuries, as the joint did not dislocate, a minimally displaced vertical avulsion fracture would be clinically the equivalent of either a grade 1 or grade 2 injury. The initial management of these types of injuries is initial rest, ice, and nonsteroidal anti-inflammatory drug treatment followed by a phased rehabilitation program.[15] Most patients would expect to be able to return to full activity after 3 months.

From the medical history of the patients in our series, 3 patients had their shoulder immobilized for the first 4 weeks after their initial injury as part of the treatment for their concomitant ipsilateral upper limb injuries. For all of the patients, once a sternal/SCJ type of problem had become apparent, their management was the same as if they had sustained a grade 1 to 2 SCJ injury. After this treatment, they all improved significantly, as evidenced by their preoperative functional scores. However, because of the specific demands of their particular sport and their desire to return to competition at an elite level, they still considered their residual symptoms to be a significant problem and underwent surgery.

At the final follow-up, all of the patients were able to return to competetion at their chosen sport at their preinjury level. One patient subsequently retired for nonmedical reasons. Although the improvement between all of the pre- and postoperative functional scores was statistically significant, none of the patients achieved the MCID for the

QuickDASH score, and only 4 patients achieved it for the Constant score. An MCID has not been described for the Rockwood score. This probably reflects the higher level of function than normal that is required to undertake certain sporting activities at an elite level.

Vertical sternal fractures are very rare, and a diagnosis can be made only after a CT or MRI scan. From the indirect mechanism of injury and the initial response to conservative treatment described by the patients in our series, it was only after their recovery had plateaued that these investigations were considered.

For individuals with less demanding physical aspirations, despite a vertical sternal fracture going on to a fibrous nonunion, it may be that conservative treatment would be sufficient to successfully treat their symptoms. As a result, the incidence of vertical fractures may be higher, as CT and MRI scans are generally considered only after failure of conservative treatment.

We recommend that for elite-level athletes sustaining this type of injury, investigation with a CT or MRI scan should be undertaken at an early stage. If a vertical sternal fracture is identified, surgical fixation should be considered, as the fracture is likely to go on to a symptomatic nonunion. Surgery is likely to achieve the quickest recovery and best functional outcome.

There are several limitations to this study. It is a small retrospective case series, and there were no comparative controls or alternative treatment options considered. Also, some of the outcome measures used in this study have not been validated for the SCJ; however, they have been used in other SCJ studies.

CONCLUSION

Vertical fractures of the sternum are very rare and tend to behave like an avulsion fracture injury to the inferior SCJ capsuloligamentous structure. The requirement of advanced imaging to diagnose this injury means that the actual incidence and natural history are not known. However, for high-demand athletes, early identification, surgical reduction, and fixation is likely to achieve the best outcome.

REFERENCES

1. Athanassiadi K, Gerazounis M, Moustardas M, Metaxas E. Sternal fractures: retrospective analysis of 100 cases. *World J Surg*. 2002; 26(10):1243-1246.
2. Benitez CL, Mintz DN, Potter HG. MR imaging of the sternoclavicular joint following trauma. *Clin Imaging*. 2004;28(1):59-63.
3. Bontempo NA, Mazzocca AD. Biomechanics and treatment of acromioclavicular and sternoclavicular joint injuries. *Br J Sports Med*. 2010;44(5):361-369.
4. Brookes JG, Dunn RJ, Rogers IR. Sternal fractures: a retrospective analysis of 272 cases. *J Trauma*. 1993;35(1):46-54.
5. Brooks JH, Kemp SP. Injury-prevention priorities according to playing position in professional rugby union players. *Br J Sports Med*. 2011; 45(10):765-775.
6. Collins J. Chest wall trauma. *J Thorac Imaging*. 2000;15(2):112-119.
7. Constant CR, Murley AH. A clinical method of functional assessment of the shoulder. *Clin Orthop Relat Res*. 1987;214:160-164.
8. Coons DA, Pitcher JD, Braxton M, Bickley BT. Sternal nonunion. *Orthopedics*. 2002;25(1):89-91.
9. Enger M, Skjaker SA, Nordsletten L, et al. Sports-related acute shoulder injuries in an urban population. *BMJ Open Sport Exerc Med*. 2019; 5(1):e000551.
10. Fowler AW. Flexion-compression injury of the sternum. *J Bone Joint Surg Br*. 1957;39(3):487-497.
11. Franchignoni F, Vercelli S, Giordano A, Sartorio F, Bravini E, Ferriero G. Minimal clinically important difference of the Disabilities of the Arm, Shoulder and Hand outcome measure (DASH) and its shortened version (QuickDASH). *J Orthop Sports Phys Ther*. 2014;44(1):30-39.
12. Gummesson C, Atroshi I, Ekdahl C. The Disabilities of the Arm, Shoulder and Hand (DASH) outcome questionnaire: longitudinal construct validity and measuring self-rated health change after surgery. *BMC Musculoskelet Disord*. 2003;4:11.
13. Gupta AK, Getgood A, Tytherleigh-Strong G. Non-union of an intra-articular fracture of the sternum. *Injury Extra*. 2011;42(8):85-87.
14. 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.
15. Hellwinkel JE, McCarty EC, Khodaee M. Sports-related sternoclavicular joint injuries. *Phys Sportsmed*. 2019;47(3):253-261.
16. Klei DS, de Jong MB, Oner FC, Leenen LPH, van Wessem KJP. Current treatment and outcomes of traumatic sternal fractures-a systematic review. *Int Orthop*. 2019;43(6):1455-1464.
17. Kukkonen J, Kauko T, Vahlberg T, Joukainen A, Aarimaa V. Investigating minimal clinically important difference for Constant score in patients undergoing rotator cuff surgery. *J Shoulder Elbow Surg*. 2013;22(12):1650-1655.
18. Levy O, Haddo O, Massoud S, Mullett H, Atoun E. A patient-derived Constant-Murley score is comparable to a clinician-derived score. *Clin Orthop Relat Res*. 2014;472(1):294-303.
19. Mayba II. Non-union of fractures of the sternum. *J Bone Joint Surg Am*. 1985;67(7):1091-1093.
20. Nikas DJ, Freeman JE, Newsome RE Jr, Fletcher JR. Late repair of chest deformity secondary to traumatic manubriosternal disruption: case report. *J Trauma*. 1995;39(4):781-783.
21. Purkiss SF, Graham TR. Sternal fractures. *Br J Hosp Med*. 1993;50(2-3):107-112.
22. Queitsch C, Kienast B, Voigt C, Gille J, Jurgens C, Schulz AP. Treatment of posttraumatic sternal non-union with a locked sternum-osteosynthesis plate (TiFix). *Injury*. 2011;42(1):44-46.
23. Rockwood CA Jr, Groh GI, Wirth MA, Grassi FA. Resection arthroplasty of the sternoclavicular joint. *J Bone Joint Surg Am*. 1997;79(3): 387-393.
24. Stacy GS, Ahmed O, Richardson A, Hatcher BM, MacMahon H, Raman J. Evaluation of sternal bone healing with computed-tomography and a quantitative scoring algorithm. *The Open Medical Imaging Journal*. 2014;8:29-35.
25. Wu LC, Renucci JD, Song DH. Sternal nonunion: a review of current treatments and a new method of rigid fixation. *Ann Plast Surg*. 2005; 54(1):55-58.