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Clin Sports Med 25 (2006) 159–174

CLINICS IN SPORTS MEDICINE

# Upper Extremity Stress Fractures

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Stress fractures occur typically in the lower extremity, caused by impact loading from running, walking, or jumping. In one large series, Matheson and colleagues [1] reported on 320 stress fractures, in which 90% occurred in the lower extremity. However, upper-extremity stress fractures are now being recognized more frequently. These fractures occur either as a result of repetitive loading at the point of muscular attachments to bone or as a result of impact loading, as seen in upper-extremity weight-bearing athletes [2]. In a recent review of 196 stress fractures [3], rib stress fractures were second only to tibia fractures in frequency, and ulnar olecranon fractures were fourth in occurrence. In this study [3], rib fractures were the most common type of stress fracture in rowing athletes, whereas olecranon fractures were most common among baseball players.

Sinha and colleagues [4] reported on 44 cases of upper-extremity stress fractures in athletes, including rib fractures but excluding spine and physeal fractures. The authors divided the patients into four categories based on the predominant type of upper-extremity activity required for participation in their sport: (1) weight lifting (eg, football, weight lifting, and wrestling); (2) upper-extremity weight bearing (eg, gymnastics, diving, and cheerleading); (3) throwing (eg, pitcher, soccer goalie, and javelin); and (4) swinging (eg, golf and tennis). The authors noted that all fractures in the weight bearers were distal to the elbow, whereas most fractures in the throwers affected the shoulder girdle. In the swingers, lower-rib fractures predominated. The weight lifters, on the other hand, had stress fractures throughout the upper extremity but none in the ribs. Overall, the ulnar shaft stress fracture was the most frequently reported stress fracture in their series and occurred in all four groups.

The present article reviews the different types of upper extremity and torso stress fractures seen in athletes, starting with the sternum and extending outward to the fingers. The presentation, diagnosis, mechanism of injury, treatment, prevention, and prognosis for each of these injuries will be discussed.

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0278-5919/06/$ – see front matter
doi:10.1016/j.csm.2005.08.008

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## STERNUM

Although they are rare, stress fractures of the sternum have been reported in a wrestler [5], a golfer [6], and an athlete performing strenuous abdominal exercises [7]. In the case of the wrestler [5], the patient had pain after weeks of modified training in preparation for a competition. The pain then suddenly increased during activity. Results of a standard radiograph were normal, but a technetium bone scan revealed an increased uptake in the sternum, exactly where his pain was located.

The golfer [6] noticed pain and swelling over the sternum at the level of the fourth rib 2 days before a tournament, and the pain increased significantly by the third day of the event. The patient revealed that he had purchased a new set of clubs before the tournament and was training intensively with this new equipment in preparation for the competition.

Again, plain radiographic results were normal, but a bone scan revealed a "hot spot" located on the sternum, consistent with a stress fracture. To rule out a neoplastic or infectious cause, exploratory surgery was performed and biopsies were taken, which were negative. The patient followed up with an orthopedic surgeon 9 weeks after surgery and was asymptomatic and beginning to train again.

The athlete who was performing strenuous abdominal exercises developed sharp, anterior chest pain and heard a "loud, sharp" sound during a training session [7]. He was tender to palpation over the sternum, and sternal radiographs revealed a transverse fracture of the manubrium sternum. A CT scan of the chest revealed no other pathology. The patient was treated subsequently with analgesics and rest from the offending activity, and his symptoms resolved after 8 weeks. The authors proposed that hyperflexion of the spine in conjunction with contraction of the thoracic and abdominal muscles during a sit-up exercise were the mechanism of injury. Hyperflexion of the spine presses the manubrium anteriorly, and the pull of the abdominal and thoracic muscles adds to this moment.

## RIBS

Rib stress fractures have been reported in several sports, including rowing, rugby, golf, weightlifting, volleyball, gymnastics, judo, tennis, table tennis, baseball, basketball, soccer, javelin throwing, backpacking, and wind surfing [8–23]. Muscular forces are predominately responsible for these stress fractures [24]. Muscles that attach to ribs are used during upper-extremity movements, trunk rotation, bending, and breathing. The stress placed on the ribs by the muscles during repetitive contraction is accentuated during training because, as in other bones such as the sternum, muscles strengthen more rapidly than bone. In addition, muscle fatigue during prolonged activity lessens the ability of a muscle to absorb and dissipate energy, which then places a bone at risk for fracture [25].

Stress fractures can occur in any portion of any rib depending on the sporting activity and the forces placed on the ribs. The most common sites of fracture include the first rib anterolaterally, the fourth through ninth ribs posterolaterally, and the upper ribs posteromedially [24].

First-rib stress fractures occur most commonly in athletes whose sports involve repetitive overhead positioning of the arm such as baseball pitching, basketball, lacrosse, weightlifting, ballet, javelin throwing, and tennis [18,21,23]. One case has been reported in a soccer player who developed the fracture after repetitively heading the ball [20]. These fractures occur at or near the subclavian groove, between the insertions of the scalenus anterior and scalenus medius muscles, where the bone is thinnest [21]. Repetitive contractions of these muscles along with the serratus anterior in overhead activities can cause a fatigue fracture. The scalene muscles stress the first rib with superiorly directed forces, while the serratus anterior and intercostals muscles cause inferiorly directed forces [18].

Patients with first-rib fractures present with an insidious onset of a dull, vague pain in the anterior cervical triangle and clavicular region, with occasional radiation to the sternum and pectoral region [23]. Initially, results of plain radiographs are commonly negative but may demonstrate the stress fracture once osseous callous appears during the healing phase. Technetium bone scanning is a very sensitive technique for the early diagnosis of these fractures and frequently will be positive when radiographs are normal [19]. The treatment of all rib stress fractures is nonoperative, and the initial goal is to provide symptomatic relief [23]. Treatment includes relative rest by avoiding throwing sports or carrying backpacks. Rib fractures usually heal with this type of management, although, there has been one reported case of a baseball pitcher who developed a nonunion of a first rib fracture [21]. The pitcher eventually became asymptomatic despite the nonunion.

Stress fractures of the middle and lower ribs occur predominantly in athletes involved in rowing and swinging sports (eg, golf and tennis) [4,17–19]. Other athletic activities associated with these stress fractures include gymnastics, throwing sports, and swimming [4,18,22]. Rib fractures in rowers are found most commonly on the antero- and posterolateral aspects of ribs five through nine and are associated most often with long-distance training and heavy load per stroke [19]. Contractions of the serratus anterior and external oblique muscles during the rowing stroke cause a repetitive bending force to the lateral aspect of the rib [19]. The serratus anterior stabilizes the scapula and draws a rib laterally and superiorly while the external oblique muscle draws a rib medially and inferiorly [18,19]. When the elastic limit of the rib is exceeded, microfractures occur that can progress to complete fractures [18]. When a stress fracture occurs, the rower experiences pain that is greatest at the finish of a stroke and is exacerbated by coughing [19].

There was an apparent increase in the incidence of rib stress fractures in the mid to late 1990s [19]. This has been attributed to several factors, including a new oar shape that was introduced in 1992 [19]. The new shape involved a bigger blade, which yielded faster speeds at the price of increased load per rowing stroke. At the same time, training volumes increased, particularly long-distance rows at low stroke rates, and along with these lower stroke rates came an increased load per stroke. This combination of factors results in increased tension required by the serratus anterior to stabilize the scapula and increased force of its eccentric contraction at the end of the stroke, which lead to increased force across the muscle's rib attachments. Therefore, the incidence of rib factors might be reduced by modification of the equipment and stroke during long-distance rows in the training phase when stress fractures are most likely to occur [19]. The faster stroke rates during competition result in less load per stroke, less muscle force per stroke, and a decreased incidence of stress fracture.

The posterolateral aspects of the fourth through sixth ribs are most commonly injured in golfers [17]. This is because compression and tension stresses of the serratus anterior are maximal on the posterolateral segment of the ribs, as demonstrated by a two-dimensional finite analysis of the muscle [26]. The ribs on the leading arm side are most commonly involved, most likely because of constant moderate activity of the serratus muscle through all phases of the golf swing on the leading side compared with the trailing side where the muscle is primarily activated only during the acceleration and early follow-through phase of the swing, as shown in an electromyographic study [27]. The constant activity of the serratus anterior muscle on the leading side may make it more susceptible to fatigue and decrease its ability to protect the ribs from stress fractures [27]. Therefore, these authors recommend a strengthening and endurance training program to prevent fatigue of this muscle [27].

Overall, rib fractures usually heal uneventfully with reduction or elimination of the inciting activity for 4 to 6 weeks [18]. Sport-specific training and endurance programs as well as correction of faulty mechanics should be included in the rehabilitation once the fracture has healed.

## SCAPULA

Stress fractures of the scapula in athletes are rare. There have been four reported cases in the literature: a gymnast, a jogger using hand-held weights, a professional American football player with a stress fracture at the base of the acromial process, and a trap shooter with a fracture in the coracoid process [4,28–31]. The jogger had been jogging with weights for an 8-week period when he presented with a 2-week history of shoulder pain [29]. A bone scan revealed a linear band of increased uptake in the superomedial portion of the scapula, which was later present on plain radiographs. The authors theorized that the likely cause was overuse of the supraspinatus muscle in stabilizing the humeral head while the patient was jogging with weights.

The football player was an offensive lineman with no history of trauma, who developed pain in his shoulder during a game [30]. The patient had point tenderness over the acromion, and plain radiographs revealed an incomplete transverse radiolucent line in an area of sclerotic bone at the underside of the acromion near its origin from the scapular spine. A bone scan also revealed increased activity in this area. Weightlifting and football activities were subsequently discontinued for 6 weeks, followed by a gradual resumption of weightlifting and contact activities. Within 2 months, the patient had returned to football without any pain. The authors suggest that an intense weightlifting program contributed to the development of the stress fracture.

The professional trapshooter was shooting trap regularly at the rate of 200 to 1000 rounds per week when she noticed an aching sensation in her shoulder where the butt of the rifle rests [31]. The patient had pinpoint tenderness over the coracoid process and had pain in this area with resisted adduction and flexion of the shoulder. A plain radiograph axillary view revealed a fracture through the mid portion of the base of the coracoid process. The patient was then treated with rest from trap shooting, followed by a gradual resumption of shooting when she was asymptomatic.

## CLAVICLE

Clavicular stress fractures have been reported in a javelin thrower, a rower, a gymnast, a diver, a weight lifter, a human tower stuntman, and a baseball player [32–38]. The fractures in the rower and gymnast involved the medial third of the clavicle [33,34]. The lightweight rower presented with increasing pain in her medial clavicular area after rapidly increasing her training intensity over a 3- to 4-week period, after a 5-month period of rest [33]. Plain radiographs demonstrated a right medial clavicular fracture, just lateral to the sternoclavicular joint. The patient was treated with cessation from rowing activity and a short course of physical therapy to improve posture, scapulothoracic mechanics, and rotator cuff strength until she was pain free, followed by a progressive increase in rowing. After 2 months from the time of diagnosis of the fracture, the rower returned to full competition. The authors suggest that the fracture was a result of the resumption of high-energy cyclic loading without prior strengthening and stabilization of the torso and upper extremity, leading to muscular imbalance and subsequent stress fracture. Muscular forces working on the clavicle include the pectoralis major and deltoid muscles that produce primarily a downward force, which is counteracted by the forces produced by the sternocleidomastoid and trapezius muscles. During the drive phase of the rowing stroke, the clavicle is elevated, rotated, and drawn posteriorly. Significant bending, shear, and torsional forces can develop across the bone, particularly if there is any imbalance in muscular contraction. The motion of the sternoclavicular and acromioclavicular joints helps dissipate this energy, but if these forces exceed the ultimate tensile strength of the bone or cause fatigue through repeated loading, a fracture can occur.

The gymnast was a 10-year-old female who presented with a 6-week history of medial clavicular pain [34]. Radiographs revealed a nondisplaced medial third clavicular fracture. The patient was treated with rest, and, after 4 weeks, she was asymptomatic, with plain radiographs revealing a bridging callus across the fracture site. Again, the authors attribute the fracture to the forces of the sternocleidomastoid and pectoralis major muscles on the medial third of the clavicle.

The diver was a collegiate platform diver who presented with a several-month history of clavicular pain [35]. Radiographs and bone scans revealed a fracture of the mid clavicle, which eventually healed with rest. The authors partially attribute the fracture to an open-hand entry diving technique, which is more traumatic on the wrist than a closed-hand technique. Theoretically, these repetitive increased forces radiate up the arm to the mid portion of the clavicle, which bears the greatest load of the clavicle, resulting in a fatigue fracture.

The fracture in the female weight lifter involved the distal clavicle [36]. The symptoms occurred after several months of lifting but, unlike the above fractures, did not heal with conservative management. A distal clavicle excision was eventually performed, and the patient's symptoms resolved. The authors propose a mechanism similar to that of distal clavicle osteolysis, in which repetitive weight lifting caused subchondral structural fatigue of the distal clavicle, resulting in a fracture.

## HUMERUS

Stress fractures have been described in baseball pitchers, a tennis player, a javelin thrower, a body-builder, weight lifters, a softball player, and a cricket player [39–49]. Humeral stress fractures in throwing athletes such as baseball pitchers most commonly are spiral fractures that involve the middle and distal third of the humerus [40,43–46]. These fractures predominate in two main age groups: adolescent Little League pitchers and healthy middle-aged pitchers [44–46], although, Polu and colleagues [40] reported a nondisplaced fracture in a collegiate pitcher. The most likely explanation for stress fractures in the adolescent age group is a high level of activity, which places a high degree of stress on immature bone, aggravated by growth spurts and inadequate muscular development [4,47]. The authors in one study believe that in the middle-aged pitchers, the most probable reason for these fractures was muscle fatigue caused by a prolonged layoff from pitching and a lack of a preseason conditioning and a regular exercise program [46]. The axial loads applied to the humerus generated by the biceps and triceps muscles during pitching serve as stress protection against torsional forces placed on the humerus [50]. Therefore, when these muscles are fatigued by overuse and lack of conditioning, more torsional stress is placed on the humerus, predisposing it to stress fracture.

These athletes present with either an acute onset of pain or a "pop" sound after a period of prodromal throwing arm pain or with an insidious onset of increasing arm pain if the fracture is incomplete or nondisplaced [40,43–46]. Plain radiographs most commonly reveal the fracture, especially if it is complete and displaced (Fig. 1). In incomplete fractures, plain radiographs may reveal only subtle cortical hypertrophy [40]. In these cases, radionuclide imaging or MRI may be needed to aid in the diagnosis. MRI will show a linear zone of decreased signal intensity within the cortex or medullary cavity or both on T1-weighted scans and increased signal in the medullary cavity on T2-weighted images. MRI also can help in determining the stage of the injury, with more recent injuries having increased signal on the T2-weighted views.

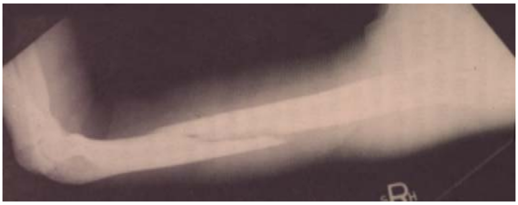

**Fig. 1.** Plain radiograph of a minimally displaced spiral stress fracture of the humeral shaft in a baseball pitcher.

Treatment is determined by many factors, including the age of the patient and degree of fracture displacement. Adolescent patients and those with non-displaced fractures often can be treated nonsurgically with a cuff and collar for 1 week, followed by a fracture brace until the fracture heals clinically and radiographically. Patients with displaced fractures often require open reduction and internal fixation. Preventive measures include a well-structured preseason strengthening and conditioning program.

The stress fractures seen in the weight lifters were transverse and involved the proximal humeral shaft [41,42]. Both patients complained of proximal arm and anterior shoulder pain, which occurred during bench press exercises for a period of time before presentation. One patient presented with a transversely oriented radiolucency in the proximal humerus, suggestive of cortical lysis with surrounding periosteal reaction, whereas the other patient presented with a transverse fracture of the proximal diaphysis with greater than 50% displacement. The former patient was treated with cessation of weight lifting for 8 weeks, followed by a gradually progressive supervised training program. The latter patient was treated with surgical fixation with an intramedullary nail. In terms of the mechanism of injury, these fractures were transverse in nature, suggesting a bending force rather than a rotational force, and occurred anatomically between the insertions of the pectoralis major and deltoid muscles. During bench pressing, the humerus is exposed to mechanical forces generated by the supporting musculature of the shoulder girdle and the weight being lifted [41]. The muscles are able to dynamically redistribute these forces across the bone, allowing the bone to endure more stress and load. However, with muscle fatigue, the “stress shielding” effect of the muscles is diminished, which predisposes the bone to fracture.

## OLECRANON

Four distinct types of olecranon stress fractures have been reported in the literature. Two fracture types occur in skeletally mature athletes, fractures of the olecranon tip and oblique fractures through the midportion of the olecranon; and two types occur in skeletally immature athletes, transverse fractures and osteochondroses [4,51–53]. Tip fractures occur in the proximal third of the olecranon and are seen typically in throwers [54]. Slocum [55] theorizes that the fractures could result from either impingement of the olecranon in its fossa, caused by hypertrophy of the osseous structures in the pitching arm, or from repeated stresses exerted on the olecranon by the pull of the triceps. These fractures are prone to nonunion and may be treated best with surgery, either by open reduction and internal fixation or by tip excision, depending on the size of the fragment [53,54].

Stress fractures involving the middle third of the olecranon have been reported in baseball pitchers, javelin throwers, and weight lifters [53,54,56–62]. These fractures result from the impaction of the medial olecranon onto the medial wall of the olecranon fossa from valgus forces [63]. Repetitive valgus stresses to the elbow may result in the tensile failure of the trabecular bone of the posteromedial olecranon [58,63]. With continued throwing or lifting, this failure may progress to a stress fracture. These patients usually present with posteromedial elbow pain during the acceleration and follow-through phases of the throwing motion. On physical examination, there is tenderness over the posteromedial elbow, and the pain is reproduced with valgus stress testing or forced hyperextension of the elbow. Plain radiographs are often negative or show very subtle findings such as periosteal reaction over the medial olecranon [58,59]. MRI findings range from poorly defined, patchy areas of low signal intensity on T1-weighted images and areas of high signal intensity on T2-weighted images if an acute stress reaction is present to more focal linear areas of intermediate signal throughout the cortex and subjacent cancellous bone of the articular surface of the proximal ulna in patients with more discrete macroscopic incomplete stress fracture lines (Fig. 2) [58].

Treatment consists of a period of rest and avoidance of throwing and other forms of valgus stress for at least 6 weeks. Schickendantz and colleagues [58] also suggest using a custom-fabricated, hinged elbow orthosis set from 20°

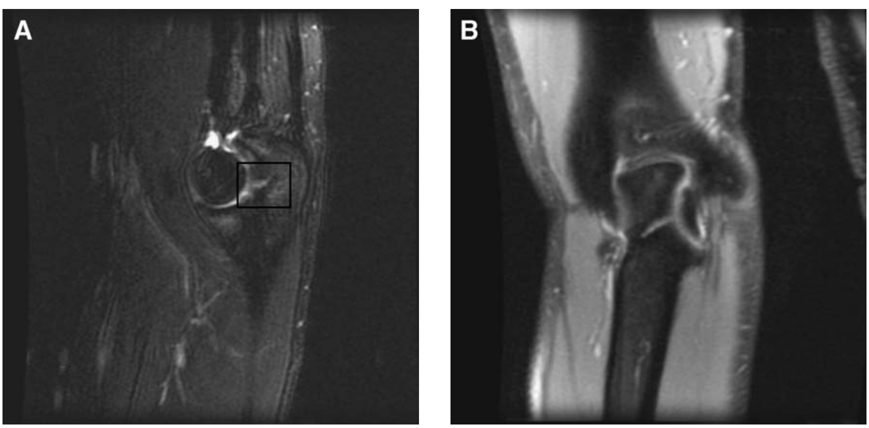


**Fig. 2.** (*A*) T2-weighted sagittal view MRI of an incomplete valgus stress-induced olecranon stress fracture in a collegiate baseball pitcher, indicated by the black box. (*B*) T2-weighted coronal MRI view of the same olecranon stress fracture.

short of extension to full flexion for the first 4 weeks to protect the elbow from full extension. At 6 weeks, sport-specific functional rehabilitation is started, followed by an interval-throwing program at 8 weeks. After completion of the throwing program, which requires approximately 4 to 6 weeks, the patient is allowed to return to play. Most of these fractures heal with nonsurgical management, but occasionally, open reduction and internal fixation is required [57–59].

There are two types of adolescent olecranon stress injuries, transverse growth plate fractures and osteochondroses [51]. Transverse physeal fractures and osteochondroses may be caused by an extensor overload of the triceps at the weak area of the olecranon, the physis [55]. The physis is injured by repeated forceful contractions of the triceps, resulting in transient localized ischemia in the olecranon physis and apophysis, which leads to disturbed ossification and fragmentation, a condition known as olecranon apophysitis or olecranon osteochondritis [4,55]. When the apophysis is more mature but not yet fused, the same forces may result in a transverse stress fracture through the growth plate. These injuries have been reported in young gymnasts, adolescent baseball pitchers, and an adolescent wrestler [51,52,64–66]. These patients present commonly with chronic, dull elbow pain and have tenderness over the olecranon. Plain radiographs reveal a widened olecranon epiphyseal plate, often with fragmentation of the olecranon apophysis. Treatment is initially nonsurgical with rest from the offending activity until the patient is asymptomatic. Rarely, the patient remains symptomatic, and a nonunion of the growth plate develops [52,64,66]. These patients are treated with open reduction and internal fixation, with bone grafting of the growth plate to promote fusion.

## ULNA

Stress fractures of the ulna have been described in baseball and softball pitchers, tennis players, volleyball players, weight lifters, bowlers, riflemen, a golfer, a polo player, a kendo player, and a baton twirler [67–82]. These athletes present with pain in the region of the ulnar shaft during and after activities and, on physical examination, have tenderness over the ulnar shaft. Radiographs demonstrate either a small crack in the cortex or subtle periosteal reaction at the site of the fracture. Radionuclide imaging or MRI is used to confirm the diagnosis. All of the reported cases have healed with nonsurgical management, which includes rest from the offending activity for a period of 6 to 8 weeks.

Mutoh and colleagues [71] have reported two ulnar stress fractures, one in a fast-pitch softball pitcher and one in volleyball player, both of whom experienced pain with underhand maneuvers. Both actions involved repetitive movements of the limb, with a light load following contraction of the wrist flexors. The authors state that the fracture was more proximal in the volleyball player, in which the wrist flexion was more prominent. Tanabe and colleagues [72] have presented three cases of ulnar stress fractures in fast-pitch softball pitchers. The authors state that the windmill softball delivery results in a strongly pronated forearm. Because of the relatively restricted rotatory motion at the distal radioulnar joint and proximal ulnohumeral joint, the ulnar rotation is restricted, allowing a strong revolving force of the radius to possibly act on the ulna. Morphologically, the middle third of the ulna has the thinnest cortex and smallest cross-sectional area compared with the proximal and distal ulna and has a triangular shape, which is less resistant to torsional stress. Therefore, large repetitive pronation torsional forces act on the weakest portion of the ulna shaft, which can result in a stress fracture of the middle third.

Bollen and colleagues [67] have reported two cases of stress fracture in the nondominant-sided ulna in tennis players who use a double-handed backhand stroke. These authors describe a similar mechanism of repetitive excessive pronation as reported by Tanabe and colleagues [72] in their softball pitchers. In other case reports of nondominant ulnar stress fractures in tennis players, Rettig [83] and Young and colleagues [68] theorize that the mechanism of injury is repetitive impact loading of the forearm during the ball strike.

Bell and Hawkins [69] have described a tennis player who developed a nondominant-sided distal ulnar stress fracture after using a double-handed backhand technique. The authors propose a hyperdorsiflexion mechanism of injury, which stresses the ulnocarpal joint and distal ulnar diaphysis. To obtain top spin, the racket head is dropped and brought backward, which results in a maximally dorsiflexed wrist position at the point of ball impact, which stresses the distal ulna. To help counteract this force, the authors used a dorsally applied wrist extension block splint on a temporary basis to prevent additional stress on the ulna.

Escher [73] has presented a bowler who developed an ulnar stress fracture while using a heavy, fingertip ball. The author states that, with the fingertip grip, the distal interphalangeal joints of the third and fourth digits are flexed to hold the bowling ball along with the thumb. Therefore, the flexor digitorum profundus muscle is activated repetitively, which results in repetitive stress on the ulnar origin of the muscle and predisposes this area of the bone to stress fracture.

Koskinen and colleagues [74] have reported a case of a golfer who had an ulnar stress fracture. The authors theorize that excessive supination together with overuse of the hand flexor muscles resulted in the fracture. After return to play, the patient's golf instructor changed the patient's grip so that the hand and forearm were in less supination.

## RADIUS

Stress fractures of the radius have been described in gymnasts, a tennis player, a pool player, a cyclist, and a badminton player [83–91]. Stress fractures of the distal radial growth plate are seen frequently in young gymnasts [83,84,87,89].

Ahluwalia and colleagues [88] have reported a skeletally mature female gymnast who presented with bilateral radial stress fractures, which were diagnosed by radionuclide imaging. Loosli and Leslie [85] have described a female tennis player in her 20s who developed increasing dominant-sided wrist pain. Plain radiograph results were normal; however, a bone scan revealed a distal radius stress fracture. The patient was subsequently placed in a short arm cast for 3 weeks, followed by a posterior splint for 3 more weeks. After the immobilization period, the subject began a strengthening program using latex tubing. The patient began hitting the tennis ball at 8 weeks and had returned to full competition by 3 months. Orloff and Resnick [90] have presented a pool player who developed a distal third radial shaft fracture after playing multiple rounds of pool over an extended period of time. Radiographs revealed a periosteal reaction over the distal radius. After 16 weeks, the patient's pain subsided, and radiographs revealed a healed fracture.

Caine and colleagues [83] studied growth plate changes in young competitive gymnasts. They noted that widening and irregularities of the distal radial physis were the first changes to appear in a spectrum of abnormal changes secondary to overuse and probably represented a stress fracture of the distal radial growth plate. These changes were associated with injury and were not normal adaptive changes seen in asymptomatic gymnasts. The fractures, seen radiographically, may appear to be only Salter-Harris type I or II fractures; however, they actually may involve more significant growth plate injury. Long-term complications may include symmetrical and asymmetrical growth plate retardation, positive ulnar variance, and associated pathoanatomic sequelae.

## SCAPHOID

Two cases of scaphoid stress fractures have been reported in the literature: one in an adolescent badminton player, associated with an ipsilateral distal radial epiphysiolysis, and one in a young gymnast who actually developed bilateral scaphoid stress fractures [86,92]. In the case of the gymnast, repetitive abduction and dorsiflexion movement of the wrist was implicated as a possible mechanism of injury [92]. In the badminton player, the authors propose that repeated shearing and torsional forces by excessive wrist movement from hitting the shuttle caused the stress injury [86].

## METACARPALS

Metacarpal stress fractures are rare but have been reported in a softball pitcher, tennis players, and a rower [93–96]. The second metacarpal was affected in both of the tennis players [94,96]. The authors in both of these tennis case studies suggest that increased training intensity combined with changes in stroke biomechanics and racket grip predisposed the second metacarpals to fracture. The movement of the second carpometacarpal joint is relatively limited, except for flexion and extension. This, in turn, may result in more stress being placed on the second metacarpal compared with the more mobile lateral metacarpals [4].

The softball pitcher developed a fifth metacarpal stress fracture [93]. The authors postulate that the abduction forces involved in the grip and release of the softball along with the muscle pull exerted by the extensor carpi ulnaris in gripping a softball may have played a role in overloading the normal dynamic balance of bony resorption and formation in the fifth metacarpal, resulting in a fracture.

The collegiate rower had a fourth metacarpal stress fracture [95]. The authors state that the pathogenesis of this fracture was related to the large mechanical forces transmitted from a gripped object. This may have been accentuated by poor grip and rowing mechanics.

All of the fractures healed with a period of relative rest followed by a gradual rehabilitation program. In addition, changes in techniques, equipment, and grip facilitated the return to competition.

## PHALANGES

Chell and colleagues [97] have reported bilateral Salter-Harris type III stress fractures at the bases of the middle phalanges of the middle fingers, occurring in an adolescent climber. The avid climber presented with a 1-week history of pain and swelling in his middle fingers, which was spontaneous in onset and without any direct trauma. Plain radiographs revealed each of these fractures; one fracture was nondisplaced, whereas the other was minimally displaced. MRI confirmed the diagnosis. The patient was treated conservatively, with relative rest from offending activities, and eventually became asymptomatic at 12 months. The proposed mechanism of injury was the prolonged gripping action required in rock climbing, with the metacarpophalangeal joint in extension and the interphalangeal joints in flexion. The prolonged activation of the finger extensors in this position resulted in the fractures.

## SUMMARY

Although they are less common than lower-extremity stress fractures, upper-extremity stress fractures are becoming recognized much more frequently. A majority of these fractures are caused by overuse and fatigue of the surrounding musculature and, as a result, may be prevented by appropriate training and conditioning. The diagnosis is made by obtaining a medical history and a physical examination with the aid of plain radiographs, bone scans, and MRI. Most of these fractures heal with a period of relative rest followed by a structured rehabilitation program. A small percentage of these fractures, however, may require surgical fixation.

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