Review Article

An Evidence-Based Approach to Managing Adolescent (Ages 10 to 19 Years) Diaphyseal Clavicle Fractures

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ABSTRACT

Diaphyseal clavicle fractures occur most frequently in adolescents (defined as ages 10 to 19 years by the World Health Organization). Multiple prospective comparative studies exist in the adult literature, whereas studies focusing on adolescents are limited. Given the notable differences in healing potential between pediatric, adolescent, and adult diaphyseal clavicle fractures, treatment algorithms tailored specifically to children, adolescents, and adults are required. In the past two decades, there has been a dramatic rise in surgical fixation of adolescent diaphyseal clavicle fractures, largely influenced by adult literature. The remodeling potential of the clavicle throughout adolescence and into early adulthood exceeds that of the adult population. Furthermore, prospective outcomes studies of displaced diaphyseal clavicle fractures have demonstrated that, when compared with surgical management, nonsurgical management portends equivalent functional outcomes but a nearly four times greater rate of complications. Even those injuries with comminution and notable shortening, nonsurgical treatment yields good functional outcomes, high rates of return to sport, and low incidence of complications, such as nonunion, symptomatic malunion, and refracture. In rare cases of unsatisfactory nonsurgical treatment, secondary surgical fixation most often results in union and good functional outcomes.

Diaphyseal clavicle fractures are a common injury occurring at an incidence of 29.14 per 100,000 per year.[1] The age group of 13 to 20 years has at least twice the incidence of any other age group, likely reflective of the involvement of this population in sports and other high-risk activities.[1] In the adolescent population (defined as ages 10 to 19 years by the World Health Organization), these injuries most commonly occur in male patients (79%) and at a mean age of 14 years.[2] Mechanism of injury most commonly involves a contact injury or a direct blow (60%) during sport participation (66%).[2] Football, rugby, and soccer account for most sports participation during which these injuries occur.[2] Nearly half of all adolescent

diaphyseal clavicle fractures are completely displaced with 18% comminuted and a mean shortening of 21 mm.[2]

Appreciating the differences in managing diaphyseal clavicle fractures in adult and adolescent populations is tantamount to providing appropriate, evidence-based care. Adult-focused research led to a paradigm shift in the management of these injuries, with increasing rates of surgical treatment in both adults and adolescents. However, more recent literature has demonstrated that unique considerations are needed when managing diaphyseal clavicle fractures in an adolescent population. This review will present an evidence-based approach to help guide treatment decision making in these injuries, highlighting the role of nonsurgical management.

Unique Considerations in the Skeletally Immature Clavicle

Although the first bone to ossify, the clavicle is also the last bone within the human body to undergo physeal fusion or physeal closure. The clavicle contains two primary ossification centers, medially and laterally, each with distinct patterns of ossification. A CT-based study of the medial ossification center showed that the epiphyseal ossification center appears from ages 11 to 21 years and, remarkably, on average does not complete fusion until 26 years.[3] Similarly, the lateral clavicular ossification center remains open well into the third decade of life.[4] A cadaveric study demonstrated that the lateral clavicular ossification center transitions from 'unfused' to 'fusing' at age approximately 17 years and 'fusing' to 'fused' between age 20 and 21 years, with most specimens demonstrating a closed physis at 24 years and older.[4]

The greatest magnitude of clavicular growth occurs between ages 0 and 12 years at an average of 8.4 mm/yr.[5] An important consideration in this growth pattern is the influence of sex on growth rates. A longitudinal case highlighted the pattern of growth and unique sex-specific characteristics throughout adolescence and into young adulthood.[6] Growth rates were found to be 4.9 mm/year and 4.7 mm/year from age 12 to 15 years, 3.2 mm/year and 1.7 mm/year from ages 16 to 19 years, and 1.7 mm/year and 0.2 mm/year from ages 20 to 25 years in male and female patients, respectively (Figure 1).[6] Notably, in this study, the authors were unable to detect the age of terminal growth in either sex because growth was ongoing in most patients in the oldest group.[6] As growth persists, so does the robust periosteum of the clavicle. The role of the periosteum in fostering an environment for fracture healing, particularly in pediatric fractures, has been well-described.[7]

The continued growth capacity of the clavicle and robust periosteum present into young adulthood enables diaphyseal clavicle fractures to settle and remodel—even those with complete displacement, shortening, and angulation. A multicenter, prospective study including 100 nonsurgically managed clavicle fractures in an adolescent population with a mean end-to-end shortening, cortex-to-cortex shortening, superior displacement, and angulation at the time of injury of 24, 15, 15 mm, and 7°, respectively, demonstrated that fracture alignment improved across all four measurements during early healing (Figures 2–4).[8] Longer-term studies have shown that fracture displacement does not predict nonunion or inferior functional outcome, further reflecting the remodeling potential of these injuries.[9] Most recently, the FACTS (Function after Adolescent Clavicle Trauma and Surgery) study group demonstrated that 85% of patients were younger than 14 years and 54% of patients were 14 years or older at the time of injury, with a minimum follow-up of 4 years for complete/near-complete remodeling (Figure 5).[10] This contrasts with adult populations in which completely displaced diaphyseal clavicle fractures demonstrate little propensity for remodeling and carry high nonunion rates with nonsurgical management.[11]

Evaluation and Imaging

A thorough history and physical should be obtained to rule out neurovascular injury and open injury. Plain radiographs should be obtained, including AP and Zanca (15° cephalic tilt) views. The Zanca view eliminates the overlapping scapula. A chest radiograph may be considered to compare sides and help determine the extent of shortening. The American Academy of Orthopaedic Surgeons (AAOS) Clinical Practice Guideline (CPG) (2022) for clavicle fractures makes a 'limited recommendation' for the use of upright radiographs to demonstrate the extent of displacement.[12] A shoulder series should be obtained to rule out any associated injury.

Trends in Management

The approach to managing adolescent diaphyseal clavicle fractures has shifted dramatically in recent decades, with a trend toward surgical treatment. Before the turn of the century, the rate of surgical fixation of clavicle

Figure 1

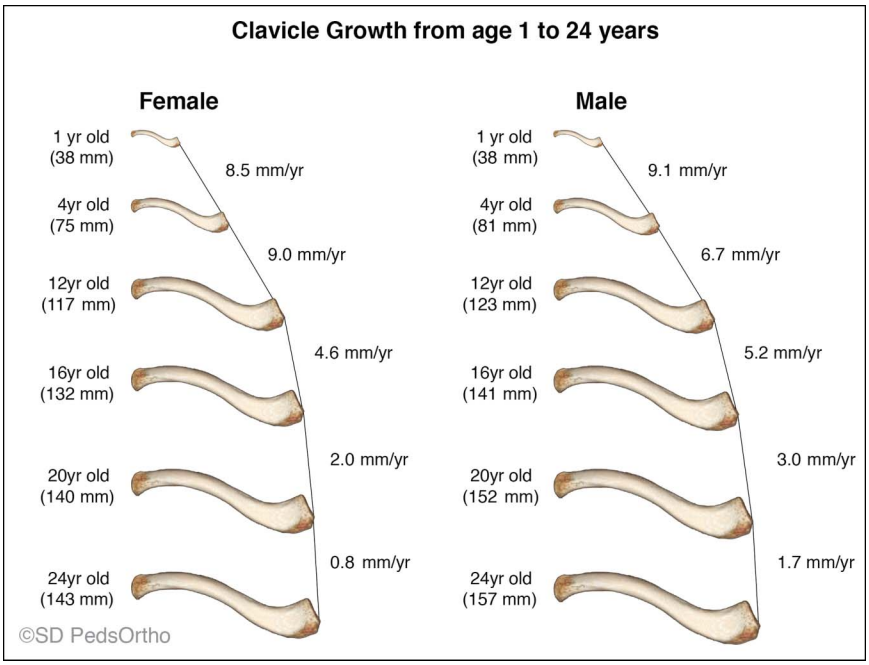


Illustration showing clavicular growth into early adulthood.[6]

fractures in children was approximately 1.6%.[13] Although in a recent prospective, multicenter study conducted in collaboration with the FACTS study group, 32% of displaced clavicles underwent fixation and 17% of all fractures regardless of displacement underwent surgical treatment,[2] these trends largely reflect the evolving shift in the management of adult clavicle fractures, which have been driven by randomized controlled trials primarily focused on adults.[14,15] There are no published randomized controlled trials comparing surgical versus nonsurgical treatment in adolescents. Trends of increased surgical treatment do not reflect the known remarkable remodeling potential of the clavicle and are not aligned with the most recent prospective work on pediatric and adolescent clavicle fractures.

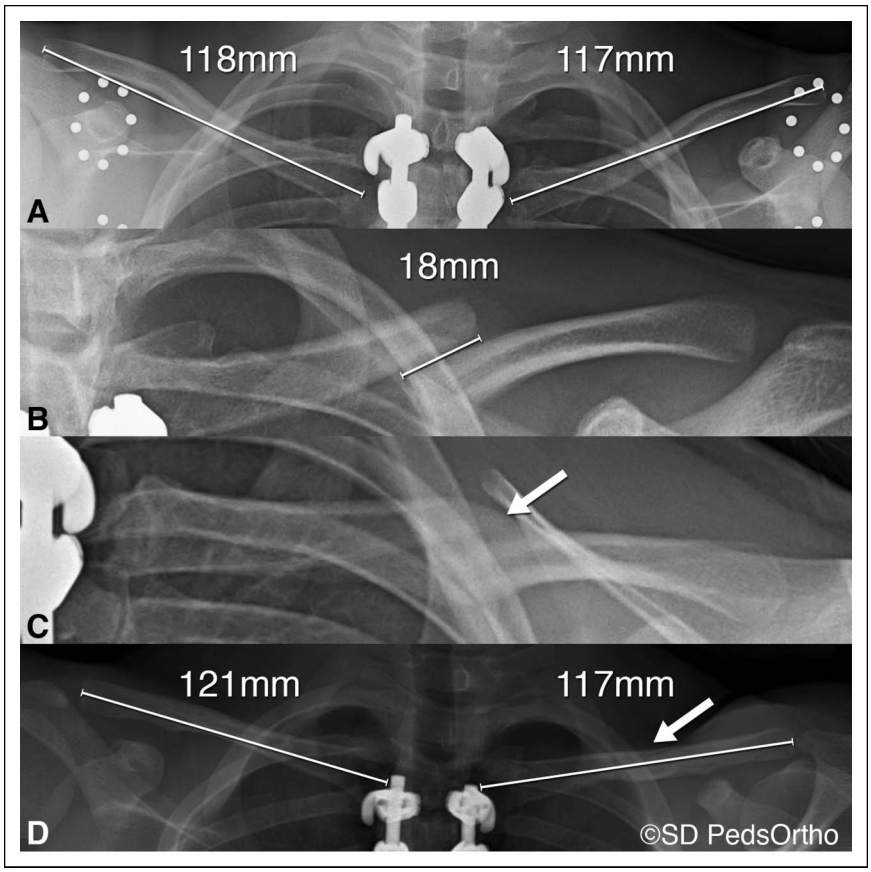
Treatment Options

There are surgical and nonsurgical options for treating adolescent clavicle fractures. Based on a recent consensus statement from the AAOS CPG (2022) for clavicle fractures, nonsurgical treatment should consist of a sling immobilization over a finger-of-eight brace because it is easily applied, tolerated well, and accessible.[12] Of note, this recommendation was based on a single randomized control trial in adults.[16] The current AAOS CPG (2022) for clavicle fractures includes a strong recommendation for surgical fixation of displaced diaphyseal clavicle fractures in adults.[12] However, in adolescents, defined as those 18 years or younger, the statement reads: '. . .surgical treatment may offer no benefit compared with nonsurgical treatment. Surgical treatment is associated with similar union rates and substantial revision surgery rates for implant removal.'[12] Surgical fixation options include plate or intramedullary fixation, although plate fixation remains the predominant choice of fixation within the adolescent population (Figure 6). Union is achieved in 99.6% of cases, regardless of treatment modality.[17]

Surgical Treatment

Surgical treatment remains a viable treatment option regarding functional outcomes and patient satisfaction. A retrospective review of 24 clavicles treated with plate fixation demonstrated a 100% rate of union and return to sports.[18] However, consideration must be given to the complication profile of surgical fixation; implant removal was performed electively in all patients.[18] Complications rates with plate fixation range from 16% to 89% and most commonly involve symptomatic implants (4% to 59%), revision surgery for implant removal (4% to 19%), anterior chest wall numbness (16%, only evaluated in one study), wound healing complications (0% to 5%), and refracture (0% to

Figure 2



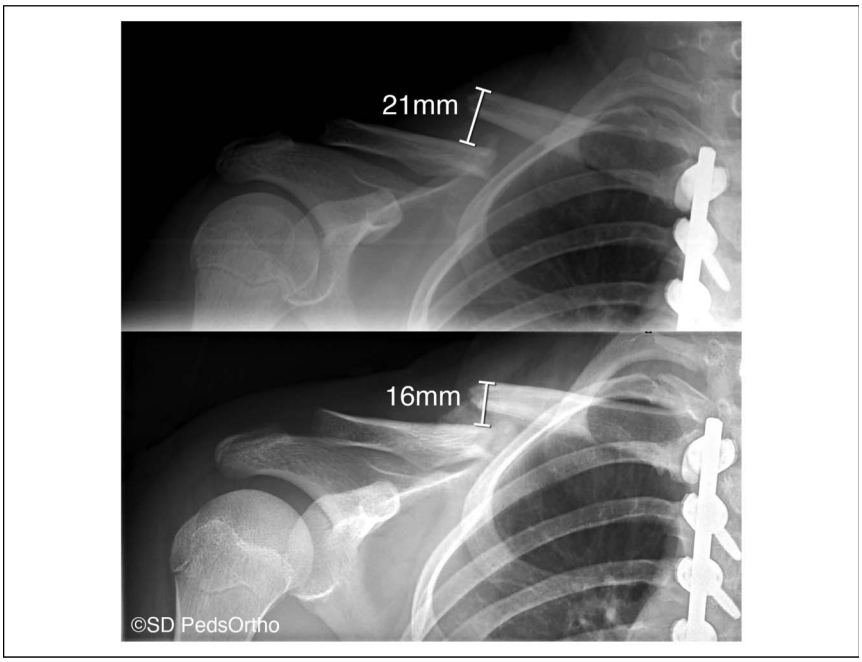
Radiographs showing early settling within the first 3 months of injury: shortening. **A,** The patient was 16.6 years during preinjury with a clavicle length of 117 mm. **B,** The patient was 17.1 years at the time of injury with 18 mm of shortening. **C,** Image obtained 1 month after injury. **D,** Image obtained 18.5 months after injury with return of the clavicle length to preinjury value and only 4 mm shorter than the uninjured, contralateral clavicle.[8]

6%).[19-22] More severe surgical complications, including iatrogenic damage to the lung (pneumothorax—rare case reports) and bleeding issues from injury to the subclavian vessels (0.8%), have also been described.[17] Although these are exceedingly rare, they should not be understated. Intramedullary fixation, although less frequently used, remains an effective modality for surgical fixation. In a retrospective case series of 17 patients treated with intramedullary fixation, the authors noted a 100% union rate at 12 weeks with American Shoulder and Elbow Surgeons scores of 44.2 for pain and 44.3 for function (of 50 points).[23] One patient reported difficulty in return to sport and one reported sensory deficit at the incision.[23] Similarly, a retrospective review of 25 fractures treated with elastic intramedullary fixation reported a return to sport rate of 100% with excellent Constant and Murley Shoulder Scores of 99.5 of 100 points. The authors did note a complication profile including one incident of implant breakage, two incidents of implant deformation, and two incidents of imminent skin perforation from the implant, which can occur in the setting of implant migration or improper positioning.[24] The AAOS CPG (2022) for clavicle fractures makes a 'moderate recommendation' for the use of both intramedullary nail and plate constructs because of equivalent long-term clinical outcomes with similar complication rates.[12] Comminution remains the only indication for plating over intramedullary nail fixation. Regardless of the implant chosen, surgical treatment results in high rates of union, return to sports, and high functional outcome scores but carries an elevated complication rate.

Indications for Acute Surgical Intervention

Absolute indications for surgical treatment of diaphyseal clavicle fractures include open fracture and acute

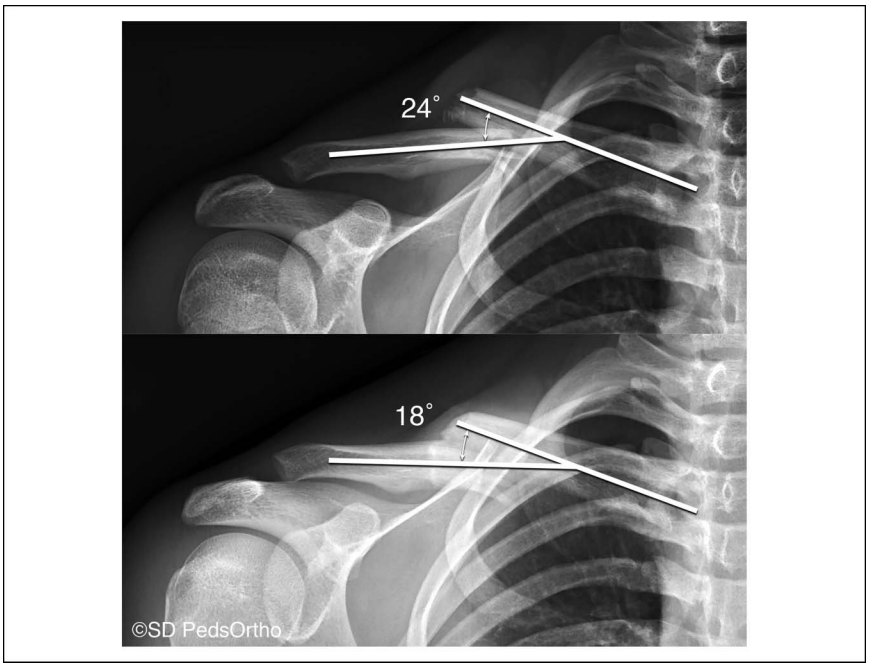
Figure 3



Radiographs showing early settling within the first 3 months of injury: Superior displacement. The patient was 13.9 years at the time of injury with a superior displacement of 21 mm. Bottom image was obtained 1.2 months after injury with 5 mm decrease in superior displacement.[8]

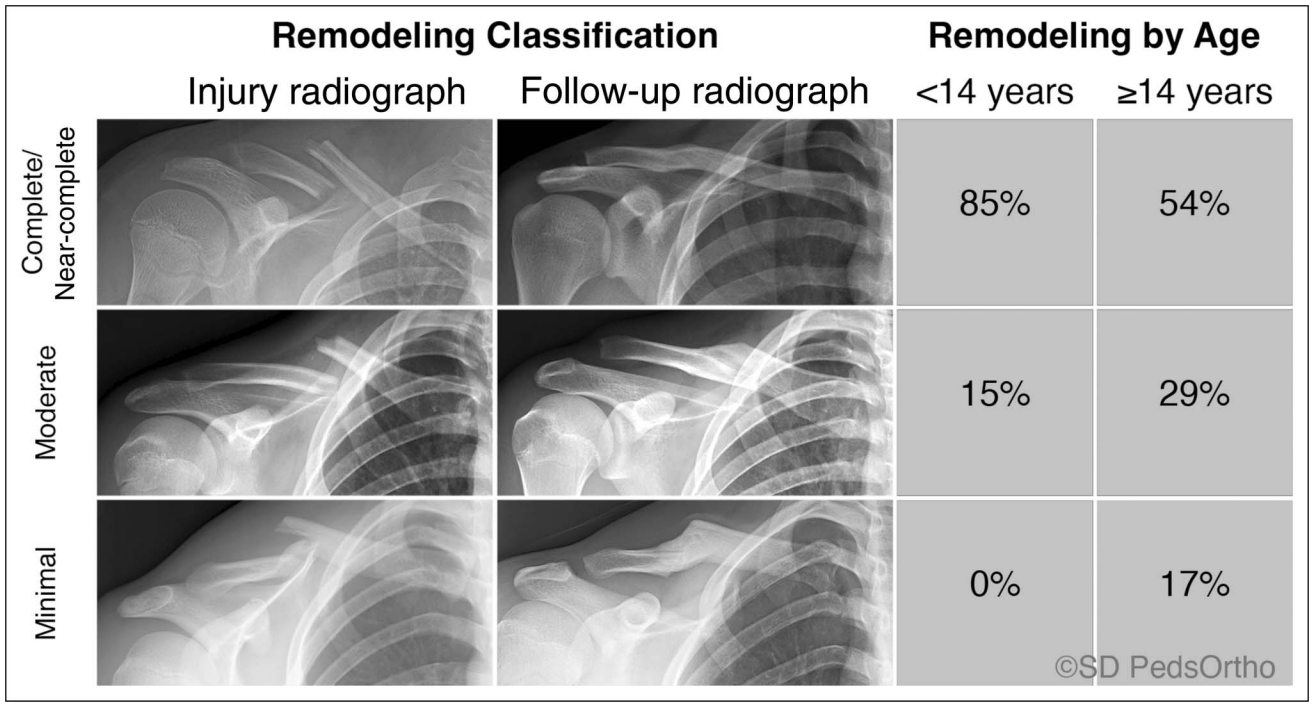
neurovascular injury—the incidences of both approach 0% and are limited to rare case reports.[2] Relative indications and rationale for surgical fixation of isolated clavicle fractures have previously included skin tenting with concern for imminent open fracture, notable shortening/displacement (which have historically been

Figure 4



Radiograph showing early settling within the first 3 months of injury: Angulation. The patient was 15 years at the time of injury with 24° of angulation. Bottom image was obtained 2.6 months after injury with 6° decrease in angulation.[8]

Figure 5



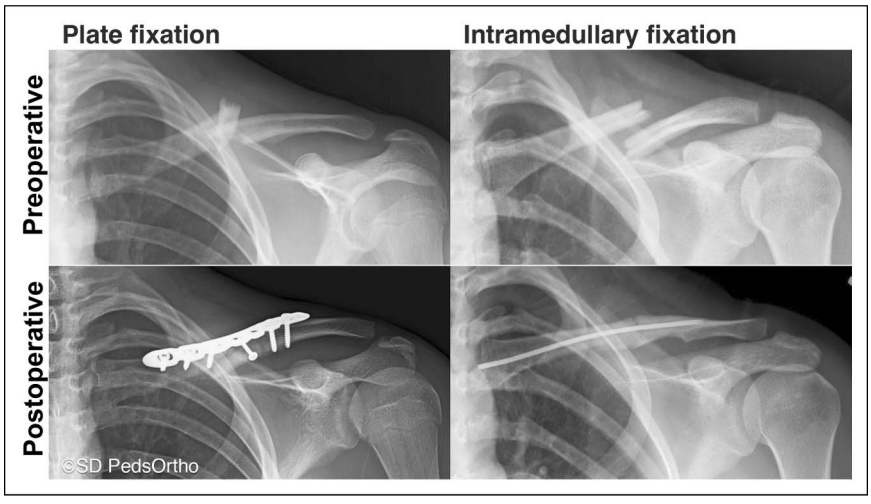
Radiographic diagram showing remodeling capacity at 4-year follow-up. Representative cases demonstrating the remodeling capacity of nonsurgically management adolescent diaphyseal clavicle fracture.[10] In this review of 81 patients at a mean follow-up of 3 years, fracture shortening, superior displacement, and angulation markedly improved by 60%, 57%, and 38%, respectively. All patients were younger than 14 years and 83% of patients were 14 years and older at the time of injury with a minimum follow-up of 4 years for complete/near-complete remodeling.[10]

thought to predispose to symptomatic malunion, nonunion, and even refracture), more rapid return to activities of daily living and sport, improved patient-reported outcomes, and better cosmetic appearance.

Malunion

Symptomatic malunions after nonsurgical treatments occur at a rate of 8.5% to 18.4% in adults and are associated with lower functional scores.[19,25] Historically, the rate of

Figure 6



Radiograph showing surgical fixation: Representative cases demonstrating the more frequently used plate fixation and the less popular intramedullary fixation. Left images demonstrate a 14-year-old patient with follow-up at 6 weeks from surgery. Right images demonstrate a 15-year-old patient with follow-up at 6 weeks from surgery.[25]

symptomatic malunion in the adolescent population was defined by retrospective case series and ranged from 2% to 20%.[20,26] A more recent prospective cohort of 292 patients with nonsurgically managed displaced and shortened pediatric and adolescent clavicle fractures, found a symptomatic malunion rate of 0.7%.[17] By contrast, there were no cases of symptomatic malunion in the 125 patients treated with surgical fixation. Concerns for altered glenohumeral mechanics and function in the setting of malunion have been evaluated through cadaveric work and functional testing. A cadaver model evaluating the effect of shortening deformity of the clavicle on scapular kinematics found that posterior tilting and external rotation of the scapula markedly decreased with ≥10% shortening.[27] However, clinical studies focusing on residual deformity in an adolescent population suggest that malunion has minimal functional effect, as measured by patient-reported outcomes, physical examination, and formal motion analysis. A review of 16 malunions in skeletally immature patients with a mean follow-up of 27.2 months found no clinically meaningful loss of shoulder motion or abduction/adduction strength.[28] This cohort reported excellent Disabilities of the Arm, Shoulder, and Hand (DASH) and Pediatric Outcomes Data Collection Instrument scores with a mean visual analog score (VAS of 2), without one of the 16 patients undergoing corrective osteotomy.[28] Similarly, final clavicle shortening has no influence on pain, strength, shoulder range of motion, strength, abduction fatigue, or subjective outcome scores (Single Assessment Numeric Evaluation, quickDASH, and constant), when compared with the uninjured extremity.[29,30] Functional outcomes are excellent in patients with malunion, and formal motion analysis has demonstrated no loss of strength or endurance with malunion in this population. Furthermore, for the 0.7% of patients who do develop a symptomatic nonunion after nonsurgical management, secondary surgical fixation results in equivalent union rates, time to return to sport, and functional outcomes because those are treated primarily with surgical fixation.

Nonunion

The adult nonunion rate for displaced diaphyseal clavicle fractures is 16.5% when treated nonsurgically and 1.9% with plate fixation.[25] While a retrospective review of nine high-volume pediatric hospitals (545 primary clavicle fractures) over a 10-year period revealed a 5% nonunion rate, the FACTS study group more recently reported a nonunion rate of 0.7% in a prospective cohort of 416 adolescents with completely displaced diaphyseal clavicle fractures with a mean shortening of 20.7 mm treated nonsurgically.[2,17] In the adult population, the risk of nonunion is substantially influenced by smoking (OR, 3.76), comminution (OR, 1.75), and fracture displacement (OR, 1.17); although the AAOS CPG (2022) on clavicle fractures notes a 'limited recommendation' that 'increasing displacement and/or comminution in midshaft clavicle fractures may be associated with higher rates of nonunion after nonsurgical treatment in adults,'[12,31] the only notable factor associated with developing a nonunion was a history of an ipsilateral clavicle fracture.[21] Notably, age, angulation, comminution, superior-inferior displacement, and shortening were all not associated with nonunion.[21] In addition, nonunions in a cohort of adolescent patients treated with secondary surgical fixation had a postoperative course comparable with that of patients treated with surgery at initial presentation (equivalent time to return to sport, rates of symptomatic implant, and union rates) (Figure 7).[20]

Refracture

Refracture is an important consideration in counseling patients because it is a potential complication of both nonsurgical and surgical fixation. In a review of 641 clavicle fractures, the refracture rates of 2.9% and 1.7% were reported with nonsurgical management and surgical fixation, respectively.[32] Interestingly, a recent FACTS prospective cohort of 416 patients demonstrated a 2.1% rate of refracture with nonsurgical management and 4% with surgical fixation.[17]

Skin Tenting

Skin tenting is a controversial indication for acute surgical intervention; the historical belief was that skin tenting may lead to skin erosion and a resultant open fracture.[33] Skin tenting is a subjective finding with great variability in clinician definition.[34] This is highlighted by an association observed between lower body mass index and shortening with a diagnosis of skin tenting in an adult population.[34] Cases of true skin breakdown secondary to skin tenting are incredibly rare after nonsurgical management and limited to only a few reported cases in the literature.[33] This warrants discussion with families in making a shared decision on treatment because scientific evidence is insufficient to support one treatment method over the other. Awareness, vigilance, and close follow-up are recommended when electing to treat a fracture with skin tenting nonsurgically.

Return to Activity and Sport-Specific Needs

Surgical treatment was initially believed to allow more rapid return to sports, other specialized functions, and activities of daily living, despite a paucity of data to confirm this benefit. In one study, faster return to sport by a few weeks was noted (12 weeks with surgical treatment

Figure 7

Radiographs showing nonunion: Representative case demonstrating nonunion after nonsurgical management and subsequent union achieved after surgical fixation. The patient was 14.1 years at the time of injury. Middle image was obtained 20 months after injury. Bottom image demonstrates open reduction and internal fixation with a plate 25 months from index injury and 3.4 months after surgical fixation.[21]

versus 16 weeks with nonsurgical treatment).[26] However, a subsequent study found no evidence of quicker return to activity with surgical fixation (approximately 12 weeks in both cohorts).[35] Further, a more recent study of adolescent athletes found that those with clavicle fractures treated nonoperatively returned to sports over 5.5 weeks sooner than those treated operatively, and that time to return to sports was related to fracture displacement, comminution, and angulation.[36] From an evidence-based perspective, quicker return to sports should not be emphasized to patients/families as a benefit of surgical management. Overhead sport activity has also been used as a justification for surgical management, but a review of 22 adolescent athletes with nonsurgically managed clavicle fractures, 11 of whom participated in ≥ 6 months per year of overhead or contact sports, noted equivalent outcomes regardless of sport participation.[37]

Patient-Reported Outcomes

Despite the literature demonstrating that excellent patient-reported outcomes can be achieved with nonsurgical management, patient/family education is needed to help reinforce this point during shared decision-making discussions.[38,39] In a well-designed study comparing the injured extremity with the uninjured extremity, the authors noted no difference in pain, strength, shoulder range of motion, or subjective outcome scores (Single Assessment Numeric Evaluation, quickDASH, and constant).[29] In addition, a study comparing nonsurgically managed and surgically managed fractures noted similar patient-reported outcomes.[40] Patients/families can be reassured that patient-reported outcomes remain high after nonsurgical management, even when compared directly with the uninjured extremity and surgically managed clavicles.

Cosmetic Appearance

Cosmetic appearance is another concern that can influence decision making by patients/families. Based on adult literature, nonsurgical treatment was considered a risk for poor cosmetic outcome.[41] However, more recent data in an adolescent cohort have shown surgical management to be associated with poorer cosmetic perception.[39]

Cost Considerations

To date, cost analysis has not been performed in the adolescent population. However, a cost analysis using four randomized control trials consisting of an adult population found that initial nonsurgical treatment of midshaft clavicle fractures, followed by delayed surgery as needed is less costly than initial surgical fixation—$3,112.65 and $14,763.21, respectively.[42] Nonsurgical treatment was found to produce a cost savings of $11,650.56 with nonsurgical treatment.[42] The practicing orthopaedic surgeon should consider these costs when generating a treatment plan. Additional research is needed to determine whether these differences are consistent within an adolescent population.

Summary

Adolescent diaphyseal clavicle fractures have low rates of nonunion, symptomatic malunion, and refracture, as well as excellent functional and patient-reported outcomes regardless of treatment modality. Surgical fixation carries an additional burden of complications, including symptomatic implant, secondary procedure for implant removal, infection, neurovascular injury, pneumothorax, and chest wall numbness. The main role for surgical management remains in treating open fractures and those with neurovascular compromise. Nonsurgical management should be considered the primary treatment of adolescent diaphyseal clavicle fractures.

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