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ORIGINAL CLINICAL ARTICLE

Open reduction of proximal humerus fractures in the adolescent population

Nirav K. Pandya · Dominque Behrends · Harish S. Hosalkar

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Abstract

Purpose Proximal humerus fractures in the pediatric population are a relatively uncommon injury, with the majority of injuries treated in a closed fashion due to the tremendous remodeling potential of the proximal humerus in the skeletally immature. Yet, in adolescent patients, open treatment is, at times, necessary due to unsatisfactory alignment following a closed reduction, loss of previously achieved closed reduction, and limited remodeling when close to skeletal maturity. The purpose of our study was to examine the open reduction of adolescent proximal humerus fractures.

Methods A retrospective review of the outcomes of proximal humerus fractures in the adolescent population which were consecutively treated at our institution with open reduction was performed.

Results Ten children met the inclusion criteria, with a mean age of 14.3 years (±1.3) and a mean weight of 60.7 kg (±14.9) at the time of injury. There were seven Salter-Harris 2 fractures and three Salter-Harris 1 fractures. The largest mean angulation was 55.0° (±33.9) and the largest mean displacement was 87.0 % (±22.8). Intra-operatively, impediments to closed reduction within the fracture site which were found included: periosteum (90.0 %), biceps tendon (90.0 %), deltoid muscle (70.0 %), and comminuted bone (10.0 %). K-wire fixation was most commonly used (70.0 %), followed by flexible nails (20.0 %) and cannulated screws (10.0 %) for fixation. All patients achieved radiographic union at a mean of 4.0 weeks (±0.7), had non-painful full shoulder range of motion and rotator cuff strength at final follow-up (mean 7.7 ± 4.6 months), and returned to pre-injury sporting activities.

Conclusions The operative treatment of proximal humerus fracture, particularly in adolescents with severe displacement/angulation having failed closed methods of treatment, is increasingly considered to be an acceptable modality of treatment. In addition to the long head of the biceps, periosteum, deltoid muscle, and bone fragments in combination can prevent fracture reduction. Surgeon preference and skill should dictate implant choice, and the risk of physeal damage utilizing these implants in this age group is low.

Keywords Proximal humerus · Pediatric · Adolescent · Open reduction · Operative

Study was conducted at Rady Children's Hospital.

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Introduction

Proximal humeral fractures in the pediatric population are relatively uncommon, accounting for less than 3 % of all fractures in children and include 4–7 % of all epiphyseal fractures [1–4]. Their treatment is rarely debated, as non-operative treatment is commonly performed and widely accepted as the standard of care [2, 5–7]. This rationale is related to the tremendous remodeling potential of the proximal humeral physis, with 80 % of the longitudinal growth of the humerus coming from this location [2, 3]. Even less than satisfactory reductions (from a perfectly anatomical standpoint) are often well tolerated due to the mobility of the shoulder joint and the ability of more distal joints (i.e., the elbow) to compensate for the loss of motion [2, 5, 7].

In girls under 13 and boys under 15 years of age, 50 % of bayonet apposition of a proximal humerus fracture and up to 20° of angulation in any plane has been noted to remodel [8]. Other studies have noted that patients up to 10 years of age, 60° of varus, anteversion, or retroversion can remodel [9]. As a result, the majority of studies which have investigated non-operative outcomes of pediatric proximal humerus fractures have concentrated on non-adolescent patients [5, 10–12].

Yet, there are a subset of studies showing excellent outcomes in patients operatively treated with severely displaced injuries, particularly those above the age of 13 years [12–15]. It is within this adolescent age group that interposition of periosteum, entrapped long head of the biceps tendon, and/or other structures have been cited as potential impediments to anatomic or acceptable near-anatomic reduction [13]. Furthermore, as patients approach skeletal maturity, remodeling potential is limited and the results can be potentially worse with non-operative treatment, particularly in non-anatomically reduced fractures. This can lead to long-term limited mobility and pain [2, 7, 10, 11, 16–18]. In addition, adolescents are placing higher demands on their shoulders with increasing participation in high-level sporting activities [19]. As a result, it is unclear what the effects of slight fracture mal-reduction may have on gleno-humeral and scapulo-thoracic range of motion and rotator cuff mechanics. Although rare, it is, therefore, imperative to have a better understanding of the open treatment of proximal humerus fractures in the adolescent population.

The purpose of our study was to assess the need for open reduction in adolescent proximal humerus fractures, delineate anatomic structures which may impede the ability to achieve successful closed treatment, review clinical and radiological outcomes, and determine the incidence of physeal damage in patients who undergo operative treatment.

Materials and methods

This was a retrospective review examining proximal humerus fractures in adolescent patients with open proximal humeral physis consecutively treated with open reduction and fixation at our institution over a 3-year period. Patients with operatively treated proximal humeral fractures were identified via a computerized search of our institution's billing database utilizing the CPT code 23615 (open treatment of proximal humeral fracture). Patients were included in the study if they sustained a proximal humeral fracture which was treated in the operating room with open reduction and fixation as the definitive treatment in an acute setting before healing of the fracture had occurred (requiring osteotomy) by a fellowship trained pediatric orthopaedic surgeon. All patients had displaced/angulated injuries that had failed attempts at closed reduction prior to open reduction and internal fixation, were felt to have poor remodeling potential by the treating surgeon (generally greater than 40° of angulation or >50 % displacement), and were skeletally immature as defined by open proximal humeral growth plates on the injured side at the time of injury based on plain radiographs. Patients were excluded from the study if they were treated with modalities other than internal fixation for their proximal humeral fractures after open reduction (i.e., casting, sling), had been operated on at an outside institution and presented to us for post-operative management, underwent operations for delayed unions, non-unions, or mal-unions, or had pathologic fractures, neuromuscular disorders, skeletal dysplasia, and/or metabolic diseases affecting the bone. The choice of surgical approach and methods of internal fixation for fracture treatment were left to the treating surgeon's discretion at our institution based on patient age, fracture pattern, and associated injuries.

Data collected from a retrospective chart review included age at the time of injury, gender, weight (kg), affected side, and mechanism of injury. Emergency room records were reviewed for past medical and surgical history, the presence of pre-operative associated injuries (both orthopaedic and non-orthopaedic), pre-operative neurovascular deficits, and attempted closed reduction treatments. Initial plain radiographs were evaluated for fracture angulation and maximum displacement (determined by measuring the largest displacement/angulation seen on any of the different radiographic views taken), as well as Salter-Harris classification. In addition, operative reports were reviewed in order to determine the time to operating room from injury, type of surgery, implants utilized, intra-operative findings (i.e., interposed structures), and complications.

The mean follow-up time was calculated from the date of surgery to the final clinical follow-up. The need for secondary procedures, including hardware removal, was recorded as well. Post-operative clinical data collected included the duration of immobilization utilized, time from surgery to initiation of range of motion, final shoulder range of motion (abduction, flexion, internal and external rotation), final rotator cuff strength, pain at final follow-up, and return to pre-injury level of sporting activity. Post-operative radiographic data collected included time to union, the presence of mal-union (defined as greater than 20° of angulation in any radiographic plane), non-union (union not achieved by 6 months), and the incidence of premature physeal arrest/growth disturbance [8, 20].

The Institutional Review Board at our institution approved the protocol for this study before initiation.

Results

Ten children (nine male and one female) met the inclusion criteria, with a mean age of 14.3 years (±1.3) and a mean weight of 60.7 kg (±14.9) at the time of injury. All patients had open proximal humeral physes and underwent open reduction as their definitive treatment, with five right and five left arms affected. The majority of patients (70.0 %) recalled a direct fall onto their shoulder as their mechanism of injury, with the remainder sustaining an injury during a motorcycle accident (30.0 %).

No patients had pre-operative neurovascular deficits, and only one patient presented with another injury (ipsilateral clavicle fracture that was treated with plate fixation). There were seven Salter-Harris 2 fractures and three Salter-Harris 1 fractures. The mean maximum fracture angulation was 55.0° (±33.9) and the mean maximum displacement was 87.0 % (±22.8). Sixty percent of patients had a failed closed reduction attempt in the operating room prior to the utilization of open methods; the remainder of the patients had attempts at closed reduction in the emergency room.

Patients presented to the operating room at a mean of 5.0 days (±4.9) after their initial injury. The surgical approach utilized included a formal delto-pectoral approach in the majority of cases (60.0 %), followed by small incisions made over the lateral humerus for the placement of instruments to aid in reduction (30.0 %). In one case, an oblique incision was made over the metaphysis anterolaterally in order to obtain access to an interposed bony fragment.

Intra-operatively, impediments to closed reduction within the fracture site which were found included: periosteum (90.0 %), biceps tendon (90.0 %), deltoid muscle (70.0 %), and comminuted bone (10 %) (Table 1). K-wire fixation was most commonly used (70.0 %), followed by flexible nails (20.0 %) and cannulated screws (10.0 %; Figs. 1, 2, 3). There were no intra-operative complications noted, except for one patient who had a K-wire break within the bone, which was left in place.

The total follow-up time was 7.7 months (±4.6). Patients started range of motion at a mean of 30.0 days (±12.4) from the time of the surgery. Seventy percent of the patients needed secondary hardware removal in the operating room. All patients achieved radiographic union at a mean of 4.0 weeks (±0.7). There were no cases of non-union, mal-union, or premature physeal arrest/growth disturbances. All patients had non-painful full shoulder range of motion and normal rotator cuff strength (comparable to the opposite side) at final follow-up, and returned to sporting activities at a mean of 3.0 months (±4.0) from the time of the surgery.

Table 1 Entrapped structures preventing closed reduction at the time of open reduction

Patient	Biceps	Periosteum	Deltoid	Bone fragments
1	Yes	Yes	Yes	No
2	No	Yes	No	No
3	Yes	Yes	Yes	No
4	Yes	Yes	Yes	No
5	Yes	Yes	Yes	No
6	Yes	Yes	No	No
7	Yes	Yes	Yes	No
8	Yes	Yes	No	No
9	Yes	No	Yes	Yes
10	Yes	Yes	Yes	No
Total	9/10	9/10	7/10	1/10

Discussion

Proximal humerus fractures have traditionally been treated non-operatively in the pediatric population [2, 5–7]. The tremendous remodeling potential of the proximal humeral physis and the ability of distal joints to compensate for a proximal loss of motion allow for increased amounts of displacement and angulation to be tolerated [2, 3, 5, 7, 21]. The success of non-operative treatment of proximal humerus fractures has been well documented.

Di Gennaro et al. [22] reviewed 91 proximal humerus fractures in children with a mean age of 10.7 years (82 treated non-operatively) and found that 96 % of patients had good to excellent clinical and radiographic results. David et al. [23] reviewed 52 children with proximal humeral fractures (49 treated non-operatively), with all patients having good or very good results, regardless of the fracture morphology or treatment. Larsen et al. [7] examined 64 patients with proximal humeral fractures and found that, of the 63 patients who were treated non-operatively, only seven had slight transient pain or restriction of motion. The authors also found full remodeling of all fractures which were displaced (even those which were severely displaced), leading to the recommendation of non-operative treatment in all fracture types. Finally, Baxter and Wiley [17] reviewed 57 patients with proximal humerus fractures from 2 to 8 years after injury and found that, regardless of treatment, the maximum shortening was 2 cm and residual varus angulation was insignificant. In addition, reduction in any form did not improve final outcome in regards to humeral growth or function in their

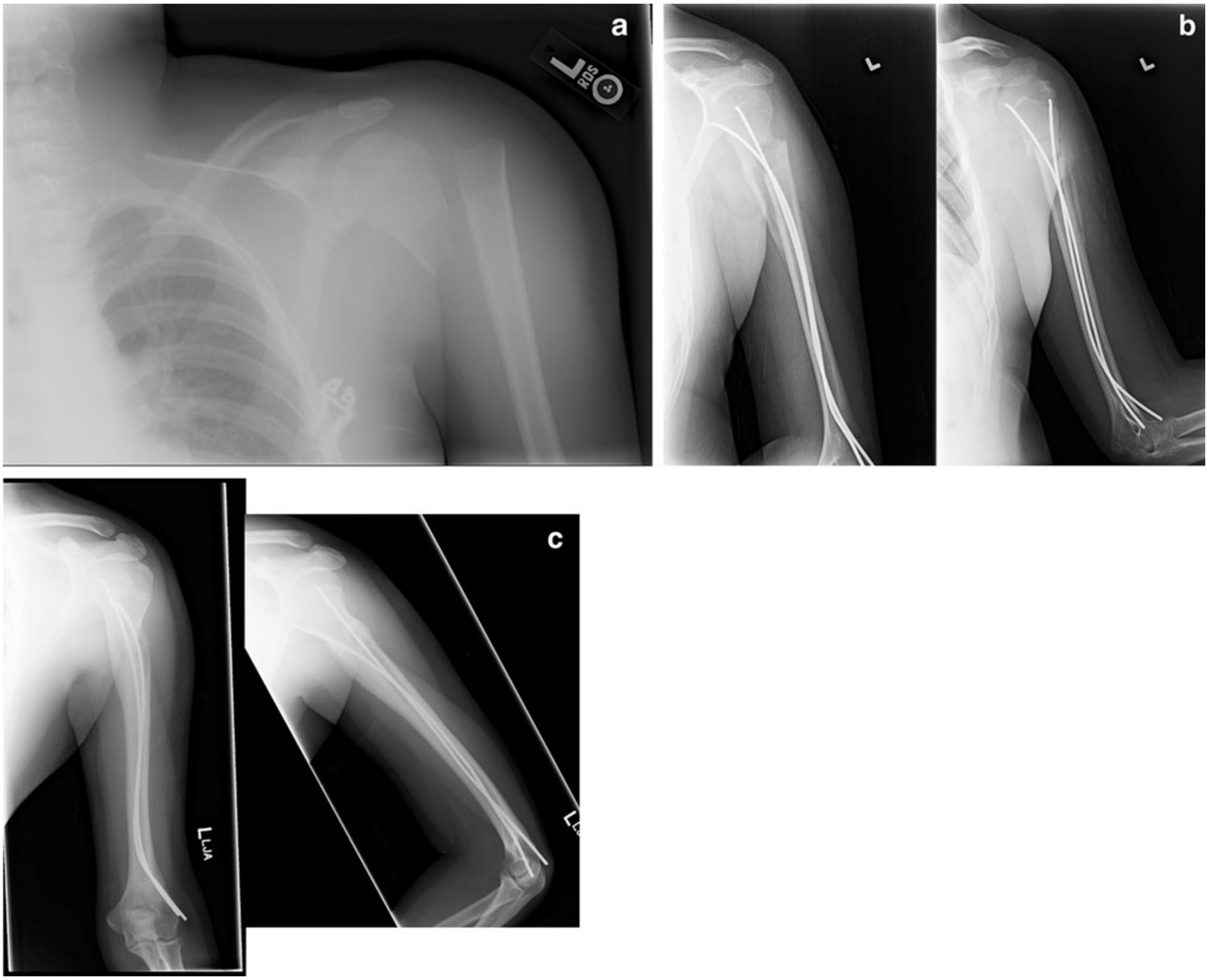

Fig. 1 A 14-year-old male with a left proximal humerus fracture sustained from a motorcycle accident. **a** Pre-operative anteroposterior (AP) radiograph. **b** Immediate post-operative AP radiograph and lateral radiograph 6 weeks after operation with flexible nails. **c** 9.5 months post-operative AP and lateral radiographs showing complete healing prior to flexible nail removal

series, leading them to conclude that open reduction is very rarely indicated.

Yet, even with the plethora of papers which expound the benefits of non-operative treatment of proximal humerus fractures [2, 3, 5, 7, 17, 22, 23], it is important to note that many of these studies contain a large number fractures which are either minimally or non-displaced, or include a large number of patients who are quite young and possess tremendous remodeling potential. These characteristics do not apply to the adolescent patient population in our series who underwent operative fixation.

Our mean patient age was 14.3 years (±1.3), with mean weight of 60.7 kg (±14.9) at the time of injury. These patients, although possessing open proximal humeral physis, should be seen as distinct from patients less than 10 years of age. These are older, adult-type patients with limited remodeling potential, placing greater demands on their shoulders (i.e., all of our patients were engaged in sporting activities). In addition, our fractures were significantly angulated and displaced with a mean maximum angulation of 55.0° (±33.9) and a mean maximum displacement of 87.0 % (±22.8).

Pahlavan et al. [15], in a systematic review of 569 proximal humerus fractures treated in the literature from 1960 to 2010, found that patients below the age of 10 and above the age of 13 years should be treated as distinct patient populations. Through a review of patient outcomes in their review, the authors found that children less than 10 years of age should be treated non-operatively due to their tremendous remodeling potential, whereas patients above the age of 13 years (as in our series) are candidates for open reduction and fixation due to a much more limited remodeling potential. Furthermore, Dameron and Reibel evaluated 46 skeletally immature patients with proximal

Fig. 2 A 16-year-old male with a right proximal humerus fracture sustained from a fall while snowboarding. **a** Pre-operative AP and transthoracic lateral radiographs. **b** Immediate post-operative AP and transthoracic lateral radiographs after K-wire fixation. **c** 3.5 months post-operative AP and lateral radiographs showing complete healing

humerus fractures and found that, in their patients above the age of 14 years, poor outcomes were noted due to loss of reduction [5]. Kohler and Trillaud [16] reported their proximal humeral fracture experience and noted that, in their subset of older patients, operative intervention was warranted, as irreducible fractures could not remodel.

In regards to severe displacement, Neer and Horwitz found that patients with severe displacement (greater than 2/3rds of the humeral shaft) had persistent deformity and arm shortening compared to the contralateral side [2]. In addition, Schwendenwein et al. [14] examined 16 patients with significantly displaced proximal humeral fractures who underwent operative intervention with excellent results, recommending operative treatment in displaced fractures.

Due to the results of studies such as those mentioned above, operative indications for proximal humerus fractures are expanding, particularly in adolescent patients with displaced fractures [2, 7, 9, 12, 13, 15, 17]. As in our study (in which all patients returned to sporting activities at a mean of 3.0 months after surgery with full shoulder strength and range of motion at final follow-up), when done appropriately, operative intervention in this population can lead to excellent results.

With an understanding of the indications for operative intervention (i.e., increased age, displacement, and angulation) which can lead to excellent results, the choice of surgical approach as well as the implant to be utilized becomes paramount. Within our cohort of ten patients, all

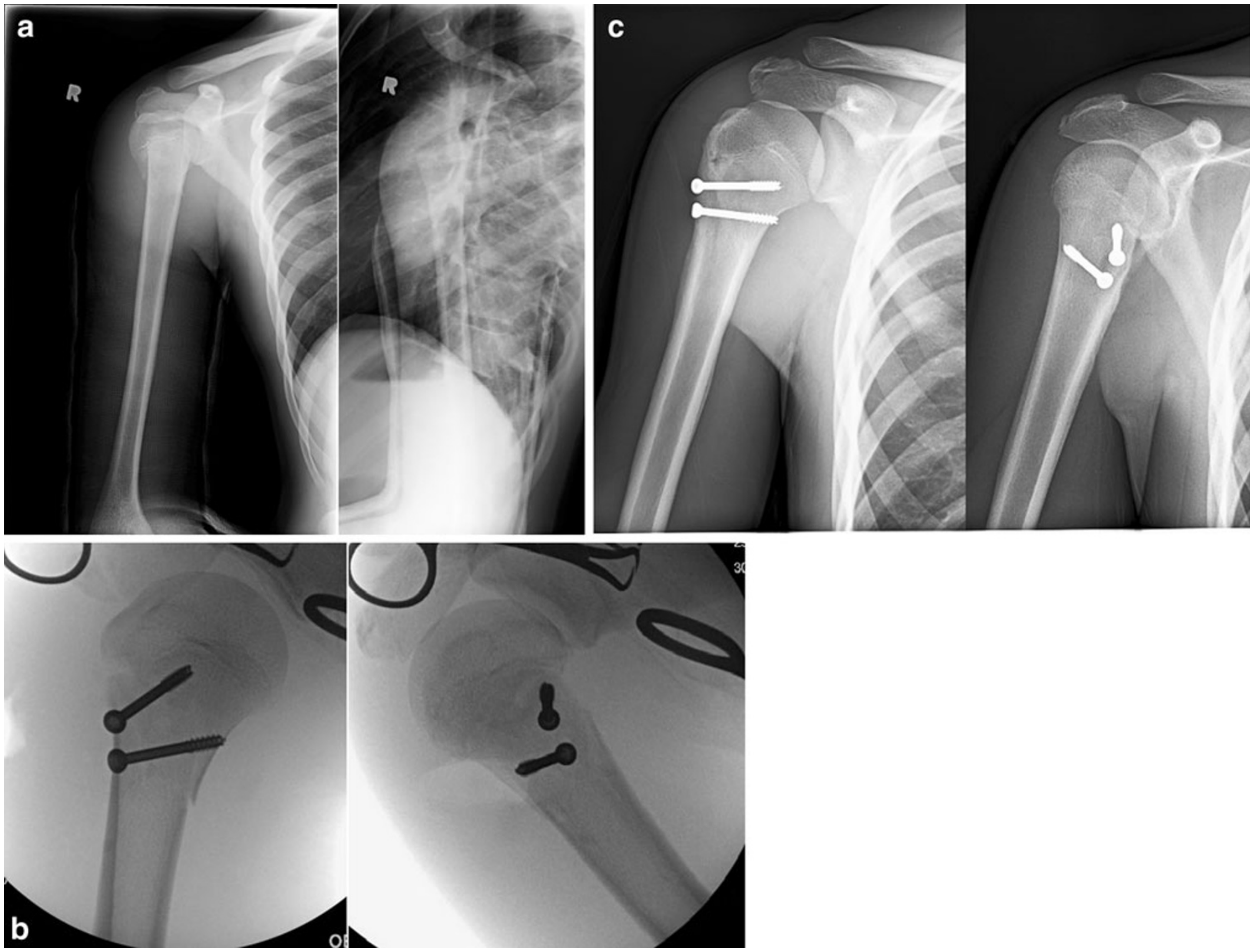

Fig. 3 A 16-year-old male with a left proximal humerus fracture sustained from a fall while snowboarding. **a** Pre-operative AP and transthoracic lateral radiographs. **b** Intra-operative fluoroscopic images showing fixation with cannulated screws. **c** 3 months post-operative AP and lateral radiographs showing complete healing

patients failed attempts at closed reduction either in the emergency room and/or the operating room. Not surprisingly, at the time of open reduction, all were found to have anatomical structures blocking reduction. Traditionally, the long head of the biceps and/or periosteum has been reported to prevent the reduction of proximal humerus fractures in a closed fashion [2, 9, 10, 12–14, 22, 24]. Bahrs et al. [13] examined 43 patients with proximal humerus fractures (33 treated operatively), in which 17 could not be closed reduced under general anesthesia. In seven cases, the biceps was entrapped, and in two cases, periosteum was entrapped. Yet, in our study, we found not only the long head of the biceps (90.0 %) and periosteum (90.0 %) entrapped within the fracture site, but also deltoid muscle (70.0 %), as well as comminuted bone (10.0 %). In addition, 90.0 % of our patients had more than one structure entrapped at the fracture site. As a result, we believe that it would be quite difficult to achieve a reduction via closed means with these multiple structures within the fracture site. A myriad of open approaches can be utilized, although formal delto-pectoral approaches were most commonly used by our surgeons.

With knowledge of the appropriate indications for operative treatment and the need for a formal open approach to adequately address all interposed structures, it is critical to understand the different fixation methods at the disposal of the treating surgeon. In our series, 70.0 % of patients underwent K-wire fixation, 20 % with flexible nails, and 10 % with cannulated screws. All of our patients achieved excellent functional and radiographic outcomes, regardless of the implant utilized.

Burgos-Flores et al. [12] noted excellent results in 22 patients with displaced proximal humerus fractures treated with K-wire fixation at a mean of 6.8 years after surgery. The authors concluded that, since patients above the age of 13 years (as in our cohort) have a greater chance of residual deformity and limitation of motion, aggressive approaches are recommended to correct displacement and angulation. Disadvantages of K-wire fixation include non-rigid fixation necessitating cumbersome post-operative immobilization, pin tract infections, and the need for secondary procedures to remove hardware. In addition, there is a risk for hardware breakage, which occurred in our study.

Retrograde flexible nailing was utilized in two of our patients, and allowed for early mobilization. Rajan et al. [25] examined 14 patients (above the age of 10 years) with severely displaced proximal humeral fractures and noted 100 % union, excellent functional outcomes, and no major complications. Fernandez et al. [9] reported on 35 children (mean age 12.7 years) who underwent flexible nailing, and also found excellent functional outcomes, with all patients returning to sporting activities. The authors did report several complications, including to two perforations of the nail at the humeral head (with subsequent loss of reduction), one loss of position without perforation, one misplacement of a nail, one revision due to hematoma, and two difficult hardware removals. These are all considerations which must be made when utilizing this implant, particularly as the technical challenges are heightened as compared to K-wire fixation.

Finally, one of our patients underwent cannulated screw fixation. Carey et al. [26] compared K-wire and cannulated screw fixation, and found no difference between the two groups in terms of operative time, rate of open reduction, or length of hospitalization. In both groups, there was complete fracture healing and no difference in the rate of physeal closure. There was a higher rate of complications in the K-wire groups, with 30 % of patients treated with K-wire fixation developing pin tract infections that required treatment. The only complication noted in the cannulated screw group was a transient axillary nerve paresthesia, which resolved.

All treatment options in our study achieved excellent functional and radiographic results. The treating surgeon must weigh the potential risks and benefits of the various implants against one another combined with his/her experience (particularly with flexible nail use). It is important to note that, regardless of the implant utilized in our study, none of the patients developed proximal humeral physeal damage.

There are several limitations in our study. First, we had relatively low numbers in our study due to the fact that this injury is rare. Furthermore, our patients were not randomized to non-operative treatment and, hence, we cannot be completely certain that these patients would not have had as successful an outcome without operative intervention. Further study is necessary in order to truly extrapolate this data. Third, due to the retrospective nature of our study, we were not able to obtain the bone ages of our patients to compare to their chronologic ages. This would have given us a more accurate representation of the patient's future remodeling potential of the proximal humerus, although information such as menarche, difference in parent height/patient height, and presence of growth spurt were used to assess for the degree of maturity. Finally, we were not able to collect formal patient outcome scores. Due to the degree of time which has elapsed from surgical treatment for many of these patients, obtaining these outcome scores retrospectively at this time would be of questionable validity. Yet, from our medical record review, we were able to ascertain if patients returned to sporting activities and had regained rotator cuff function. As mentioned above, a prospectively designed trial randomizing patients to operative and non-operative treatment would be the most rigorous manner to perform this study in the future.

In conclusion, we believe that operative treatment of proximal humerus fractures, particularly in adolescents with severe displacement/angulation and failure of closed methods, is increasingly being seen as an acceptable modality of management. In addition to the long head of the biceps, periosteum, deltoid muscle, and bone fragments in combination can prevent fracture reduction. Surgeon preference and skill should dictate implant choice, as patients achieved excellent functional and radiographic outcomes at the final follow-up with the use of K-wires, flexible nails, or cannulated screws. The risk of physeal damage with these implants is low. Further randomized, controlled studies are necessary so as to examine the operative treatment of proximal humeral fractures in the adolescent population.

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