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Operative Techniques in
Orthopaedics

Proximal Metaphyseal and Diaphyseal Humerus Fractures

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Pediatric humeral proximal metaphyseal and diaphyseal fractures are mostly caused by trauma. Pathological fractures and stress fractures should always be ruled out. Nonoperative treatment is the preferred modality of treatment for most of these fractures. Operative treatment is indicated for open fractures, vascular injuries or if adequate functional reduction cannot be maintained. For pediatric proximal humeral metaphyseal fractures, percutaneous pinning and flexible intramedullary nailing may be necessary, both of which are reported to have good outcomes. For humeral diaphyseal fractures which cannot be managed nonoperatively, elastic intramedullary nailing or plate and screw fixation can be used with good outcomes. These methods of fixation are usually associated with low complication rates. Complications are mainly related to skin and soft tissue irritation by pins or nails or radial nerve injury. External fixation can also used for open fractures with extensive soft tissue injury. While postoperative stiffness is feared complication after surgical fixation of humeral fractures in adults, it is not a common complication after fixation of pediatric fractures. Similarly, nonunions and malunion requiring corrective osteotomy are not common.
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Introduction

Humeral diaphyseal and proximal metaphyseal fractures represent less than 5% of all musculoskeletal injuries in the pediatric population.[1-3] The incidence is estimated to be between 12 and 30 per 100,000.[4,5] Humeral diaphyseal fractures have a bimodal distribution with higher incidence in patients younger than 3 years and older than 12 years.[6]

Etiology and Mechanisms of Fracture

Humeral shaft and proximal metaphysis fractures may be due to trauma including birth trauma, accidental, and nonaccidental injuries.[1,7,8] Pathological fractures may be associated with bone disease, benign lesions such as unicameral bone cysts and aneurysmal bone cysts or malignant lesions such as osteosarcoma or Ewing's sarcoma.[9-12] Repetitive traumas may cause stress fractures.[13,14]

Diagnosis

Clinical assessment will vary according to the age of presentation and mechanism of injury.

For birth-related injuries, the infants frequently present with pseudoparalysis with intact distal neurological functions. There may also be tenderness, swelling, and crepitus on palpation.[15]

Older children usually present with pain, ecchymosis, swelling, tenderness, and deformity. Careful neurovascular assessment is essential to evaluate radial nerve injury which can be seen with diaphyseal fractures and axillary nerve injury which can be seen with proximal humeral fractures. Orthogonal X-ray views show the fracture and should be thoroughly inspected to exclude any lesions suggestive of pathological fractures.[15,16] Nonaccidental trauma warrants a

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skeletal survey.[8] Ultrasound may help to diagnose proximal humeral physeal separation.[17] Advanced imaging in the form CT and MRI may be needed to assess pathological fractures and stress fractures. To confirm the diagnosis in pathological fractures, biopsy may be needed in some cases.[6,9]

Classification

The classification of humeral diaphyseal fractures is mainly descriptive. The location of the fracture, its pattern, direction of displacement, and angulation are usually used. For proximal humeral fractures, Neer and Horwitz proposed a classification system depending on the amount of displacement.[18] The AO pediatric fracture classification which was updated in 2018 is still not widely used.[19] Interobserver variations exist in classification of different fractures using the AO classification.[20]

Treatment

Nonoperative Treatment

Proximal metaphyseal humeral fractures Neer and Horwitz type 1 and 2 are treated conservatively. Sling is adequate for older children and sling and swath can be used for younger children.[21] The majority of humeral diaphyseal fractures can be managed by nonoperative care. Younger patients have greater remodeling potentials. Sling and swath can be used for incomplete diaphyseal fractures in very young.[22-24] Coaptation splint can be used for treatment of diaphyseal humeral fractures although it may not be effective if there is severe initial displacement.[23,25,26] Hanging casts can be used although they require maintaining an upright position which is difficult for the patients in many cases.[27] Functional bracing can be then fitted after subsidence of swelling to allow range of motion of the elbow.[28,29]

Operative Treatment

Operative treatment is occasionally required in proximal metaphyseal humeral fractures in Neer and Horwitz types 3 and 4 in older patients with angulated fractures.[21] Indications for operative treatment of diaphyseal fractures include floating elbow injuries, open fractures, vascular injury, and inability to achieve adequate reduction with closed methods. Relative indications include patients with secondary radial nerve injury and multitrauma patients.[15] Options for surgical fixation will vary according to the site of the fracture and include percutaneous pinning, plates and screws, intramedullary nailing, and external fixation.

Percutaneous Pin Fixation for Proximal Humeral Fractures

Percutaneous pin fixation can be employed for proximal humeral fractures. Smooth K-wires between 0.0625 and 3/32 in. in diameter are used.[30-32] Some authors recommended the use of cannulated screws to give better stability,[32] but concerns regarding physeal disruption and the need for second surgery for removal discourage many surgeons from using them. Appropriate orthogonal X-rays and careful neurovascular assessment are essential before surgery.

Patient Positioning: Surgery can be performed either in a beach chair or supine position. For beach chair position, the fluoroscopy unit can be brought from the head of the bed and the surgeon can be standing lateral to the arm. For the supine position, a bump can be placed between the scapulae or under the ipsilateral pelvis and the fluoroscopy unit can be placed at the head of the table or the contralateral side.[15]

Fracture Reduction and Pinning: Muscle relaxation is essential to achieve a successful closed reduction. Some find it easier to place the pins in the distal fragment before the reduction maneuver is initiated which puts the arm in an abducted, flexed, and externally rotated position. The pins are placed just proximal to the deltoid tubercle by sharp skin incision followed by using a hemostat to spread the soft tissues down to the bone. Care should be taken not to injure the axillary nerve. The height of the articular surface should be measured on the X-ray and the pins should be inserted distal to the most proximal end of the humerus by twice the height of the articular surface (Fig. 1). The closed reduction maneuver is started by internal rotation and adduction to relax the pectoralis major. This is followed by application of longitudinal traction with abduction, flexion, and external rotation to reduce the distal fragment to the proximal fragment. In difficult fractures, K-wire can be used as joysticks to manipulate the proximal or distal fragments. After confirmation of reduction by fluoroscopy, one pin is driven in the proximal fragment followed by fluoroscopic confirmation that

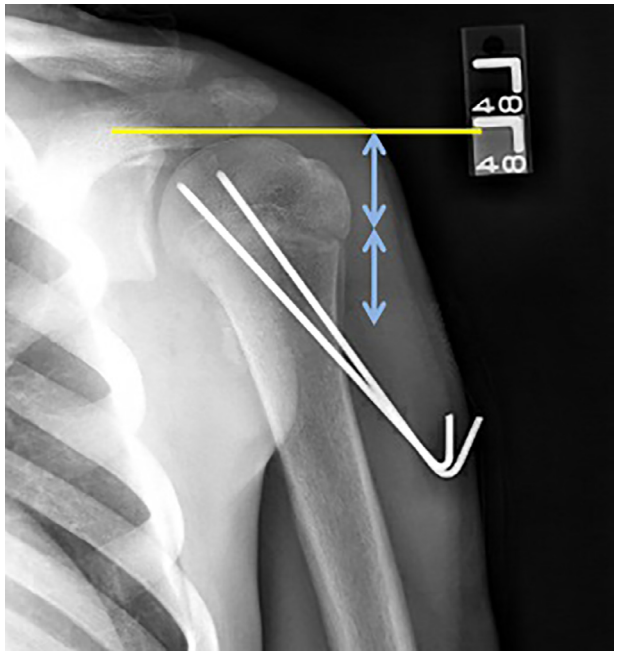

Figure 1 K-wires are inserted more than twice the height of the epiphysis distal to the proximal end of the humerus to avoid injury to the axillary nerve.

adequate reduction is still maintained. One or 2 additional pins can be placed. Care should be taken to avoid violation of the glenohumeral joint by the pins which should be confirmed by fluoroscopy. An antegrade pin may be placed in from the greater tuberosity to the medial cortex. This pin should engage the medial cortex at least 2 cm inferior to the most medial aspect of the articular surface. The pins can be cut and bent outside the skin. The patient is placed in sling and swath. The pins are typically removed 4 weeks after surgery. If closed reduction is not successful, open reduction can be performed through a deltopectoral approach.[30-33] The surgical technique for percutaneous pinning of proximal humeral fractures is summarized in Table 1.

Open Reduction and Internal Fixation

Open reduction and internal fixation with plates and screws can be used to treat humeral diaphyseal fractures and may be used for proximal metaphyseal fractures after skeletal maturity. The size of the plate is selected according to the size of the patient. Anatomical proximal humeral plates are available and may be appropriate for larger patients with proximal humeral fractures. A careful preoperative neurovascular assessment is essential as radial and axillary nerve injuries can be seen with the initial trauma or can occur as a complication of surgery.[15]

Patient Positioning: For proximal humeral fractures, a beach chair or semirecumbent position can be used with the surgeon standing at the axilla or lateral to the arm with the C-arm coming from the head of the table.[34] For the diaphyseal fractures, the patient positioning is dictated by the used approach. For the anterolateral approach, the patient can be placed in supine position. The arm should be positioned on the radiolucent table and it is convenient to have the fluoroscopy unit coming in from the head of the patient.[15] For the posterior or posterolateral approaches, prone or lateral decubitus positions can be used with the arm resting on a bolster.[35]

Table 1 Surgical Technique for Pinning of Proximal Humeral Fractures

- Beach chair/semirecumbent position, fluoroscopy unit of the head of the table/contralateral side.
- No tourniquet is needed.
- Use smooth K-wires with sizes between 0.0625 and 3/32.
- Skin incision by 15 blades proximal to the deltoid tubercle.
- Blunt dissection down to the bone.
- Partially insert K-wires.
- Confirm K-wire position by fluoroscopy.
- Closed reduction.
  - Adduction and internal rotation to relax the pectoralis major.
  - Traction, abduction, and external rotation to achieve reduction.
  - Confirm reduction by fluoroscopy.
- Drive 1 K-wire into the humeral head and confirm its position by fluoroscopy.
- Drive an additional 1 or 2 wires into the humeral head.
- Confirm satisfactory reduction and the pins are short of the glenohumeral joint by fluoroscopy.
- Cut and bend the wires outside skin.
- Sling for rest.

Surgical Approaches:

i. The Deltopectoral Approach: For proximal metaphyseal fractures, the deltopectoral approach is usually used. The cephalic vein is identified and retracted medially or laterally. Then, the deltopectoral interval is developed between the pectoralis major and deltoid followed by subperiosteal exposure of the bone. Excessive traction on the deltoid should be avoided to avoid iatrogenic neurapraxia to axillary nerve.[34,35]

ii. The Anterolateral Approach: This approach provides adequate exposure to the humeral diaphysis. The incision extends from the deltopectoral interval proximally downward along the lateral border of the biceps. The interval between the biceps and brachialis is developed. The brachialis is split with subperiosteal exposure of the anterior aspect of the humerus.[34,35] This approach does not visualize the radial nerve which must be protected by avoiding excessive retraction posterior to the humerus or placing bicortical screws in the middle portion of the humerus.[15]

iii. The Posterolateral or Lateral Paratricipital Approach: To expose the humeral shaft and the radial nerve, the posterolateral or the lateral paratricipital approach can be used. The skin incision is placed distal to the deltoid insertion and can be extended distally to the lateral epicondyle. The deep fascia covering the triceps posterior to the lateral intermuscular septum is identified and opened. The triceps is elevated from the lateral intermuscular septum from distal to proximal direction. The radial nerve is identified as it passes from the posterior to the anterior compartments of the arm (Fig. 2). The posterior antebrachial cutaneous nerve is sometimes first identified which can be followed proximally to the radial nerve.[35] The radial nerve is vulnerable to injury during the procedure and must be carefully protected.

iv. The Posterior Approach: The posterior triceps splitting approach may be utilized for more distal fractures. This involves a posterior midline incision through the skin and subcutaneous tissue. The interval between the long of the lateral heads of the triceps is identified and developed and extended distally to the triceps tendon. The radial nerve and accompanying profunda brachii artery should be identified crossing the field and must be protected. The medial head of the triceps distal to the radial nerve can be split longitudinally followed by subperiosteal elevation to expose the posterior aspect of the humerus.[34,35]

Fracture Reduction and Fixation: The fracture hematoma is evacuated and the cortical edges of the bone are defined. Reduction can be achieved under direct visualization and can be maintained by bone clamps or K-wires. Once reduction is obtained stabilization with the appropriate implant can be achieved. After screw placement for proximal metaphyseal fractures, intraoperative fluoroscopy should confirm the position of the screws to ensure that the glenohumeral joint is not violated by the screws. Obtaining 6 cortices of

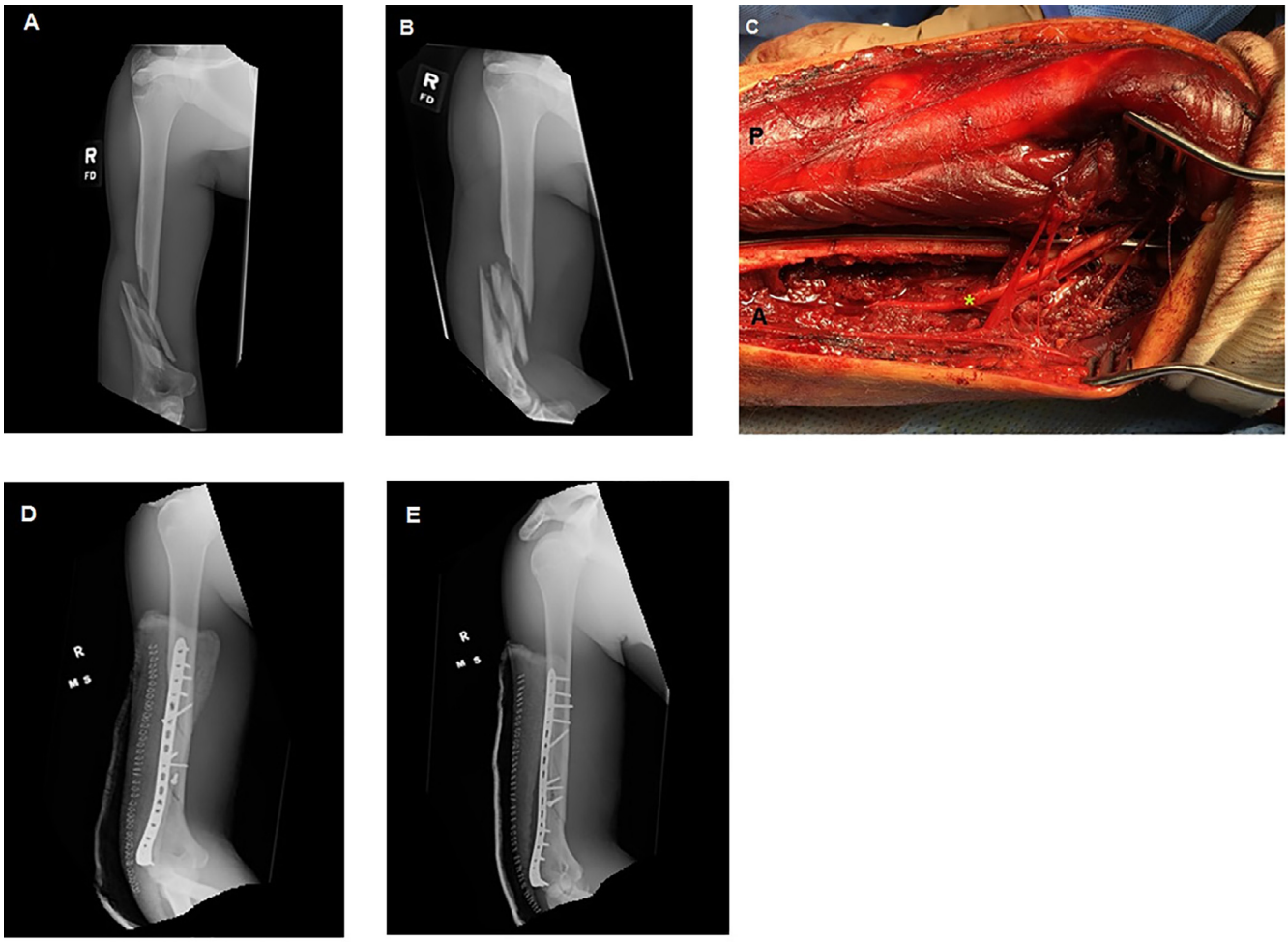

Figure 2 A 17-year-old male patient who was an unrestrained passenger in a golf cart that rolled over and sustained a right humerus fracture. (A and B) Preoperative X-rays. (C) A lateral paratricipital approach is used. The radial nerve can be seen running from the posterior to the anterior compartments. A, anterior compartment; P, posterior compartment; *, radial nerve. (D and E) Postoperative X-rays.

fixation proximal and distal to the fracture is usually sufficient.[15] After fracture fixation, the wound is closed in layers and the patient can be placed in a sling. The surgical technique for plate and screw fixation of the humerus is summarized in Table 2.

Intramedullary Nailing

Intramedullary nailing allows functional reduction with preservation of the fracture hematoma in a closed manner and avoids the stress riser effect created by plate fixation. This technique may be considered for diaphyseal length stable fractures (transverse or short oblique).[36,37] Intramedullary nailing is useful for diaphyseal or proximal metaphyseal humeral fractures with sufficient metaphysis to provide adequate purchase for the nails.[15] Titanium elastic nails, Ender nails, K-wires, and Rush rods have been described.[37-40] Antegrade locked intramedullary nails have also been described in older children after closure of the physis.

Patient Positioning: The nails can be placed retrograde through a cortical window above the olecranon fossa posteriorly or above the medial and lateral epicondyles. A supine position is utilized when the epicondylar entry is used for diaphyseal or proximal metaphyseal fractures with the affected limb placed over radiolucent table. Fluoroscopy can be placed at the head of the table or the contralateral side. For proximal metaphyseal fractures, a beach chair position can be used. The C-arm can come in from the head of the patient. If posterior entry will be used, a lateral decubitus or prone position is preferred.

Fracture Reduction and Fixation: Currently, titanium elastic nails are the preferred implants for nailing. Usually 2 nails with combined diameter of 80% of the medulla are sufficient. Typically, 3-4 mm nails are used. Intramedullary nails can be inserted through the lateral and/or medial columns of the distal humerus. A small incision is placed proximal to the level olecranon fossa on the medial and lateral aspect of the humerus and the muscle fibers are separated. Care should be taken not to injure the radial nerve laterally or the ulnar nerve medially. When the bone is exposed, a corticotomy can be placed to allow the passage of the nail. A 3.2 or 4.5 mm drill bit or special awls can be used to create the corticotomy. The obliquity of the cortical tunnel should follow the anticipated trajectory of the nail. Alternatively, a

Table 2 Surgical Technique for Open Reduction and Internal Fixation of the Humeral Diaphysis by Plates and Screws

- Supine position for the anterolateral approach. Lateral or prone positions for the lateral para-tricipital or posterior approaches.
- Sterile tourniquet if needed.
- Used 3.5 mm, 4.5 mm, or anatomical plates.
- Anterolateral approach.
  - Incision: from the deltopectoral interval proximally down the lateral border of the biceps.
  - Proximally.
    - Identify and protect the cephalic vein.
    - Developed the interval between the deltoid and pectoralis major.
  - Distally.
    - Developed the interval between the brachialis and biceps.
    - Spread the brachialis muscle down to the bone.
- Posterior approach.
  - Posterior midline incision.
  - Developed the interval between the long and lateral heads of the triceps.
  - Identify the radial nerve.
  - Split the medial head of triceps distal to the radial nerve.
- Lateral para-tricipital or posterolateral approach.
  - Skin incision distal to the deltoid insertion.
  - Elevate the triceps from the lateral intermuscular septum from distal to proximal.
  - Identify and protect the radial nerve.
- Expose the shaft of the humerus.
- Evacuate the hematoma and refresh the edges of the proximal and distal fragment.
- Reduce the fractures with the help of bone clamps are K-wires.
- Apply the plate to the humerus.
- Fix the fracture by 6 cortices proximally and distally.
- Closure in layers.
- Sling/slab for rest.

posterior entry can be used to avoid neural structures but may be difficult to place 2 pins through this entry, thus providing less stability. A small incision is placed proximal to the olecranon fossa followed by splitting of the muscle fibers of the triceps. An oval corticotomy is made to allow the passage of the nails. The elastic nail should be prebent into the shape of "C" with the maximal spread to be of the level of the fracture to increase the stability. The proximal end of the nail can be given a small bend to help the end of the nail to engage the proximal fragment. The humerus should be reduced guided by fluoroscopy before the passage of the nails, to avoid repeated false passage of the nails to the adjacent soft tissue, especially posteriorly which could endanger the radial nerve in humeral diaphyseal fractures. If closed reduction failed, open reduction through an anterolateral approach can be used. For proximal metaphyseal fractures, closed reduction can be performed using the same maneuver described with percutaneous pinning, otherwise, a deltopectoral approach can be used for reduction. The nails can be passed proximally till 1 or 2 cm from the proximal humeral physis. If the 2 nails are inserted from a lateral entry, one of them should be rotated 180°. The distal end of the nail can be cut as close as possible to the cortex to decrease the soft tissue irritation, yet allowing some implant to be available for hardware removal. The entry wound can be closed in layers and the slab or sling and swath can be applied. Typically the nails can be removed 6 months after surgery.[40-42] The surgical technique for titanium elastic nailing is summarized in Table 3.

External Fixation

External fixation is a treatment option that is valid especially for open fractures with extensive soft tissue damage and multitrauma patients.[43-46]

Patient Positioning: The patient is usually positioned in a supine position with a bump between scapulae or a bump under the ipsilateral pelvis. The arm is abducted 90° and placed on the radiolucent table with the C-arm coming from the ipsilateral side of the table or the contralateral side or the head of the table.

Fracture Reduction and Fixation: Unilateral constructs are usually sufficient. However, multiplanar constructs and ring fixators can be used for more complex injuries.[15,44] Knowledge of the safe zones of pin insertion of the humerus is essential.[45] The pins' diameter will depend on the size of the humerus. Proximal pins should be inserted into the anterolateral surface of the humerus while distal pins should be inserted posterolaterally through the triceps muscle fibers. Maximal spread of the

Table 3 Surgical Technique for Titanium Elastic Intramedullary Nailing of the Humeral Diaphysis

- Supine or prone position for diaphyseal fractures according to the used entry, fluoroscopy unit at head of the table/contralateral side, beach chair position for proximal fractures, fluoroscopy unit of the head of the table.
- No tourniquet is needed.
- Two nails should occupy 80% of the medulla.
- Posterior entry.
  - Skin incision by 15 blade above the olecranon fossa.
  - Blunt dissection until reaching the bone.
  - Corticotomy to allow the passage of 2 nails.
- Lateral/medial entry
  - Incision by 15 blade above the level of the olecranon fossa on the lateral/medial columns.
  - Blunt dissection down to bone.
  - Corticotomy by an awl/drill. The direction of the corticotomy should take into consideration the trajectory of the titanium elastic nails.
- Precontour titanium elastic nails to be C-shaped. Bend the tip of the nail.
- Insert the nails through the entries and pass them to the fracture site.
- Align the bone under fluoroscopy and proceed with the nails to the proximal fragment until 1 or 2 cm distal to the physis.
- Rotate the nails within the medulla to ensure maximal spread at the fracture site.
- Cut the nail.
- Closure in layers.
- Sling/slab for rest.

pins will allow the most stable biomechanical construct. At the site of the desired pin insertion, the skin is cut sharply with a knife then a hemostat can be used to spread the muscle fibers down to the bone. It is required to use soft tissue protectors while introducing the pins. Connect the pins to the bar and use the proximal and distal half to manipulate the proximal and distal fragments. The surgeon can release any interposed soft tissue through the open wounds. When satisfactory reduction is obtained and confirmed by fluoroscopy, a bar is tightened to the half pins. The patient is given a sling for rest after surgery. When bridging bone is seen at least at 3 cortices, the external fixator can be removed.[15,44,47] The surgical technique for external fixation is summarized in Table 4.

Postoperative Care

After stable operative treatment, a sling can be used for comfort. This can be discontinued after 4-6 weeks or earlier after plate and screw fixation. Gentle pendulum exercise and range of motion exercise for the elbow can be initiated once the patient is comfortable after plate and screw fixation, or once clinical and radiographic evidence of healing is observed with other methods of fixation.

Management of Associated Injuries and Complications

Radial nerve palsies can occur with diaphyseal humeral fractures. They can be classified according to the time of presentation. Primary radial palsies occur at the time of humeral fractures and can be recognized on the initial examination. Secondary radial nerve palsies occur during fracture reduction or manipulation in a patient in whom the radial nerve function was previously intact.[6]

It is reported that spontaneous recovery occurs in the majority of the patients with primary radial nerve injury with a rate up to 100%.[48-53] This is because the injury is usually caused by nerve contusion or stretching and rarely due to nerve transection especially in low energy trauma.[54] For primary radial nerve palsy, conservative treatment is usually recommended with exploration indicated after 2-6 months if there is no improvement.[49,55,56] Treatment of secondary radial nerve injuries is still controversial, observation is still supported as spontaneous resolution can occur in many cases.[48,57,58] Other authors support early exploration as the nerve may be incarcerated in the fracture site and later extraction from the fracture site and callus will be more difficult.[59] For open fractures, the radial nerve should be explored at the time of surgical debridement and stabilization. Options for traumatic laceration or cut of the radial nerve include immediate nerve repair or secondary reconstruction.[60,61]

Table 4 Surgical Technique for External Fixation of the Humerus

- **Supine position, fluoroscopy unit from an ipsilateral/contralateral side.**
- **No tourniquet is needed.**
- **Pin diameter will depend on the size of the humerus, pins should be maximally spread.**
- **Proximal pins are inserted through the anterolateral surface, distal pins are inserted posterolaterally.**
- **Skin incision by 15 blade.**
- **Blunt dissection down to the bone.**
- **Use soft tissue protectors during drilling/pin insertion.**
- **Connect the pins to the bar.**
- **Provisionally reduce the fracture. Assess the reduction by fluoroscopy.**
- **Tighten the bar to the pins when satisfactory reduction is obtained.**

Compartment syndrome is uncommon in humeral shaft fractures. Patients with associated ipsilateral upper extremity fractures or vascular injuries are generally more prone to compartment syndrome. Patients with compartment syndrome should be treated by immediate fasciotomy.[62-65]

For humeral diaphyseal fractures, brachial artery transection although reported before is uncommon. For proximal humeral fractures, brachial and axillary artery injuries were reported. Urgent vascular assessment with repair reconstruction if needed.[66-70]

Injury to the brachial plexus and axillary nerve have been reported with valgus injuries of the proximal humerus in which the distal segment is driven proximally and medially.[71-73] Spontaneous recovery usually occurs in 9-12 months. However, some patients may develop neurogenic pain syndromes.[72,73]

As large degrees of angulation are accepted in diaphyseal humeral fractures, malunion leading to functional limitation is uncommon especially in younger children. For proximal metphyseal fracutre, 100% displacement and 70° angulation are accepted in children Up to 30° of varus angulation and 20 of apex anterior deformity and 15° of internal rotation are tolerated.[15,53] The wide range of motion of the shoulder, elbow, and forearm together with the remodeling potential in children make corrective osteotomies for diaphyseal malunion rarely needed.[74,75]

Nonunions of diaphyseal fractures are very rare in children. Risk factors include bony abnormalities as osteogenesis imperfecta, segmental bone defects, extensive soft tissue injuries, and vascular insufficiencies. The treatment principles of nonunions are similar to the treatment principles of nonunions in adults.[15,76]

Stiffness of elbow and shoulder joints is not common complications of pediatric diaphyseal humeral fractures and can be treated by range of motion exercises.[15,77]

Outcomes of Treatment

Overall the outcomes of surgical treatment of humeral diaphyseal and proximal humeral metaphyseal fractures are good.[31,39,44,45,47,78-90] Most of the data regarding plate and screw fixation are derived from the adult trauma literature.[44,45,47,86-89] Most of the studies are retrospective case series [31,78-80,82,83,90] with few prospective[81,84] and comparative studies.[30,85] Most of the studies relied on radiographic

or physician derived judgement[31,39,78-82] and few studies used objective outcome scores.[83-85,90]

Canavese et al. reported 16 patients with mean age of 12 years treated by elastic intramedullary nails for diaphyseal fractures and followed up for a mean of 25 months. The patients had good radiographic and clinical outcome with a mean Quick DASH score of 1. They concluded that elastic intramedullary nails can maintain a stable reduction with good rotational control in 14 out of 16 patients and good functional outcome.[90] Garg et al. reported treating 13 patients with elastic intramedullary nails with a mean age of 12 years. Twelve of these patients returned to sports with no limitations. They concluded that the technique is effective with low complications. However, 3 patients in this series had follow up less than 8 months.[78] Sénès and Catena reviewed 22 humeral metaphyseal and diaphyseal fractures with a mean age of 8.8 years. Half of the patients were treated by titanium elastic nails and half of them were treated by intramedullary K-wires. They reported that both techniques are safe and effective. However, the titanium elastic nails group had 3 cases of local skin infection and 1 case of temporary paralysis of the radial nerve but the K-wires group did not have these complications.[79] Pogorelic published a series of 118 patients with humeral shaft and proximal humeral fractures with average age of 12 years treated by elastic intramedullary nails and followed up for 77 months. There were 9 complications, 6 of them were skin irritation or infection, 2 radial nerve palsies, and 1 intraoperative fracture in a patient with osteogenesis imperfect. There were no residual angular deformities. They concluded that elastic intramedullary nailing has good functional and cosmetic results.[80] Sahu published a series of 68 patients, from which 64 were treated by multiple intramedullary K-wires. The mean age in his series was 7.7 years.[81] Similarly, Qidwai reported 29 patients with age ranging from 14 to 60 years.[39] Both series reported that the technique is simple, safe, and effective especially for transverse and short oblique fractures.

For proximal humeral fractures, surgical treatment is proven to be safe and effective.[31,82-84] Dobbs published a case series of 29 patients around the age of 15 years with Neer-Horwitz grade III and IV fractures. The patients were treated by closed or open reduction with pin or screw fixation. All patients improved to grade I or II deformity with no surgical complications with normal or near normal strength and range of motion at 4-year follow-up. The authors concluded that surgical treatment is safe and effective for severely displaced proximal humeral fractures.[31] Chee et al. published a series of 14 patients with mean age of 13 years with displaced proximal humeral fractures treated with single intramedullary flexible nail. All patients had full range of motion at final follow-up. The authors concluded that intramedullary fixation is effective for treating displaced proximal humeral fractures.[82] Rajan et al. published a series of 14 patients with mean age of 12.5 years with mean DASH score of 2.26 and mean Neer shoulder score of 96.79.[83] Similarly, Khan et al. reported a series of 27 patients with average age of 11.2 with a mean Quick Dash score of 2.[84] Hutchinson et al. compared intramedullary nailing to percutaneous pinning in 50 patients with a mean age of 13 years. Both techniques were safe and effective. Intramedullary nailing had fewer complications but longer operative time, increased EBL, and the need of second surgery for implant removal.[30] Kraus et al. compared the 16 patients with a mean age of 10.1 years treated with elastic intramedullary nails vs 15 patients with a mean age of 12.5 years treated with K-wire fixation. All patients have Neer-Horowitz classification III or IV. The operative time was shorter for the intramedullary nail group but hospital stay and time till implant removal was longer. The mean DASH score was 1.44 for the intramedullary nailing group and 1.66 for the K-wire group. The mean Constant-Murley score was 89.5 for the intramedullary nail group and 92 for the K-wire group. Both scores did not show statistically significant differences between the 2 groups.[85]

Conclusions

Operative fixation of fractures of pediatric proximal metaphyseal fractures can be done by percutaneous pinning and intramedullary nailing. Operative fixation of pediatric fractures of humeral diaphysis can be done by intramedullary nailing, plate and screw fixation, and external fixation. These methods of fixation appear to have high union rates and low complications rates. Most of the literature regarding plate and screw fixation and external fixation is generated from adult trauma patients. Outcomes of percutaneous pinning and intramedullary nailing are generally good, although most of the reported outcomes are based on retrospective studies with limited objective assessment tools.

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