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Galeazzi and Essex-Lopresti Injuries

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Abstract

Injuries to the forearm can lead to fractures of either or both the radius and ulna as well as dissociation between the bones in the forearm. Galeazzi fractures occur when the current of injury in the forearm fractures the radius shaft and then proceeds through the distal radioulnar joint (DRUJ) to cause dislocation or subluxation of the joint. In children, this can be a true DRUJ dislocation or can also be a fracture-separation of the distal ulnar physis. Anatomic reduction of the fracture typically leads to DRUJ stability unless soft tissues are interposed in the joint or physis. The key to treatment of these complex injuries is an anatomic reduction and the creation of a stable joint whether by closed or open methods. Once fracture healing is identified, therapeutic exercises can be initiated and a gradual return to full activities can be expected. Essex-Lopresti injuries are seen in patients that have interruption of the interosseous membrane and dissociation of the radius and ulna. They have not been described in skeletally immature patients, but clinicians should be aware of the risks of proximal migration of the radius that can occur after radial head resection in these patients.

Introduction to Galeazzi Fractures

Galeazzi described a series of fractures of the radius shaft and dislocation of the distal-radial ulnar joint, which have since come to bear his name, in 1934 (Galeazzi 1934). However, he is not the first person to describe the injury pattern, as it was first described by Sir Astley Cooper in 1822 (Reckling and Peltier 1964; Reckling and Cordell 1968). Walsh was the first to describe a series consisting solely of pediatric Galeazzi fractures (Walsh et al. 1987), and Landfried et al. described the pediatric variant of Galeazzi fractures which consists of a fracture of the shaft of the radius and a physeal fracture of the distal ulna (Landfried et al. 1991). Galeazzi fractures in children are uncommon with a noted incidence of 2.8 % among 1,453 children with radial shaft fractures (Walsh et al. 1987). The authors also noted that 41 % of the cases were not recognized at first and the peak age was between 9 and 13 years (Walsh et al. 1987). Galeazzi fractures in children often occur at the junction of middle and distal thirds of the radius, and the direction of dislocation of the ulna can be either volar or dorsal (Walsh et al. 1987; Eberl et al. 2008).

Essex-Lopresti injuries are described as a fracture of the radial head with disruption of the distal radioulnar joint (DRUJ) which occurs through a concomitant injury to the interosseous membrane. Peter Essex-Lopresti was a British orthopedic surgeon who reported a case series in 1951 describing the injury (Essex-Lopresti 1951). There are no reported Essex-Lopresti injuries in skeletally immature children. However, there are multiple case series of pediatric Galeazzi fractures and

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with ipsilateral radial head dislocations, known as a Monteggia fracture variant (Reckling 1982; Kontakis et al. 2008; Akalin et al. 2010).

Anatomy and Pathoanatomy Relating to Galeazzi Fractures

Distal Radioulnar Joint Anatomy

The distal radioulnar joint (DRUJ) is the articulation of the convex ulnar head and the concave distal-radial sigmoid notch. The ulnar head, with its smaller radius of curvature, sits shallowly in the sigmoid notch, whose radius of curvature is greater, which allows for some translation of the ulnar head in the sigmoid notch as the distal radius moves around the ulnar head with forearm pronation and supination. Only 10–60 % of the DRUJ articular surface represents actual contact surface of the sigmoid notch and the ulnar head through various degrees of pronosupination (Leversedge et al. 2010).

This incongruous articulation is stabilized by multiple ligamentous and soft tissue structures. The triangular fibrocartilage complex (TFCC) is the most important of these structures. The TFCC inserts at the ulnar fovea at the base of the ulnar styloid. It is composed of the triangular fibrocartilage articular disk centrally, the ulnocarpal meniscus homologue, the dorsal and volar radioulnar ligaments, the floor of the extensor carpi ulnaris tendon sheath, and the volar ulnocarpal ligaments (V ligament) running from the ulna to the lunate and the triquetrum. The dorsal and volar radioulnar ligaments are the primary stabilizers of the DRUJ. The confluence of the dorsal and volar radioulnar ligaments insert proximally into the fovea as the ligamentum subcruentum as well as distally, directly into the base of the ulnar styloid independent of the insertion of the ligamentum subcruentum.

Attachments of the TFCC provide tensile stability to the DRUJ throughout forearm rotation to counterbalance the bony compression at the articulation. At extremes of pronation and supination, the tension through the TFCC is maximized thereby stabilizing the joint the greatest in these positions, where, otherwise, the joint would be at most risk of dislocation. In pronation, the bony articulation dorsally is under compression, whereas the volar TFCC is under tension. The opposite pattern of compressive and tensile forces is seen in supination. Thus, any disruption of the volar TFCC would allow for dorsal displacement of the ulnar head in the sigmoid notch in pronation, while disruption of the dorsal TFCC would allow for volar translation of the ulnar head in the sigmoid notch in supination (Waters and Bae 2010).

Forearm and Interosseous Membrane Anatomy

In addition to the DRUJ, the radius and ulna are stabilized by their proximal articulation and the interosseous ligament complex (IOLC). The IOLC stabilizes both longitudinal and transverse forces on the radius and ulna and allows for load transfer between the two. The IOLC is composed of three groups of fibers all originating proximally on the radius and inserting distally on the ulna. The proximal band, or oblique ligament, is the most proximal of these fibers. The central ligament is the largest and strongest of these fibers and is primarily responsible for providing longitudinal and transverse stability between the radius and ulna. The accessory bands can number between 1 and 5 and are distal to the central band with fibers running in the same direction (Leversedge et al. 2010). Additionally, the distal oblique band of the distal interosseous membrane, which can be seen in 40 % of specimens, assists with stability of the DRUJ via its insertion on the volar lip of the sigmoid notch (Moritomo 2012).

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Pathoanatomy

Galeazzi fractures in adults involve a fracture of the radius coupled with dislocation of the DRUJ, most commonly dorsally. This is due to disruption of the DRUJ capsule and often the strong ligamentous stabilizers of the DRUJ. In children, energy transmitted through the DRUJ more commonly leads to a distal ulnar physeal fracture rather than injury to the ligamentous attachments (Imatani 1996; Waters and Bae 2010). This is due to the fact that the physeal plate of children is biomechanically weaker than the ligamentous stabilizers of the DRUJ (Imatani 1996). Additionally, periosteum or other soft tissues such as the extensor digiti minimi and extensor carpi ulnaris can become entrapped in the fracture site preventing reduction of the distal ulnar physis (Landfried et al. 1991).

Assessment of Galeazzi Fractures

Signs and Symptoms of Galeazzi Fractures

Most children do not recall their exact mechanism of injury. It is postulated that the mechanism is from an axial load with some rotational component. Assessing instability of the DRUJ clinically is difficult, as a child frequently will not allow the examiner to move the wrist. Subtle injury to DRUJ can be easily missed. The neurovascular exam is typically normal. However, anterior interosseous nerve palsy has been seen with pediatric Galeazzi fractures (Stahl et al. 2000), and the ulnar nerve can be injured with volar dislocation of the DRUJ.

Galeazzi Fractures Imaging and Other Diagnostic Studies

It is important to image the joint above and below the level of injury. If the elbow joint is not imaged, then a concomitant Monteggia injury can be missed. In pediatric Galeazzi fractures, lateral radiographs typically show a dorsal or volar dislocation of the ulna. Typically, the apex of the radius fracture will be the same direction as the distal ulna dislocation (Fig. 1). A true lateral is paramount in order to assess for a DRUJ dislocation. This true lateral view has the pisiform at the distal aspect of the scaphoid with the pisiform in line with the central axis of scaphoid. Additional advanced imaging, such as three-dimensional or cross-sectional imaging, is not typically necessary in skeletally immature children.

Injuries Associated with Galeazzi Fractures

Galeazzi fractures in children are associated with distal ulnar physeal separations. These Salter-Harris I, II, or III injuries lead to a remarkably high rate of distal ulnar physeal arrest, as high as 50 %. Additionally, Galeazzi fractures have been associated with ipsilateral radial head dislocations or proximal radioulnar joint dislocations (Reckling 1982; Kontakis et al. 2008; Akalin et al. 2010). These injuries are described as Monteggia variants of Galeazzi fractures.

Classification of Galeazzi Fractures

Letts and Rowhani developed the classification for pediatric Galeazzi fractures (Letts and Rowhani 1993) which is described in Table 1. In Letts' case series, the most common type of Galeazzi fracture was Type BII. This type of fracture is a distal third radius fracture with an epiphyseal fracture of distal ulna and dorsal displacement of ulnar metaphysis (Fig. 2).

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Fig. 1 Lateral radiograph of a Galeazzi fracture with apex volar angulation and volar dislocation of the DRUJ. The distal ulnar physis is intact (Photo courtesy of Kevin J. Little, MD)

Galeazzi Fracture Outcome Tools

In assessing the outcomes, no validated instrument has specifically been designed for these types of injury. Previous studies have classified Galeazzi fracture outcomes as excellent, fair, and poor. Table 2 shows the classification and the definition as described by Mikic in 1975 (Mikić 1975; Letts

Table 1 Galeazzi equivalent fractures in children

Letts and Rowhani classification of pediatric Galeazzi equivalent fractures	
Type A: Fracture of the radius at the junction of the middle third with the distal third	I: Dorsal dislocation of the distal ulnar end
	II: Distal epiphysiolysis of the ulna with dorsal displacement of the metaphysis
Type B: Fracture of the radius at the distal third level	I: Dorsal dislocation of the distal ulnar end
	II: Distal epiphysiolysis of the ulna with dorsal displacement of the metaphysis
Type C: Greenstick fracture of the radius with dorsal bowing	I: Dorsal dislocation of the distal ulnar end
	II: Distal epiphysiolysis of the ulna with dorsal displacement of the metaphysis
Type D: Fracture of the radius with volar angulation	I: Volar dislocation of the distal ulnar end
	II: Distal epiphysiolysis of the ulna with volar displacement of the metaphysis

Adapted from Letts and Rowhani (1993)

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Fig. 2 Lateral radiograph of a Letts and Rowhani Type B II pediatric Galeazzi equivalent fracture with partial epiphyseal fracture (*yellow arrow*) (Photo courtesy of Kevin J. Little, MD)

and Rowhani 1993). The authors do not use this outcome measure and prefer to base outcomes based

Table 2 Mikic classification of outcomes following Galeazzi fractures

Outcome	Criteria
Excellent	Radiographic union
	Anatomical alignment
	Congruent DRUJ
	Full wrist and elbow motion
	Full forearm pronosupination
Fair	Patient satisfied with outcome but one or more of the following
	Delayed union
	Minimum malalignment or shortening of the radius
	Subluxation of the ulnar head
	Excessive scar formation
	Limitation of pronosupination of less than 45°
Poor	Patient dissatisfied with outcome plus one or more of the following
	Pain
	Deformity of the forearm
	Nonunion
	Remarkable shortening or angulation of the radius
	Limitation of pronosupination of more than 45°
	Excessive restriction of elbow or wrist motion

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Table 3 Indications for nonsurgical management

Pediatric Galeazzi fractures	
Nonoperative management	
Indications	Contraindications
Closed fractures in skeletally immature patients	Open fractures
	Skeletally mature patients
	Inability to reduce DRUJ (malreduced radius fracture, interposed extensor tendon, ulnar head buttonholed through capsule, infolded periosteum)
	Loss of closed reduction
	Malreduced unrecognized injury

on range of motion, pain, and functional use of the upper extremity.

Galeazzi Fracture Treatment Options

Nonoperative

Indications/Contraindications

Unlike adults, where Galeazzi fractures have been termed the fracture of necessity (necessitating operative fixation), the majority of Galeazzi fractures in children can be successfully treated nonoperatively. However, the moniker of "fracture of necessity" still applies, in that, in order to treat this fracture nonoperatively, an anatomic reduction is necessary, as is weekly radiographic follow-up to ensure appropriate alignment is maintained. The indications and contraindications to nonoperative management are illustrated in Table 3. Though successful treatment with immobilization in both long- and short-arm casts has been reported, inferior results have been reported with short-arm compared to long-arm casting in a case series of pediatric Galeazzi fractures (Walsh et al. 1987). As children approach skeletal maturity, the chance for failure of nonoperative treatment approaches that of adults (up to 92 %) and operative treatment should be strongly considered in any patient with closed physes (Eberl et al. 2008).

Technique

The reduction maneuver for pediatric Galeazzi fractures is dependent on the characteristics of the injury, including the apex of the radius fracture and associated ulnar head dislocation. In the case of an apex volar radius fracture and an associated volar dislocation of the ulnar head, forearm pronation and volar forearm pressure often provide the reduction force necessary to allow for reduction of the radius angulation and a dorsal relocation of the ulnar head. Apex dorsal radius fracture angulation with an associated dorsal ulnar dislocation is reduced with supination of the forearm and dorsal forearm pressure. The arm is placed in a sugar-tong splint following reduction and overwrapped into a cast after the initial period of swelling subsides. Healing typically takes 4–6 weeks, and a protective splint is recommended for an additional 6–12 weeks due to increased refracture rates in distal shaft fractures (Fig. 3).

In the event that an anatomic closed reduction cannot be obtained or maintained, open reduction is required. Reduction of the DRUJ can be blocked by the extensor tendons, buttonholing of the ulnar head through the wrist capsule and extensor retinaculum, and interposed periosteum (Karlsson and Appelqvist 1987; Hanel and Scheid 1988; Castellanos et al. 1999; Landfried et al. 1991). Figure 4 illustrates the pediatric Galeazzi fracture variant involving a radius fracture coupled with a dorsal

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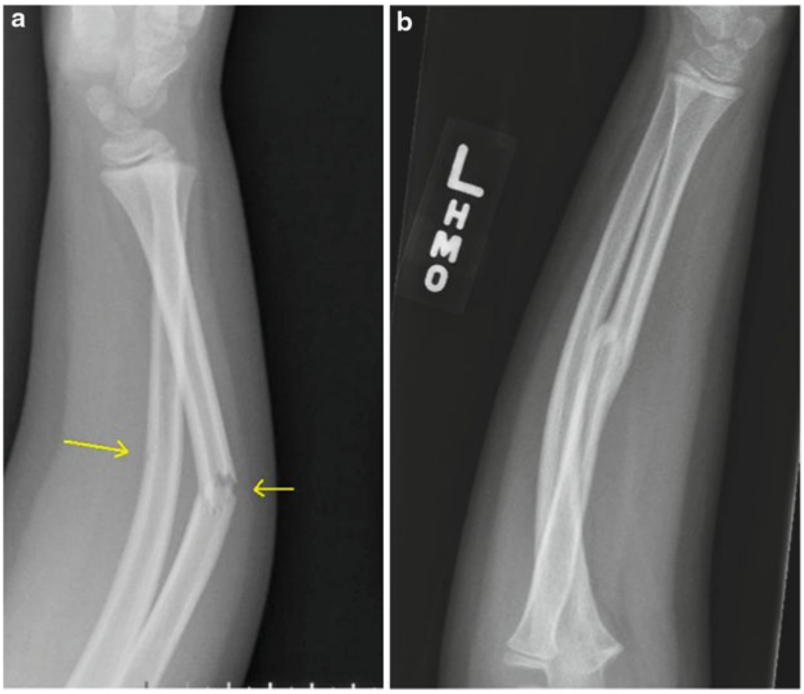

Fig. 3 (**a**) Lateral radiograph of a greenstick fracture of the radius with a dorsal DRUJ dislocation treated with closed reduction and casting with (**b**) radiographic union noted at 3 months and a clinically stable DRUJ with full ROM (Photo courtesy of Kevin J. Little, MD)

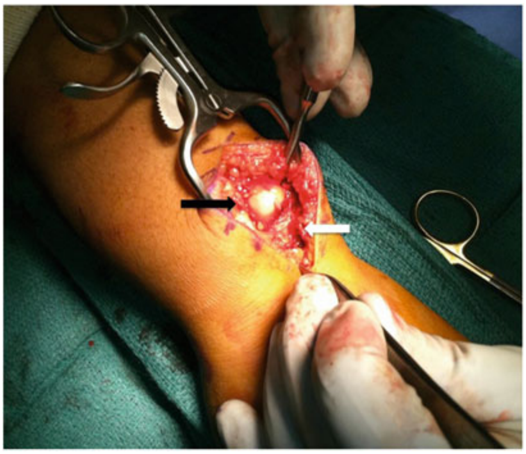

Fig. 4 Clinical photograph of a patient with an irreducible dorsal DRUJ dislocation. Note the ulnar head (*black arrow*) subcutaneously with the extensor retinaculum (*white arrow*) blocking reduction (Photo courtesy of Kevin J. Little, MD)

DRUJ dislocation, with a block to reduction by interposed extensor retinaculum (Landfried et al. 1991). Additionally, malreduction of the radius fracture can lead to an irreducible DRUJ.

Close radiographic follow-up is essential in these cases as loss of reduction can occur in up to 15 % of cases. The chance of a Galeazzi fracture requiring surgical treatment in a child increases as the patient nears skeletal maturity. Additionally, late presentation of an unrecognized Galeazzi fracture can prove challenging to treat nonoperatively, due to difficulty in obtaining an anatomic reduction of the radius and DRUJ, and operative stabilization may be necessary for these patients.

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Table 4 Operative procedure

Operative fixation of Galeazzi fractures	
Preoperative planning	
OR table	Regular OR bed
Position	Supine with arm on hand table
Fluoroscopy location	Mini-C arm coming in from the end of the hand table
Equipment	Small fragment fixation set. Kirschner wires. Flexible nails
Tourniquet	Unsterile tourniquet based on the patient's arm circumference

Outcomes

Outcome data for nonoperative treatment of Galeazzi fractures are limited, as there are few large series of these injuries. However, the overall outcomes for closed reduction and casting for these injuries are generally excellent or good with minimal sequelae (Eberl et al. 2008; Imatani et al. 1996). Even patients with Galeazzi fractures that are misdiagnosed initially and treated as simple radial shaft or distal radius fractures tend to regain full range of motion and suffer no long-term disability (Eberl et al. 2008). A minority of patients treated without surgery may lose some terminal motion (usually around 10°) at the wrist, most often terminal supination or wrist extension (Imatani et al. 1996; Letts and Rowhani 1993). Additionally, one series reported a 10 % rate of subjective occasional mild weakness and pain in nonoperatively treated patients (Eberl et al. 2008).

Operative Treatment for Galeazzi Fractures

Indications/Contraindications

Surgical treatment is indicated for a subset of pediatric Galeazzi fractures who fail initial closed reduction attempts. Open fracture/dislocations, injuries treated closed that experience loss of reduction or are unable to be anatomically reduced primarily, or those fractures in skeletally mature individuals are indications for operative intervention.

Surgical Procedure

The patient is placed under general anesthesia and placed on a regular operating table with a hand table attached (Table 4). Care is taken to position the patient as close to the hand table as possible to maximize the amount of the patient's upper extremity located on the hand table. A non-sterile tourniquet is used. Prior to skin incision, the surgeon should attempt to reduce the fracture in the manner mentioned in the previous section. If anatomic reduction cannot be obtained, open reduction is necessary. The arm is exsanguinated with an Esmarch bandage, and the pneumatic tourniquet is then inflated. The recommended tourniquet pressure in children is 50–100 mmHg above systolic pressure (Table 5).

Reduction and Fixation of the Radius

Plate Fixation

Anatomic open reduction of the radius is performed first. A standard volar approach of Henry is used for the radius fracture. The majority of these fractures are located at the junction of the middle and distal thirds of the radius, so the interval commonly exploited to access the fracture is the internervous plane between the brachioradialis (BR) and the flexor carpi radialis (FCR). Fluoroscopy is used to localize the fracture, and an 8–10 cm incision is made centered about the fracture site on the volar-radial side of the forearm along a line drawn from just lateral to the biceps tendon at the elbow proximally to the radial styloid distally. The interval between the BR and FCR is identified,

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Table 5 Surgical checklist for operative treatment of Galeazzi fractures

Open reduction and internal fixation for Galeazzi fractures
OR table: standard with arm table
Position/positioning aids: supine with arm table without legs
Fluoroscopy location: lateral from end of arm table
Equipment: small or mini fragment plates, flexible intramedullary nails of appropriate size as was measured preoperatively
Tourniquet: non-sterile to brachium

Table 6 Surgical steps for plate fixation

Open reduction and internal fixation for Galeazzi fractures with plate fixation
Volar approach along FCR tendon
Retract FCR ulnarly and incise subsheath of FCR
Dissect FPL ulnarly and expose interval between radial artery and FCR
Dissect FPL and PQ off radius shaft subperiosteally to expose fracture
Precontour plate to fit anatomic bow of radius
Lag screw across fracture if appropriate
Apply plate in compression mode if no lag screw possible
Irrigate wound
Layered closure
Apply above-elbow cast or splint based on edema and risks of swelling

and the fascia between the two is incised longitudinally allowing for radial retraction of the BR and the superficial branch of the radial nerve on its undersurface. The FCR can be retracted ulnarly along with the radial artery. In the distal forearm, the pronator quadratus (PQ) and the flexor pollicis longus (FPL) are encountered deep in this interval. With the forearm supinated, the lateral aspect of the PQ may be released from the radius to allow for ulnar retraction of the PQ and FPL and exposure of the fracture site. It should be noted that in many cases the fracture will have traumatically dissected the tissue, and in this case, the fracture site may be accessed through the interval created by the traumatic dissection (Table 6).

Upon exposure of the fracture site, the fracture ends are irrigated and debrided of any hematoma. A pointed reduction clamp or manual force may then be used to anatomically reduce the fracture under direct visualization. Anatomic reduction, relying on cortical keys when present, is important in neutralizing potential deforming forces on the DRUJ, which could negatively impact its stable reduction.

Plate fixation is then undertaken using a 3.5 mm "small frag" dynamic compression plate which has been precontoured to fit the patient's anatomy. In younger patients with smaller diameter bone, flexible nail insertion is ideal but may not be possible to restore anatomical alignment. In these cases a 2.7 mm "Mini-Frag" plate or 2.4 mm "Modular Hand" plate can be used with similar results. Oblique fractures may be amenable to initial lag screw fixation followed by neutralization plating, while transverse fractures are appropriately treated with compression plating (Fig. 5). At least six cortices of screw purchase proximal and distal to the fracture site are customary. The wound is thoroughly irrigated. The deep dermal tissue is reapproximated with absorbable braided suture, and the skin is closed with an absorbable monofilament running subcuticular suture.

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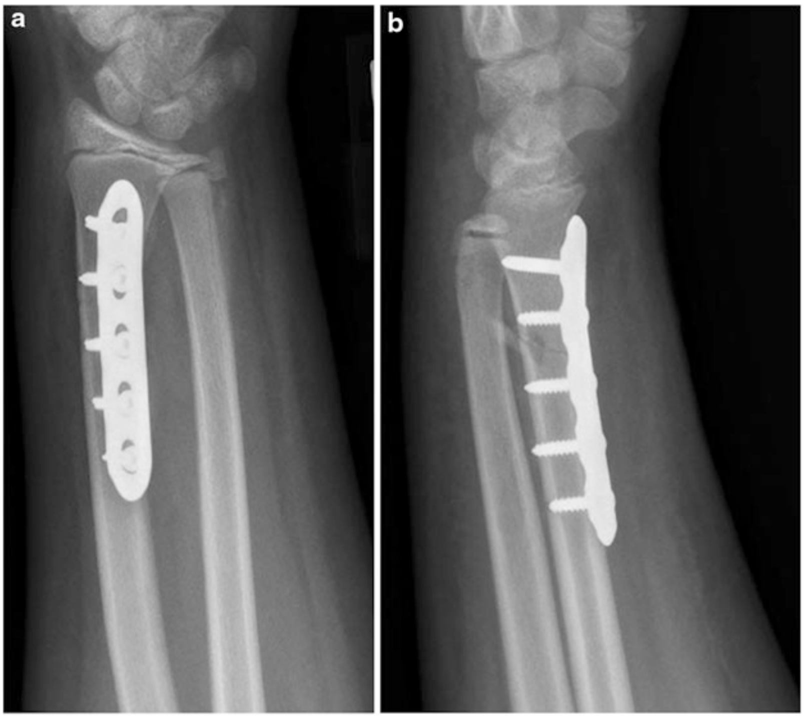

Fig. 5 (**a**) AP and (**b**) lateral radiographs following ORIF of the same Galeazzi fracture depicted in Fig. 2 (Photo courtesy of Kevin J. Little, MD)

Flexible Intramedullary Nail Fixation

In transverse fractures or those too unstable after closed reduction for cast immobilization alone, a flexible intramedullary nail may be elected for fracture fixation in skeletally immature patients.

To insert the nail, a 0.5–1 cm incision is made either over the volar-radial lip of the radius or just proximal to Lister's tubercle. There is a higher rate of complications associated with the dorsal entry point, which is typically related to extensor pollicis longus (EPL) tendon irritation or rupture and can easily be treated with tendon transfer. However, radial entry portal complications are typically injuries to a branch of the radial sensory nerve, which is difficult to treat. Fluoroscopy is used to localize the incision just proximal to the distal-radial physis. When utilizing a radial entry portal, branches of the superficial radial nerve must be protected with careful blunt dissection. The abductor pollicis longus (APL) and extensor pollicis brevis (EPB) tendons are identified and retracted dorsally, and the radius cortex is identified. When utilizing the dorsal entry portal, dissection is carried down to Lister's tubercle and the extensor retinaculum is incised longitudinally. The interval between the extensor carpi radialis longus (ECRL) and EPL is used to find the bare area just proximal to Lister's tubercle. Under fluoroscopic visualization, a curved awl is used to enter the intramedullary canal of the radius proximal to its distal physis with care taken not to violate the far cortex. A flexible nail with a diameter 60 % less than the diameter of the isthmus of the radius (determined from preoperative radiographs) is then gradually bent over the course of the nail to approximate the radial bow. The nail is then introduced at the entry site and advanced in a distal-to-proximal direction to the level of the fracture under fluoroscopic imaging. The radius fracture is manipulated with manual force and traction until the desired reduction can be obtained and the nail passed into the proximal medullary canal. If closed reduction is not possible, a limited exposure through a volar approach of Henry is employed and the reduction is held with a pointed reduction clamp or towel clamp while the flexible nail can be advanced across the fracture site.

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Table 7 Surgical steps for flexible nail insertion

Operative fixation for Galeazzi fractures with flexible nail insertion
Using fluoroscopy, identify the physis and mark just proximal to physis
Make a 0.5–1 cm incision at either (A) Lister's tubercle or (B) over the volar lip of the radius between the radial artery and first compartment
Carefully dissect bluntly to the fascia, and either (A) identify the interval between the EPL and ECRB tendons at a bare area proximal to Lister's tubercle or (B) protect superficial radial nerves and identify the bare area between the radial artery and first compartment on the volar lip of the radius
Using fluoroscopy, use a curved awl to penetrate the cortex and angle proximally, taking care not to disturb the physis
Choose a nail with a diameter 60 % less than the inner diameter at the radius isthmus
Precontour the nail with a large C-shape bend in the direction of the pointed tip
Using gentle twisting motion or a mallet, advance the nail to the fracture
Manually reduce the fracture under fluoroscopic visualization
If unable to pass the nail after 3 tries, proceed to open reduction as in Table 5
Pass the nail proximally until just distal to radial neck physis, rotating the nail to match the normal radial bow
Verify anatomic reduction and DRUJ stability clinically and radiographically
Irrigate wound and close the wound with absorbable, buried sutures

Once across the fracture site, the nail is advanced to a point just distal to the proximal radial physis. The nail is cut subcutaneously and superficial to the fascia and tendons to facilitate later removal. The wound is irrigated and the skin is closed with a running, absorbable, subcuticular monofilament suture (Table 7). Nail removal is advocated at 6 months postoperatively when bridging callus is noted on 4/4 cortices.

DRUJ Operative Treatment

Following fixation of the radius fracture, the DRUJ should be assessed clinically and with multiplanar fluoroscopic imaging. If the DRUJ appears well reduced and is stable to stress testing, the patient can be immobilized in the position of maximal stability of the dislocation pattern, which may be neutral, pronation, or supination depending on the injury.

If the patient's DRUJ remains dislocated or there remains a displaced distal ulnar physeal fracture, there is likely soft tissue interposition that is blocking its reduction. This requires open reduction of the DRUJ or the distal ulna physeal fracture and possible fixation if, after reduction, the joint remains unstable and easily subluxatable or dislocatable.

The DRUJ can be approached through a dorsal incision overlying the fifth extensor compartment. Care is taken to avoid the dorsal sensory branch of the ulnar nerve, and the fifth extensor compartment is opened longitudinally. The extensor digiti minimi tendon is retracted ulnarly, and the floor of the compartment is incised longitudinally. Capsular flaps are then raised exposing the DRUJ. The DRUJ can then be reduced under direct visualization. Often the traumatic injury creates a dissection plane along this interval, and care must be taken not to injure structures that are not in an anatomic location due to the DRUJ dislocation. In the event that extensor tendons, capsule, or extensor retinaculum are blocking the reduction of the joint (Fig. 4), these can be extracted through this approach to allow for reduction. If a distal ulnar physeal fracture is present, infolded periosteum can block the reduction of the physeal injury (Landfried et al. 1991). This can be manually extracted with a Freer elevator or forceps. The distal ulnar epiphysis can then be anatomically reduced.

After reduction of the DRUJ or the distal ulnar epiphysis, one or two appropriately sized Kirschner wires may be placed through the skin outside of the dorsal incision to secure the joint

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Table 8 Surgical steps for open DRUJ reduction

Operative fixation for irreducible distal radioulnar joint dislocation
Using fluoroscopy, examine and stress the DRUJ to identify an irreducible dislocation or physeal fracture
Make a 3–5 cm incision longitudinally over the 5th dorsal compartment
Bluntly dissect down to the extensor digiti minimi (EDM) tendon and release it from the extensor retinaculum
Retract the EDM ulnarly and incise the floor of the compartment longitudinally until the TFCC is identified and the distal margin
Transversely incise the capsule just proximal to the TFCC to create a triangular flap to expose the DRUJ
Identify and release the soft tissue structure blocking reduction
Reduce the DRUJ or physeal fracture
Unstable SH 3 fractures of the ulnar styloid may need fixation with a tension band or headless compression screw if persistent DRUJ instability is identified
Irrigate the joint and suture the capsule closed
Ensure DRUJ stability throughout pronosupination
Leave the EDM tendon outside the extensor retinaculum during layered closure
Close the retinaculum and skin
Immobilize with above-elbow cast or splint

or fracture. This is done under multiplanar fluoroscopic guidance. Fixation is not always required once the block to reduction is removed and the DRUJ is able to be reduced (Table 8).

Postoperative Immobilization

An above-elbow plaster splint is applied following wound closure with absorbable monofilament suture. This can be a sugar-tong-type splint to immobilize the forearm in the most stable rotational position. Stability of the DRUJ in neutral, pronation, or supination depends on the initial injury and on intraoperative fluoroscopic assessment of stability following fracture fixation. This splint is overwrapped with fiberglass at the first postoperative visit, approximately 1 week following the operation. Films are obtained at this visit to verify maintenance of reduction. The overwrapped splint is left in place for four additional weeks at which time it is removed and additional films are obtained.

With closed treatment of Galeazzi fractures, an above-elbow cast is maintained for 4 weeks to immobilize forearm rotation followed by a below-elbow cast when possible for an additional 2 weeks. Following operative fixation of the radius, a cast or splint can be discontinued once sufficient bony healing is obtained to allow for gentle passive ROM exercise, typically in 4–6 weeks. Once osseous union is confirmed with radiographs, gentle active ROM exercises can be initiated, but full-time brace wear, either with a forearm splint or Sarmiento brace, is recommended for an additional 6 weeks to limit the risks of refracture. Active assist and passive ROM exercises are generally initiated at 8 weeks after surgery or injury, followed by strengthening at 10–12 weeks for patients who have obtained full active and passive ROM to the arm and wrist. After 12 weeks bracing is discontinued unless the patient wishes to participate in high-contact, upper-extremity activities such as football, basketball, or gymnastics, where the brace should be worn for an additional 3 months or more (Table 9).

Surgical Treatment Outcomes

There are limited outcome data on surgical treatment of pediatric Galeazzi fractures. Most studies report normal postoperative forearm, wrist, and hand functions in patients treated operatively (Imatani et al. 1996). In a small percentage of patients, slightly limited wrist extension is reported

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Table 9 Postoperative protocol for Galeazzi fractures

Operative treatment for Galeazzi injuries
Postoperative protocol
Type of immobilization: above-elbow cast or sugar-tong splint
Duration of immobilization: 4–6 weeks based on fracture healing
Rehab protocol: 4–6 weeks AROM, 6–8 weeks add AAROM, 8–12 weeks add PROM. At 10–12 weeks, one can add strengthening based on return of motion
Return to sport: may return with forearm brace at 12 weeks for upper-extremity contact. Full return at 6 months

(Letts and Rowhani 1993). Overall, our experience with surgical fixation is that results are generally good with minimal long-term sequelae.

Preferred Treatment

Nearly all pediatric Galeazzi fractures deserve an attempt at nonoperative management. Even fractures that will be treated operatively should undergo an initial closed reduction attempt and splinting. However, reduction attempts should be limited to avoid damage to the distal ulnar physis in cases in which a distal ulnar physeal fracture is present. Initial immobilization should be in a sugar-tong (above-elbow) splint to accommodate initial soft tissue swelling and to immobilize forearm rotation. Weekly radiographs for 3 weeks following the injury allow for the detection of any loss of reduction that might then necessitate intervention. This should be followed by long-arm casting for a total of 6 weeks post-injury until both the radius fracture and the DRUJ injury have healed. In patients with a distal ulnar physeal injury, radiographic growth checks should be obtained at 3-month intervals during the first year to ensure adequate resumption of growth via a symmetric Park-Harris line on the distal ulna or via a consistent ulnar variance in the presence of radial growth.

If anatomic reduction cannot be obtained with nonoperative treatment, surgical treatment is necessary. Transverse radial shaft fractures can often be managed best with a flexible intramedullary nail, while oblique fractures, which are length unstable, are best treated with open reduction and plate fixation. Following reduction of the radius, it is uncommon for the DRUJ to remain unreduced. If despite anatomic reduction of the radius, the DRUJ does remain unreduced, a dorsal exposure of the DRUJ can aid in visualization and extraction of any interposed soft tissue that may be obstructing reduction. Fixation of the DRUJ is often not necessary following reduction, but the joint should be interrogated with multiplanar fluoroscopic images to ensure that the DRUJ remains stably reduced. Postoperative immobilization is accomplished with an above-elbow sugar-tong splint. Above-elbow immobilization is continued for 4–6 weeks postoperatively.

Surgical Pitfalls and Prevention

Patients with apex volar angulation and volar dislocation should be immobilized in pronation, whereas patients with apex dorsal angulation and dorsal DRUJ dislocation should be immobilized in supination. Fractures involving the distal metadiaphyseal radius are prone to angulation with intramedullary rods due to the proximity of the fracture to the entry portal. As such, in patients with these distal injuries, the surgeon should have a low threshold to proceed to open reduction and internal fixation of the fracture and appropriately counsel the patient and family preoperatively. In patients with irreducible DRUJ dislocations, the distal ulna typically lies subcutaneously and can

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Table 10 Pitfalls and prevention strategies for Galeazzi fractures

Galeazzi fractures	
Pitfalls and prevention strategies	
Tented neurovascular structures can be present over the prominent, dislocated ulnar head	Carefully make a skin incision down to the subcutaneous layer and then bluntly dissect to isolate ulnar nerve and artery volarly or dorsal sensory nerves dorsally
Distal-radial shaft fractures may be unstable after intramedullary fixation	Proceed to plate fixation if this occurs
	Ensure all appropriate implants are available prior to case
Intramedullary nail will not fit down the proximal radius shaft	Start with a nail with a diameter no greater than 60 % of the internal diameter of the isthmus of the radius
	Straighten the pre-bent tip of the nail so that it may pass easily
Ulnar growth arrest is common following distal ulnar physeal injury	Follow longitudinal growth until evidence of ulnar growth or growth arrest occurs

easily trap neurovascular structures in the superficial subcutaneous layers. Careful blunt dissection should be performed to ensure that these structures are not sharply divided during the skin incision.

Essex-Lopresti injuries are rare in childhood and usually present only after radial head resection with radial shortening. The clinician should attempt to salvage the radial head in all pediatric patients with radial head or neck fractures to ensure the radial buttress can prevent proximal migration and significant pain. Additionally, in pediatric patients, stump overgrowth of the proximal radius can lead to significant radiocapitellar arthropathy following radial head resection (Table 10).

Management of Complications

Fortunately, complications are somewhat rare in the treatment of pediatric patients. The most significant complication noted is a loss of reduction seen in 15 % of patients following closed treatment of injuries. This can be managed by repeat closed reduction or surgical fixation as indicated by the amount of displacement and the patient's age. In patients with a distal ulna physeal fracture, ulnar growth arrest can occur in up to 50 % of patients (Fig. 6). This complication is best managed by anticipating physeal arrest and monitoring wrist radiographs every 3 months. If an asymptomatic growth arrest is identified, physeal imaging with an MRI is preferred, and distal radius epiphysiodesis is performed to prevent overgrowth and ulnar tethering. In symptomatic patients, wrist arthroscopy and possible step cut ulnar lengthening can be performed to restore ulnar length in addition to distal radius epiphysiodesis.

Pin tract infections can occur in patients where the DRUJ has been stabilized with percutaneous pins. These typically resolve with oral antibiotics and, if necessary, pin removal. Deep infections are rare and should be treated with operative debridement and hardware removal if the fracture has healed. In closed Galeazzi fractures with neurovascular injury, the nerve injury is typically a neurapraxia and will resolve with observation.

Summary and Future Directions

Proper education of orthopedic and emergency room physicians can lead to early diagnosis and treatment of Galeazzi and Essex-Lopresti injuries. Once anatomic alignment has been restored, healing of these injuries is typically routine with minimal long-term complications. Future directions

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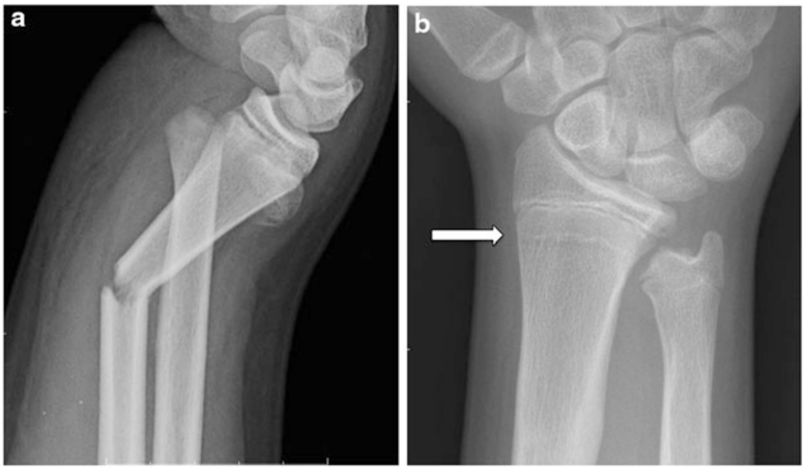

Fig. 6 (**a**) Lateral radiograph of a patient with a volar Galeazzi equivalent fracture and distal ulnar physeal fracture with complete displacement. (**b**) 1 year following closed treatment, the fracture healed but resulted in a distal ulnar physeal arrest. Note the Park-Harris line (*white arrow*) on the distal radius implying growth of the radius without matching ulnar growth (Photo courtesy of Kevin J. Little, MD)

in treatment may include strategies to prevent reoperation for hardware removal or to limit complications inherent to operative treatment. Additionally, validated outcome measurements should be created to appropriately measure return of forearm, wrist, and hand functions, especially in terms of forearm rotation, as well as incorporate patient goals and satisfaction.

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Index Terms: