Traumatic Physeal Arrests at the Wrist

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Abstract:
Fractures involving the physes of the distal forearm are exceedingly common in children, representing upwards of one-third of all pediatric fractures. These injuries are often amenable to closed treatment, but physeal injury can lead to premature arrest and significant related long-term sequela. Common practice guidelines have not been established amongst the pediatric orthopaedic community for radiographic monitoring, need for three-dimensional imaging, and treatment algorithms in these injuries. This review seeks to outline the literature and share the perspective and methods of a panel of pediatric upper extremity experts in order to provide a framework for better understanding these injuries and treating their growth-related sequelae.

Key Concepts:

- Patients with traumatic injuries to the distal radial or ulnar physes should be followed clinically and radiographically until they demonstrate resumed symmetric growth, often > 6-12 months.
- Ulna epiphysiodesis is reserved for patients with a radial growth arrest who are at risk for developing ulnocarpal abutment.
- Completion of a partial radial arrest is considered if remaining growth would lead to deformity.
- Ulnar shortening osteotomy is indicated for ulnar positive wrists with normal alignment of the distal radius. Distal radius corrective osteotomy (addressing both length and deformity) should be considered for those with ulnar positive wrists and deformity.
- Wrist arthroscopy for evaluation and possible repair of the TFCC could be considered in patients with ulnar-sided wrist pain and/or clinical instability of the DRUJ.

Introduction

The distal radial ossification center forms prior to 12 months of age. The distal ulna ossification center forms later, between 5-7 years of age. Both of these ossification centers account for 70-80% of longitudinal growth of their respective bones; injury of one or both of these physes at a young age can lead to length discrepancy and deformity. Fractures involving the physes of the distal forearm are exceedingly common in children, representing upwards of 1/3 of pediatric fractures in large population studies.[1-4]

While the Salter-Harris classification system is a valuable tool at describing physeal injuries, it does not predict which fractures will be more likely lead to a growth arrest. Fracture of the distal ulna physis can have a growth arrest in up to 50% of cases. Distal radius physeal fractures are less susceptible to arrest, but those that are widely displaced or require multiple attempts at reduction are also at risk. Rapid growth at the distal radius and ulna physes leads to continuous remodeling of the metaphysis making the thin cortices susceptible to fracture. Fractures can range from buckle, to displaced and shortened metaphyseal, and to Galeazzi fracture dislocations; most of these injuries are amenable to closed treatment. Interestingly, there are reports of patients who sustain metaphyseal fractures without apparent physeal fracture extension who develop a growth disturbance.[5,6]

When a growth arrest occurs, there are a variety of differing treatment options available. This review seeks to outline the literature and share the perspective and methods of a panel of pediatric upper extremity experts in hopes of providing a framework for better understanding these injuries and treating their growth-related sequelae.

Guidance from the Literature

The question of why a fall on an outstretched hand—the most common mechanism for distal forearm injuries—leads to a fracture through the epiphysis, physis, or metaphysis of the radius and/or ulna has been addressed in recent literature.[11,12] Younger children more often sustain diaphyseal radius and ulna shaft fractures, while teens fractures tend to be more distal. When the distal physes are involved, females are 1.5 years younger than their male counterparts on average.[3] Tredwell et al. proposed the concept that forearm fractures "migrate distally" with age due to changes in the geometry of the shaft and metaphyses of these bones, the ratio of cancellous to cortical bone, and the transition of forces as the length of these long bones increase with age.[13]

The radius and the ulna converge at the wrist joint, with the radius pronating and supinating around the ulna at the distal radial ulnar joint (DRUJ), which also stabilizes the wrist during rotation and loading. True Galeazzi injuries with DRUJ dislocation are rare in the pediatric population; rather, the force of injury is transmitted through the path of lesser resistance—namely, distal radius and distal ulna physeal separation—leading to a Galeazzi-equivalent or pseudo-Galeazzi injury, an injury previously shown to have a high growth-related complication rate.[14]

Distal radius physeal fractures outnumber those of the distal ulna; however, isolated distal ulna physeal fractures (which must be distinguished from styloid fractures) are almost always associated with a fractured radius and are more likely to develop physeal arrest, regardless of whether they are treated open or closed.[3,4,15,16] Golz et al. reviewed 18 patients with distal ulna physeal fractures and found that 10 of these (55%) developed premature physeal closure and a resultant ulnar minus variance of 2-30 mm. Seven of those 10 patients developed secondary changes of the distal radius and carpus. The difference seen in the rates of physeal arrest between the radius and the ulna may reflect the anatomy of this articulation—namely, the continuity provided by the DRUJ complex and the force required to overcome the protective effect of the meniscus between the ulna and the proximal carpal row.[14,15]

Rate of growth abnormalities relates to fracture morphology, energy of mechanism, and patient age. In general, studies cite rates of physeal arrest of the distal radius to be less than 5%, however, asymptomatic mild discrepancies may exceed this.[11,17-20] A long-term outcomes study of consecutive distal forearm physeal injuries provided an average of 25.5 (range 14-46) year follow-up of 163 lesions in 157 patients. Of these, 48 patients (31%) had a radioulnar length discrepancy ranging from 2 mm to 6.5 cm—of these, 38 patients had a small discrepancy (2-9 mm) and were asymptomatic, leaving 10 patients with radioulnar length discrepancies > 10 mm, all of whom were symptomatic and two of whom had disabling functional deficits.[21]

Guidance from Expert Panel

A panel of five experts from different centers across the U.S. were asked to participate in a comprehensive review of 13 cases with the hope that each of these experts' perspectives will reflect their differences in training, patient populations, and operative experience in order to provide an encompassing approach to these injuries. Cases were selected for review such that a variety of patient ages, fracture patterns, severity, and injury mechanisms were represented (Table 1). Several representative cases will be described for illustration, then the results of this survey will be outlined more comprehensively.

Case 1: A 14+8-year-old boy fell playing hockey and injured his right wrist. He was found to have a dorsally translated Salter Harris (SH) 1 distal radius fracture and minimally displaced ulnar styloid fracture shown in

Figure 1 (left). *R wrist injury films for Case 1*
Figure 2 (right). *Post-cast films for Case 1*

Figure 1. This was treated with closed reduction and casting (Figure 2).

Three of our five panelists reported they would plan to follow this patient for 6 months, and two panelists would follow for 12 months. Of note, one panelist noted that they would follow the patient beyond 6 months if any

Table 1. Summary of Cases Reviewed by Expert Panel

Case #	Age/ Gender	Initial Injury	Initial Treatment	Interval at Which Disturbance Identified	Resultant Deformity
1	13 F	SH2 DR fx, USF	CR, cast	1 year	Partial DR arrest, dorsal DR tilt, ulna +
2	10 F	Metaphyseal DR and DU fxs	CR, cast	3.5 years	Full DU arrest, ulna -
3	13 M	DR fx, ulna shaft fx, USF	CRPP	5 mos	Full DR arrest, ulna +
4	14 M	SH1 DR fx, USF	CR, cast	1 year	Full DR arrest, ulna +
5	14 M	Metaphyseal DR fx, USF	CR, cast	1 year	DR healed short, ulna +
6	12 M	Metaphyseal DR fx, SH3 DU physeal separation	CR, cast	3 years	Elevated radial inclination, full DU arrest, ulna -
7	11 F	DR fx and DU physeal separation	CR, cast	1 year	Full DU arrest, ulna -
8	12 M	SH4 DR fx, USF	CRPP	8 mos	DR physeal bar, decreased radial inclination
9	10 M	Open SH2 DR fx, segmental ulna shaft fx	I&D, DR pinning, ulna flex nail	14 mos	Full DR arrest, ulna +
10	10 F	Metaphyseal DR fx	CR, cast	18 mos	Partial DR arrest, dorsal tilt of DR, ulna +
11	13 M	SH2 DR fx	CRPP	1 year	Full DR arrest, ulna +
12	13 F	SH2 DR fx, USF	CR, cast	4 mos	Full DR arrest, dorsal tilt of DR, ulna +
13	10 M	Atraumatic premature DR physeal arrest	Unknown	Unknown	Full DR arrest, dorsal tilt of DR, ulna +

** Abbreviations: DR (distal radius), DU (distal ulna), fx (fracture), USF (ulnar styloid fracture), SH (Salter Harris), CR (closed reduction), CRPP (closed reduction with percutaneous pinning)*

Figure 3. *R wrist 1-year post injury (AP, lat)* *Unaffected L wrist*

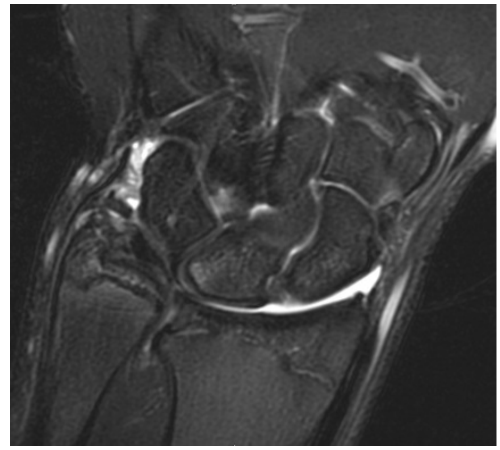

Figure 4. *MRI 1-year post injury*

asymmetry of the Parker Harris growth arrest lines or change in ulnar variance was noted.

The patient then followed up 1 year later with the complaint of vague ulnar-sided wrist pain. New radiographs (Figure 3) demonstrated 2.5 mm positive ulnar variance compared to the contralateral wrist. When queried about the need for three-dimensional imaging, three of our panelists advised they would proceed with wrist MRI at this time, one panelist would proceed with CT scan, and one panelist would obtain 3D imaging only if the patient had a recent/new traumatic injury with pain and instability of the distal ulna. This patient had a wrist MRI performed (Figure 4).

Based on the imaging above, four of our panelists would plan to perform drill epiphysiodesis of the distal ulna and an ulnar shortening osteotomy (USO) at this time. One panelist would perform USO followed by a wrist scope to evaluate +/- repair the TFCC if there was evidence of DRUJ instability on exam after osteotomy fixation. In reality, this patient underwent isolated drill epiphysiodesis of the distal ulna (Figure 5), and he experienced radiographic improvement in his ulnar variance and complete resolution of his wrist pain 9 months later (Figure 6).

Case 2: A 12-year-old boy fell from his scooter injuring his left wrist. He was found to have a displaced metaphyseal distal radius fracture and a displaced SH4 distal ulna fracture which was treated with closed reduction and casting (Figure 7).

Figure 5. *Fluoro imaging of drill epiphysiodesis of ulna*

Figure 6. *Nine months after drilling, ulnar variance near neutral*

Of our five panelists, two would plan to follow this injury radiographically for 6 months and three would plan to follow for 12 months. Two panelists emphasized that they would follow this patient longer than stated if there

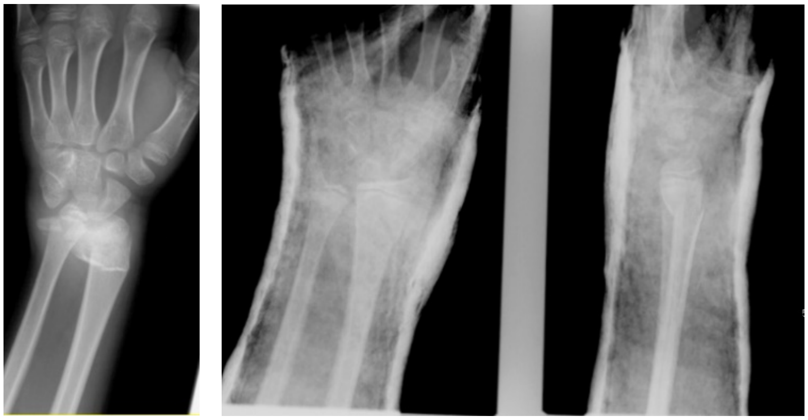

Figure 7. *Injury and post-reduction casted films for Case 2*

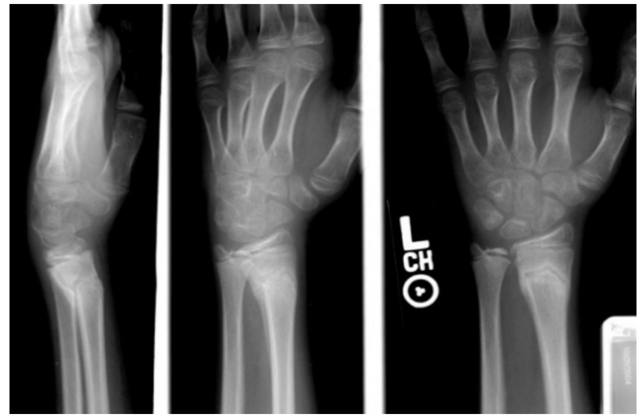

Figure 8. *Six-week post-injury films*

was asymmetry in Park-Harris growth arrest line or change in ulnar variance. This patient was seen 6 weeks post injury (Figure 8), then lost to follow-up until 3 years late r (at 15 years of age) with wrist pain and deformity (Figure 9). One panelist would not plan to obtain additional imaging at this time. Two panelists would plan to get a CT at this time, one an MRI, and one a CT and MRI. In reality, this patient did not have additional 3D imaging performed. Based on the radiographs available, three panelists would proceed with an isolated shortening and closing wedge radial osteotomy to address length and angular deformity and drill epiphysiodesis of the distal radius. The other two panelists proposed the same plan and would also consider gradual ulnar lengthening. One panelist advised that the ulna should be left negative given its atypical shape. In reality, this patient underwent distal radius hemi-epiphysiodesis and underwent ulna lengthening with fixator removal once the regenerate developed cortical continuity. His course was complicated by a fall while skateboarding and his ulna was subsequently rodded (Figure 10). After all his implants were removed, his distal radial inclination and ulnar variance was improved (Figure 11).

Case 3: A 12-year-old boy sustained a right SH4 distal radius fracture and was treated with closed reduction and percutaneous pinning (Figure 12). Four of our five panelists agreed that they would follow this patient radiographically for 12 months or more. Our fifth panelist advised following a minimum of 6 months or until there

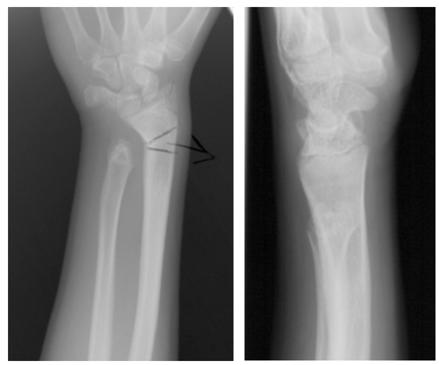

Figure 9. *Three-year post-injury films*

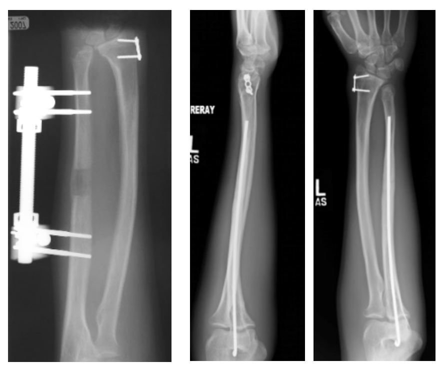

Figure 10. *Patient underwent distal radius hemiepiphysiodesis with a plate and screws and gradual ulnar lengthening, followed by rodding of the ulna after a fall.*

Figure 11. *Fluoro image at implant removal*

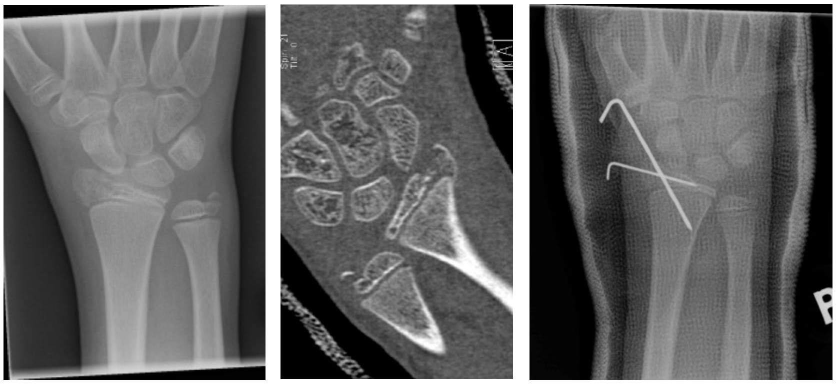

Figure 12. *Injury x-ray, CT and post-pinning x-ray*

Figure 13. *Eight-months post-injury x-ray and MRI*

was clear evidence of symmetric distal radial growth without change in ulnar variance.

The patient was evaluated at 8 months post injury. He remained asymptomatic. Based on the findings at 8 month follow-up, three of our panelists would proceed with MRI, one with CT, and one would defer further imaging unless the patient had new onset of pain with a new injury—in this case, an MRI arthrogram would be obtained to evaluate the TFCC.

Based on the patient's radiographs and MRI findings (Figure 13), three of our panelists would proceed with radial bar resection and one with close observation. Our final panelist would base the decision more heavily on clinical symptoms: if asymptomatic, drill epiphysiodesis of the distal radius and ulna would be performed, if the patient had ulnar sided wrist pain, an USO would be added, and if the patient had ulnar sided pain with instability, a wrist scope and TFCC repair would also be added. In reality, this patient underwent bar resection but maintained significant residual vs. partially recurrent deformity and ultimately underwent osteotomy and pin fixation and completion drill epiphysiodesis of the radius and ulna (Figure 14).

Table 2. Summary of Our Panelists' Follow-Up Recommendations Based on Injury Type

Injury Description	**Anticipated Length of Follow-Up**
SH distal radius fracture +/- ulnar styloid fracture	Panelists were divided between recommending 6 vs. 12 months of radiographic follow-up, with slight preference for 12 months. Clarification provided that follow-up should continue until the physis "declares itself," symmetric Parker Harris growth arrest lines are noted, and no progressive change in ulnar variance is identified.
SH distal radius fracture and SH distal ulna fracture	Panelists emphasized that distal ulna physeal separations are bad actors and must be followed until resumed growth can be seen via growth arrest lines or absence of change in ulnar variance over 6-12 months.
SH distal radius fracture and ulnar metaphyseal or diaphyseal fracture	Two panelists recommended 6-month follow-up. Three recommended 12-month follow-up.
Metaphyseal radial fracture and ulna styloid fracture	Two panelists recommended 6-month follow-up. Three recommended 12-month follow-up.
Metaphyseal radius and ulna fractures	Two panelists recommended follow-up only until evidence of radiographic healing is present. Two recommended 6-month follow up, and one recommended at least 12-month follow-up (until fracture is fully remodeled).

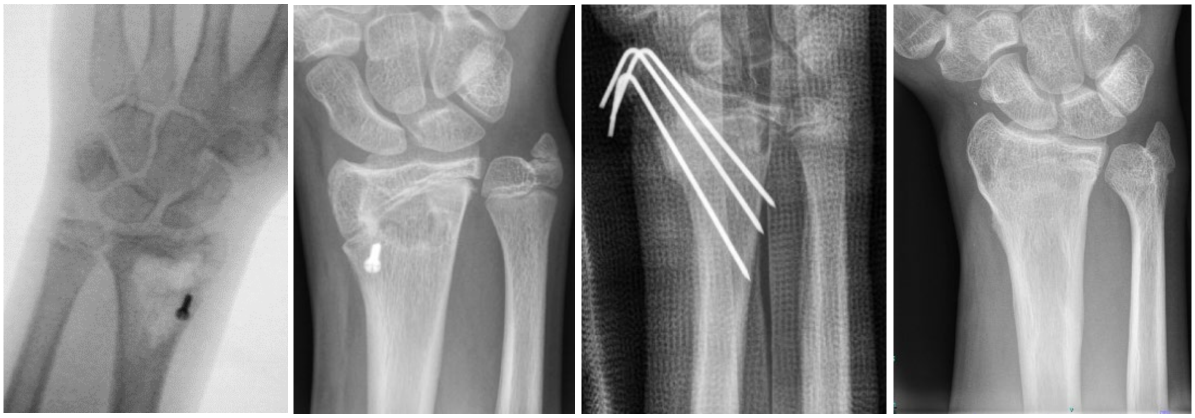

Figure 14. *Bar resection, recurrence/residual, osteotomy/drilling, and final follow-up x-ray*

Table 3. Description of Imaging and Treatment Preferences Based on Growth Disturbance Type

Description of Growth-Related Sequelae	**Preference for 3D Imaging**	**Treatment Recommendations**
Positive ulnar variance with normal alignment/ tilt of the distal radius	Panelists varied in their preference for MRI vs. CT on a case-by-case basis; however, MRI was favored by a factor of 2:1 over CT when cases were combined.	All five panelists would perform ulnar shortening osteotomy and drill epiphysiodesis of the distal ulna in the majority of these cases. In less than half of these cases, one to two panelists noted they would consider a wrist scope with TFCC evaluation +/- repair if the patient had instability of the DRUJ on exam.
Positive ulnar variance with deformity of the distal radius	Three panelists favored MRI. Two favored CT. In one particular case, one panelist favored both CT and MRI.	All panelists would proceed with completion drill epiphysiodesis of the distal ulna and radius (as needed). In ADDITION: Three panelists would proceed with radius corrective osteotomy. One panelist would proceed with planned distal radius corrective osteotomy and USO. One panelist would proceed with USO.
Negative ulnar variance with normal alignment/ tilt of the distal radius	Four panelists favored MRI. One favored CT.	Four panelists would proceed with radial osteotomy, one of whom would also perform a wrist scope for TFCC evaluation/repair. One panelist would proceed with rotational ulnar osteotomy and wrist scope.
Negative ulnar variance with deformity of the distal radius	Two panelists would obtain CT. One would obtain MRI. One would obtain both MRI and CT. One did not feel 3D imaging was needed.	All five panelists would proceed with distal radius osteotomy to correct angulation and tilt. Three would also perform drill epiphysiodesis of the distal radius. Two panelists would also plan for gradual ulnar lengthening.
Potential physeal bar formation	Four panelists would obtain MRI. One would obtain CT.	Three panelists would plan for surgical bar resection. One panelist would closely observe the patient so long as they remain asymptomatic. One panelist would perform drill epiphysiodesis of both the distal radius and ulna.

The remaining cases were similarly reviewed. The need for follow-up was determined based on injury films and preference for imaging and treatment modalities were determined based on later follow-up radiographs once a growth disturbance had been identified.

Recommendations for follow-up in these injuries (Table 2) as well as imaging recommendations and treatment approaches for the differing growth arrests (Table 3) were then summarized.

Summary

The abundance of distal forearm fractures requires almost all pediatric orthopaedic surgeons to treat and follow these injuries. There is a wide variability in practice pattern in regards to length of follow-up and need for treatment should growth arrest ensue. The literature highlights the wide variability in outcomes of these injuries. Our panel of experts demonstrated that significant variability exists in how we monitor, image, and treat these patients, but review of their responses does highlight several critically important concepts:

Summary for Follow-Up Recommendations

- Length of necessary follow-up is difficult to standardize. Rather, these patients should be followed until they demonstrate resumed symmetric growth of both the distal and ulna physes. This can be inferred based on symmetric migration of Park Harris growth arrest lines and/or absence of change in ulnar variance on successive radiographs. If there is any doubt, at least 12 months of follow-up is preferred.

Summary for Evaluation

- In addition to contralateral wrist films, the diagnosis of growth arrests via CT versus MRI is provider dependent. There was a preference for MRI amongst providers who were more consistently planning to perform a wrist arthroscopy and possible TFCC interventions; however, this was variable. There was significant preference for MRI in the setting of evaluation for possible physeal bar.

Summary for Treatment Strategies

- Early ulna epiphysiodesis is utilized fairly liberally in asymptomatic patients with complete radial arrest (no radial deformity) and there is growth remaining for the ulna to become problematic with pain from abutment.
- Drill epiphysiodesis of the distal radius should be considered (provided substantial growth remains) in the setting of mild angular deformity due to partial arrest. If growth remains, concomitant ulna epiphysiodesis is recommended to prevent ulna abutment from developing.
- Distal radius corrective osteotomy (addressing both length and angulation) for patients with moderate to severe deformity of the distal radius (angulation or tilt) is preferred. If the ulna remains positive after correction, then growth arrest and/or ulna shortening osteotomy (USO) should be considered.
- USO is favored for patients with symptomatic ulnar positive wrists with normal alignment of the distal radius
- The addition of wrist arthroscopy for evaluation and possible repair of the TFCC is provider dependent and tends to be favored in those patients who have both ulnar-sided wrist pain and/or clinical instability of the DRUJ.
- Use of guided growth for excessive radial tilt as a result of ulna tethering from extreme shortening and ulna lengthening via acute step cut or via distraction osteogenesis can be considered in select cases depending on degree of ulna shortening.

Additional Links

- Ulnar Shortening Osteotomy for Ulnocarpal Impaction http://www.posnacademy.org/media/Ulnar%20Shortening%20Osteotomy%20for%20Ulnocarpal%20Impaction/1_zgdq4zmk

- Displaced Distal Radius Fractures in Children: To Reduce or Not to Reduce? To Pin or Not to Pin? https://www.jposna.org/ojs/index.php/jposna/article/view/77
- Pediatric Hand and Wrist Trauma: Distal Radius Fractures http://www.posnacademy.org/media/Distal%20Radius%20Fractures%20(Pediatric%20Hand%20and%20Wrist%20Trauma)/0_ljc1jg4n

References

1. Landin, L.A., *Fracture patterns in children. Analysis of 8,682 fractures with special reference to incidence, etiology and secular changes in a Swedish urban population 1950-1979.* Acta Orthop Scand Suppl, 1983. **202**: p. 1-109.

2. Worlock, P. and M. Stower, *Fracture patterns in Nottingham children.* J Pediatr Orthop, 1986. **6**(6): p. 656-60.

3. Mann, D.C. and S. Rajmaira, *Distribution of physeal and nonphyseal fractures in 2,650 long-bone fractures in children aged 0-16 years.* J Pediatr Orthop, 1990. **10**(6): p. 713-6.

4. Mizuta, T., et al., *Statistical analysis of the incidence of physeal injuries.* J Pediatr Orthop, 1987. **7**(5): p. 518-23.

5. Bailey, D.A., et al., *Epidemiology of fractures of the distal end of the radius in children as associated with growth.* J Bone Joint Surg Am, 1989. **71**(8): p. 1225-31.

6. Tang, C.W., R.M. Kay, and D.L. Skaggs, *Growth arrest of the distal radius following a metaphyseal fracture: case report and review of the literature.* J Pediatr Orthop B, 2002. **11**(1): p. 89-92.

7. Foucher, J., *De la divulsion des epiphyses.* Cong Med France, 1863. **1**: p. 63-72.

8. Poland, J., *Traumatic Separation of the Epiphyses.* London, England: Smith, Elder & Co, 1898.

9. Salter, R. and W. Harris, *Injuries of the Epiphyseal Plate.* J Bone Joint Surg Am, 1963. **45**: p. 587-622.

10. Peterson, H.A., *Physeal fractures: Part 3. Classification.* J Pediatr Orthop, 1994. **14**(4): p. 439-48.

11. Davis, D.R. and D.P. Green, *Forearm fractures in children: pitfalls and complications.* Clin Orthop Relat Res, 1976(120): p. 172-83.

12. Herring, J.A., *Tachdijan's Pediatric Orthopaedics from the Texas Scottish Rite Hospital for Children, 5th ed.* 2014. **1-3**.

13. Tredwell, S.J., K. Van Peteghem, and M. Clough, *Pattern of forearm fractures in children.* J Pediatr Orthop, 1984. **4**(5): p. 604-8.

14. Imatani, J., et al., *The Galeazzi-equivalent lesion in children revisited.* J Hand Surg Br, 1996. **21**(4): p. 455-7.

15. Golz, R.J., et al., *Distal ulnar physeal injury.* J Pediatr Orthop, 1991. **11**(3): p. 318-26.

16. Nelson, O.A., J.R. Buchanan, and C.S. Harrison, *Distal ulnar growth arrest.* J Hand Surg Am, 1984. **9**(2): p. 164-70.

17. Aitken, A., *Further observations on the fractured distal radial epiphysis.* J Bone Joint Surg, 1935. **17**: p. 922-927.

18. Fodden, D.I., *A study of wrist injuries in children: the incidence of various injuries and of premature closure of the distal radial growth plate.* Arch Emerg Med, 1992. **9**(1): p. 9-13.

19. Lee, B.S., J.L. Esterhai, Jr., and M. Das, *Fracture of the distal radial epiphysis. Characteristics and surgical treatment of premature, post-traumatic epiphyseal closure.* Clin Orthop Relat Res, 1984(185): p. 90-6.

20. Waters, P.M., D.S. Bae, and K.D. Montgomery, *Surgical management of posttraumatic distal radial growth arrest in adolescents.* J Pediatr Orthop, 2002. **22**(6): p. 717-24.

21. Cannata, G., et al., *Physeal fractures of the distal radius and ulna: long-term prognosis.* J Orthop Trauma, 2003. **17**(3): p. 172-9; discussion 179-80.