

# Chapter 29:

## Pediatric Upper Extremity Disorders

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Pediatric upper extremity disorders include a variety of congenital and acquired conditions. These disorders require coordinated care by the upper extremity team in order to maximize the child's hand use and functional independence. Accurate diagnosis and adequate time for education is important and referrals to pediatric specialists and geneticists are appropriate in many cases of congenital conditions.

This chapter reviews a number of congenital and acquired pediatric upper extremity disorders. Realistic treatment goals are highlighted for each condition and techniques for nonoperative, operative, and postoperative management are detailed. Select classification schemes provide guidelines for nonoperative and operative management.

### General Guidelines for Therapy Evaluation

- I. History
- II. Physical Examination
  - a. Detailed active/passive range of motion (A/PROM) of entire upper extremity
  - b. Upper extremity manual muscle testing
  - c. Strength assessment: pinch and grip measurements<sup>1</sup>
  - d. Sensory evaluation
    - i. Threshold and two-point discrimination<sup>2</sup> for patients 6 years and older
    - ii. O'Riain wrinkle test<sup>3</sup> (immerse affected hand in warm water for 30 min; denervated skin will not shrivel)
    - iii. Stereognosis
  - e. Observation of prehensile patterns
- III. Functional Assessment
  - a. Developmental milestone achievement
  - b. Observation of upper extremity positioning during functional activities (e.g. compensatory patterns in perineal or hand to mouth activities)
  - c. Review of adaptive equipment/techniques incorporated into daily routine
  - d. Manual dexterity and coordination measures (i.e. Box and Block Test,<sup>4</sup> Nine-hole Peg Test,<sup>5</sup> Strength-dexterity Test<sup>6</sup>)
- IV. Client/Family Therapy Goals (e.g. Canadian Occupational Performance Measure<sup>7</sup>)

### Congenital Hand Differences

- I. Embryology/Genetics<sup>8,9</sup>
  - a. Commences with formation of the upper limb bud on lateral wall of the embryo 26 days after fertilization
  - b. Complete 8 weeks after fertilization
  - c. Thickened layer of ectoderm condenses over limb bud (apical ectodermal ridge (AER), acts as signaling center to guide underlying mesoderm to differentiate into appropriate structures

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- d. Lateral plate mesoderm (destined to become bone, cartilage and tendon) and somatic mesoderm (muscle, nerve and vasculature) grow out from the embryo under the AER
- e. AER responsible for proximal to distal growth
- f. Role of clinical geneticist expanding and genetic testing for limb malformations is gradually increasing. Currently only a small number of limb anomalies have been mapped to specific chromosomal segments. Mutations may affect a single gene, multiple genes, or entire chromosomes.

### II. Classification

- a. Most widely accepted classification of congenital limb anomalies based on embryonic failure during development and relies upon clinical diagnosis for categorization (Table 1)

### III. Failure of Formation - Transverse Deficiencies

- a. Also called congenital amputation, transverse deficiency is termed according to the anatomical level of limb termination. The most common site of amputation occurs at the proximal third of forearm (short below-the-elbow). Rudimentary digits can be located on the end of the residual limb. (Fig. 1)
- b. Loss of the AER leads to limb truncation
- c. Vascular insult during limb development is the most prevalent explanation for these deficiencies
  - i. Misoprostol (Cytotec, Searle, Brasil) to induce uterine contractions and vaginal bleeding with potential for termination of pregnancy. May induce vascular disruption to the developing embryo without abortion □ terminal transverse limb defects.
  - ii. Early chorionic villus sampling and failed attempts at pregnancy termination by dilatation and curettage □ transverse limb defects
- d. Nonoperative treatment
  - i. Assessment
    - 1. A/PROM
    - 2. Upper extremity manual muscle testing (observation of overall strength for infants and young children)
    - 3. Achievement of developmental milestones
  - ii. Prosthetic fitting
    - 1. Passive prosthesis: fit around 6-9 months, once independent sitting achieved; provides equal limb length for gross motor activity and introduces socket wear
    - 2. Active body powered prosthesis: fit around 18-24 months; components vary by level of amputation, typically start with voluntary opening hand; provides functional assist for bimanual activities in unilateral amputees
    - 3. Myoelectric prosthesis: fit around 3-5 years, although some proponents fit at 18-24 months with a single site myoelectric (“Cookie Crusher” system). Single site includes control over opening by contraction of the control

## Chapter 29 Figures

Classification	Subheading	Subgroup	Category
I. Failure of formation	A. Transverse arrest	1. Shoulder 2. Arm 3. Elbow 4. Forearm 5. Wrist 6. Carpal 7. Metacarpal 8. Phalanx	
	B. Longitudinal arrest	1. Radial deficiency 2. Ulnar deficiency 3. Central deficiency 4. Intersegmental	Phocomelia
II. Failure of differentiation	A. Soft tissue	1. Disseminated 2. Shoulder 3. Elbow & forearm 4. Wrist & hand	a. Arthrogyposis  a. Cutaneous syndactyly b. Camptodactyly c. Thumb-in-palm d. Deviated/deformed digits
	B. Skeletal	1. Shoulder 2. Elbow 3. Forearm  4. Wrist & hand	Synostosis a. Proximal b. Distal  a. Osseous syndactyly b. Carpal bone synostosis c. Symphalangia d. Clinodactyly
	C. Tumerous conditions	1. Hemangiomatic 2. Lymphatic 3. Neurogenic 4. Connective tissue 5. Skeletal	

**Table 1. Embryologic classification of congenital anomalies.<sup>42</sup>**

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Classification	Subheading	Subgroup	Category
III. Duplication	A. Whole limb	1. Mirror hand	
	B. Humeral		
	C. Radial	1. Polydactyly	a. Radial (preaxial) b. Central c. Ulnar (postaxial)
	D. Ulnar		
IV. Overgrowth	E. Digit	1. Macrodactyly	
	A. Whole limb		
	B. Partial limb		
	C. Digit		
V. Undergrowth	A. Whole limb	1. Brachysyndactyly 2. Brachydactyly	
	B. Whole hand		
	C. Metacarpal		
	D. Digit		
VI. Constriction band syndrome			
VII. Generalized skeletal abnormalities			

**Table 1. Embryologic classification of congenital anomalies.**<sup>42</sup> (continued)

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muscle and closing achieved automatically upon relaxation of the muscle. Dual site myoelectrics typically introduced at 5 years.

4. For children with congenital one side below elbow transverse deficiency, recent multicenter study found few differences in function and quality of life between prosthesis wearers and non-wearers- prosthesis is a tool<sup>10</sup>
  - e. Operative management
    - i. Surgery typically not indicated except in instances where bony spicule or rudimentary nubbins irritate residual limb. Excision of bone or removal of nubbins can alleviate problem. Use of limb lengthening for transverse deficiencies is controversial.
  - f. Postoperative management
    - i. Minimal needs following bony spicule or nubbin removal; may include scar management and desensitization in preparation for prosthetic fitting
  - g. Outcomes
    - i. Children with below elbow deficiency function well with or without a prosthesis. More distal the amputation, less need for prosthesis. Individuals with proximal deficiencies have increased reliance on a prosthesis for daily function, as a result are more frequently prosthesis wearers.
- IV. Failure of Formation - Phocomelia
- a. Phocomelia is considered an intercalary or intersegmental deficiency and there is a high association with thalidomide use during the first trimester. The absent segment is variable, but includes a portion of the limb between the shoulder and the hand. (Fig. 2) In profound cases, the hand appears to be emanating from the glenohumeral joint.
  - b. Treatment
    - i. Few indications for surgery
    - ii. Prosthetic fitting – challenging, but can be helpful
    - iii. Adaptive techniques – vary by child but often involve use of lower extremities for hand to mouth and other self-care activities including perineal care
- V. Failure of Formation - Radial Deficiency
- a. Radial deficiency involves a total or partial absence of the preaxial or radial border of the upper extremity (Fig. 3). Removal of a portion of the AER in chick embryos has produced anomalies similar to radial deficiency. The extent of deformity is related to the degree and extent of the AER absence. The majority of cases are sporadic, although exposure to teratogens can yield radial deficiencies. Radial deficiency is bilateral in 50% of cases and is slightly more common in males than females (3:2). Incidence within same family is small (5-10% of reported cases), more common in radial deficiency associated with cardiac abnormalities.
  - b. Associated syndromes
    - i. Holt-Oram Syndrome (cardiac septal defects)

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- ii. TAR (thrombocytopenia absent radius syndrome)
  - iii. Fanconi's anemia (aplastic anemia, not present at birth, develops at about 6 years of age, fatal without bone marrow transplantation; chromosomal challenge test available for early diagnosis)
  - iv. VACTERL (vertebral abnormalities, anal atresia, cardiac abnormalities, tracheoesophageal fistula, esophageal atresia, renal defects, radial dysplasia, lower limb abnormalities)
- c. Anomalies
- i. Bone
    1. Scapula is often reduced in size and the clavicle shorter with an increased curvature
    2. Humerus may or may not be shorter than expected with deficiencies of the capitellum and trochlea common. Elbow motion is usually diminished more in flexion than extension.
    3. Forearm is always decreased in length as the ulna is approximately 60% of the normal length at birth and this discrepancy persists throughout the growth period. The ulna is thickened and frequently bowed toward the absent radius with an apex posterior direction.
    4. Forearm rotation is absent in partial or complete aplasia of the radius
    5. Articulation between carpus and ulna not a normal joint
    6. Carpal bones are delayed in ossification with the scaphoid and trapezium often absent or hypoplastic.
  - ii. Nerve
    1. Ulnar nerve is normal
    2. Radial nerve usually terminates at the elbow
    3. Enlarged median nerve substitutes with a large dorsal branch for sensation to the radial aspect of the hand. It is positioned in the fold between the wrist and forearm and in jeopardy during surgical incision along the radial aspect of the limb.
  - iii. Tendon
    1. Deltoid or pectoralis major muscle can be hypoplastic, partially absent, or have abnormal insertion
    2. Biceps may be absent or fused to the underlying brachialis muscle
    3. Forearm demonstrates severe abnormalities
      - a. Muscles that originate or attach to the radius, such as the pronator teres, flexor carpi radialis, palmaris longus, flexor pollicis longus, pronator quadrates, and supinator abnormal or absent
      - b. Radial wrist extensors (extensor carpi radialis longus and brevis) are frequently absent or fused

## Chapter 29 Figures



**Fig. 1. Short congenital below elbow transverse deficiency with nubbins present along distal residual limb.**  
(Courtesy of Shriners Hospital for Children, Philadelphia)



**Fig. 2. Three-year-old female with phocomelia of left upper extremity.**  
(Courtesy of Shriners Hospital for Children, Philadelphia)



**Fig. 3. Young male with bilateral radial deficiency and bilateral hypoplastic thumbs demonstrating expanded webspace between index and long digits.**  
(Courtesy of Shriners Hospital for Children, Philadelphia)



**Fig. 4. Pouce flottant.**  
(Courtesy of Shriners Hospital for Children, Philadelphia)

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- c. Extrinsic flexors and extensors of the fingers are usually anomalous with abnormal origins and insertions
      - d. Flexor and extensor carpi ulnaris, as well as the interossei, lumbricales, and hypothenar muscles are often normal
    - iv. Artery
      - 1. Normal brachial and ulnar artery
      - 2. Radial artery often absent
      - 3. Interosseous arteries well developed
  - d. Classification of thumb deficiency – (Table 2)
    - i. Minor deficiency with minimal shortening
    - ii. Moderate deficiency
      - 1. 1<sup>st</sup> web space contracture
      - 2. MP instability
      - 3. Thenar hypoplasia
    - iii. Severe deficiency
      - 1. Type II plus extrinsic abnormalities
      - 2. 2<sup>nd</sup> metacarpal deficiency
        - a. IIIA □ CMC stable
        - b. IIIB □ CMC unstable
    - iv. Pouce flottant (Fig. 4)
      - 1. Rudimentary bony elements
      - 2. Narrow skin pedicle
    - v. Complete absence
  - e. Treatment paradigm<sup>11</sup>
    - i. Type I □ usually unnecessary
    - ii. Type II □ opponensplasty/first web release/UCL reconstruction
    - iii. Type IIIA □ reconstruction
    - iv. Type IIIB □ pollicization
    - v. Type IV □ pollicization
    - vi. Type V □ pollicization
  - f. Reconstruction options<sup>12</sup>
    - i. Adduction posture of thumb □ web space deepening and reconstruction by z-plasty or dorsal transposition flap (Fig. 5A)
    - ii. MCP joint instability involves the ulnar side □ ulnar collateral ligament reconstruction (Fig. 5B)
    - iii. Thenar hypoplasia □ abductor digit quinti or flexor digitorum superficialis (FDS) opponensplasty (Fig. 5C and Fig. 5D)
    - iv. Extrinsic musculotendonous abnormalities of EPL and/or FPL tendons – tendon transfer as appropriate
    - v. Pollicization
  - g. Pollicization principles (Fig. 6)
    - i. Neurovascular pedicle
      - 1. Long finger radial proper suture ligated
      - 2. Bipedicule transfer index to thumb position

## Chapter 29 Figures



**Fig. 5A. Z-plasty of thumb webspace.**  
(Courtesy of Shriners Hospital for Children, Philadelphia)



**Fig. 5B. Flexor digitorum superficialis opponensplasty.**  
(Courtesy of Shriners Hospital for Children, Philadelphia)



**Fig. 5C. Ulnar collateral ligament reconstruction.**  
(Courtesy of Shriners Hospital for Children, Philadelphia)



**Fig. 5D. Typical appearance of closed incisions following z-plasty, flexor digitorum superficialis from the long digit, and ulnar collateral ligament reconstruction with pinning of thumb MCP joint.**  
(Courtesy of Shriners Hospital for Children, Philadelphia)

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3. Nerve dissection
- ii. Bone and joint reorganization
  1. DIP joint □ IP joint
  2. PIP joint □ MP joint
  3. MP joint □ CMC joint
  4. Metacarpal □ trapezium
- iii. Muscle reorganization
  1. 1<sup>st</sup> palmar interosseous □ adductor pollicis
  2. 1<sup>st</sup> dorsal interosseous □ abductor pollicis brevis
  3. Extensor indicis □ extensor pollicis longus
  4. Extensor communis □ abductor pollicis longus
- h. Postoperative treatment - thumb reconstruction
  - i. Postoperative indications: types I-III A thumb hypoplasia necessitating surgical intervention
  - ii. Postoperative precautions
    1. Ulnar collateral ligament (UCL) repair: avoid PROM thumb palmar or radial abduction for 12 weeks after surgery
    2. Opponensplasty: avoid PROM radial abduction or thumb extension for 12 weeks after surgery; avoid resistive activities until 8 weeks after surgery
  - iii. Postoperative therapy
    1. Z-plasty and skin flap: cast for 3-4 weeks, followed by whirlpool, wound care, and dressings until incisions are healed
    2. UCL repair
      - a. Cast 4 weeks, followed by orthosis for protection
      - b. Wean from daytime orthosis at 6-8 weeks after surgery
      - c. Continue orthosis at night until 12 weeks after surgery
      - d. Initiate AROM for light play activities following cast removal
    3. Opponensplasty
      - a. Cast for 3-4 weeks, followed by protective orthosis
      - b. Wean from daytime orthosis at 6-8 weeks after surgery
      - c. Continue orthosis at night until 12 weeks after surgery
      - d. AROM of tendon transfer and place-hold exercises
        - i. For FDS opponensplasty, complete isolated FDS glide with ring finger to obtain small objects (e.g. crayon, clay)
        - ii. Avoid use of compensatory thumb flexion during opposition exercises
  - iv. Postoperative complications
    1. Decreased AROM/PROM of thumb

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2. Scar contracture
- i. Postoperative treatment - pollicization
  - i. Postoperative indications: types IIIB to V thumb hypoplasia necessitating surgical intervention
  - ii. Postoperative precautions
    1. Avoid PROM thumb CMC joint for 12 weeks following surgery
    2. Avoid extreme A/PROM thumb extension/flexion for 12 weeks after surgery
    3. Avoid resistive activities for 12 weeks after surgery
  - iii. Postoperative therapy
    1. Orthosis
      - a. Immobilize in long arm cast 4 to 6 weeks
      - b. Thumb spica orthosis
        - i. Wean from day use between weeks 6 to 7
        - ii. Continue at night until 12 weeks after surgery
        - iii. Taping: in medial direction, wrap self-adherent tape around thumb CMC joint three times, then wrap tape around wrist three times in medial direction to position thumb into palmar abduction for enhanced tip-to-tip pinch
        - iv. Buddy taping: tape long and ring fingers together to decrease scissor grasp
      - c. A/PROM of thumb IP and MCP joints
      - d. Play activities to promote thumb opposition for objects of various sizes and shapes
- j. Results and complications after pollicization<sup>13,14,15</sup>
  - i. Neurovascular problems
  - ii. Stiffness
  - iii. Decreased motors (tendon transfer augmentation may further improve function)
  - iv. Results related to index finger function prior to pollicization
- k. Classification of radial deficiency – (Table 3)
  - i. Slight shortening
  - ii. Miniature radius
  - iii. Portion of radius missing, usually distal 1/3 to 1/2
  - iv. Absent
- l. Treatment goals
  - i. Correct the radial deviation of the wrist
  - ii. Balance the wrist on the forearm
  - iii. Maintain wrist and finger motion
  - iv. Promote growth of the forearm
  - v. Improve the function of the extremity
- m. Treatment paradigm

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- i. Early and frequent stretching
  - ii. Orthosis in corrected position
  - iii. Surgery at approximately 1 year of age
  - iv. Therapy to maximize function via adaptive techniques
- n. Centralization indications/contraindications
  - i. Elbow motion - lack of elbow motion necessitates radial deviation for hand to mouth activity
  - ii. Systemic conditions (e.g., untreated Fanconi Anemia)
  - iii. Age – surgery may not be appropriate in older child who has functionally compensated for deficiency
- o. Centralization principles (Fig. 7)
  - i. Release tight radial structures to allow centralization
  - ii. Carpal realignment over ulna
  - iii. Tendon balance
  - iv. Ulnar osteotomy (if greater than 30 degrees)
- p. Results and complications after centralization
  - i. Recurrence common<sup>16</sup>
  - ii. Stiffness
  - iii. Functional impact remains unclear
- q. Advances in treatment
  - i. Soft tissue lengthening<sup>17,18</sup>
  - ii. Bone lengthening<sup>19</sup>
  - iii. Lengthening may need to be done multiple times until skeletal maturity, despite high complication rates remains appealing as hand use can be improved if near normal arm length achieved; therapy focuses on preserving A/PROM and ongoing orthosis
- r. Nonoperative management – radial deficiency
  - i. Indications
    - 1. Radial deviation posturing of wrist
    - 2. Potential coinciding UE limitations in ROM, strength, and joint stability
    - 3. Functional limitations – may be present with increased severity of anomaly or bilateral involvement
  - ii. Precautions
    - 1. Presence of concomitant systemic conditions necessitating priority of medical attention
    - 2. Skin integrity
      - a. age related factors
      - b. presence of pterygium - careful monitoring of webbed region is essential, treatment may be negatively affected by underlying abnormal blood vessels, nerves and muscular abnormalities
  - iii. Therapy
    - 1. A/PROM
    - 2. Orthoses
      - a. Considerations:

## Chapter 29 Figures

Type	Findings	Treatment
I	Minor generalized hypoplasia	Augmentation
II	Absence of intrinsic thenar muscles  First web space narrowing Ulnar collateral ligament (UCL) insufficiency	Opponensplasty First-web release UCL reconstruction
III	Similar findings as type II plus: Extrinsic muscle & tendon abnormalities Skeletal deficiency A: Stable carpometacarpal joint B: Unstable carpometacarpal joint	A: Reconstruction B: Pollicization
IV	“Pouce flottant” or floating thumb	Pollicization
V	Absence	Pollicization

**Table 2. Thumb deficiency classification.<sup>11</sup>**

Type	Thumb anomaly	Carpal anomaly*	Distal radius	Proximal radius
N	Absent or hypoplasia	Normal	Normal	Normal
0	Absent or hypoplasia	Absence, hypoplasia, or coalition	Normal	Normal, radioulnar synostosis, or radial head dislocation
1	Absent or hypoplasia	Absence, hypoplasia, or coalition	> 2mm shorter than ulna	Normal, radioulnar synostosis, or radial head dislocation
2	Absent or hypoplasia	Absence, hypoplasia, or coalition	Hypoplasia	Hypoplasia
3	Absent or hypoplasia	Absence, hypoplasia, or coalition	Physis absent	Variable hypoplasia
4	Absent or hypoplasia	Absence, hypoplasia, or coalition	Absent	Absent

**Table 3. Global classification of radial longitudinal deficiency.<sup>43</sup>**

- \*Carpal anomaly implies hypoplasia, coalition, absence or bipartite carpal bones. Hypoplasia and absence are more common on the radial side of the carpus and coalitions more frequent on the ulnar side.
- X-rays must be of children older than 8 years to allow for ossification of the carpal bones.

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- i. Increased prominence of ulnar styloid requires soft tissue protection
    - b. Daytime: radial gutter style wrist support to minimize radial deviation and flexor posturing
    - c. Nighttime:
      - i. Resting hand orthosis – goal to minimize interphalangeal (IP) flexion contractures and/or radial drift of digits
      - ii. Wrist support
      - iii. Elbow orthosis – goal to improve elbow flexion or extension contracture as appropriate
    - d. Note: for individuals with severe Type II through Type IV deficiency, orthosis is often accompanied by surgical intervention. For individuals with moderate to severe deficiency, wrist orthosis typically recommended to preserve alignment until skeletal maturity.
  3. Functional training to minimize radial deviation posturing
  - iv. Nonoperative complications
    1. Skin breakdown
    2. Decreased compliance with home exercises or orthosis
    3. Progressive functional deficits with age and growth of limb
- VI. Failure of Formation - Central Deficiency
  - a. Deficiencies of the second, third, and fourth rays (digits and underlying carpus) (Fig. 8)
  - b. A rare anomaly
  - c. Major difference centers between typical and atypical (a.k.a. severe symbrachydactyly) cleft hand, which may segregate them into different categories of embryologic malformation
  - d. Treatment
    - i. Typical cleft
      1. Functional triumph, social disaster
      2. Address syndactyly
      3. Cleft closure at 18 months to 2 years of age
        - a. Avoid scar in commissure
        - b. Intermetacarpal ligament reconstruction technique variable, but critical to outcome
    - ii. Atypical or symbrachydactyly
      1. Individualize treatment
      2. Obtain thumb and additional digit adequate for pinch
      3. Multiple techniques for reconstruction depending upon severity of difference and level of function
- VII. Failure of Formation - Ulnar Deficiency<sup>20</sup> (Fig. 9)
  - a. Total or partial absence of the postaxial or ulnar border of extremity
  - b. Less common

## Chapter 29 Figures



**Fig. 6. Index finger pollicization.**  
(Courtesy of Shriners Hospital for Children, Philadelphia)



**Fig. 7. Centralization via an ulnar approach.**  
(Courtesy of Shriners Hospital for Children, Philadelphia)



**Fig. 8. Eight-month-old male with bilateral cleft hands.**  
(Courtesy of Shriners Hospital for Children, Philadelphia)



**Fig. 9. Six-year-old male with left ulnar deficiency.**  
(Courtesy of Shriners Hospital for Children, Philadelphia)

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- c. Classification<sup>21</sup> – (Table 4)
- d. Often associated with anatomy of the first web space
  - i. Type A is a normal first web space and thumb, although forearm deformities are still prevalent
  - ii. Type B is mild first web deficiency and mild thumb hypoplasia
  - iii. Type C is moderate to severe first web deficiency and thumb hypoplasia defined as diminished motion, malrotation, and absent motors
  - iv. Type D is extreme manifestation with complete absence of the thumb
  - v. Does not correlate with severity of forearm and elbow anomalies
- e. Treatment
  - i. Depends upon degree of hypoplasia and progression of deformity
  - ii. Most forearms do not require surgery, hand surgery is common
  - iii. Presence of ulna anlage in types II and IV may lead to continued ulnar deviation (progressive deformity warrants resection)
  - iv. No treatment to restore elbow motion (synostosis) or forearm integrity
  - v. Consider corrective osteotomy if elbow severely malpositioned (hand on flank deformity), although some spontaneous correction tends to occur over time
  - vi. One bone forearm restores stability, but sacrifices forearm motion
- VIII. Failure of Formation – Hypoplastic Hand and Digits (Fig. 10)
  - a. Hypoplasia accompanies many anomalies and syndromes (e.g., syndactyly)
  - b. Shortening of fingers most commonly affects middle phalanx
  - c. Short metacarpals not common. Short ring and small associated with pseudohypoparathyroidism or pseudopseudohypoparathyroidism.
  - d. Treatment
    - i. Depends upon degree of skeletal and soft tissue support
    - ii. Range from observation to digital reconstruction
      - 1. Digital lengthening
      - 2. On-top-plasty
      - 3. Web deepening
      - 4. Free tissue transfer
- IX. Failure of Differentiation – Synostosis Hand and Wrist
  - a. Can occur anywhere throughout limb
  - b. May be complete or incomplete
  - c. Carpus – lunotriquetral most common
  - d. Metacarpal synostosis (Fig. 11A and Fig. 11B)
    - i. Ring and small most common
    - ii. Small metacarpal often short and abducted
    - iii. Small finger abduction can be problematic
    - iv. Treat with release synostosis, lengthening, and angular correction
- X. Failure of Differentiation – Synostosis Elbow (Fig. 12)
  - a. Radioulnar synostosis

## Chapter 29 Figures

Type	Grade	Characteristics
0		Normal forearm, deficiencies in hand and carpus
I	Hypoplasia	Hypoplasia of the ulna with presence of distal and proximal ulnar epiphysis, minimal shortening
II	Partial aplasia	Partial aplasia with absence of the distal or middle one-third of the ulna
III	Complete aplasia	Total agenesis of the ulna
IV	Synostosis	Fusion of the radius to the humerus

**Table 4. Classification of ulnar deficiencies.<sup>21</sup>**

Pattern	Nerve Roots Involved	Primary Deficiency
Erb-Duchenne lesion Upper brachial plexus	C5 and C6	Shoulder abduction and external rotation Elbow flexion
Extended Erb's lesion Upper & middle plexus	C5 through C7	Above plus Elbow and finger extension
Dejerine-Klumpke lesion Lower brachial plexus	C8 and T1	Hand intrinsic muscles Finger flexors
Total or global lesion Entire brachial plexus	C5 through T1	Entire extremity

**Table 5. Patterns of Brachial Plexus Injuries.<sup>37</sup>**

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- i. Proximal and unilateral most common
    - ii. Often delay in diagnosis
    - iii. Treatment when extremely pronated or supinated
    - iv. Rotation osteotomy through synostosis
    - v. Therapy includes detailed preoperative assessment of patient goals
    - vi. Children greater than 10 years old  increased neurovascular problems
  - b. Radial head dislocation
    - i. May occur with synostosis
    - ii. Most common posterior, followed by anterior, and lateral
    - iii. Differentiate from traumatic
      - 1. No history trauma
      - 2. Bilateral
      - 3. Familial
      - 4. Ulnar positive
      - 5. Hypoplastic capitellum
      - 6. Convex radial head
    - iv. Examination
      - 1. Small loss flexion/extension
      - 2. 50% supination/pronation
    - v. Treatment controversial
      - 1. Observation is the rule!
      - 2. Early reduction and annular ligament reconstruction still evolving
- XI. Failure of Differentiation – Symphalangism (Fig. 13)
  - a. Hereditary stiffness of the interphalangeal joints (most common PIP)
  - b. Longitudinal synostosis
  - c. No active or passive motion
  - d. No skin or joint creases
  - e. X-rays often normal as infants, bony consolidation overtime
  - f. No successful treatment to restore motion
- XII. Failure of differentiation – Syndactyly<sup>22</sup> (Fig. 14A and Fig. 14B)
  - a. History and physical examination
    - i. Apert's syndrome (acrocephalosyndactyly)
    - ii. Poland's syndrome
    - iii. Constriction band syndrome
  - b. Classification
    - i. Incomplete versus complete
    - ii. Simple versus complex
    - iii. Complicated
  - c. Surgical principles
    - i. Simple syndactyly of any considerable degree warrants surgical reconstruction for improved appearance and function
  - d. Post-operative care
    - i. Minimal therapy needs – whirlpool/dressings if flap not fully healed/AROM

## Chapter 29 Figures



**Fig. 10. Brachydactyly of bilateral long, ring, and small metacarpals.**  
(Courtesy of Shriners Hospital for Children, Philadelphia)



**Fig. 11A. Clinical presentation of ring-small metacarpal synostosis.**  
(Courtesy of Shriners Hospital for Children, Philadelphia)



**Fig. 11B. Radiographic view of ring-small metacarpal synostosis.** (Courtesy of Shriners Hospital for Children, Philadelphia)



**Fig. 12. Five-year-old male with bilateral elbow synostosis.**  
(Courtesy of Shriners Hospital for Children, Philadelphia)

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- e. Complications
  - i. Skin graft
  - ii. Nail bed
  - iii. Web creep
  - iv. Stiffness
- XIII. Failure of Differentiation – Arthrogryposis
  - a. Congenital joint contractures, variable expression
  - b. Neurogenic form most common (90%) with anterior horn cell abnormality
  - c. Not progressive
  - d. Absent joint creases, waxy skin, little subcutaneous tissue
  - e. Upper extremity presentation – shoulder internal rotation, elbow extension, wrist flexion, finger flexion, stiff digits (Fig. 15)
  - f. Treatment
    - i. Multidisciplinary approach
    - ii. Early PROM beneficial
    - iii. Gain PROM through daily stretching regime/orthoses/serial casting
    - iv. Consider transfers for active motion, difficult to gauge donor strength
    - v. Lack of elbow flexion common and prohibits hand to mouth activity
      - 1. First goal is restoration of PROM elbow flexion; may consider surgical release via triceps lengthening and posterior capsule release if PROM regime fails
      - 2. Second goal is restoration of AROM elbow flexion via flexorplasty – procedure difficult, results less predictable in arthrogryposis compared with other diagnoses
    - vi. Wrist flexion posture can be corrected by closing wedge osteotomy or Ilizarov external fixator
    - vii. Therapy focus on A/PROM, orthoses, and adaptive techniques to maximize function
- XIV. Failure of Differentiation – Soft Tissue
  - a. Pterygium cubitale (Fig. 16)
    - i. Uncommon
    - ii. Can be associated with pterygium syndrome, radial deficiency, or other syndromes
    - iii. No treatment
  - b. Trigger digits<sup>23</sup> (Fig. 17)
    - i. Thumb most common
      - 1. Presents with fixed flexion deformity
      - 2. 30% of those noted at birth can resolve over time
      - 3. Release A1 pulley if no resolution
    - ii. Trigger digits less common
      - 1. Can involve A1 or A3 pulley
      - 2. Can be disparity between tendon and sheath
      - 3. Treatment
        - a. Exploration

## Chapter 29 Figures



**Fig. 13. Eighteen-year-old male with symphalangism of ring and small finger proximal interphalangeal joints, note the lack of skin creases.**  
(Courtesy of Shriners Hospital for Children, Philadelphia)



**Fig. 14A. Dorsal view of syndactyly.**  
(Courtesy of Shriners Hospital for Children, Philadelphia)



**Fig. 14B. Volar view of syndactyly.**  
(Courtesy of Shriners Hospital for Children, Philadelphia)



**Fig. 15. Nine-year-old female with arthrogryposis.**  
(Courtesy of Shriners Hospital for Children, Philadelphia)

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- b. A1 release
- c. Check A3 if persistent triggering
- d. Excise single FDS slip
- XV. Failure of Differentiation – Hypoplastic Thumb – see radial deficiency
- XVI. Failure of Differentiation – Skeletal
  - a. Clinodactyly (Fig. 18)
    - i. Deviation in radioulnar plane
    - ii. Small finger most commonly affected
    - iii. Treatment
      - 1. Observation for mild deformity
      - 2. Osteotomy for severe angulation
  - b. Kirner’s deformity
  - c. Delta phalanx
    - i. Abnormal physis that extends longitudinal (a.k.a longitudinal epiphyseal bracket)
    - ii. Can lead to progressive angulation
    - iii. May require surgical intervention
  - d. Minimal therapy needs
- XVII. Duplication – minimal therapy needs
- XVIII. Macrodactyly (Fig. 19)
  - a. Uncommon in occurrence, but dramatic in presentation
  - b. Underlying etiologies for limb overgrowth (e.g. vascular abnormalities or malformations) must be considered during patient evaluation
  - c. Can be a constituent of a variety of syndromes (e.g. neurofibromatosis or Klippel-Trenaunay-Weber)
  - d. Minimal therapy needs
- XIX. Congenital Constriction Bands (Fig. 20)
  - a. Not hereditary and cause remains controversial
    - i. Intrinsic (localized lack of mesodermal development) and extrinsic theories (amniotic membrane traps the developing hand or an amniotic band encircles the affected part)
    - ii. Extrinsic hypothesis is favored as amnion has been found in the constriction rings
  - b. Extremity normal proximal to band
  - c. Degree of constriction dictates clinical pictures, ranges from mild bands to complete amputations
  - d. Treatment
    - i. Release of bands (z-plasty)
    - ii. Correction of pseudosyndactyly
      - 1. Intrauterine release - Uncommonly diagnosed
      - 2. Associated with 10% loss of embryo
      - 3. Risk/ benefit ratio

### Pediatric Upper Extremity Fractures

- I. Introduction
  - a. Fractures of upper extremity extremely common in children

## Chapter 29 Figures



**Fig. 16. Pterygium cubitale in a four-year-old female.** (Courtesy of Shriners Hospital for Children, Philadelphia)



**Fig. 17. Clinical presentation of trigger thumb.** (Courtesy of Shriners Hospital for Children, Philadelphia)



**Fig. 18. Clinodactyly in multiple digits.** (Courtesy of Shriners Hospital for Children, Philadelphia)



**Fig. 19. Macroductyly of the left long digit.** (Courtesy of Shriners Hospital for Children, Philadelphia)

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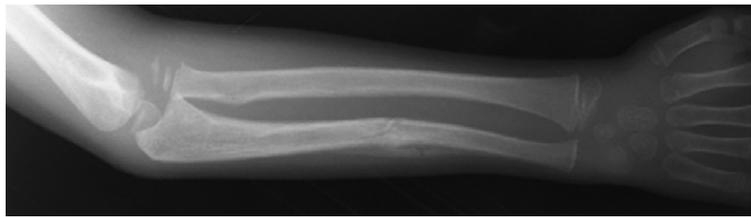
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- b. Children incur physeal injuries, unicortical (greenstick or buckle) fractures, and plastic deformation, in addition to the types of injuries that also occur in adults
  - c. Avulsion fractures common – due to more robust nature of children’s ligaments and tendons than bone
  - d. Increased capability of remodeling potential in pediatrics but influencing factors include amount of growth remaining at nearest physis, proximity of injury to physis, and plane of motion of nearest joint.
  - e. Treatment approach based on remodeling potential, a comparison of the risks of closed, percutaneous, and open management, and the likelihood that long-term disability will result from a nonanatomic reduction
- II. Monteggia Fracture-Dislocations<sup>24,25</sup> (Fig. 21)
- a. Assessment
    - i. An isolated ulnar shaft fracture results in dislocation of the radiocapitellar joint if there is sufficient angulation and/or shortening at the ulna
    - ii. Although anterior dislocation is most common, lateral dislocation may be more common in children than in adults and is difficult to see on lateral radiographs alone
    - iii. The pediatric variants of the adult Monteggia fracture include greenstick fracture and plastic deformation
    - iv. All fractures of the ulna should be evaluated for radial head subluxation-dislocation, no matter how minimally displaced they appear to be on initial radiographs
    - v. The physical examination should include a neurovascular and compartment assessment
  - b. Treatment
    - i. Closed reduction and casting has been recommended for an incomplete fracture or plastic deformation; intramedullary fixation, for a transverse or short oblique fracture; and plate-and-screw fixation, for a comminuted or long oblique fracture
    - ii. In older children with minimal remodeling potential, plate-and-screw fixation is preferred
  - c. Complications
    - i. Persistent radial head dislocation can lead to elbow instability with loss of motion, pain, and late onset ulnar nerve palsies
    - ii. Early intervention is recommended if there is an impending or recent malunion of the ulna
    - iii. Caution with circumferential casting particularly for a higher energy fracture - cumulative edema and soft-tissue injury can lead to compartment syndrome
      - 1. Splitting the cast and maintaining elbow flexion at less than 90° can reduce the risk
      - 2. Close monitoring during the first 1 to 2 days
      - 3. Serial radiographs at one and two weeks post to ensure that reduction maintained as edema subsides

## Chapter 29 Figures



**Fig. 20. Congenital constriction bands in an infant.**  
(Courtesy of Shriners Hospital for Children, Philadelphia)



**Fig. 21. Radiographic view of Monteggia fracture.**  
(Courtesy of Shriners Hospital for Children, Philadelphia)



**Fig. 22A. Radiographic view of both bone forearm fracture.**  
(Courtesy of Shriners Hospital for Children, Philadelphia)



**Fig. 22B. Radiographic view of both bone forearm fracture following intramedullary rod fixation.** (Courtesy of Shriners Hospital for Children, Philadelphia)

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4. Indications for surgery: loss of reduction, irreducibility of the fracture-dislocation, and questionable patient or family compliance

### III. Diaphyseal Forearm Fractures (Fig. 22A)

- a. Assessment
  - i. Rotational injuries most common
  - ii. Symptoms range from mild pain and loss of forearm rotation with plastic deformation to severe pain and deformity with a complete fracture
  - iii. Neurovascular injuries and open fractures rare
  - iv. Younger the child, greater the deformity can be accepted
- b. Treatment
  - i. Treatment algorithm influenced by social aspects including child's compliance, activity level, and caretaker support
  - ii. In children younger than 8 years, most fractures can be treated with closed reduction and casting
  - iii. Plastic deformation of more than 20° is likely to limit forearm rotation and typically requires closed reduction
  - iv. Any fracture that limits functional forearm rotation should be reduced regardless of its strict angular measurement<sup>26</sup>
  - v. Rotational deformities of as much as 30° are well tolerated because of compensatory rotation at the wrist, but they do not remodel over time
  - vi. Indications for intramedullary or rigid fixation in a young child include the presence of an open, irreducible, or segmental fracture; a floating elbow injury; loss of reduction; and an evolving neurovascular injury
  - vii. The current trend favors intramedullary fixation unless the fracture is open, segmental, or comminuted; there is neurovascular injury requiring exploration and repair; or the child is within 1 year of skeletal maturity (Fig. 22B)
  - viii. The closer the child is to skeletal maturity, the greater the need is for an anatomic reduction with rigid fixation
  - ix. In older children, fixation is recommended for any fracture that limits functional forearm rotation or has more than 10° of angulation
- c. Complications<sup>27</sup>
  - i. Nonunions rare, malunions with persistent loss of forearm motion are more common
  - ii. Corrective osteotomy of one or both forearm fractures within 1 year of the original fracture can dramatically improve forearm rotation<sup>28</sup>
  - iii. After the first year, recovery of forearm rotation is less predictable because of secondary soft-tissue contractures
  - iv. Radioulnar synostosis rare but challenging complication; difficult to treat
  - v. Refracturing can occur at any time but is most likely soon after removal of the cast or hardware<sup>29</sup>
  - vi. The incidence may be as high as 5%, and it is inversely proportional to the length of time the cast was used

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- vii. Activity modification and orthosis for as long as 2 months after union may limit the risk, but no firm guidelines exist
- viii. Compartment syndrome is the most worrisome complication
  1. common signs of pain, paresthesias, pulselessness, and pallor typically not encountered until irreversible injury has occurred
  2. increased analgesia, agitation, and anxiety are the warning signs/ symptoms of a compartment syndrome in children
  3. Increasing analgesic needs after cast placement, pain with motion or unwillingness to actively move the digits, and worsening digital edema should prompt bivalving and removal of the anterior shell of the cast to examine the compartments
  4. Release of the entire flexor compartment can restore some muscle function if viable muscle persists, and a neurolysis may allow for some nerve recovery, tendon transfers may be required to augment function

### IV. Distal Radius and Ulna Fractures

- a. Assessment
  - i. Fractures of the distal end of the radius,<sup>30</sup> with or without a distal ulna fracture, are among the most common pediatric injuries - typical mechanism is fall on outstretched hand (e.g. from bicycle, bunk bed, or scooter)
  - ii. Children tend to tolerate these injuries, especially if the fracture is minimally displaced or incomplete, and therefore delays in seeking treatment are common
- b. Treatment
  - i. In young children, all but the most severely displaced and angulated fractures can remodel because of the proximity of the fracture to the distal ulnar and radial physes
  - ii. Buckle fractures and plastic deformation are inherently stable, and respond well to 3 weeks in a removable orthosis
  - iii. Most bicortical or greenstick fractures can be reduced and casted. Recent studies indicate that a well-molded short arm cast is just as effective as a long arm cast<sup>31,32</sup>
- c. Complications
  - i. Unlike distal radial physeal fractures, distal ulnar physeal fractures carry a high risk growth disturbance
  - ii. Physeal arrest occurs after almost 5% of distal radial physeal injuries and in 50% of distal ulnar physeal injuries<sup>33,34</sup>
  - iii. Child who is near skeletal maturity and has minimal deformity should undergo radial and ulnar epiphysiodesis
  - iv. Corrective osteotomies, selective epiphysiodesis, and lengthening or shortening procedures are other treatment options<sup>35</sup>

### V. Scaphoid Fractures

- a. Assessment

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- i. Because the scaphoid does not begin to ossify until age 5 years, a fracture that occurs in a child younger than 7 years is difficult to diagnose; fortunately, these fractures are rare.
  - b. Treatment
    - i. Immobilize suspected fracture (forearm-based thumb spica orthosis or cast)
    - ii. Repeat radiographs should be taken if snuff box tenderness persists after 2 weeks. If radiographs inconclusive, the immobilization can be continued until pain is resolved or the fracture can be seen on radiographs or advanced imaging studies, such as MRI.
    - iii. Two treatments options are available for a nondisplaced fracture: a long arm thumb spica cast for the first 6 weeks, followed by a short arm thumb spica cast until fracture healing; or percutaneous compression screw fixation and a removable orthosis- two modalities are similar in efficacy and risk.
  - c. Complications
    - i. Nonunion of appropriately treated fracture rare in children
    - ii. Most nonunions are result of delay in diagnosis or late presentation
- VI. Hand Fractures<sup>36</sup>
  - a. Assessment
    - i. Most hand fractures in children occur as a result of crush injury or torsional and axial load
    - ii. Phalangeal fractures common with small finger ray most at risk
    - iii. Children have ligament avulsion fractures, transphyseal injuries, plastic deformation, buckle fractures, and greenstick fractures, in addition to the types of fractures seen in adults – obtain radiograph of area in question not just entire hand or may miss a finding
  - b. Treatment
    - i. Immobilization until union typically sufficient via casting, orthosis, or buddy strapping
    - ii. Metacarpal fractures and proximal and distal phalangeal fractures generally heal within 3 to 4 weeks, although the middle phalanx may require 4 to 5 weeks
    - iii. Reduction or percutaneous pinning for more involved cases
    - iv. Surgery is indicated for an open fracture or an unstable fracture that cannot be reduced or held within an acceptable angulation of less than 30° by closed means
      - v. In children who are near skeletal maturity, an apex dorsal deformity of the thumb metacarpal should not be accepted because it can predispose the child to basal joint arthritis later in life
    - vi. Treat tendinous avulsion injuries acutely via immobilization and/or surgery as may lead to long term deformity
    - vii. Extensor mechanism avulsions such as central slip insertion and mallet fracture rarely retract, and most can be treated acutely with extension orthoses at the proximal and distal interphalangeal joints, respectively

## Chapter 29 Figures



**Fig. 23. Five-month-old male with brachial plexus palsy affecting the right upper trunk.** (Courtesy of Shriners Hospital for Children, Philadelphia)



**Fig. 24. Infant with global brachial plexus palsy and Horner's syndrome of the left eye.** (Courtesy of Shriners Hospital for Children, Philadelphia)

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- viii. A mallet fracture often is a Salter-Harris type III fracture - successful management includes closed reduction and continuous wearing of orthosis for at least 6 weeks
- c. Complications
  - i. An untreated Seymour fracture (epiphyseal fracture of the distal phalanx) can lead to chronic osteomyelitis, permanent nail deformity, and gross fingertip angulation
  - ii. Phalangeal neck fracture malunion leads to loss of proximal or distal interphalangeal joint motion
  - iii. Ligament avulsion injury can lead to chronic instability requiring ligament repair or reconstruction or joint fusion
  - iv. Unrecognized extensor mechanism tendinous avulsion injury can lead to a swan neck or boutonnière deformity requiring surgical reconstruction
  - v. Malrotation in the phalanges and metacarpals does not remodel and requires osteotomy for correction
  - vi. The complications of surgical management include pin site infection, neurovascular injury, and loss of reduction that creates the need for further surgery – the risks of surgery should be weighed against the risks of malunion and nonunion

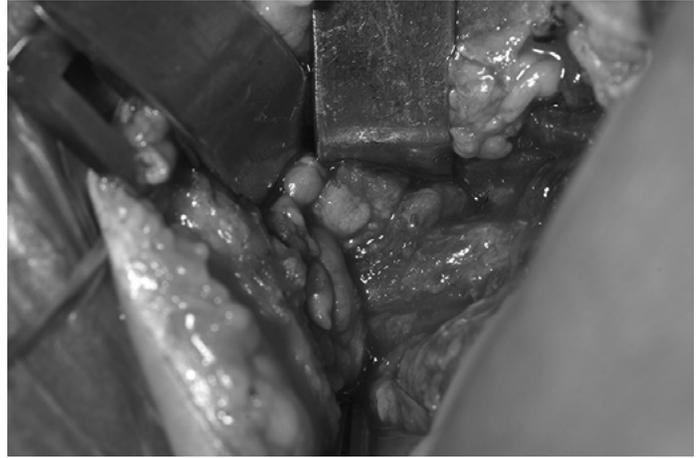
### Considerations for Tendon and Nerve Repairs and Transfers in Children

- I. General Considerations
  - a. Consider child/family compliance prior to surgical intervention
  - b. Small size of tendons necessitates longer immobilization
  - c. Use of blocking orthoses to allow motion but block restrictions
  - d. Incorporate play activities to complete therapeutic exercises
- II. Neonatal Brachial Plexus Injuries<sup>37</sup>
  - a. Incidence is 1 to 2 per 1000 live births
  - b. Risk factors – fetal macrosomia, prolonged or difficult labor, shoulder dystocia, breech presentation, forceful extraction with aid of forceps or vacuum, uterine anomalies, and previous child with brachial plexus injury
  - c. Caesarian delivery decreases chances but does not eliminate risk of brachial plexus injury
  - d. Assessment
    - i. Right side more common than left
    - ii. Upper trunk injury most common (Erb's palsy, C5-C6) (Fig. 23)
    - iii. Extended upper plexus lesion involves C5, C6, C7
    - iv. Global plexus lesion involves C5-C8 and T1 (Table 5) (Fig. 24)
    - v. Isolated lower plexus injuries rare (Klumpke's palsy)
    - vi. Lower plexus involvement may result in a Horner's syndrome (ptosis, miosis, enophthalmos, anhidrosis)
    - vii. Most neonatal palsies are neuropraxic injuries, improve within 2 months
    - viii. Axonometric injuries undergo Wallerian degeneration, require nerve regeneration within intact nerve sheath

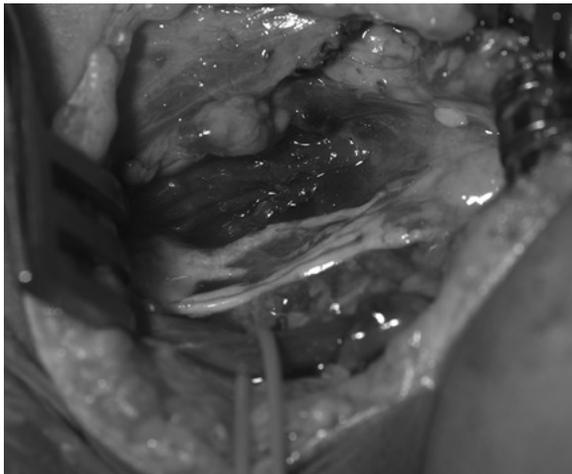
## Chapter 29 Figures



**Fig. 25A. Intraoperative view of brachial plexus palsy demonstrating the neuroma.** (Courtesy of Shriners Hospital for Children, Philadelphia)



**Fig. 25B. Intraoperative view of cable grafting following resection of the neuroma.** (Courtesy of Shriners Hospital for Children, Philadelphia)



**Fig. 25C. Intraoperative view of cable grafting for brachial plexus palsy demonstrating the graft.** (Courtesy of Shriners Hospital for Children, Philadelphia)



**Fig. 26. Stabilization of the scapulothoracic joint is essential in order to mobilize the glenohumeral joint during external rotation stretches.** (Courtesy of Shriners Hospital for Children, Philadelphia)

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- ix. Functional recovery of elbow flexion by 4 to 6 months indicative of some nerve continuity
- x. Limited/absent elbow flexion at 6 months necessitates nerve surgery
  - 1. Excision of neuroma
  - 2. Cable grafting of defect (most commonly with sural nerve) (Fig. 25A-C)
  - 3. Direct repair not possible
- xi. Nerve root avulsions from spinal cord (pre-ganglionic injuries) not repairable – require nerve grafting from viable roots and/or delayed tendon transfers to improve function
- xii. Indicators of possible avulsion injury
  - 1. Horner’s syndrome
  - 2. Scapular winging
  - 3. Phrenic nerve dysfunction with elevated hemidiaphragm on inspiratory imaging (e.g., ultrasound or fluoroscopy)
- xiii. Typical shoulder presentation
  - 1. Internal rotation and adduction (C6-C7) with absent/limited external rotation and abduction (C5-C6)
  - 2. If untreated, anterior capsule/muscle tightness, posterior glenohumeral subluxation, posterior glenoid version, and eventual formation of pseudoglenoid on posterior surface of scapula
- e. Treatment
  - i. Early and frequent PROM abduction/external rotation with scapular stabilization (at every diaper change) (Fig. 26)
  - ii. Botulinum toxin injections
    - 1. For persistent internal rotation contractures
    - 2. For triceps to weaken antagonist and promote biceps activation
  - iii. Orthoses
    - 1. Shoulder external rotation orthosis (prefab or custom)
    - 2. Elbow extension
    - 3. Wrist extension
    - 4. Wrist extension crawling orthosis (dorsal design with narrow section along wrist to promote extension for crawling but allow some wrist flexion for function)
    - 5. Resting hand orthosis for night
    - 6. Supination strap
  - iv. Surgical intervention
    - 1. Late presentation or persistent contractures require open or arthroscopic glenohumeral reduction with or without tendon transfers to augment external rotation and overhead reach
    - 2. Humeral osteotomy – improve forearm position for enhanced function

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3. Tendon transfers to augment wrist extension/supination/finger extension
- v. Postoperative considerations
  1. Vary by procedure, details beyond scope of this chapter

### Considerations for Pediatric Orthoses<sup>38,39,40,41</sup>

#### I. Materials

- a. Infants and young children
  - i. 1/16" solid or perforated materials (increased comfort and conformability, quick dry time) (i.e. Orfilight, Aquaplast)
  - ii. Mouthing
    1. Avoid small components - prevent choking hazard
    2. If needed, use replaceable padding- minimize odor/infection
  - iii. Color choice - increased compliance
  - iv. Consider alternatives to outriggers i.e. neoprene radial tunnel orthosis (Benik Corporation, Silverdale, WA)
- b. Older children and adolescents
  - i. Color choice for orthoses and straps
  - ii. Cosmesis and appearance among peers are major concerns for this age group. Lowest profile orthosis that will adequately protect or provide desired function will improve motivation to comply with use.

#### II. Fabrication

- a. Durability
  - i. Serial orthoses often used from infancy through skeletal maturity (i.e. spasticity, radial deficiency)
  - ii. Static orthoses for stretching (example: elbow extension orthosis, resting hand orthosis)
    1. Fabricate with extra space to allow for growth
    2. Apply tape then thin padding to prevent migration of orthosis, remove with growth (tape increases ease of padding removal)
- b. Immobilization orthoses
  - i. The very active child may require a bivalved cast or clamshell orthosis for immobilization to provide added protection
- c. Functional orthoses
  - i. Neoprene, Fabrifoam or other soft materials may be supportive enough for functional orthoses
  - ii. Bulky or very restrictive thermoplastic orthoses may discourage child from using involved extremity
  - iii. Pediatric prefabricated orthoses i.e. Benik orthoses (Benik Corporation, Silverdale WA) or McKie thumb supports (Mckie Splints, Duluth MN)
- d. Fabrication of orthoses
  - i. Explain the process in simple, age appropriate terms

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- ii. Use distraction techniques (music, cartoons, or even a parent reading a book) during molding of orthoses
- iii. Incorporate child in process – increased compliance (i.e. fabricate orthosis for doll/toy)

### III. Compliance

- a. In younger children, consider including more than the affected joints for resting/protective orthoses to make it more difficult for the child to remove the orthosis
- b. Anti-Houdini techniques
  - i. Straps
    - 1. D-rings straps
    - 2. Cut any excess length from straps
    - 3. Rivet one side of the strap to the orthosis
    - 4. Punch holes and use shoestring to tie orthosis on
    - 5. Put strap through a small slit in edge of orthotic material before fastening with Velcro
    - 6. Self-adhesive wrap over strap
    - 7. Pad strap for to provide friction
    - 8. Cover orthosis with stockinette or a sock to make removing orthosis difficult
- c. Sticker chart
- d. Functional/exercise orthoses for home use initially (if concerns re: peers)

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## Multiple Choice Questions

- Upper extremity limb bud development begins at \_\_\_ days post fertilization.
  - 60
  - 5
  - 26
  - 90
- True or False. Surgical correction of radial deviation/flexion deformity in radial deficiency may not be warranted in the older child who:
  - Has functionally compensated for the deficiency
  - Has adequate elbow flexion
  - Has a significantly shortened forearm
  - Has had a pollicization
- Surgical treatment for radioulnar synostosis may include:
  - Humeral osteotomy to improve arm positioning
  - Rotational osteotomy through the forearm synostosis
  - Tendon transfers
  - No surgical intervention is available for this diagnosis
- True or False. Arthrogryposis:
  - Affects only the upper extremities
  - Is characterized by underdeveloped pectoralis muscle and central deficiency of the hand
  - Only affects the skeletal system
  - Is a non-progressive disease process
- Typical posturing in an individual with arthrogryposis includes:
  - IR, elbow flexion, forearm pronation, wrist flexion, finger flexion
  - ER, elbow flexion, forearm supination, wrist extension, finger flexion
  - Shoulder internal rotation, elbow extension, forearm pronation, wrist flexion, finger flexion
  - ER, elbow extension, forearm supination, wrist extension, finger extension
- The cause of congenital constriction band syndrome is:
  - Unknown
  - Hereditary
  - Maternal alcohol use during pregnancy
  - Birth trauma
- Caution should be taken with circumferential casting of a higher energy Monteggia fracture, as cumulative edema and soft tissue injury may lead to:
  - Delayed bone healing
  - Radial head subluxation
  - Ulnocarpal impaction
  - Compartment syndrome

## Chapter 29: Pediatric Upper Extremity Disorders

Cheryl S. Lutz, OTR/L, Sarah Ashworth, OTR/L, and Scott H. Kozin, MD

### Multiple Choice Questions

8. Early indications of compartment syndrome in children include:
  - A. Pain, paresthesias, pulselessness and pallor
  - B. Increased analgesia, agitation and anxiety
  - C. Pitting edema, pain
  - D. Compartment syndrome is not an issue with children
  
9. Buckle fractures and plastic deformation in pediatric distal radius and ulna fractures respond well to:
  - A. 3 weeks in a removable splint
  - B. 8 weeks in a removable splint
  - C. 3 weeks in a cast followed by 6 weeks in a removable splint
  - D. Observation
  
10. Risk factors for neonatal brachial plexus palsy include:
  - A. Shoulder dystocia, forceful extraction with aid of forceps or vacuum, and fetal microsomia
  - B. Uterine anomalies and rapid labor
  - C. Fetal macrosomia, prolonged or difficult labor, shoulder dystocia, breech presentation, forceful extraction with aid of forceps or vacuum, uterine anomalies, and previous child with brachial plexus injury
  - D. Fetal macrosomia, prolonged or difficult labor, forceful extraction with aid of forceps or vacuum, and use of epidural
  
11. The most common level of injury in neonatal brachial plexus palsy is:
  - A. Extended upper plexus (C5, C6, C7)
  - B. Global plexus (C5, C6, C7, C8, T1)
  - C. Lower plexus (C8, T1)
  - D. Upper plexus (C5, C6)
  
12. Limited/absent elbow flexion at the age of \_\_\_\_\_ in neonatal brachial plexus palsy indicates the need for nerve surgery.
  - A. 6 months
  - B. 12 months
  - C. 2 years
  - D. 3 years
  
13. Typical shoulder presentation in the child with neonatal brachial plexus palsy with upper trunk involvement is:
  - A. External rotation and abduction
  - B. Internal rotation and adduction
  - C. Neutral shoulder rotation and adduction
  - D. External rotation and shoulder flexion

## Multiple Choice Questions

14. A very active child referred for a splint following cast removal from a distal radius fracture may benefit from:
- A. A soft, neoprene wrist support
  - B. A prefabricated carpal tunnel wrist support to wear during sports
  - C. A sling to prevent use of affected extremity
  - D. A clamshell splint for added protection

**Multiple Choice Question Answer Key  
Chapter 29**

1-C, 2-A, 3-B, 4-D, 5-C, 6-A, 7-D,  
8-B, 9-A, 10-C, 11-D, 12-A, 13-B, 14-D

## **Chapter 29: Pediatric Upper Extremity Disorders**

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