Amr Abdelgawad
Osama Naga *Editors*

Pediatric Orthopedics

A Handbook for Primary Care Physicians

Springer

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Children's Pediatric Practice
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Dedication

To my parents who gave me all the support in my life and never asked for anything in return and to my wife whom without her help I could not have written this book.

Amr Abdelgawad

To my parents, my wife, my daughter, and my friends who supported me to complete the book.

Osama Naga

Preface

"Pediatric Orthopedics: A Handbook for Primary Care Physicians" is designed to be a quick and practical resource for pediatricians, family medicine physicians, residents, nurse practitioners, physician assistants, and medical students caring for pediatric population with musculoskeletal disorders in their busy daily practice. This book is a concise, clinically oriented and readily available resource to study common pediatric musculoskeletal diseases. Great emphasis was given to the natural history of the diseases and indications for referring the child to an orthopedic surgeon. The details of surgical treatment and procedures were not included as this will not be of major benefits to our readers.

This book has a very interesting and easy to follow format. We tried to stay away from long paragraphs and controversial statements. The book is printed in "pocket" size and is easy to carry around. The information in the book is presented in a simple "bullet" format that allows the reader to understand the topic easily and with minimal effort. More than 300 figures were included in this handbook.

At the end of each chapter, we added "high yield facts" that summarize the important topics. In addition, a table of common orthopedic scenarios that the health care providers may encounter in their daily work is included, to guide them through the next steps in managing children with particular orthopedic presentations.

We are confident that this handbook will assist health care providers with a structured approach to the management of pediatric musculoskeletal conditions, and that they will find it a valuable tool in their daily practice.

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Contents

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Chapter 1
Introduction to Orthopedic Nomenclature

Amr Abdelgawad and Osama Naga

PHYSIS (THE GROWTH PLATE)

- It is a cartilaginous area that is responsible for the longitudinal growth of the bone.
- It appears as a radiolucent area in the radiographs.
- It should not be confused with fractures (physis has specific anatomic location with smooth outline) (Fig. 1.1).

EPIPHYSIS

- It is the proximal or the distal part of the bone (Fig. 1.1).
- The physis separates the epiphysis from the diaphysis.
- Usually articulate with the epiphysis of another bone to form a "joint."
- Epiphysis develops by **"secondary ossification center"** (see later).

APOPHYSIS

- Epiphysis which does not articulate with another bone (e.g., iliac crest apophysis, greater trochanter apophysis, calcaneal apophysis, tibial tubercle apophysis) (Fig. 1.2).
- Has a muscle attached to it and exposed to traction from this muscle (e.g., abdominal muscles and gluteal muscles attached to iliac crest).

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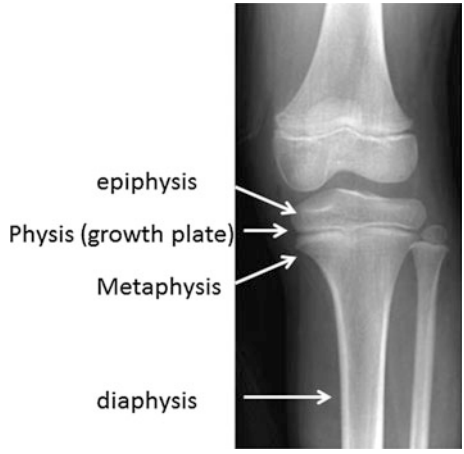

Fig. 1.1 Radiograph of the knee of an 9-year-old child showing anterio-posterior view of the knee. *Arrows* show the epiphysis, physis, metaphysis, and diaphysis

- Can get inflamed "apophysistis" causing pain (e.g., calcaneal apophysitis (Sever's disease), tibial tubercle apophysitis (Osgood Schlatter disease).

DIAPHYSIS (SHAFT)

- It is the midsection part of a long bone (Fig. 1.1).
- It is the middle tubular part of the long bone composed of compact bone (cortical bone) which surrounds a central marrow cavity.
- Diaphysis develops by **"primary ossification center"** (see later).

METAPHYSIS

- The part of the diaphysis which is the adjacent to the physis (Fig. 1.1).

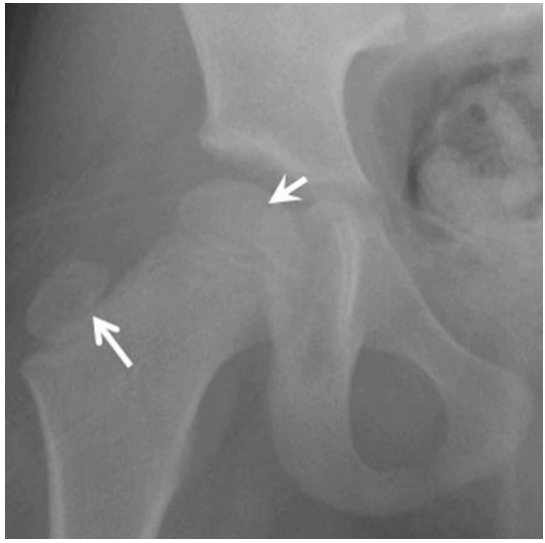

Fig. 1.2 Anatomical nomenclature:proximal femoral epiphysis (*arrow head*) and greater trochanter apophysis (*arrow*). Proximal femoral epiphysis articulate with acetabulum to form the hip joint while the greater trochanter does not articulate with other bone, it has the attachment of the hip abductors muscles

- This is a very active part of the bone with active cell division (cell added from physis are laid in the metaphysis).
- Most of the bone tumors arise in the metaphysis.
- The metaphysis is formed of less dense bone (cancellous bone).
- The circulation in the Metaphysis is sluggish as this is an end-capillary area (the physis is a relatively avascular structure separating the circulation of the metaphysis from the one in the epiphysis) (Fig. 1.3).
    - Hematogenous osteomyelitis usually occurs in the metaphysis. This is because bacteria from remote site will migrate in blood and settle in the metaphysis with its sluggish circulation (see also Chap. 21).

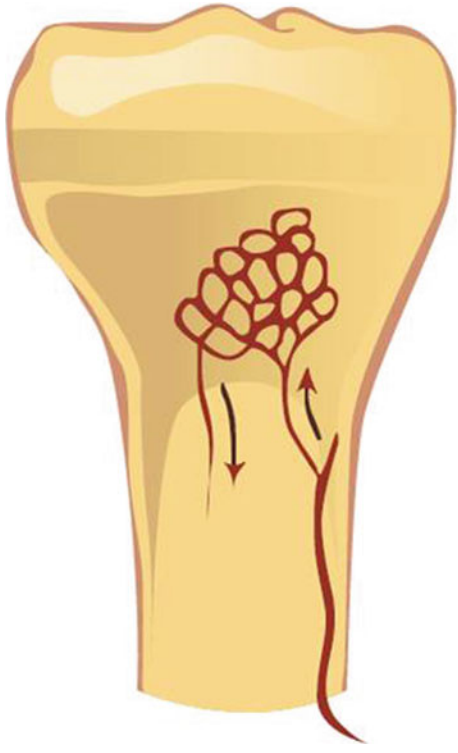

Fig. 1.3 Metaphyseal circulation. The *blood flow* in the metaphysis is slow as it passes from arterial system to venous system. The physis is relatively avascular structure separating the flow in the metaphysis from the epiphysis

PRIMARY CENTER OF OSSIFICATION

- It is the ossification island responsible for changing cartilage tissue to osteoid tissue.
- These develop in the **diaphysis** of all long bones in the **intra uterine life.**

SECONDARY CENTER OF OSSIFICATION

- It differs from the primary center of ossification in that it develops in the **epiphysis after birth** at different ages (except distal femur epiphysis which develops in intrauterine life) (Fig. 1.4).
- The secondary centers of ossification are used to identify the skeletal age of the child. (see identification of bone age in Chap. 2).

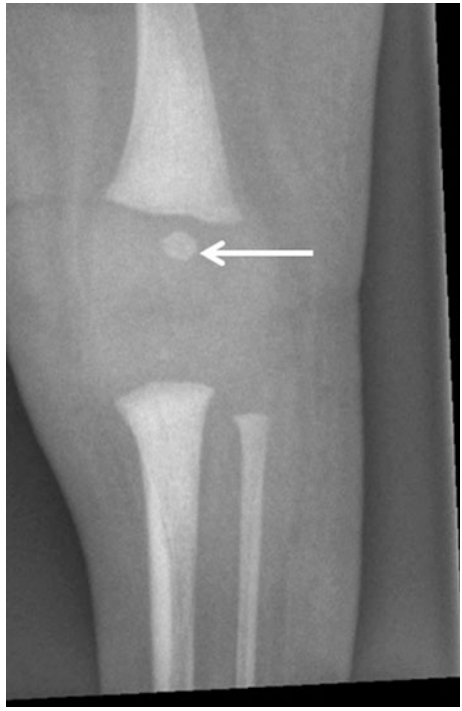

Fig. 1.4 Radiograph of a 3-day-old boy showing the shaft of the femur, tibia, and fibula (primary centers of ossification developing intrauterine). The radiograph also shows the distal femur ossific center which is the only secondary ossific center present at birth (*arrow*).Proximal tibial and fibular epiphyses cannot be seen in the radiograph because they are still cartilaginous

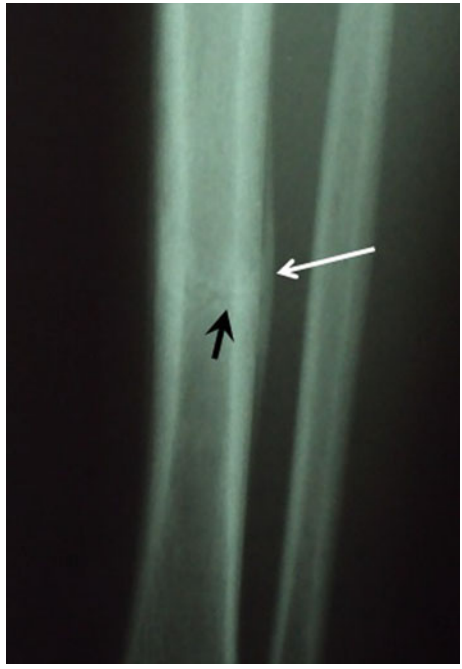

Fig. 1.5 Periosteal new bone formation in case of fracture healing. Plain radiograph of the tibia and fibula anteroposterior view showing periosteal new bone formation (*white arrow*) that happened during fracture healing (*black arrow*)

PERIOSTEUM

- It is a membrane that lines the outer surface of all bones, except at the joints surfaces.
- In children, periosteum is **thick and loosely attached to the bone** (except at the physis where it becomes firmly attached to the bone).
- Raising the periosteum away from the bone surface for any reason (e.g., infections, tumors, trauma) will **cause new periosteal bone formation** (Fig. 1.5).

SOME ANATOMICAL NOMENCLATURE

Proximal:

- The part close to trunk (axial skeleton) of the body.

Distal:

- The part further away from the trunk (axial skeleton) of the body.

Medial:

- The part close to the Medline.

Lateral:

- The part away from the Medline.

DEFORMITIES

Varus Deformity:

- The deformity in which the distal part points medially (Fig. 1.6).

Valgus Deformity:

- The deformity in which the distal part points laterally (Fig. 1.6).

Contracture Deformity:

- The joint is contracted in certain position.
- For example: **flexion contracture** of the knee means the knee is always in flexed position cannot reach **full extension (**Fig. 1.7**)**.

General Joint Examination:

- **Inspection:**

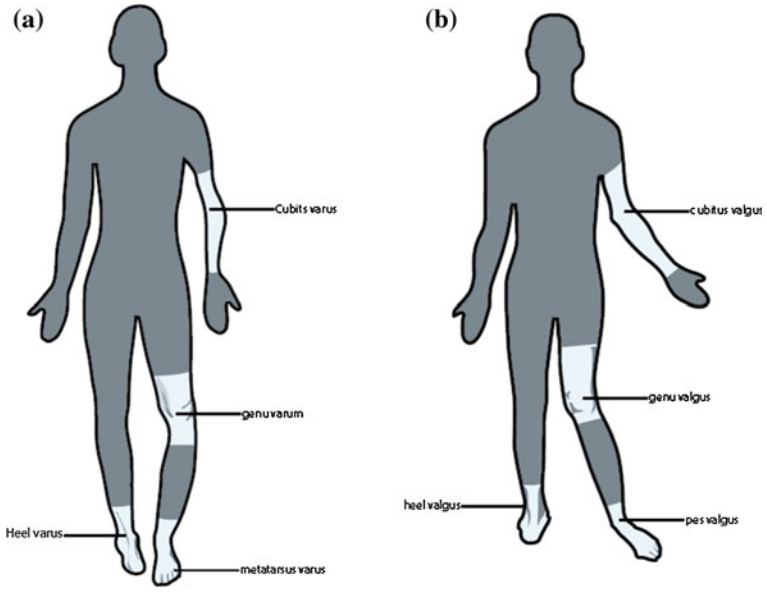

Fig. 1.6 (**a**) varus deformity and (**b**) valgus deformity. In varus deformity, the distal part of the joint is pointing medially and in valgus deformity, the distal part of the joint in pointing laterally

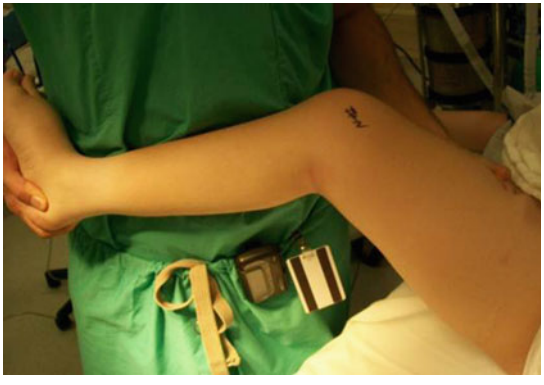

Fig. 1.7 Knee flexion contracture. An 11-year-old girl with spina bifida and 30° flexion contracture of the knee. The knee cannot be extended more than the position in the picture

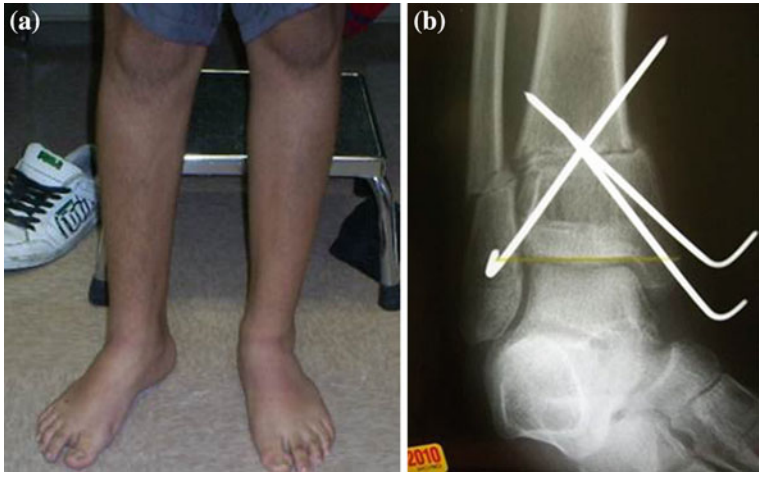

Fig. 1.8 Osteotomy. A 14-year-old boy who had fracture right tibia and fibula treated in cast. (**a**) Patient had malunion in external rotation. The family did not like the shape of the leg. (**b**) Osteotomy of the distal tibia and fibula was done to re-align the extremity in appropriate rotation. The osteotomy was fixed by metal (K-wires)

- Swelling
- Deformity
- Scars of previous surgeries
- Atrophy of the muscles.

■ **Palpation:**

- Anatomical landmark
- Tenderness
- Swelling and effusion.

■ **Movement (active and passive)**

- Assessment of the range of the motion of the joint both active and passive.

■ **Special test (varies according to the examined joint).**

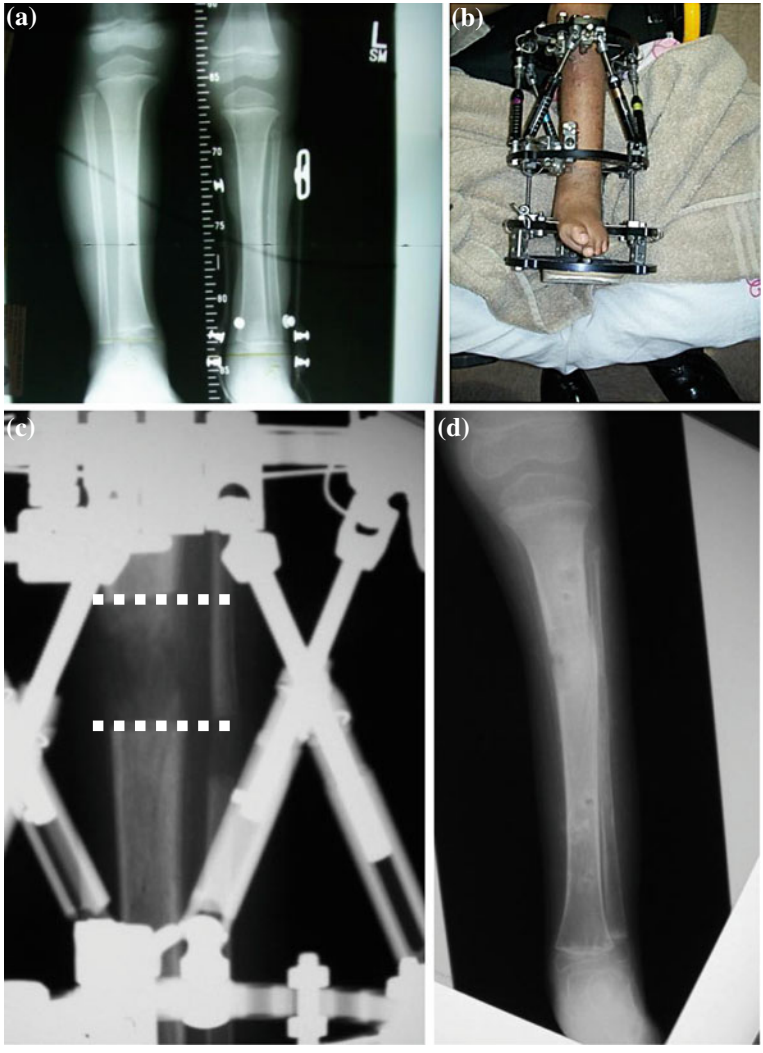

Fig. 1.9 Distraction osteogenesis. (**a**) A 4-year-old girl with limb length discrepancy due to fibular hemimelia (*left side shorter*). (**b**) Lengthening was done by application of external fixator. (**c**) The bone was cut and then the soft callus was stretched to lengthen the bone (distance between two dotted line). The callus is then left to consolidate to hard bone. (**d**) Radiograph taken after removal of the fixator showing the new bone formation and increase length of the bone

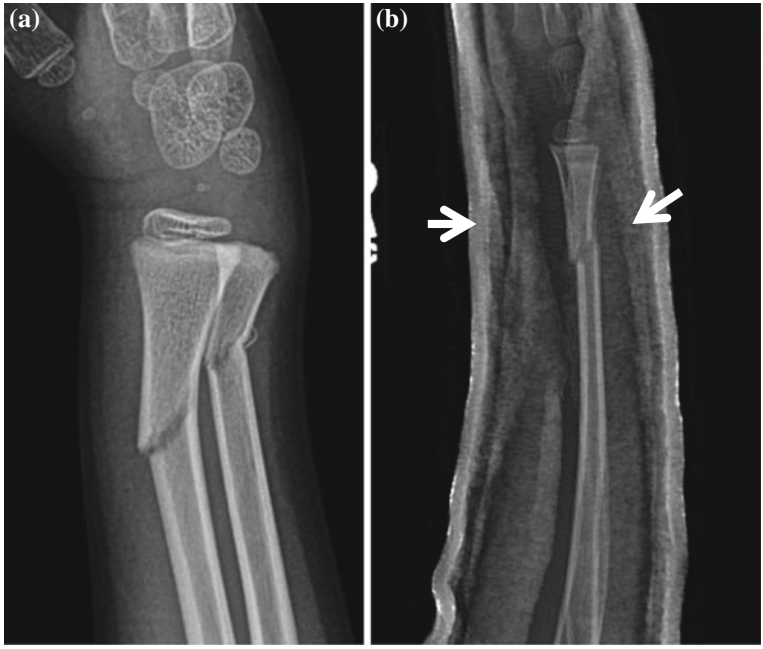

Fig. 1.10 Closed reduction. (**a**) A 6-year-old boy distal radius and ulna fracture with angulation. (**b**) Closed reduction was done by manipulation of the fracture and then sugar tongue splint (*arrows*) was applied to maintain the reduction

ORTHOPEDIC SURGERIES/PROCEDURES

Osteotomy:

- Cutting of the bone. This surgery is used to correct deformity (Fig. 1.8).

Distraction osteogenesis:

- Lengthening of bone by performing osteotomy and then stretching the soft callus tissue which develop at the site of osteotomy 7–10 days after the surgery (Fig. 1.9).

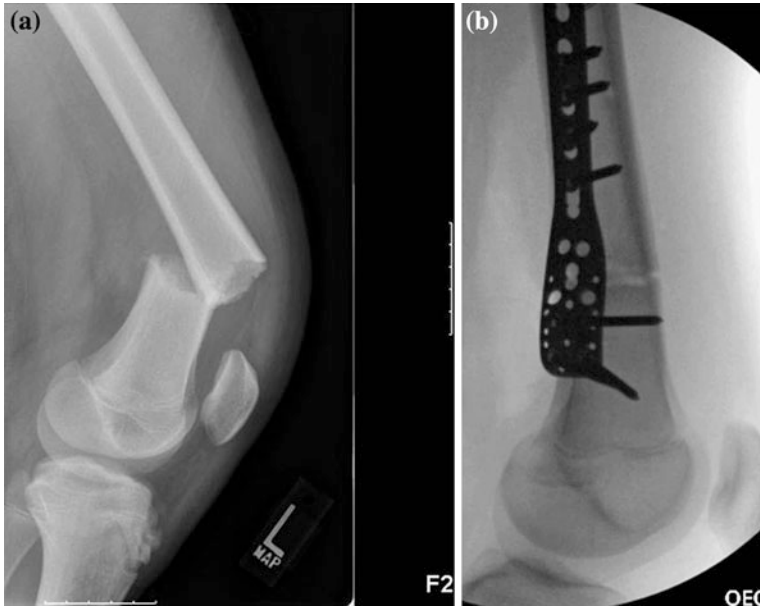

Fig. 1.11 Open reduction internal fixation. (**a**) A 12-year-old boy fell down a hill and fractured distal femur. (**b**) Open reduction internal fixation was done using plate and screws

Closed reduction:

- Reduction of the fracture by manipulation of the extremity without surgical incision (Fig. 1.10).

Open reduction:

- Reduction of the fracture by manipulation of the bone ends directly after performing surgical incision (Fig. 1.11).

Internal fixation:

- Fixation of the fracture or the osteotomy by implant (usually metal) inside the patient body (Fig. 1.11).

Open reduction internal fixation:

- One of the most commonly performed surgeries in orthopedic (Fig. 1.11).

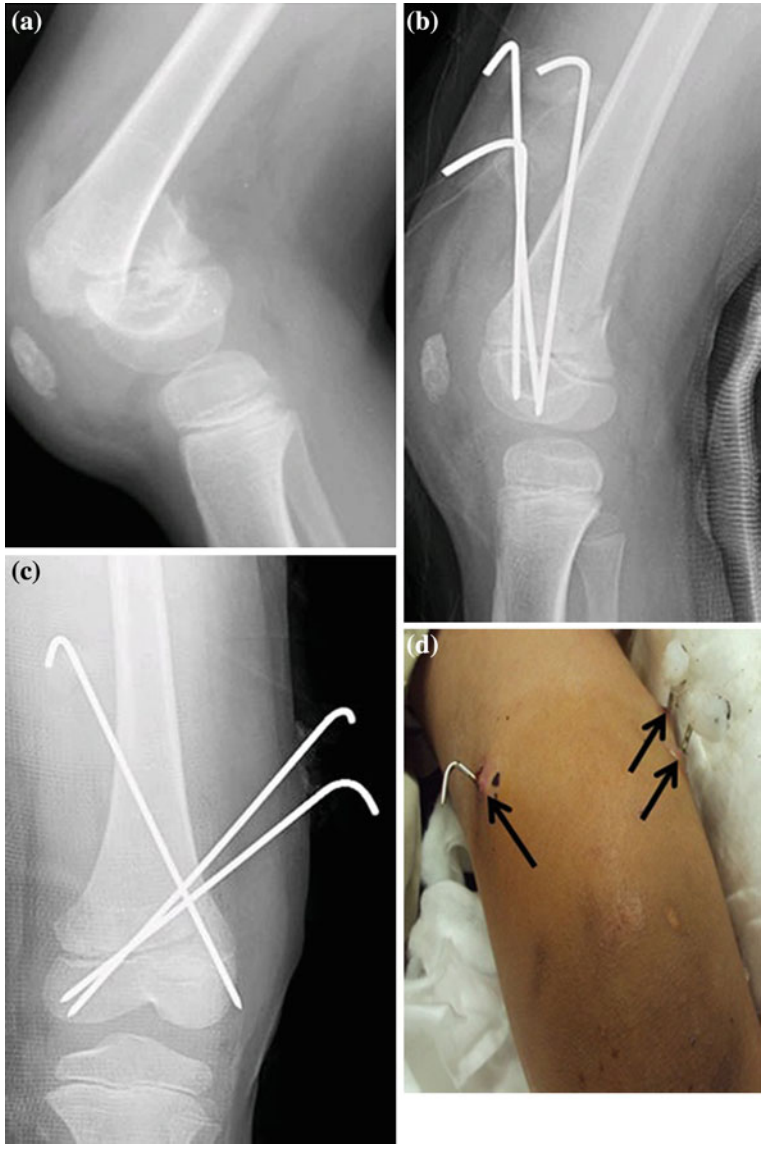

Fig. 1.12 Closed reduction and Percutaneus fixation. (**a**) Salter Harris type II distal femur fracture treated with closed reduction and percutaneous fixation by K-wires (**b**), (**c**). The wires were introduced from the skin without opening by the help of intra-operative fluoroscopy. (**d**) Notice that there is no skin incision around the pin entry points (*arrows*)

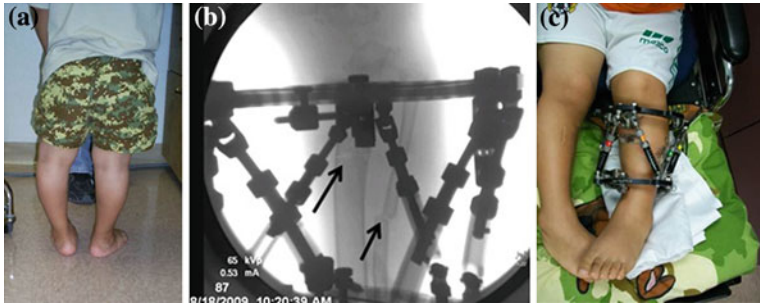

Fig. 1.13 External fixator. (**a**) An 8-year-old child with pseudo-achondroplasia. (**b**) Patient had osteotomy of left tibia and fibula to correct the genu varum (*arrows*). (**c**) External fixator was applied to obtain gradual correction

- The procedure includes open reduction of the fracture ends followed by internal fixation of the fracture.

Closed reduction and Percutaneus fixation:

- The implant used to fix the fracture or the osteotomy is introduced by small opening in the skin (Fig. 1.12).
- Intra-operative fluoroscopy is used to guide the insertion of the implant.

External Fixator:

- A device used to fix the fractures or osteotomies (Fig. 1.13).
- Pins or wires are introduced in the bone and these are connected together from outside by rods.
- Used mainly to corrected deformities or for open fractures.

Cast, splints, and braces:

- See Chap. 18.

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Chapter 2

Growth and Development and Their Relation to Musculoskeletal Conditions

Ahmed M. Thabet

INTRODUCTION

- Growth and development have close relation with many pediatric orthopedic conditions.
- Orthopedic conditions as cerebral palsy and spina bifida can adversely affect the children normal growth. In most pediatric orthopedic disorders the multi-displinary approach and **especially the co-operation between the pediatrician and the orthopedic surgeons is crucial for successful outcome.**
- Knowing the normal growth and development can affect the surgical planning of lots of musculoskeletal conditions.
- Typical examples of growth disturbances in the musculoskeletal system are limb length discrepancy (LLD), spine deformities, skeletal dysplasia, and paralytic disorders.

BASICS OF NORMAL GROWTH

Children's bones have unique ability to grow. This particular feature of children skeleton differentiates between **children (skeletally immature) and adults (skeletally mature).**

A. Basic definitions:

- **Growth:** increase in total individual body size or increase in size of a particular organ or organ systems
- **Development:** physical changes of maturation that occurs as the child gets older

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TABLE 2.1 DEFINITIONS OF ABNORMAL GROWTH AND DEVELOPMENT

Congenital	Anomaly that is present at birth e.g., congenital radial club hand
Deformation	A normally formed structure that is pushed out of shape by mechanical forces
Deformity	A body part altered in shape from normal, outside the normal range
Developmental	A deviation that occurs over time; one that might not be present or apparent at birth e.g., developmental dysplasia of the hip (DDH)
Disruption	A structure undergoing normal development that stops developing or is destroyed or removed
Dysplasia	A tissue that is abnormal or wrongly constructed e.g., Achondroplasia
Malformation	A structure that is wrongly built; failure of embryologic development or differentiation resulting in abnormal or missing structure

B. Abnormal growth and development definitions:

- It is very important to understand the basic definitions reflecting the deviation from normal growth and development.
- Table 2.1 provides these basic definitions about the faults of growth and development (Table 2.1).

C. Structure of the growth plate (Fig. 2.1):

- Reserve zone
- Proliferative zone
- Hypertrophic zone**: is divided into three zones**
  - Maturation zone
  - Degenerative zone
  - Provisional calcification zone.
- The growth plates are responsible for longitudinal growth of the long bones.
- Growth plate can be affected by various pathological processes (e.g., traumatic, neoplastic, infectious, genetic, and nutritional causes).

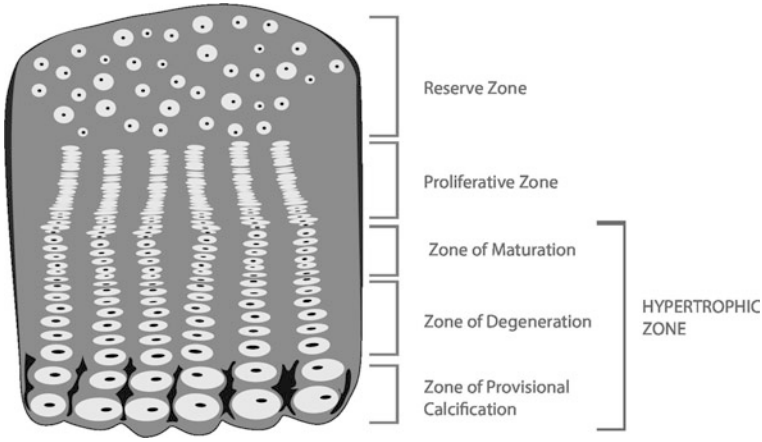

Fig. 2.1 Growth plate histology

- Injuries or infection to growth plate can affect the normal limb development. Limb shortening and/or angular deformities can result from these kinds of injuries (Figs. 16.9/trauma and 16.44/trauma).
- Achondroplasia children have deficiency of fibroblast growth factor receptors (FBGR) which affects the growth plate.

D. Types of growth plates:

There are different types of growth plates. The type of growth plates depends upon the shape of the bone. These include:

- Epiphyseal growth plate: lies at the ends of long bones and provide longitudinal growth.
- Ring epiphyses surround round bones such as the tarsals. These bones grow circumferentially.

E. The contribution of each bone to the overall growth of the extremity:

- The upper limb growth:
  - 40 % proximal humerus

- 40 % distal radius
- 20 % around the elbow

- The lower limb growth:

  - 65 % around the knee
  - 15 % proximal femur
  - 20 % distal tibia

F. Evolution of proportionate body size:

- At birth: the head is 25 % of body size.
- At birth: the upper body segment/lower body segment is 1.7.
- At the age of 10 the ratio between upper and lower body segments is less than 1.
- Children with skeletal dysplasia have abnormalities of these ratios. Measurements of these ratios are very useful in establishing the diagnosis.
- Extremity growth: Girls stop growing around the age of 14 years, and boys around the age of 16 years.
- Spine growth: spine growth continues after puberty. The additional increase in height after puberty is through spine growth.

G. Phases of growth:

1. Fetal phase: in this phase the child grows very fast and limb rotation occurs during this period.

   - Limb rotation: During the seventh week, the upper limb rotates externally and the thumb will be laterally. The lower limb rotates internally and the great toe moves medially).
   - Abnormalities of lower limb rotation can result in tibia internal rotational or external rotational deformities.

2. Early childhood:

   - The child reaches half of his adult height during the 4th year of life.
   - The foot growth reaches half the adult length by the age of 2 years. **The foot matures earlier than the long bones to provide stable base during walking.**

3. Adolescent:

- **The adolescent stage is a phase of rapid growth (peak growth velocity)**.
- Most of the limb and spine deformities accelerate during that time e.g.,: adolescent Blount's disease and idiopathic scoliosis (peak growth velocity).
- **The child continues to grow for 3 years after adolescent growth spurt.**
- The spurt in trunk length is greater than the spurt in lower limb growth, so the increase in height in the adolescent growth spurt is more derived from the trunk than the limbs.
- Gender differences in growth become evident during adolescence with proportionally greater growth of the male shoulders and the female pelvis.

ASSESSMENT OF GROWTH POTENTIAL AND ESTIMATION OF DEGREE OF SKELETAL MATURITY

The concept of growth remaining:

- It is very crucial to know the amount of growth remaining for surgical planning and determination of different orthopedic intervention (e.g., spinal fusion for scoliosis or epiphysiodesis for LLD in the growing children).
- The assessment of skeletal maturity can be achieved through clinical and radiological methods.

1. Clinical assessment:

- Using the serial height measurements and Tanner's staging of secondary sexual characters. This can detect the peak growth velocity period (children continue to grow three years after the peak growth)

A. Peak Growth velocity:

- The peak growth velocity is the maximum skeletal growth during adolescent growth spurt.
- The timing of peak growth velocity is estimated by serial (every 6 months) height measurements over time.

- The peak growth velocity is the earliest and best index of adolescent growth spurt. After this peak the growth slows down.
- The peak growth velocity **occurs after closure of triradiate cartilage and before Risser stage 1 and menarche (see Chap. 19)**.

B. Tanner staging:

- The assessment of the secondary sexual characters is an important tool in identification of level of skeletal maturity and puberty.
- Tanner's staging uses secondary sexual characters in boys and girls.
- The first physical sign of puberty in boys (which is usually testicular growth), occurs about 1.5 years before the peak height velocity and 3.5 years before attaining final adult height.
- The first physical sign of puberty in girls (which is usually breast budding), occurs about 1 year before peak height velocity. Menarche occurs about 2 years after breast budding, and final height is usually achieved 2.5–3 years after menarche.

C. The height measurement:

Before the age of 5 years, it can measured while the child is lying down which is easier and reliable. After that age it can be measured as standing. It can be subdivided into:

- **Sitting height:**
  - The sitting height is reflecting the trunk growth.
- **Sub-ischial height:**
  - Reflecting the lower limb growth. It can be calculated by subtracting the sitting height from the standing height
- **Arm span:**
  - The span can be measured using tape between the middle fingers of both arms. In 77 % of normal children the arm span is 0–5 cm greater than standing height.

- In certain conditions like Marfan syndrome, the span is greater than standing height by more than 5 cm (see Chap. 4).

2. Radiological assessment:

A. Bone age:

- The bone age is more important that the chronological age in determining the future growth potentials.
- The bone age is the average age at which the bones reach specific maturation stage.
- The average bone age and chronological ages for large group of children should be the same, however for individual child the difference may be up to 1 or 2 years (earlier or delayed bone age).
- The bone age can be studied through hand and elbow radiographs.
- Children with constitutional short stature can have delayed bone age. These children will later on continue to grow and achieve normal final adult height.
- **Radiographs are taken for left hand** and compared with known characteristics of the radiographs for boys and girls hands at certain ages using "Greulich and Pyle Atlas" (Fig. 2.2).

B. The order of ossification centers about the elbow:

- The ossific centers of the elbow are very important in knowing the child's bone age.
- The eponym for remembering these ossification centers is **CRITOE** (the order of appearance is Capitellum, Radial head, Internal (medial) epicondyle, Trochlea, Olecranon, and External (lateral) epicondyle).

  - The ossification centers at the elbow **appear** as the following (**in girls**) (Fig. 2.3):

    - The capitellum appears by about 8 months–1 year.
    - The radial head at about age 3 years.
    - The medial epicondyle at about age 5 years.
    - The trochlea at about age 7 years.
    - The olecranon at about age 9.
    - The lateral epicondyle at about age 11.

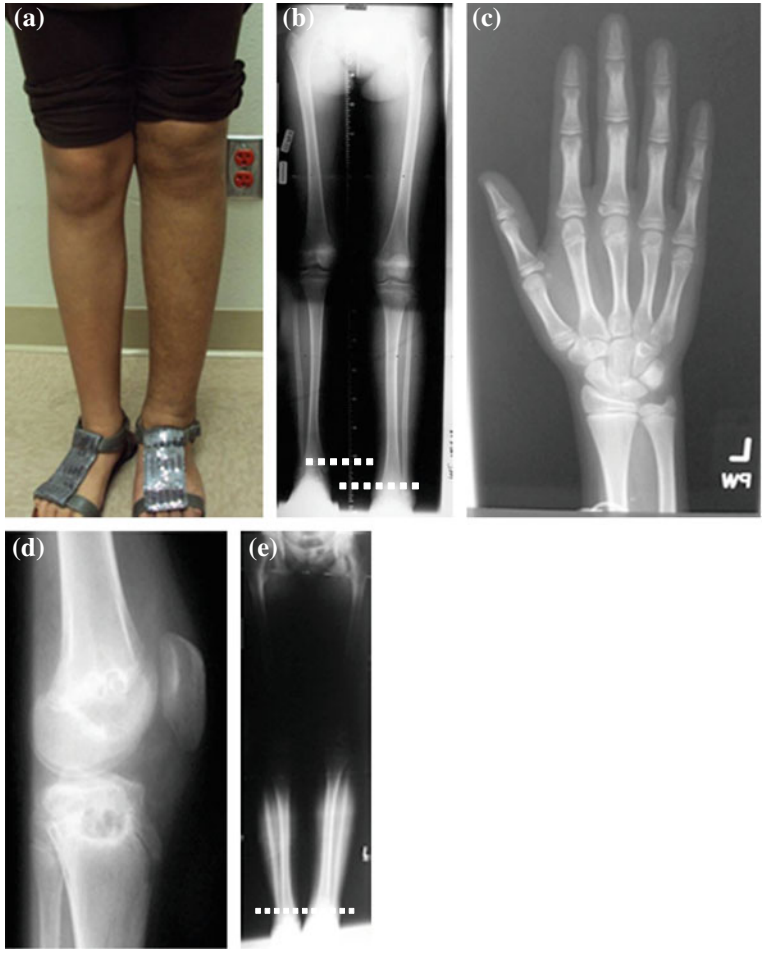

Fig. 2.2 Epiphysiodesis. (**a**) A 13-year-old girl with *left* lower extremity (LE) diffuse hemangioma causing increased blood supply to *left* LE and *left* LE longer than *right* LE by about one inch. One inch block is used underneath the right LE to equalize the length (notice the dotted lines) (**b**). (**c**) Hand radiograph compared to Greulich and Pyle atlas showed bone age of about 12 years and six months. Epiphysiodesis of the distal femur and proximal tibia (**d**). 2 years of follow-up showed equalization of the limb length between *right* and *left* LE (**e**)

- The age of appearance in boys is 1–2 years older than girls (except the capitellum).
- Fusion of the these ossification centers is around the age of 15 years old in girls and 16 years old in boys.

C. Risser's sign and tri-radiate cartilage (**see Chap. 19**):

- The Risser sign is a radiological sign based on the ossification of the iliac apophysis. The sign can be interpreted from the spine radiographs. It is very useful in surgical planning of all spine deformities (Fig. 19.9/spine).
- Closure of the tri-radiate cartilage occurs about one year after the start of adolescent growth spurt and about one and half years before Risser stage 1.

DEVELOPMENTAL MILESTONES

- Gross motor skills: The timing of development of motor milestones is part of routine assessment of the child during office visits. Children with cerebral palsy have delayed development of the motor milestones.
- Examples of the major development of the motor milestones are:
  - Sitting independently at age of 6 months.
  - Walks independently at age of 12 months.
- Gait maturation:
  - Infant's gait is unstable gait and walks with wide base. The walking speed is variable.
  - The infants' unstable gait is due to high center of gravity; under development of their nervous system; low muscle mass to body ratio and immaturity of balance controlling system.
  - As the child continue to grow, the gait becomes more stable and more energy efficient.
  - The gait pattern of children mature to become close to adult walking by the age of 4 years old.