10 Biomechanically Based Clinical Decision Making in Pediatric Foot and Ankle Surgery

Jon R. Davids

Introduction

The understanding and classification of functional deviations and deficits at the ankle and foot are based upon an appreciation of normal function during the gait cycle [1–3]. The interaction between the ankle, foot and the floor is a critical element of normal gait. Function of the ankle and foot is determined by a complex interaction of anatomy, physiology, and physics. Proper ankle and foot alignment is required for optimal function of the knee and hip during gait. Disruption of normal function of the ankle and foot may disrupt knee and hip function, compromising the energy efficiency of gait and in extreme cases precluding the ability to ambulate.

Clinical decision making for the management of ankle and foot deformities in children can be standardized by the use of a diagnostic matrix (Table 10.1) [4]. This paradigm is based upon the collection and integration of data from five sources: the clinical history, physical examination, plain radiographs, observational gait analysis, and in complex cases associated with certain disease processes (e.g., cerebral palsy, myelodysplasia, and hereditary sensorimotor neuropathies), quantitative gait analysis (which may include kinematic/kinetic analyses, dynamic electromyography (EMG), and dynamic pedobarography).

This chapter will begin with an overview of normal ankle and foot function during the gait cycle. This will provide a framework for the identification of common (or coupled), and uncommon (or uncoupled), segmental malalignments of the ankle and foot. This will be followed by an overview (principles and indications) of the most common interventions (i.e., soft tissue surgery, guided growth, osteotomies, and arthrodeses) utilized to correct these segmental malalignments. Finally, a standardized approach for the preoperative, intraoperative, postoperative, and surveillance of ankle and foot alignment and function will be presented.

Ankle and Foot Function During Normal Gait

The understanding of ankle and foot function during normal gait is facilitated by considering the lower leg to consist of four segments: the tibial or shank segment, the hindfoot (talus and calcaneus), the midfoot (navicular, cuneiforms, and cuboid), and the forefoot (metatarsals and phalanges) [1–3, 5, 6] (Fig. 10.1a, b). It is also helpful to consider the foot to consist of two columns: the medial column (talus, navicular, cuneiforms, great toe metatarsal, and phalanges), and the lateral column (calcaneus, cuboid, lesser toe metatarsals, and phalanges) [7] (Fig. 10.2a–c). Standardized, consistent terminology is required to describe the alignment of the separate segments of the ankle and foot [8]. Movement of the plantar aspect of the segment in question during the gait cycle is described as *inversion* (towards the midline) or *eversion* (away from the midline). Movement of the distal aspect of the segment in question during the gait cycle is described as *adduction* (towards the midline) or *abduction* (away from the midline). *Supination* is a combination of inversion and adduction. *Pronation* is a combination of eversion and abduction. Rotation of the segment about its longitudinal axis towards the midline is described as *internal rotation*. Rotation of the segment about its longitudinal axis away from the midline is described as *external rotation*.

The gait cycle is a period of time beginning with the initial contact of the reference foot with the ground, continuing through ipsilateral stance and swing phases until the subsequent ipsilateral initial contact. Stance phase occurs when the reference limb is in contact with the ground. Swing phase occurs when the reference limb is not in contact with the ground. The interaction of the ankle and foot with the ground during the stance phase of the gait cycle is described by the

An erratum to this chapter can be found at
DOI 10.1007/978-3-319-17097-8_33

J.R. Davids, MD (✉)
Shriners Hospital for Children, 2425 Stockton Boulevard, Sacramento, CA 95817, USA
e-mail: jdavids@shrinenet.org

S. Sabharwal (ed.), *Pediatric Lower Limb Deformities*,
DOI 10.1007/978-3-319-17097-8_10, © Springer International Publishing Switzerland 2016

Table 10.1 The diagnostic matrix for the assessment of the ankle and foot deformities

Source	Information
Clinical history	Pain
	Tripping
	In-/Out-toeing
Physical examination	Gross foot shape weight-bearing/non weight-bearing
	Flexible/rigid
	Plantar callous pattern
Radiographic examination	Segmental alignment weight-bearing, AP and LAT views
Observational gait analysis	Foot contact with floor (3 rockers)
	Foot progression angle
	Foot clearance in swing phase
Quantitative gait analysis	Kinematics
	Kinetics
	Dynamic EMG
	Pedobarography

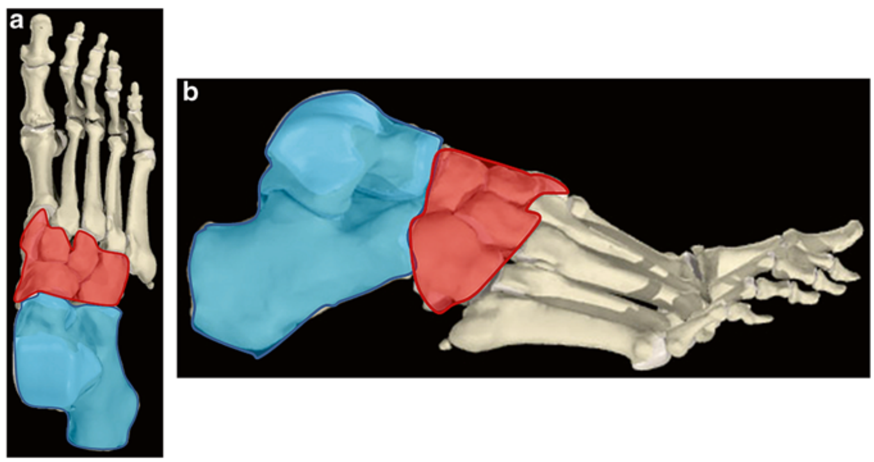

Fig. 10.1 Three segments of the foot. (**a**) Diagram of the anteroposterior view of the right foot. The hindfoot segment is *blue*, the midfoot segment is *red*, and the forefoot segment is *white*. (**b**) Diagram of the lateral view of the right foot. The hindfoot segment is *blue*, the midfoot segment is *red*, and the forefoot segment is *white*

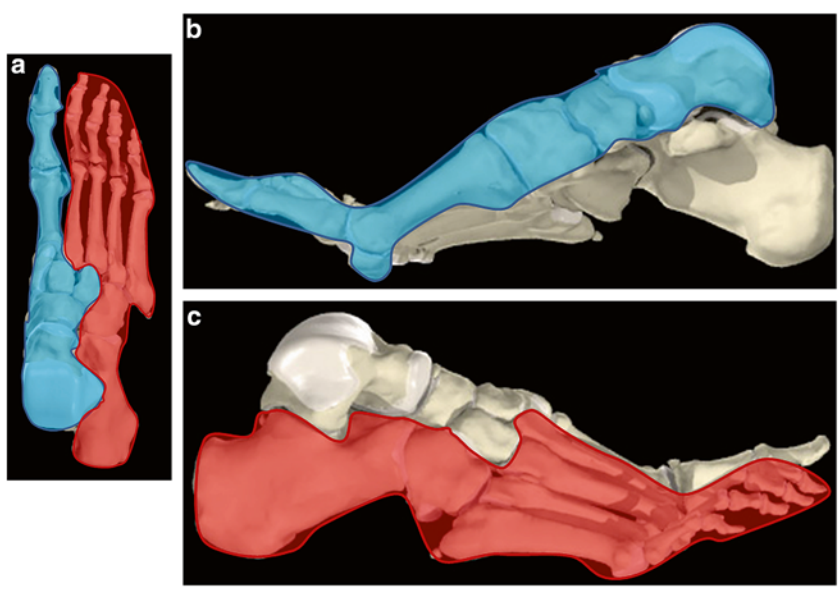

Fig. 10.2 Two columns of the foot. (**a**) Diagram of the anteroposterior view of the right foot. The medial column is *blue*, and the lateral column is *red*. (**b**) Diagram of the lateral view (medial side) of the right foot. The medial column is *blue*. (**c**) Diagram of the lateral view (lateral side) of the right foot. The lateral column is *red*

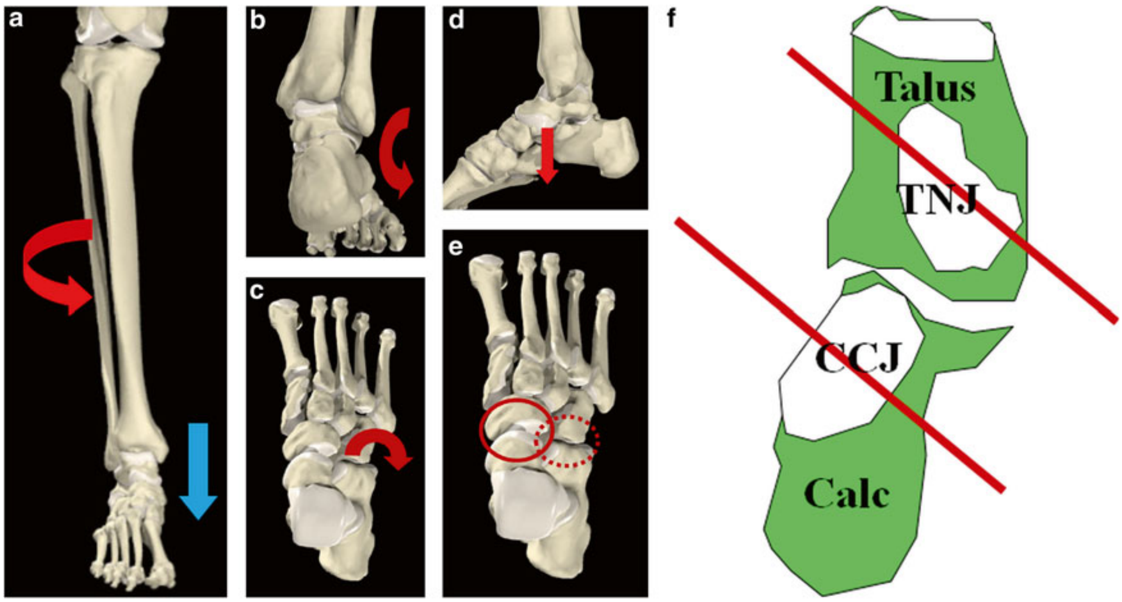

Fig. 10.3 Skeletal alignment of the lower extremity during the first rocker of stance phase. (**a**) The tibia is rotating internally (*red arrow*) and the ankle is plantarflexing (*blue arrow*). (**b**) Hindfoot alignment during the first rocker of stance phase consists of calcaneal eversion (*red arrow*). (**c**) Hindfoot alignment during the first rocker of stance phase consists of calcaneal abduction (*red arrow*). (**d**) Hindfoot pronation (eversion and abduction) forces the talus to plantarflex (*red arrow*) during the first rocker of stance phase. (**e**) This "unlocks" the primary joints of the midfoot (talo-navicular in *solid circle*, calcaneocuboid in *dashed circle*). (**f**) Coronal view of the articulation between the hindfoot and midfoot in first rocker of stance phase. Lateral is to the left, medial is to the right. *TNJ* talo-navicular joint, *CCJ* calcaneocuboid joint, *Calc* calcaneus. The main axes of the TNJ and CCJ are parallel (*red lines*), which allows motion and "unlocks" the midfoot

concept of three rockers [2, 3]. In normal gait, the heel is the first part of the foot to contact the ground at initial contact. The ankle subsequently plantar flexes until the foot is flat on the floor. This motion is controlled by the eccentric activity of the ankle dorsiflexor muscle group. The *first, or heel rocker*, occurs from heel strike to foot flat during the loading response subphase of stance. As the body progresses forward, the tibia advances forward over the foot, which is achieved by ankle dorsiflexion. This motion is controlled by eccentric activity of the ankle plantar flexor muscle group. The *second, or ankle rocker*, occurs as the tibia advances over the foot during the midstance subphase of stance. Immediately prior to the initial contact of the opposite foot, the heel of the reference foot rises off the ground and dorsiflexion occurs through the metatarsophalangeal joints of the forefoot. This motion is controlled by concentric activity of the ankle plantar flexor muscle group. The *third, or forefoot rocker*, occurs as the ankle begins to plantar flex during the terminal stance subphase of stance. This is an essential event during normal gait, as the largest moment generated by any single muscle group during the gait cycle is the internal plantar flexion moment generated by the ankle plantar flexor muscle group during third rocker in terminal stance [2, 3, 9].

In the stance phase of the normal gait cycle, the ankle and foot provide shock absorption during loading response (first or heel rocker), stability during midstance (second or ankle rocker), and a rigid lever during terminal stance (third or forefoot rocker) [2, 3]. During loading response, the tibial or shank segment rotates internally, and the ankle is plantarflexing (Fig. 10.3a). This results in eversion and abduction of the hindfoot, primarily through the subtalar joint (see Fig. 10.3b, c). Pronation of the hindfoot forces the talus to plantarflex, which "unlocks" the joints of the midfoot, which follows into pronation (see Fig. 10.3d, e) This coupled movement of the hindfoot and midfoot results in maximum flexibility of the foot, which allows the joints to contribute to shock absorption. During midstance, the tibial or shank segment is rotating externally, and the ankle is dorsiflexing (Fig. 10.4a). This results in inversion and adduction of the hindfoot, primarily through the subtalar joint (see Fig. 10.4b, c). Supination of the hindfoot forces the talus to dorsiflex, which "locks" the joints of the midfoot, which follows into supination (see Fig. 10.4d, e) This coupled movement of the hindfoot and the midfoot results in restoration of the longitudinal arch of the foot and maximum rigidity of the foot, which enhances stability. During terminal stance, the tibial or shank segment continues to rotate externally, and the ankle continues to dorsiflex. As the body progresses forward, the center of pressure beneath the foot advances distally into the forefoot. Because the segments of the foot are aligned to promote maximum rigidity, the forefoot is stable as it is loaded. The rigidity of the foot segments provides an optimal

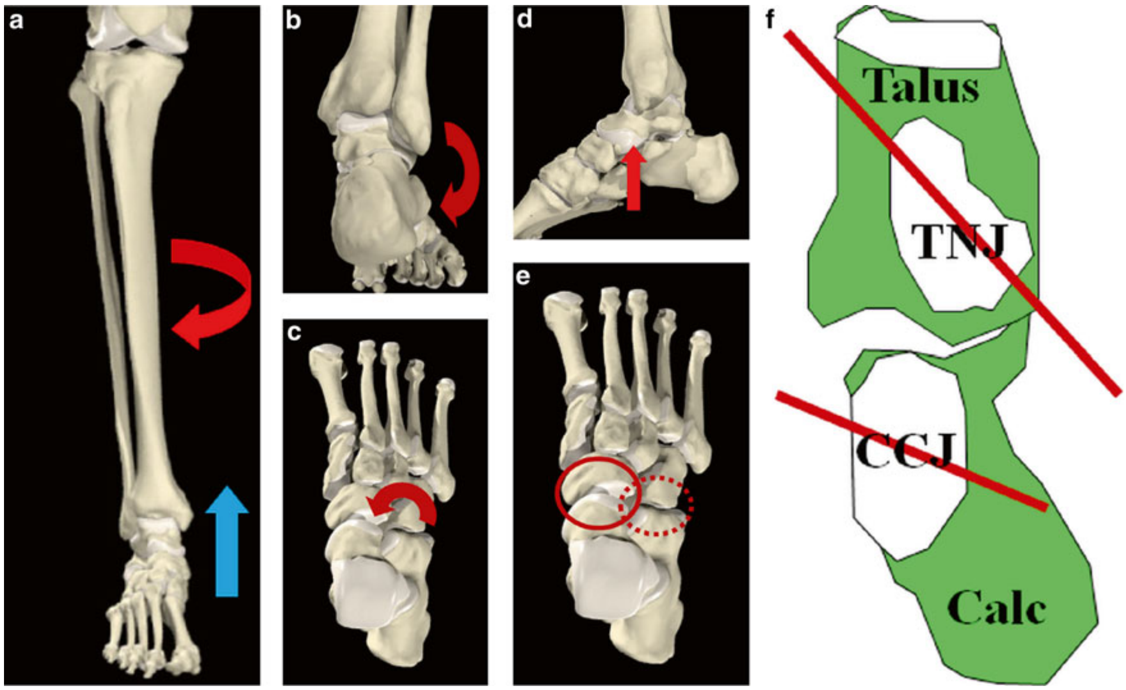

Fig. 10.4 Skeletal alignment of the lower extremity during the second rocker of stance phase. (**a**) The tibia is rotating externally (*red arrow*) and the ankle is dorsiflexing (*blue arrow*). (**b**) Hindfoot alignment during the second rocker of stance phase consists of calcaneal inversion (*red arrow*). (**c**) Hindfoot alignment during the second rocker of stance phase consists of calcaneal adduction (*red arrow*). (**d**) Hindfoot supination (inversion and adduction) forces the talus to dorsiflex (*red arrow*) during the second rocker of stance phase. (**e**) This "locks" the primary joints of the midfoot (talo-navicular in *solid circle*, calcaneo-cuboid in *dashed circle*). (**f**) Coronal view of the articulation between the hindfoot and midfoot in second rocker of stance phase. Lateral is to the left, medial is to the right. *TNJ* talo-navicular joint, *CCJ* calcaneocuboid joint, *Calc* calcaneus. The main axes of the TNJ and CCJ are no longer parallel (*red lines*), which restricts motion and "locks" the midfoot

lever arm to the ankle plantar flexor muscles during terminal stance. Normal, expected segmental alignment patterns of the ankle and foot during the stance phase of the gait cycle, as described above, are the consequence of coupled movements between the anatomical segments.

In the swing phase of the normal gait cycle, the foot and ankle contribute to clearance and pre-positioning for the subsequent stance phase [2, 3, 6]. During pre- and initial swing the tibia or shank segment is rotating externally and the ankle is plantar flexing. The segments of the foot are "unlocked" as the limb is unloaded. During mid swing the tibia or shank segment is rotating internally and the ankle is dorsiflexing. These coupled motions serve to functionally shorten the limb and promote clearance. During terminal swing these coupled motions continue and the foot is maintained in a plantigrade alignment, perpendicular to the anatomical axis of the tibia or shank segment. This pre-positioning of the foot during terminal swing will result in a heel strike at the initial contact, which is the optimal alignment for the ankle and foot as the extremity enters the subsequent stance phase in loading response.

Box 10.1

- The lower leg consists of four segments: the tibial or shank segment, the hindfoot (talus and calcaneus), the midfoot (navicular, cuneiforms and cuboid), and the forefoot (metatarsals and phalanges).
- The interaction of the ankle and foot with the ground during the stance phase of the gait cycle is described by the concept of three rockers; first or heel rocker, second or ankle rocker, and third or forefoot rocker.
- In the stance phase of the normal gait cycle, the ankle and foot provide shock absorption during loading response (first or heel rocker), stability during midstance (second or ankle rocker), and a rigid lever during terminal stance (third or forefoot rocker).
- In the swing phase of the normal gait cycle, the foot and ankle contribute to clearance and pre-positioning for the subsequent stance phase.

Segmental Malalignment Patterns of the Ankle and Foot

Segmental malalignments of the ankle and foot may be categorized as coupled or uncoupled. *Coupled* segmental malalignments represent exaggerations of normal segmental alignments that occur during the gait cycle (as described above). The three most common coupled segmental malalignments are equinus, equinoplanovalgus, and equinocavovarus. Equinus is characterized by excessive plantar flexion of the hindfoot relative to the ankle, with normal midfoot and forefoot alignment (Fig. 10.5a, b) Equinoplanovalgus is characterized by equinus deformity of the hindfoot, coupled with pronation deformities of the midfoot and forefoot (Fig. 10.6a, b). The lateral column of the foot is functionally and/or structurally shorter than the medial column. Ankle valgus and hallux valgus deformities are frequently seen in association with equinoplanovalgus foot segmental malalignment (see Fig. 10.6c, d) Equinocavovarus is characterized by equinus deformity of the hindfoot, coupled with supination deformity of the midfoot and variable malalignment of the forefoot (Fig. 10.7a, b) The lateral column is functionally and/or structurally longer than the medial column. Compensatory ankle valgus deformity may be seen in association with equinocavovarus foot segmental malalignment.

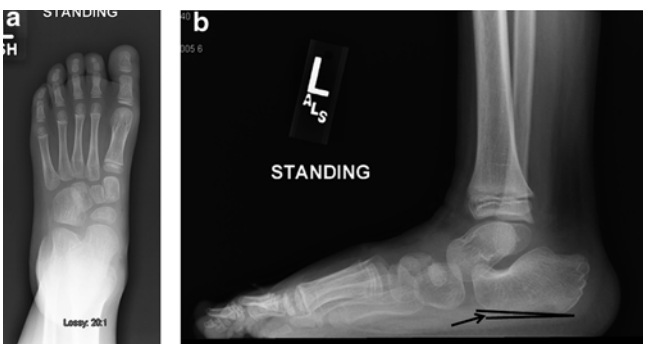

Fig. 10.5 Plain radiographs of the foot in a child with equinus deformity. (**a**) Anteroposterior view shows normal segmental alignment. (**b**) Lateral view shows hindfoot plantarflexion (diminished calcaneal pitch, indicated by *solid arrow* towards angle formed by *solid lines*, normal is approximately 20°), with otherwise normal segmental alignment

In all three coupled segmental malalignment patterns, heel strike at initial contact does not occur, disrupting the first or hindfoot rocker and shock absorption function in loading response. Equinus and equinocavovarus malalignment patterns disrupt the second or ankle rocker by blocking ankle dorsiflexion, compromising stability function in midstance. Equinoplanovalgus malalignment maintains the mid- and forefoot segments in an "unlocked" alignment, compromising stability function in midstance, which may result in excessive loading of the plantar, medial portion of the midfoot. All three coupled segmental malalignments may compromise the ability of the ankle plantar flexor muscles to generate an adequate internal plantar flexion moment during third or forefoot rocker. The hindfoot malalignment associated with equinus and equinocavovarus malalignment patterns shortens the length of the plantar flexor muscles, compromising their ability to generate tension, as described by the length-tension curve for skeletal muscle [10, 11]. With equinoplanovalgus, the moment generating capacity of the ankle plantarflexor muscles is further compromised by the malalignment of mid-and forefoot segments, which effectively shortens the lever arm available to this muscle group during the third or forefoot rocker. All three segmental malalignment patterns of the ankle and foot may inhibit ankle dorsiflexion in swing phase, compromising clearance in midswing and proper positioning of the foot and ankle in terminal swing.

Uncoupled segmental malalignments are alignment patterns between the hind-, mid-, and forefoot that never occur during the gait cycle. Equinocavovalgus is an example of an uncoupled segmental malalignment pattern (Fig. 10.8a, b). Uncoupled segmental malalignments of the ankle and foot are relatively uncommon, and are frequently the consequence of deformity following previous surgery.

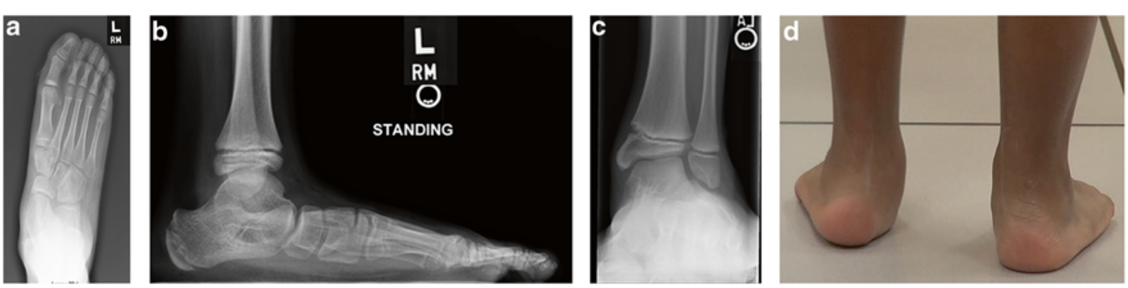

Fig. 10.6 Plain radiographs of the foot in a child with equinoplanovalgus deformity. (**a**) Anteroposterior view shows hindfoot pronation, talonavicular uncoverage, forefoot abduction and hallux valgus. (**b**) Lateral view shows hindfoot plantarflextion, midfoot pronation (excessive naviculocuboid overlap), and forefoot pronation (excessive overlap of the metatarsals). (**c**) Anteroposterior view of the ankle shows ankle valgus deformity (increased tibiotalar angle, lateral wedging of the distal tibial epiphysis, and a high fibular station). (**d**) Clinical photograph of the left hindfoot in weight-bearing for this child. There is significant hindfoot valgus deformity, which the radiographs show to be a consequence of both tibiotalar (ankle) and talo-calcaneal (subtalar) valgus malalignments

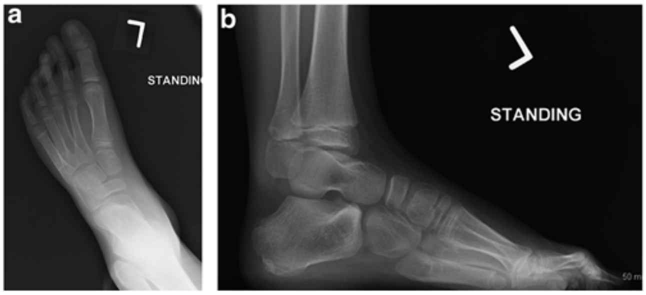

Fig. 10.7 Plain radiographs of the foot in a child with equinocavovarus deformity. (**a**) Anteroposterior view shows hindfoot supination (excessive overlap of the talus and calcaneus), and forefoot adduction (medial deviation of the great toe metatarsal relative to the talus). (**b**) Lateral view shows hindfoot varus (parallelism of the talus and calcaneus), midfoot supination (diminished naviculocuboid overlap), and forefoot supination (excessive stacking of the metatarsals)

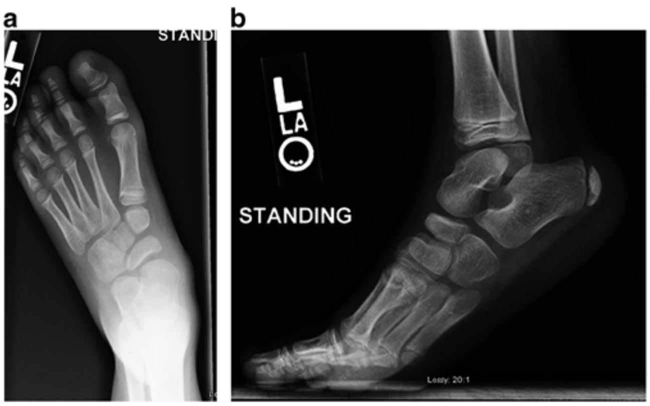

Fig. 10.8 Plain radiographs of the foot in a child with equinocavovalgus deformity, which is an example of an uncoupled malalignment. (**a**) Anteroposterior view shows hindfoot pronation, talonavicular uncoverage, forefoot abduction and hallux valgus interphalangeus. (**b**) Lateral view shows hindfoot varus (parallelism of the talus and calcaneus), midfoot supination (diminished naviculocuboid overlap), and forefoot supination (excessive stacking of the metatarsals). The normal coupling between the three segments of the foot is disrupted, as shown by the dissonance between anteroposterior and lateral radiographic views

Box 10.2

- Segmental malalignments of the ankle and foot may be categorized as coupled or uncoupled. *Coupled* segmental malalignments represent exaggerations of normal segmental alignments that occur during the gait cycle. *Uncoupled* segmental malalignments are alignment patterns between the three segments of the foot that never occur during the gait cycle.
- The three most common coupled segmental malalignments are equinus, equinoplanovalgus, and equinocavovarus.

Surgical Interventions

Interventions to correct foot deformities in children may be selected to improve function and/or cosmesis. Both of these goals may be achieved by surgeries designed to improve foot shape. It is presumed that improved foot shape following soft tissue and skeletal surgery can restore both the stability function of the foot during the second or ankle rocker in midstance and the skeletal lever arm function of the foot during the third or forefoot rocker in terminal stance [12–15]. However, it is important to recognize that increased foot stiffness associated with many skeletal surgical procedures (e.g., arthrodesis) utilized to improve foot shape may compromise shock absorption function of the foot during the first or ankle rocker in loading response [16]. Cosmetic improvements following foot surgery are related to improved visual assessment of static standing foot alignment (particularly restoration of the medial longitudinal arch and toe alignment) and improved foot progression angle during stance phase.

Soft tissue surgeries include release, lengthening, or shortening of muscles, tendons, ligaments, and joint capsules; or transfer of the muscle tendon unit. Release of soft tissue structures is generally reserved for fixed ankle and foot deformities associated with progressive disease processes in subjects who have significant impairment and whose goals are to improve static alignment in order to promote brace wear, shoe wear, or foot position in a wheelchair, and to facilitate transfer level motor activities. Lengthening of soft tissue structures is appropriate for fixed ankle and foot deformities associated with static or stable disease processes in subjects whose goals are to improve alignment to facilitate dynamic functional motor activities. It is important to recognize that in most cases there is preexisting weakness of the muscle tendon unit that is being lengthened, and that all lengthening surgical procedures result in additional weakening. When operating on muscles and tendons, selective surgical lengthening techniques that minimize the subsequent weakness of the muscle tendon unit are therefore favored [10, 11]. Surgical procedures that partially (also called "split") or completely transfer the muscle tendon unit are reserved for completely dynamic ankle and foot deformities associated with static or stable disease processes in subjects who have relatively lower levels of motor impairment [17–19]. Partial and complete transfers are performed to address a dynamic muscle imbalance. Achieving perfect dynamic balance with all types of tendon transfer can be challenging. Over correction may occur with either partial or complete transfers, and under correction may be seen following partial transfers. Proper patient selection is essential.

Skeletal surgeries include guided growth, osteotomy, and arthrodesis. Guided growth can be utilized to correct ankle valgus deformity and metatarsus/phalangeal deformity

Table 10.2 Levels of ankle and foot deformity and treatment options

Levels of deformity	Treatment options: Pharmacologic/neurosurgery	Muscle tendon surgeries	Skeletal surgeries
I: Dynamic soft tissue imbalance, no skeletal deformities	Neuromuscular junction blockade Selective dorsal rhizotomy Intrathecal baclofen	Partial or complete tendon transfers	Usually not necessary
II: Fixed soft tissue imbalance, no fixed skeletal deformities	Not appropriate as isolated intervention	Sequential lengthening (Myotendinous Junction Recession, Tendon Lengthening)	Usually not necessary
III: Fixed soft tissue imbalance, with structural skeletal deformities	Not appropriate as isolated intervention	Sequential lengthening Appropriate in conjunction with skeletal surgery	Osteotomy or arthrodesis (Lengthening, shortening, angular, rotational)

associated with juvenile hallux valgus [20–22]. Typically two or more years of growth remaining is required to achieve correction by guided growth strategies. Osteotomy and arthrodesis techniques may correct deformity by addition (i.e., lengthening), subtraction (i.e., shortening), angulation, or rotation. Acute skeletal lengthening techniques are preferred as they utilize coupled segmental relations between the segments of the foot to achieve correction [12, 23, 24]. These procedures require a bone graft, and in most cases internal fixation. The use of allograft is favored over autograft, though late allograft collapse during the re-ossification phase of graft incorporation has been reported [25]. Acute skeletal shortening procedures are used for the correction of the most rigid foot deformities, which are usually associated with congenital conditions (e.g., arthrogryposis) or peripheral neuropathies and myopathies (e.g., dystrophin deficient muscular dystrophies).

Clinical decision-making for surgery is guided by the classification of foot deformities into three levels (Table 10.2). Level I deformities are characterized by dynamic soft tissue imbalance. Skeletal anatomy is normal. Level II deformities are characterized by fixed or myostatic soft tissue imbalance. However, the underlying skeletal segmental malalignments are flexible and correctable on manipulation. Level III deformities are characterized by structural skeletal deformities that are usually associated with fixed or myostatic soft tissue imbalance. For foot deformities associated central nervous system conditions (e.g., cerebral palsy) it is not always possible to determine preoperatively if the deformity is level II or III. In such cases, sequential soft tissue lengthening is performed first, followed by intraoperative assessment of segmental foot alignment with stress radiographs under fluoroscopy (Fig. 10.9). If correction of alignment is determined to be insufficient, then sequential skeletal surgery, focused on the segment(s) that remain malaligned is performed.

Fig. 10.9 Intraoperative clinical photograph of the use of a "foot pusher" to achieve simulated weight bearing lateral radiographs

Box 10.3

- *Soft tissue surgeries* include release, lengthening, or shortening of muscles, tendons, ligaments, and joint capsules; or transfer of the muscle tendon unit.
- *Skeletal surgeries* include guided growth, osteotomy, and arthrodesis.
- *Clinical decision-making for surgery* is guided by the classification of foot deformities into three levels

Assessment Tools and Indications

Clinical decision making for the management of ankle and foot deformities in children integrates a range of data by the use of a diagnostic matrix (see Table 10.1) [4]. The integration of data from multiple sources results in a degree of redundancy that improves decision making and quality of outcomes. When the data is consistent across the fields, and the problem is common, the confidence in decision making should be high. When the data is apparently inconsistent across the fields, or the problem is unusual, then the confidence in decision making should be lowered. Surgical treatment paradigms for coupled segmental malalignments of the ankle and foot are more advanced and generally more effective than those for uncoupled segmental malalignments. The latter deformities are individually unique, and therefore require careful, case-by-case surgical planning and treatment.

Different types of ankle and foot deformities are best evaluated with different combinations of assessment tools at different points in the course of management (Table 10.3). Plain radiographic views at all points include standing anteroposterior and lateral views of the foot, and a standing anteroposterior view of the ankle. Additional views of the hindfoot (Cobey view) and subtalar joint (Harris heel view), while not part of the routine radiographic assessment paradigm, may be used to further assess for overall hindfoot alignment and the presence of a talocalcaneal coalition. In the case of the latter, computed tomography scan (CT) is required to confirm the diagnosis and for adequate planning prior to surgical management. True or simulated weight bearing is essential; foot segmental alignment may be dramatically different in loaded versus unloaded conditions, and non-weight bearing views are of little value. Qualitative and quantitative assessment of plain radiographs should be done is a systematic fashion, referring to normative data to objectively describe the ankle and foot segmental alignment (Table 10.4) [7, 26]. Accurate assessment of the causes of hindfoot alignment in the coronal plane (i.e., determining the relative contributions of deformity at the tibiotalar and talocalcaneal joints) requires analysis of the anteroposterior radiograph of the ankle in addition to the views of the foot [27] (see Fig. 10.6) For the *preoperative assessment* of the valgus and varus foot, kinematics is limited by the reliance on a single segment foot model that can notaccount for abnormal midfoot alignments [28, 29]. Dynamic electromyography (EMG) is only necessary for feet with dynamic varus deviations, to sort out the relative contributions of the gastrocsoleus complex, the tibialis posterior, and tibialis anterior muscles [30, 31]. Pedobarography is indicated for valgus and varus malalignments [32]. The relation between static standing foot alignment (as indicated by plain radiographs) and dynamic foot loading (as indicated by pedobarography) is complex [33, 34]. The former is not always a good predictor of the latter, and when there is apparent discrepancy between the two modalities, priority should be given to the pedobarograph data as it is a closer measure of actual function [32, 34]. *Intraoperative assessment* relies

Table 10.3 Assessment tools for the ankle/foot

Deformity	Assessment tools						
	History	Physical examination (ROM, OGA)	Standing/stress radiographs	Kinematics	Kinetics	EMG	Pedobarography
	Preoperative						
	Preoperative						
Equinus	X	X	X	X			
Valgus	X	X	X	Limited	X		X
Varus	X	X	X	Limited	X	X	X
	Intraoperative						
Equinus			X				
Valgus			X				
Varus			X				
	Postoperative						
Equinus	X	X	X				
Valgus	X	X	X		X		X
Varus	X	X	X		X		X
	Surveillance						
Equinus	X	X					
Valgus	X	X					
Varus	X	X					

ROM range of motion, *OGA* observational gait analysis, *EMG* electromyography, *X* appropriate tool to use

Table 10.4 Normal radiographic angle measurements [7, 26]

Ankle and foot segments and columns*	Normal mean ±1 SD*	Increased value (>Mean + 1 SD)	Decreased value (<Mean − 1 SD)
Hindfoot			
Tibiotalar Angle (anteroposterior view, degrees)	1.1 ± 3.75	Eversion	Inversion
Calcaneal Pitch (lateral view, degrees)	17 ± 6.0	Calcaneus	Equinus
Tibiocalcaneal Angle (lateral view, degrees)	69 ± 8.4	Equinus	Calcaneus
Talocalcaneal Angle (lateral view, degrees)	49 ± 6.9	Eversion	Inversion
Midfoot			
Naviculocuboid Overlap (anteroposterior view, percentage)	47 ± 13.8	Pronation	Supination
Talonavicular Coverage Angle (anteroposterior view, degrees)	20 ± 9.8	Abduction	Adduction
Lateral Talo-First Metatarsal Angle (lateral view, degrees)	13 ± 7.5	Pronation	Supination
Forefoot			
Anteroposterior Talo-First Metatarsal Angle (anteroposterior view, degrees)	10 ± 7.0	Abduction	Adduction
Metatarsal Stacking Angle (lateral view, degrees)	8.2 ± 9	Supination	Pronation
Columns			
Medial-Lateral Column Ratio (lateral view)	0.9 ± 0.1	Abduction	Adduction

For direction on how to measure each angle or distance ratio on plain radiographs, see reference [7]
* See figure 10.2

primarily on stress radiographs, which requires the use of a "foot pusher" device to obtain simulated weight bearing views of the foot (see Fig. 10.9). *Postoperative assessment*, once recovery, healing, and rehabilitation following surgery have been completed, should be as quantitative as possible, mirroring the preoperative assessment to allow objective assessment of outcome in multiple domains. Finally, *surveillance* is guided by the history and physical examination, with additional assessment tools utilized only if a problem has been identified.

Box 10.4

- Clinical decision making for the management of ankle and foot deformities in children integrates a range of data by the use of a diagnostic matrix, which considers and integrates data from five domains.
- Coupled segmental malalignments are easier to treat surgically than uncoupled segmental malalignments.
- Different types of ankle and foot deformities are best evaluated with different combinations of assessment tools at different points in the course of management

References

1. Davids JR. Normal function of the ankle and foot: biomechanics and quantitative analysis. In: Drennan J, McCarthy J, editors. Drennan's the child's foot and ankle. 2nd ed. Philadelphia, PA: Lippincott Williams and Wilkins; 2009. p. 54–63.
2. Inman VT, Ralston HJ, Todd F. Human walking. Baltimore, MD: Williams & Wilkins; 1981.
3. Perry J. Gait analysis: normal and pathological function. Thorofare, NJ: Slack Inc.; 1992.
4. Davids JR. Orthopaedic treatment of foot deformities. In: Gage J, Schwartz M, Koop S, Novacheck T, editors. The identification and treatment of gait problems in cerebral palsy. 2nd ed. London: MacKeith Press; 2009. p. 514–33.
5. Inman VT. The human foot. Manit Med Rev. 1966;46(8):513–5.
6. Inman VT. The influence of the foot-ankle complex on the proximal skeletal structures. Artif Limbs. 1969;13(1):59–65.
7. Davids JR, Gibson TW, Pugh LI. Quantitative segmental analysis of weight-bearing radiographs of the foot and ankle for children: normal alignment. J Pediatr Orthop. 2005;25(6):769–76.
8. Ponseti IV, El-Khoury GY, Ippolito E, Weinstein SL. A radiographic study of skeletal deformities in treated clubfeet. Clin Orthop. 1981;160:30–42.
9. Gage JR. The clinical use of kinetics for evaluation of pathologic gait in cerebral palsy. Instr Course Lect. 1995;44:507–15.
10. Delp SL, Statler K, Carroll NC. Preserving plantar flexion strength after surgical treatment for contracture of the triceps surae: a computer simulation study. J Orthop Res. 1995;13(1):96–104.
11. Firth GB, McMullan M, Chin T, Ma F, Selber P, Eizenberg N, et al. Lengthening of the gastrocnemius-soleus complex: an anatomical and biomechanical study in human cadavers. J Bone Joint Surg Am. 2013;95(16):1489–96.
12. Davids JR. The foot and ankle in cerebral palsy. Orthop Clin North Am. 2010;41(4):579–93.
13. Mosca VS. The child's foot: principles of management. J Pediatr Orthop. 1998;18(3):281–2.
14. Kadhim M, Holmes Jr L, Miller F. Long-term outcome of planovalgus foot surgical correction in children with cerebral palsy. J Foot Ankle Surg. 2013;52(6):697–703.
15. Shore BJ, Smith KR, Riazi A, Symons SB, Khot A, Graham K. Subtalar fusion for pes valgus in cerebral palsy: results of a modified technique in the setting of single event multilevel surgery. J Pediatr Orthop. 2013;33(4):431–8.
16. Astion DJ, Deland JT, Otis JC, Kenneally S. Motion of the hindfoot after simulated arthrodesis. J Bone Joint Surg Am. 1997;79(2):241–6.
17. Barnes MJ, Herring JA. Combined split anterior tibial-tendon transfer and intramuscular lengthening of the posterior tibial tendon.

Results in patients who have a varus deformity of the foot due to spastic cerebral palsy. J Bone Joint Surg Am. 1991;73(5):734–8.
18. Hoffer MM, Barakat G, Koffman M. 10-year follow-up of split anterior tibial tendon transfer in cerebral palsied patients with spastic equinovarus deformity. J Pediatr Orthop. 1985;5(4):432–4.
19. Scott AC, Scarborough N. The use of dynamic EMG in predicting the outcome of split posterior tibial tendon transfers in spastic hemiplegia. J Pediatr Orthop. 2006;26(6):777–80.
20. Davids JR, McBrayer D, Blackhurst DW. Juvenile hallux valgus deformity: surgical management by lateral hemiepiphyseodesis of the great toe metatarsal. J Pediatr Orthop. 2007;27(7):826–30.
21. Davids JR, Valadie AL, Ferguson RL, Bray 3rd EW, Allen Jr BL. Surgical management of ankle valgus in children: use of a transphyseal medial malleolar screw. J Pediatr Orthop. 1997;17(1):3–8.
22. Stevens PM, Belle RM. Screw epiphysiodesis for ankle valgus. J Pediatr Orthop. 1997;17(1):9–12.
23. Mosca VS. Calcaneal lengthening for valgus deformity of the hindfoot. Results in children who had severe, symptomatic flatfoot and skewfoot. J Bone Joint Surg Am. 1995;77(4):500–12.
24. Yoo WJ, Chung CY, Choi IH, Cho TJ, Kim DH. Calcaneal lengthening for the planovalgus foot deformity in children with cerebral palsy. J Pediatr Orthop. 2005;25(6):781–5.
25. Danko AM, Allen Jr B, Pugh L, Stasikelis P. Early graft failure in lateral column lengthening. J Pediatr Orthop. 2004;24(6):716–20.
26. Westberry DE, Davids JR, Roush TF, Pugh LI. Qualitative versus quantitative radiographic analysis of foot deformities in children with hemiplegic cerebral palsy. J Pediatr Orthop. 2008;28(3):359–65.
27. Stevens PM. Effect of ankle valgus on radiographic appearance of the hindfoot. J Pediatr Orthop. 1988;8(2):184–6.
28. Davis RB, Jameson EG, Davids JR, Christopher LM, Rogozinski BM, Anderson JP. The design, development, and initial evaluation of a multisegment foot model for routine clinical gait analysis. In: Harris GF, Smith P, Marks R, editors. Foot and ankle motion analysis: clinical treatment and technology. Boca Raton, FL: CRC Press; 2007. p. 425–44.
29. Davis RBOS, Tyburski D, Gage JR. A gait analysis data collection and reduction technique. Hum Mov Sci. 1991;10:575–87.
30. Perry J, Hoffer MM. Preoperative and postoperative dynamic electromyography as an aid in planning tendon transfers in children with cerebral palsy. J Bone Joint Surg Am. 1977;59(4):531–7.
31. Sutherland DH. Varus foot in cerebral palsy: an overview. Instr Course Lect. 1993;42:539–43.
32. Jameson EG, Davids JR, Anderson JP, Davis 3rd RB, Blackhurst DW, Christopher LM. Dynamic pedobarography for children: use of the center of pressure progression. J Pediatr Orthop. 2008;28(2):254–8.
33. Cavanagh PR, Rodgers MM, Iiboshi A. Pressure distribution under symptom-free feet during barefoot standing. Foot Ankle. 1987;7(5):262–76.
34. Westberry DE, Davids JR, Anderson JP, Pugh LI, Davis RB, Hardin JW. The operative correction of symptomatic flat foot deformities in children: the relationship between static alignment and dynamic loading. Bone Joint J. 2013;95-B(5):706–13.