CHAPTER 1

Growth and Development

This chapter on growth and development is presented first for several important reasons. One of the unique aspects of pediatric care is the dynamic evolution of the patient from neonate to adolescent. During this period a remarkable process of growth and development takes place in gross and fine motor skills; intellectual, social, and verbal skills; body size; gait; and sexual characteristics.

Growth refers to an increase in an individual's total body size or to an increase in the physical size of a particular organ or organ system.[9,17] References to normal human growth parameters from third trimester to adulthood are provided in *Proceedings of the Greenwood Genetic Center: Growth References.*[10] This publication also provides parameters for growth patterns seen in specific diseases, such as achondroplasia, diastrophic dysplasia, Down syndrome, Marfan syndrome, and skeletal dysplasias (comparative curves). Growth standards are also available in Hensinger's *Standards in Pediatric Orthopedics.*[7]

Development refers to the physical changes of maturation that occur as a child gets older. The developmental process encompasses other aspects of differentiation of form, but it primarily involves changes in function that transform humans into increasingly more complex beings.[9] Development is influenced by many interrelated factors, including genetics, physical trauma, nutrition, and socioeconomic status.[17]

The age at which children reach specific milestones of development depends on the maturation rate of their central nervous system (CNS), which varies from child to child. Ranges for variations in normal have been developed to assist in the assessment of the pediatric patient, with the most commonly used being the revised Denver Developmental Screening Test (DDST) (Fig. 1–1).[5–7] It is important to know when a child should normally achieve expected milestones of growth and development so that potentially abnormal situations are evident to the physician when taking a patient's history and performing a physical examination.

The significance of various findings must be related to the child's particular stage of growth and development. While no one should expect a 4-month-old infant to be walking, it is distinctly abnormal for an 18-month-old child not to be ambulating. Similarly, a 12-month-old child is likely to have some degree of genu varum, whereas the presence of genu varum in a 3-year-old child should be cause for concern and a focus of further investigation.

Normal Growth and Development

Neonates are primarily reflexive in nature, but they do exhibit some cognitive traits.[8] These traits include showing more curiosity in facelike figures than in other figures of comparable brightness, and a preference for black-and-white tones rather than gray. They should turn their eyes toward sound and be able to distinguish their mother from other people.

The normal neonate is born with a predominant flexor tone, and physiologic flexion contractures are typical (Fig. 1–2). At birth, the newborn's limbs are maintained in flexion posture, and passive movement of the extremities and neck will elicit strong flexor tone. A normal neonate's limbs will move in an alternating fashion when they are stimulated.

Normal development progresses cephalocaudally, with infants acquiring the ability to control their head and hands before they are able to control their legs.[8] During the first few months, gaining head control predominates. Hand control follows, such as the ability to grasp objects. As development continues, the infant gains more and more control of the legs.

To determine whether an infant's growth and development are progressing normally, the examiner needs to find out from the parents what developmental milestones the child has attained and when, and compare them with the norms. If the child appears to have developmental delays, referral to a physician who specializes in growth and development problems is called for.

Because there are wide variations in the times at which developmental milestones are achieved and numerous reasons for delays, the diagnosis of developmental delay can be difficult to make. In addition, a child may exhibit delay in acquiring certain skills and unusual rapidity in acquiring others. When a delay is evident, the physician must determine the cause, which may be a neuromuscular condition. Factors suggesting a neurologic cause include failure of nor-

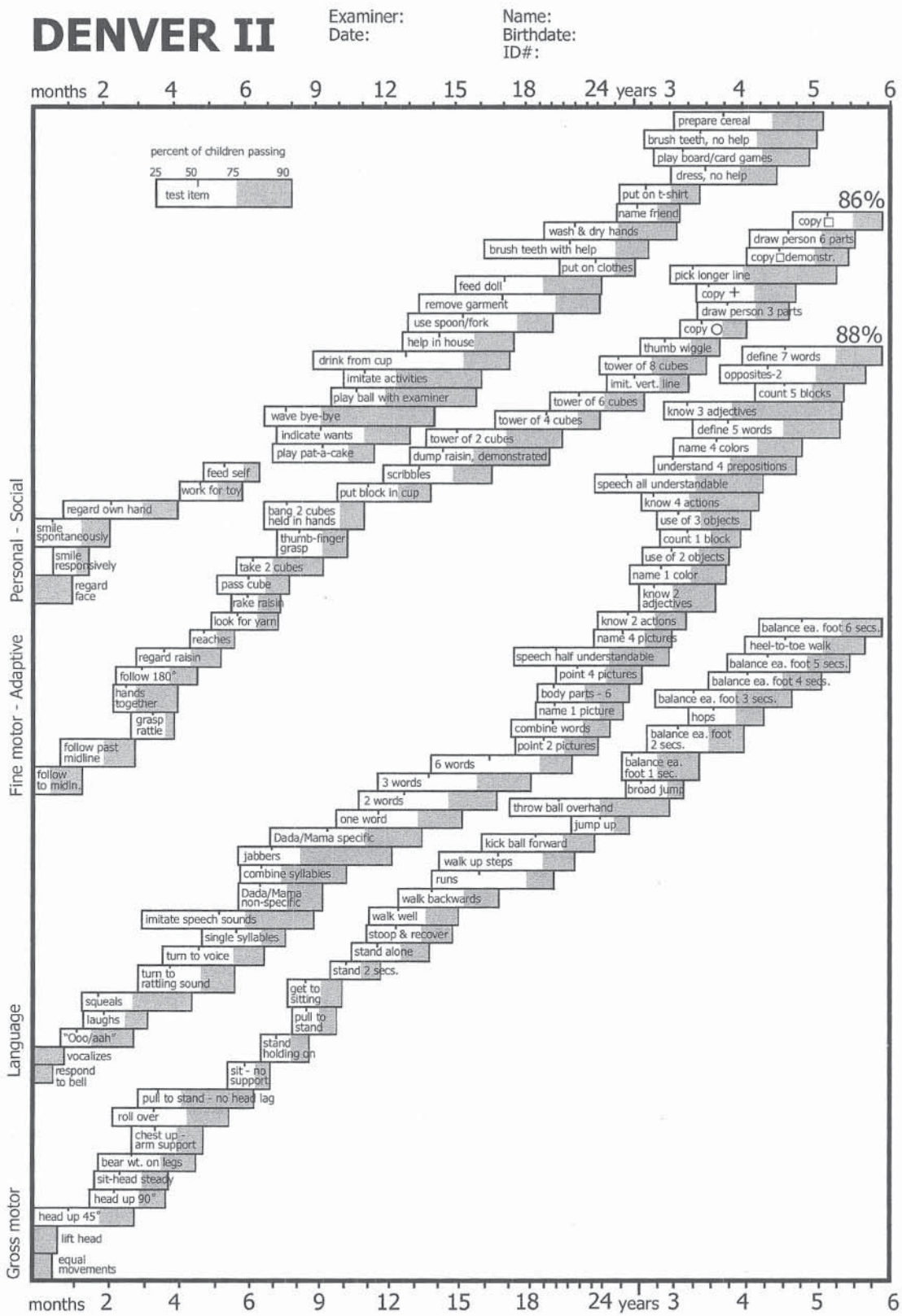

FIGURE 1–1 The revised Denver Developmental Screening Test showing the range of age when a child should achieve milestones in the development of gross motor skills, fine motor-adaptive skills, language, and personal-social skills. (Modified from Frankenburg WK, Dodds JB: The Denver Developmental Screening Test. J Pediatr 1967;71:181, and Hensinger RN: Standards in Pediatric Orthopedics. New York, Raven Press, 1986.)

FIGURE 1–2 Typical position of the neonate with vertex presentation. The hips and knees are flexed, the lower legs are rotated internally, and the feet are rotated further inward on the lower leg. The lower limbs are contracted into this position for a variable period after birth.

mal developmental responses to appear, prolonged retention of primitive infant reflexes, or a delay in the ability to walk.

Disorders of Normal Growth and Development

Many pediatric orthopaedic problems are due to disorders or conditions that adversely affect normal growth and development. The four major failures of normal growth and development are malformations, deformations, disruptions, and dysplasias.[4,12]

MALFORMATIONS

Malformations are structural defects that result from interruption of normal organogenesis during the second month of gestation. Examples include myelomeningocele, syndactyly, preaxial polydactyly, Poland's syndrome, and proximal focal femoral deficiency (congenital femoral deficiency).

DEFORMATIONS

Deformations are defects in the form, shape, or site of body parts caused by mechanical stress. The mechanical stress, which may be intrinsic or extrinsic, alters or distorts tissues. Because the fetus grows considerably faster than the infant, fetuses are more vulnerable to deformations. Examples include supple metatarsus adductus, calcaneovalgus feet, congenital knee hyperextension, and physiologic bowing of the tibia.

It is important to differentiate deformations from malformations. During a cursory examination, severe deformations may look like malformations.[3] Careful assessment is essential if the child is to receive appropriate care for the condition. Malformations cannot be corrected directly, whereas deformations can often be reversed relatively easily either by eliminating the deforming force or by counteracting the force with stretching, casting, or bracing.

DISRUPTIONS

Disruptions are morphologic abnormalities that result from an extrinsic interference with or breakdown of the normal growth and development process. Disruptions can be caused by drugs or toxic materials. These structural defects may affect organs or systems that were normal during organogenesis. Congenital constriction bands in limbs are an example of a disruption.

DYSPLASIAS

Dysplasias are structural defects caused by abnormal tissue differentiation as cells organize into tissues. Examples include osteogenesis imperfecta, achondroplasia, and spondyloepiphyseal dysplasia.

Evolution of Proportionate Body Size

At birth, the neonate's head is disproportionately large, comprising approximately one-quarter of the body's total length. During the first year of infancy, the head continues to grow

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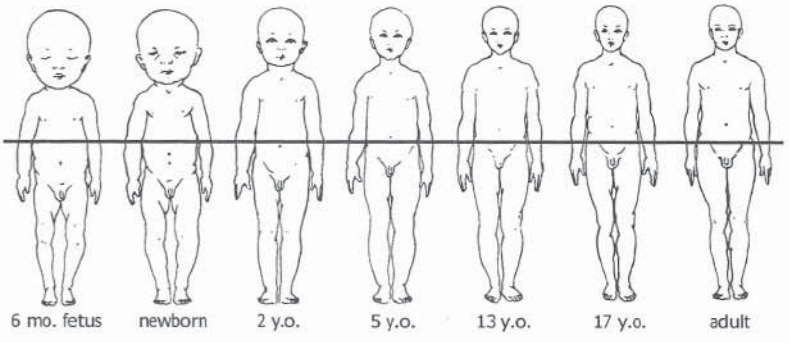

FIGURE 1–3 Evolution of head-to-trunk proportion throughout growth. In the neonate, the head is proportionally significantly larger relative to the trunk than it will be at skeletal maturity. (Reproduced from Hensinger RN: Standards in Pediatric Orthopedics. New York, Raven Press, 1986.)

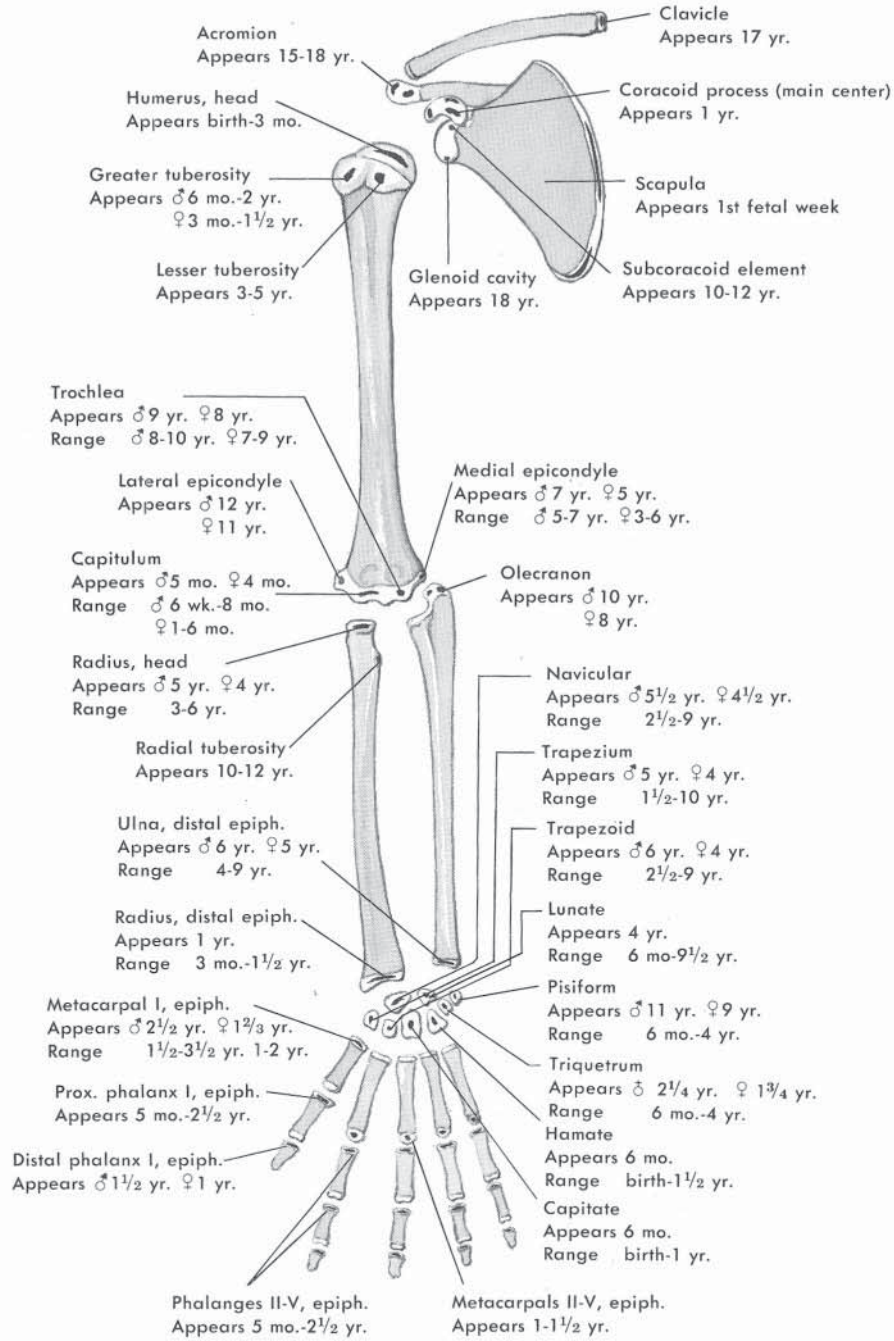

FIGURE 1–4 Average age at appearance of secondary centers of ossification in the epiphyses of the upper extremity, with ranges for boys and girls. (Adapted from von Lanz T, Wachsmuth W: Praktische Anatomie, p 28. Berlin, Julius Springer, 1938.)

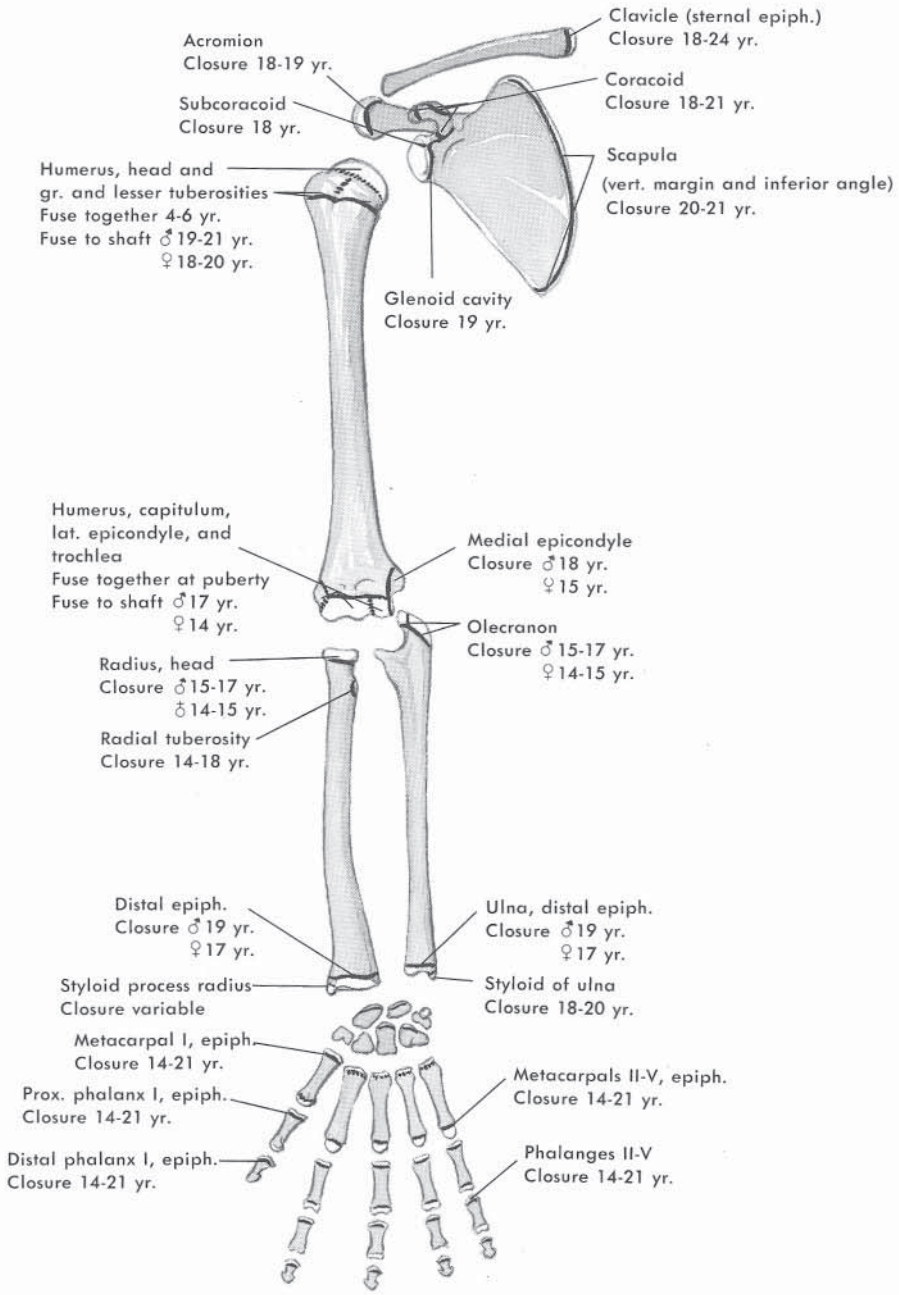

FIGURE 1–5 Average age at closure of growth plates (physes) in the epiphyses of the upper extremity, with ranges for boys and girls. (Adapted from von Lanz T, Wachsmuth W: Praktische Anatomie, p 28. Berlin, Julius Springer, 1938.)

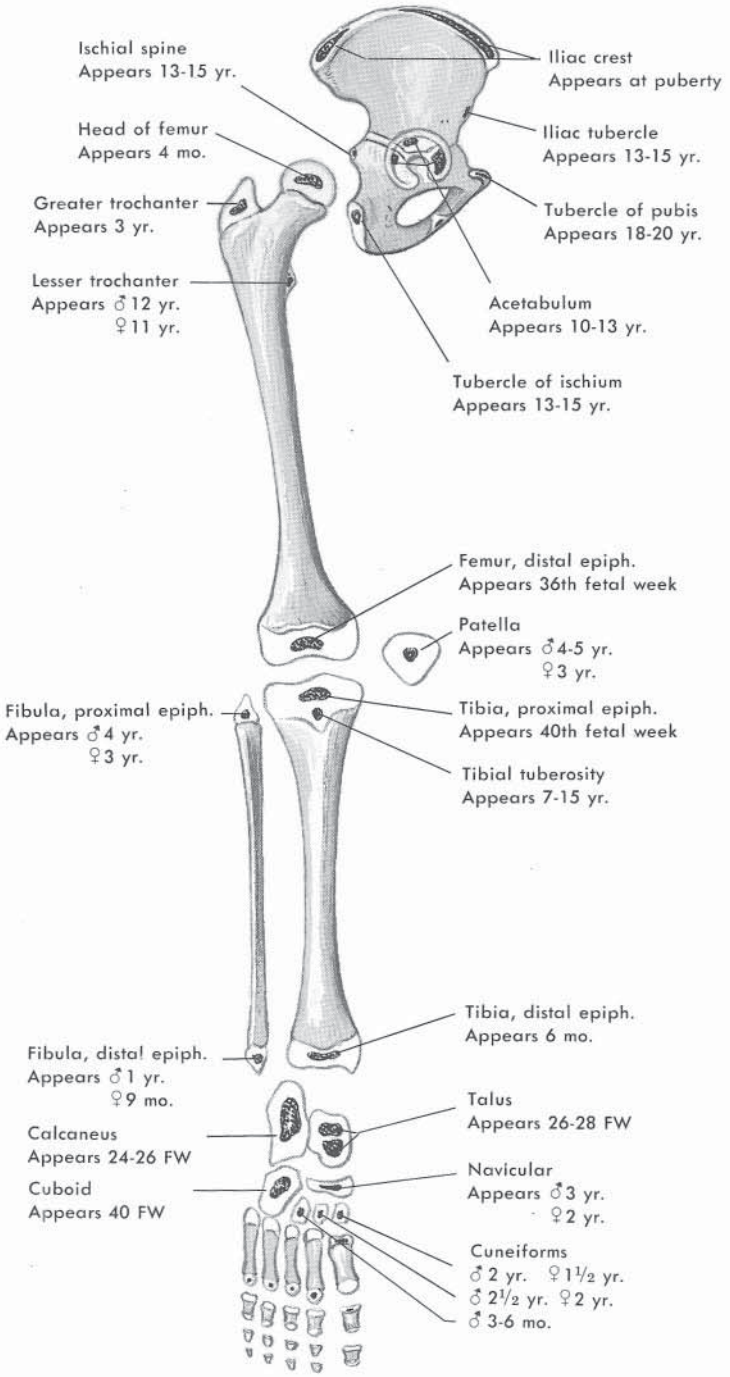

FIGURE 1–6 Average age at appearance of secondary centers of ossification in the epiphyses of the lower extremity, with ranges for boys and girls. (Adapted from von Lanz T, Wachsmuth W: Praktische Anatomie, p 28. Berlin, Julius Springer, 1938.)

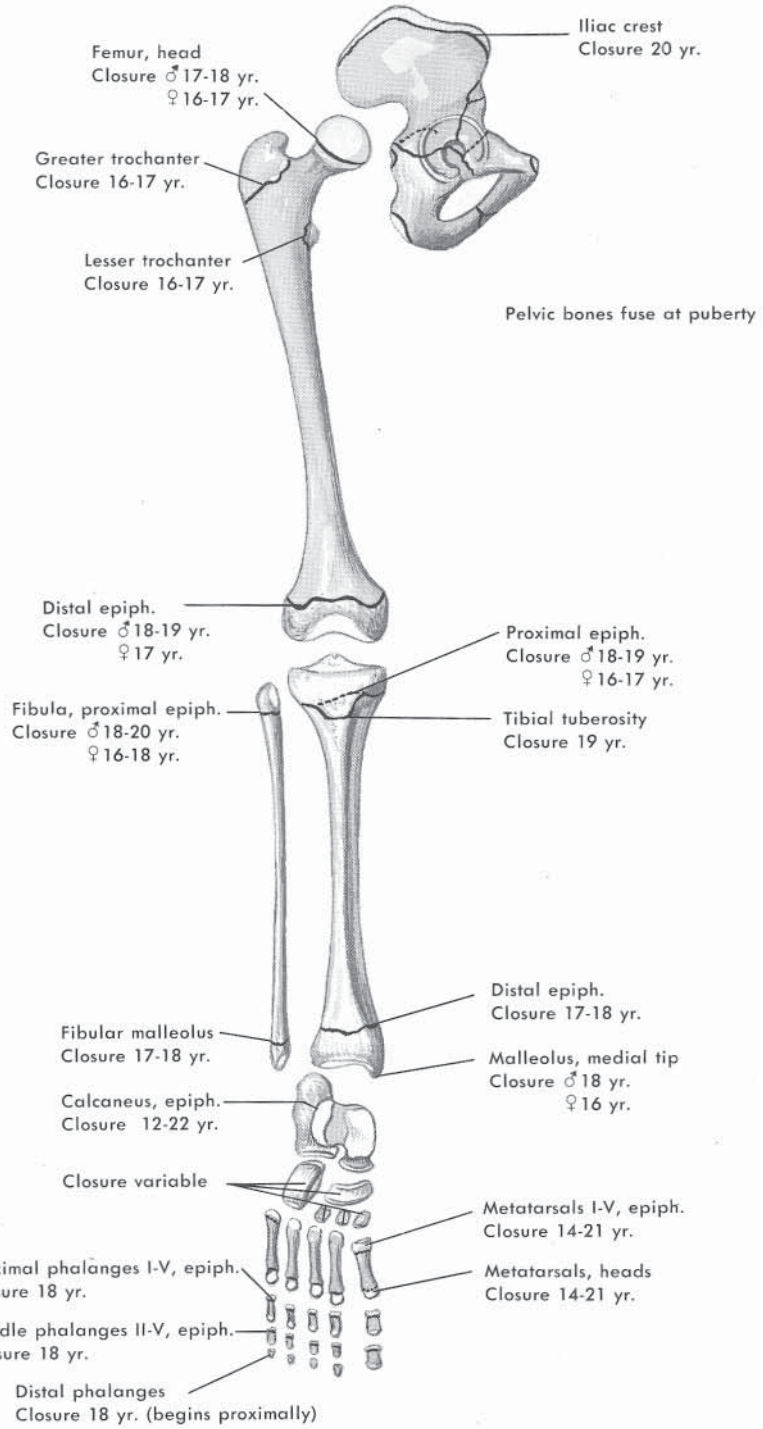

FIGURE 1–7 Average age at closure of growth plate (physis) in the epiphyses of the lower extremity, with ranges for boys and girls. (Adapted from von Lanz T, Wachsmuth W: Praktische Anatomie, p 29. Berlin, Julius Springer, 1938.)

rapidly, and the head circumference usually is greater than the circumference of the infant's chest. The evolution of body proportions is indicated by a change in the child's upper to lower segment ratio (the relation of the center of gravity to body segments). This ratio is measured as the distance from the top of the head to the symphysis pubis divided by the distance from the symphysis pubis to the bottom of the feet (Fig. 1–3).[7] At birth the ratio is approximately 1.7. At around 10 years of age, the upper and lower segments are almost equal in length (i.e., the ratio is about 1.0). After 10 years of age, as individuals become adolescents and adults, the ratio normally becomes less than 1.0, as the upper segment becomes shorter than the lower segment.

Physical Growth

EPIPHYSEAL GROWTH AND CLOSURE

During normal growth and development, there is an orderly pattern in the appearance of centers of ossification and fusion of epiphyses in the upper and lower limbs. This pattern varies among individuals and is different for boys and girls (Figs. 1–4 to 1–7). Thus, it is important for the orthopaedist to understand the ranges of normal when treating the pediatric patient, particularly when interpreting radiographs. The percent contribution of each epiphysis to longitudinal growth of the upper and lower extremity long bones is shown in Figures 1–8 and 1–9.

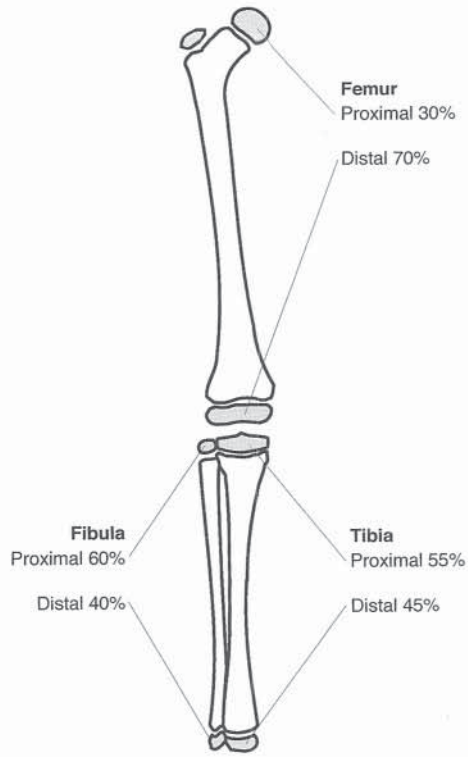

FIGURE 1–9 Average percent contribution of the proximal and distal physes to the longitudinal growth of the lower extremity long bones.

HEAD CIRCUMFERENCE

During infancy, it is essential to obtain individual or serial measurements of the patient's head circumference to determine whether head growth is slower or faster than normal. Head circumference should be measured at every physical examination during the first 2 years and at least biennially thereafter. With the child supine, the examiner places a centimeter tape over the occipital, parietal, and frontal prominences of the head. The tape should be stretched and the reading noted at the point of greatest circumference. Possible conditions that can affect head growth include microcephaly, premature closure of the sutures, hydrocephalus, subdural hematoma, and brain tumor. Head circumference should be charted for age and percentile as noted (Fig. 1–10).

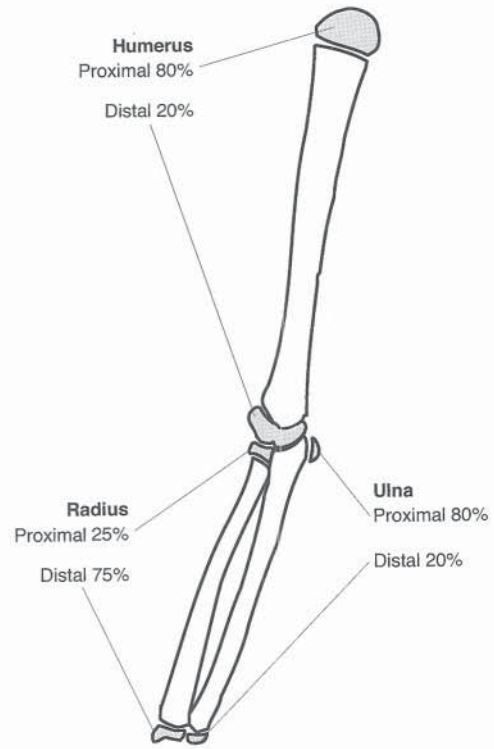

FIGURE 1–8 Average percent contribution of the proximal and distal physes to the longitudinal growth of the upper extremity long bones.

HEIGHT AND WEIGHT

A child's growth, as demonstrated by an increase in body height and weight within predetermined normal limits, is one of the best indicators of health during infancy and childhood. The child's height and weight should be plotted on a standard growth chart to verify that normal progress is being made. Numerous tables, charts, and graphs depicting pediatric growth standards are available in Hensinger's *Standards in Pediatric Orthopedics*[7] and in *Proceedings of the Greenwood Genetic Center: Growth References: Third Trimester to Adulthood.*[10] Height and weight should be charted for age and percentile as noted (Fig. 1–11). If growth measurements are below the third percentile or above the 97th percentile, or if there has been a recent deviation from previously stable percentile rankings, further investigation is called for.

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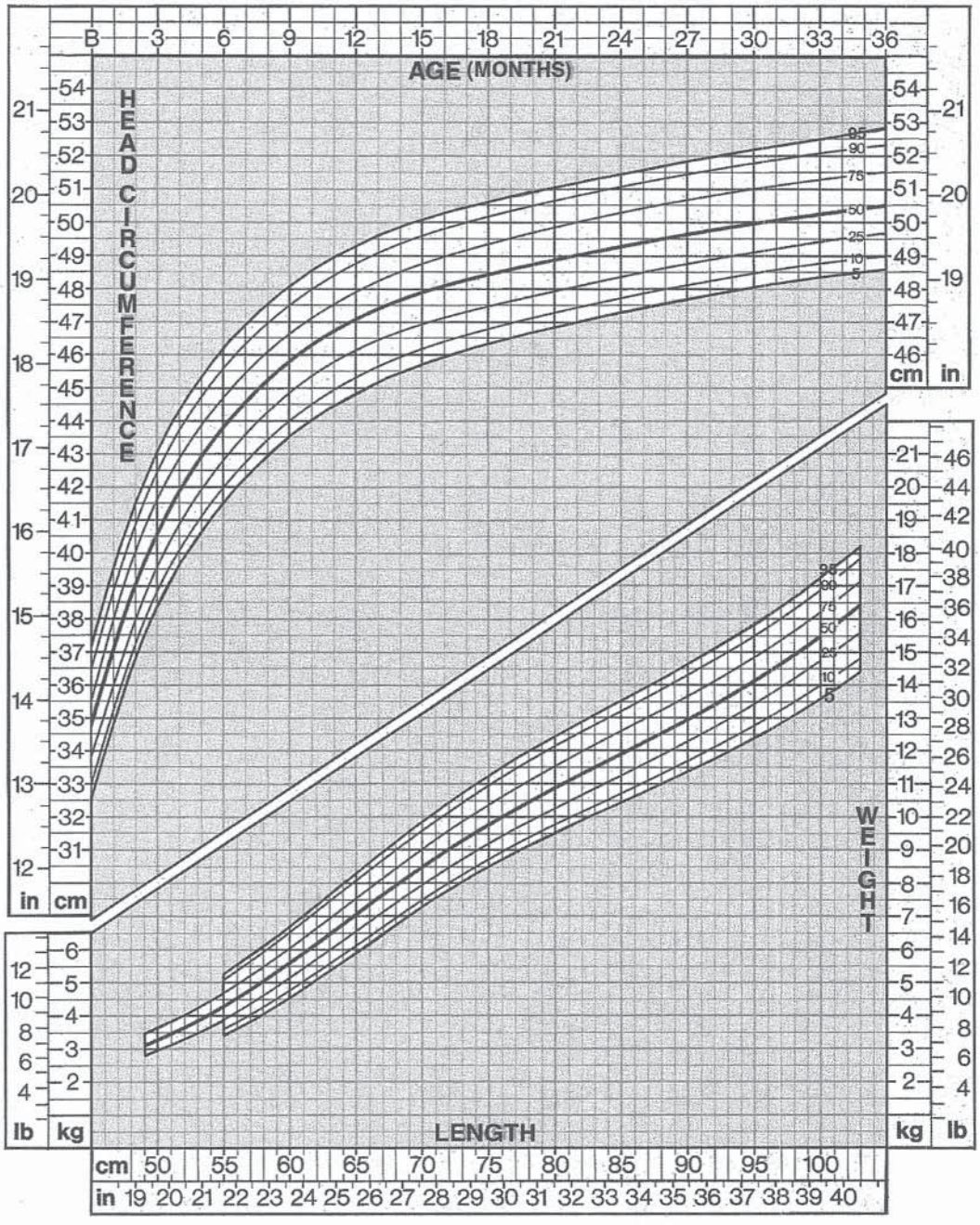
BOYS: BIRTH TO 36 MONTHS
PHYSICAL GROWTH
NCHS PERCENTILES

Name _____ Record # _____



DATE	AGE	LENGTH	WEIGHT	HEAD CIRC.	COMMENT

A

FIGURE 1–10 Normal head circumference parameters for boys and girls from birth to 36 months. **A,** Boys 0 to 36 months.

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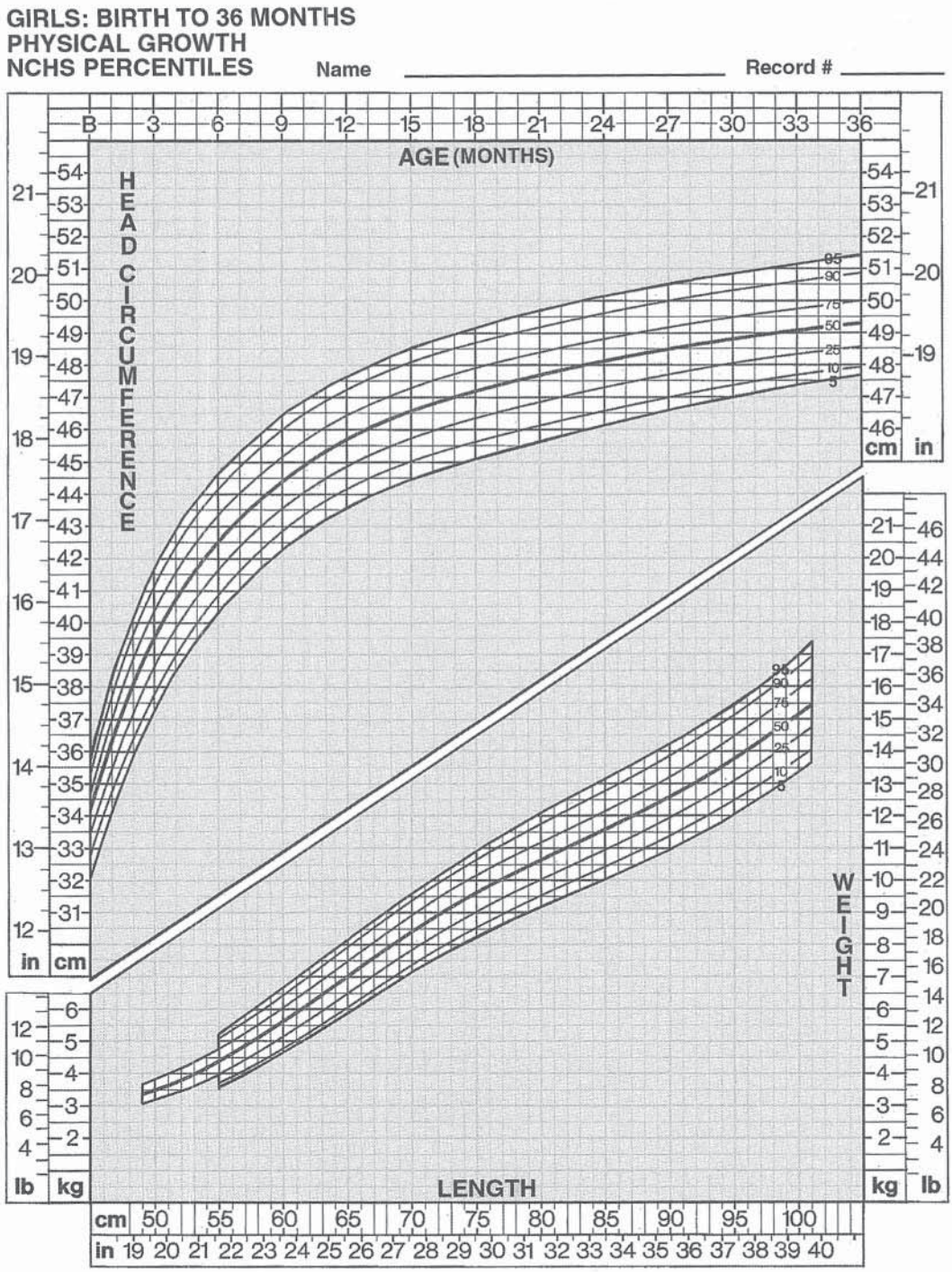
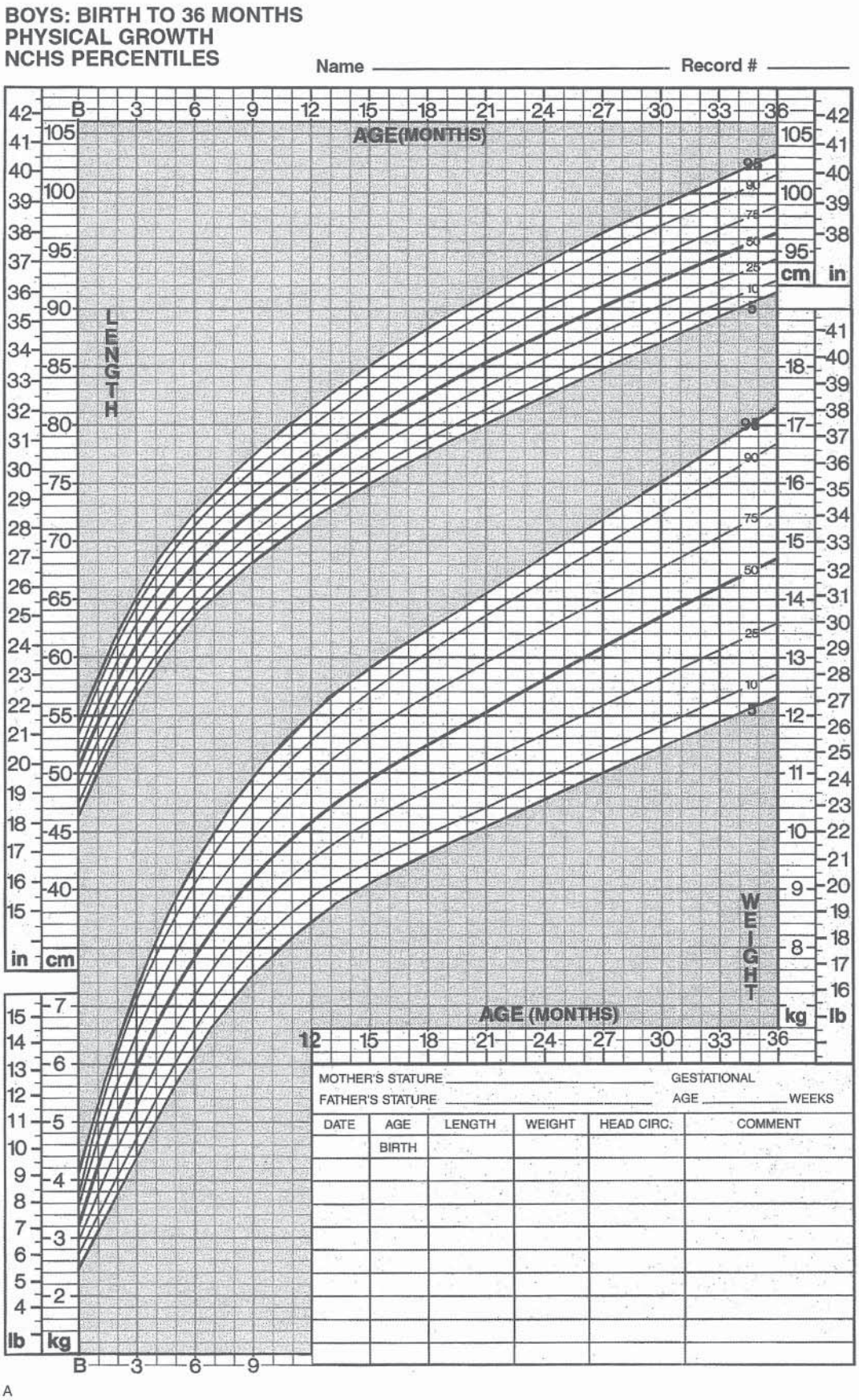


DATE	AGE	LENGTH	WEIGHT	HEAD CIRC.	COMMENT

B

FIGURE 1–10 *Continued.* **B,** Girls 0 to 36 months.



A

FIGURE 1–11 Normal length and weight parameters for boys and girls from birth to 18 years. **A,** Boys 0 to 36 months.

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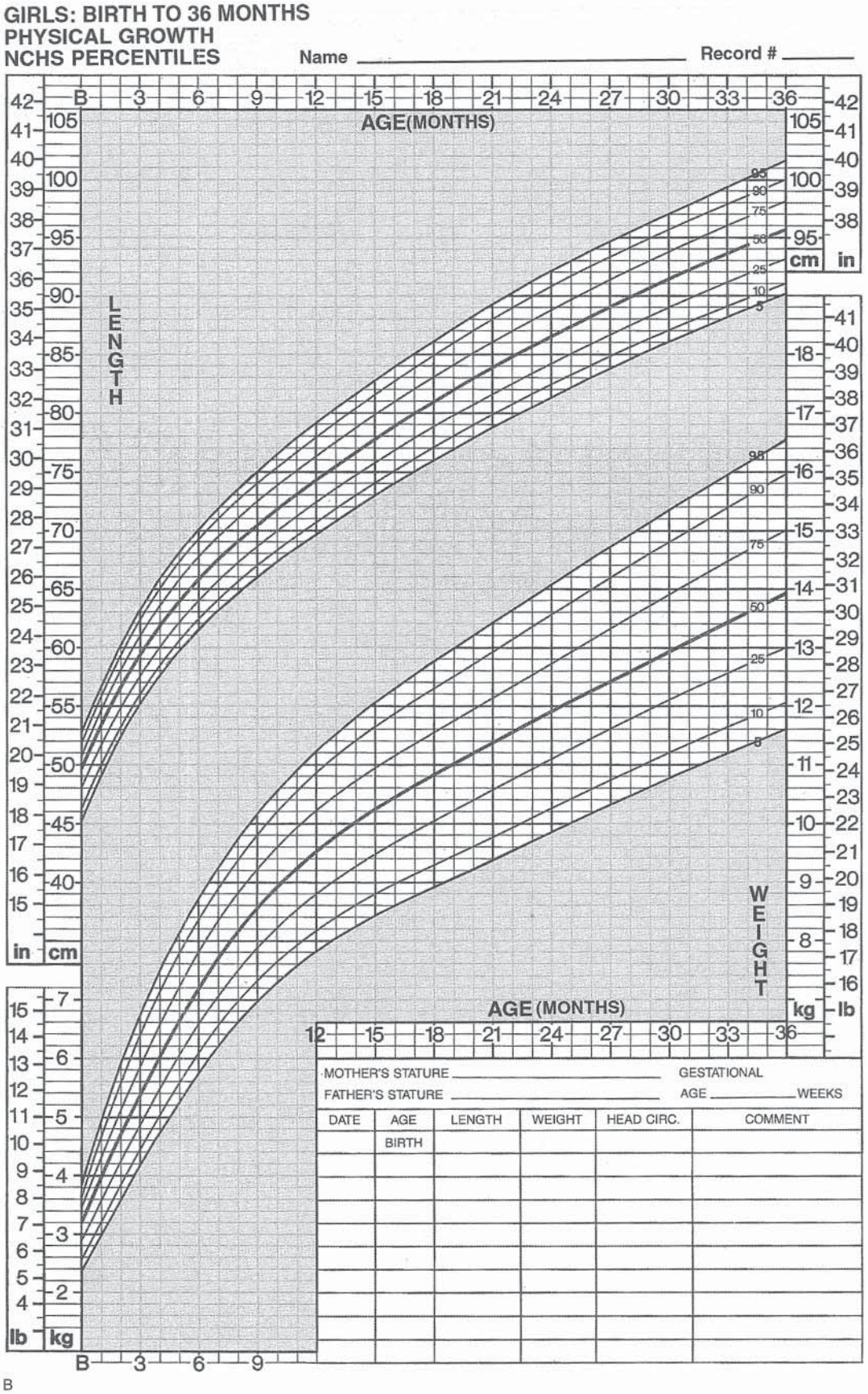
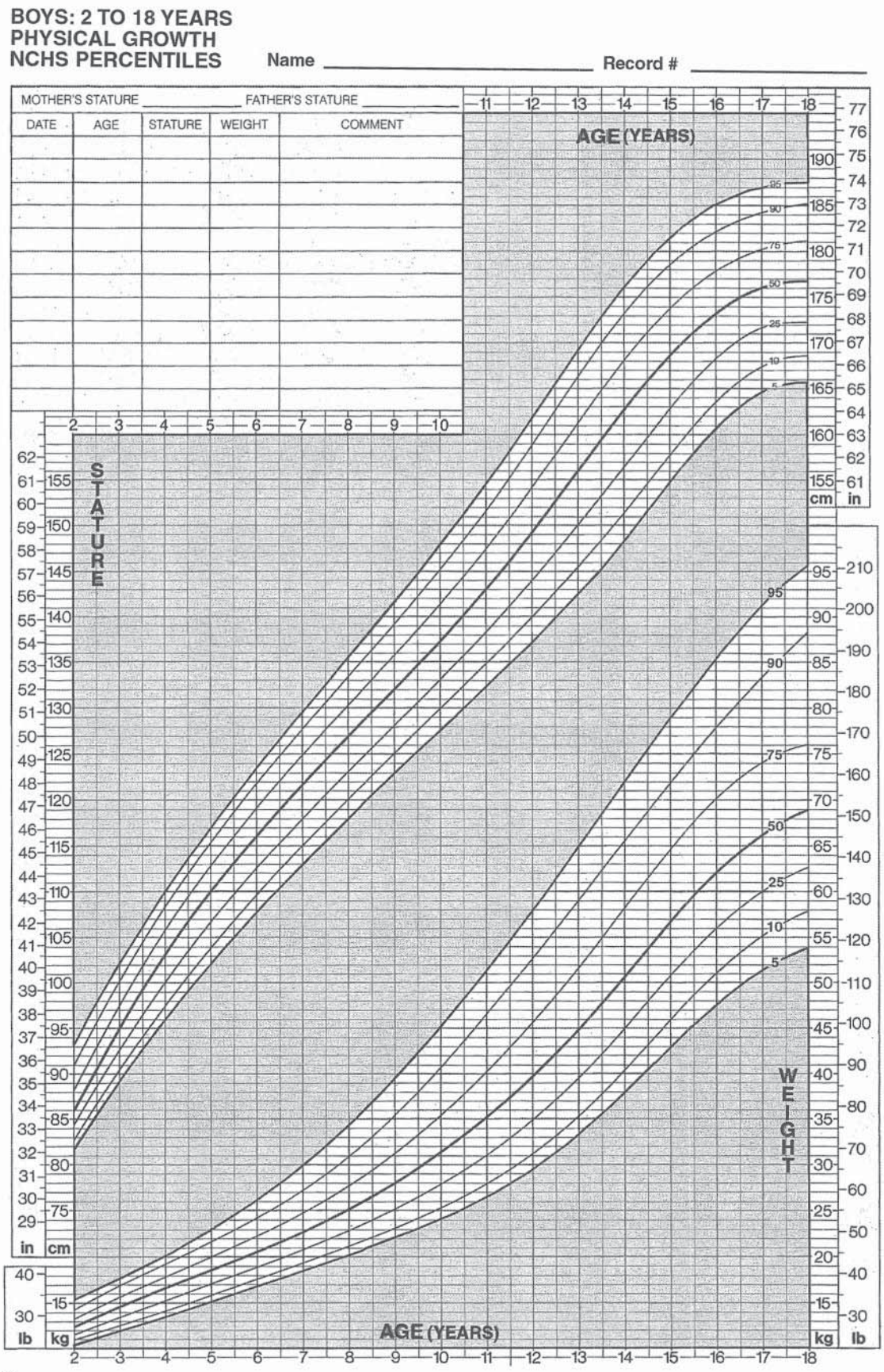


B

FIGURE 1–11 *Continued.* **B,** Girls 0 to 36 months.



C

FIGURE 1–11 *Continued.* **C,** Boys 2 to 18 years.

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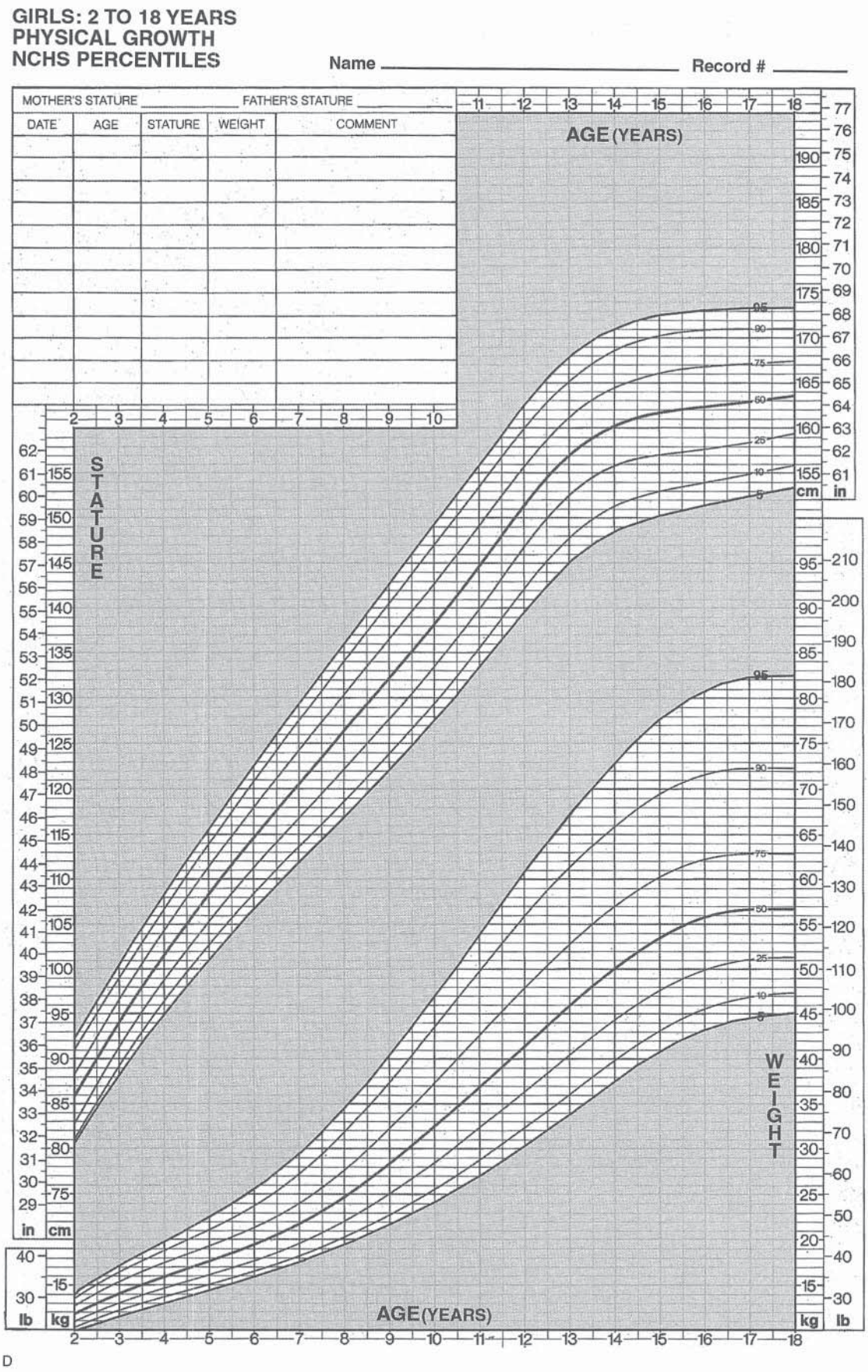
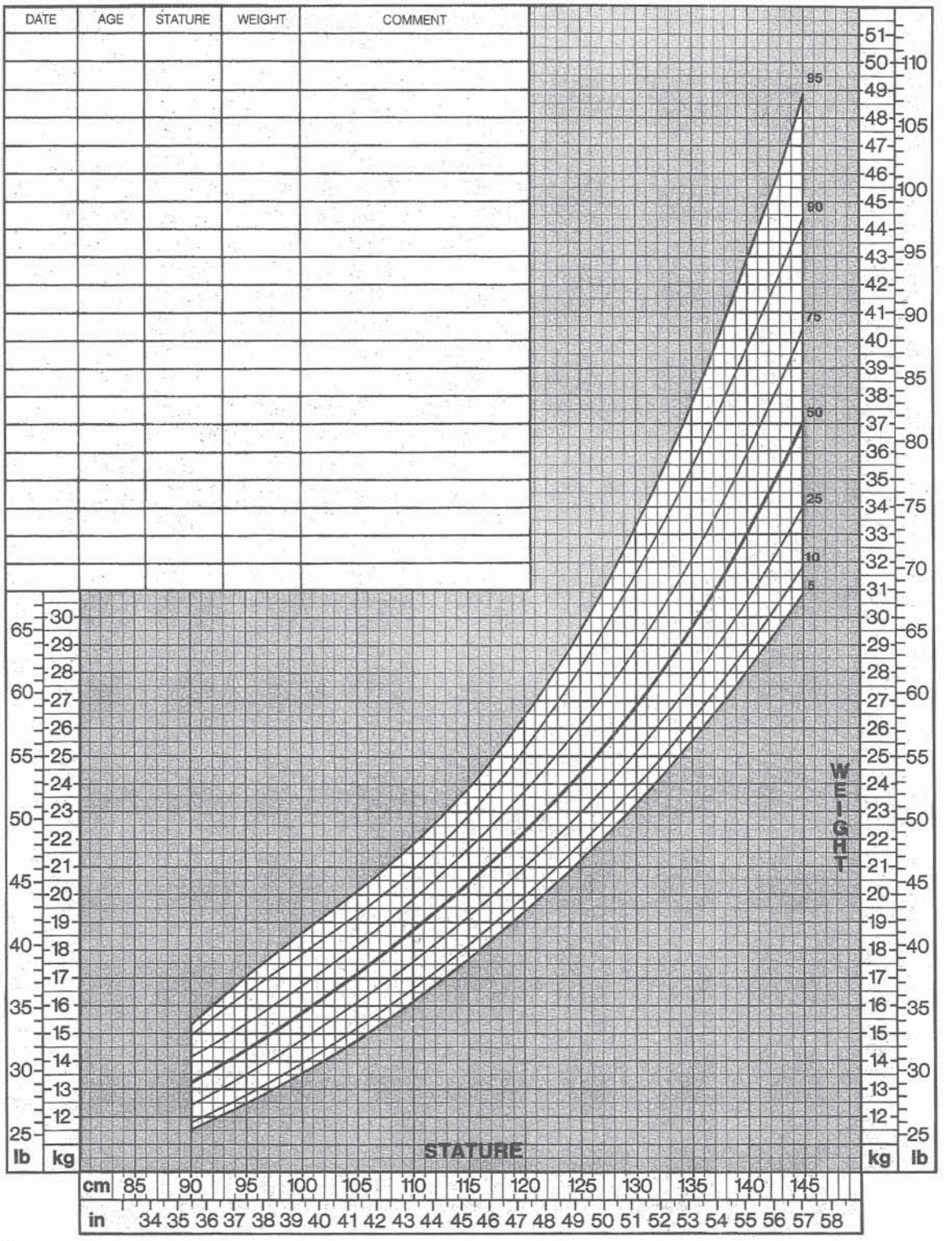


D

FIGURE 1–11 *Continued.* **D,** Girls 2 to 18 years.



E

FIGURE 1–11 *Continued.* **E,** Boys, prepubescent.

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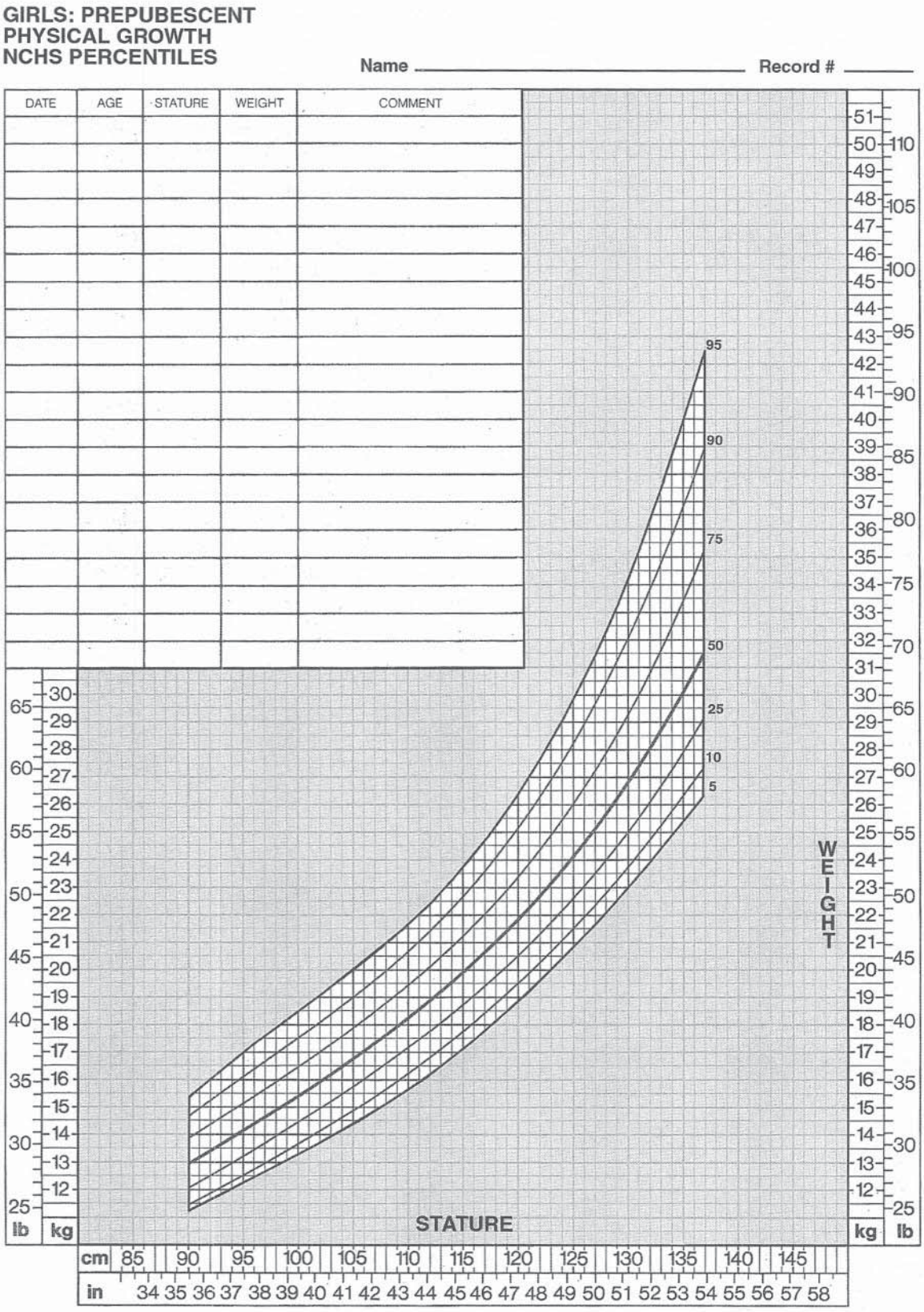

F

FIGURE 1–11 *Continued.* **F,** Girls, prepubescent.

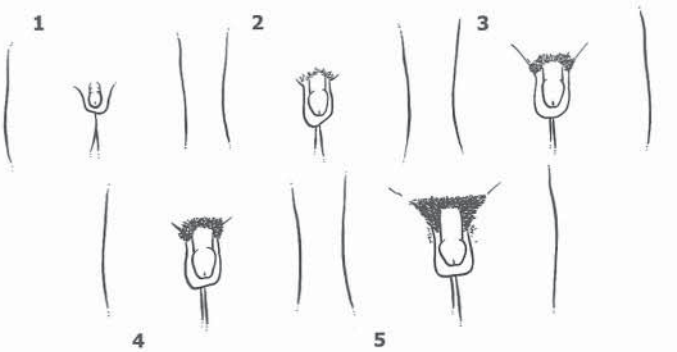

FIGURE 1–12 Tanner's stages of development of secondary sexual characteristics (male).

TANNER'S STAGES OF DEVELOPMENT

The physical maturation of a child can also be compared with his or her chronological age using the pubertal stages of development as described by Tanner (Figs. 1–12 and 1–13).[15,16] The Tanner stages of maturation are based on breast size in girls, genital size in boys, and pubic hair stages for both girls and boys. The onset of menstruation is also an important milestone in the physical maturation of girls.

Developmental Milestones

GROSS MOTOR SKILLS

The development of gross motor skills depends on maturation of the CNS, which proceeds in a cephalocaudal direction.[8] The approximate ages at which children should normally attain various gross motor skills are given in Table 1–1.

By 3 months of age, infants should be able to hold their

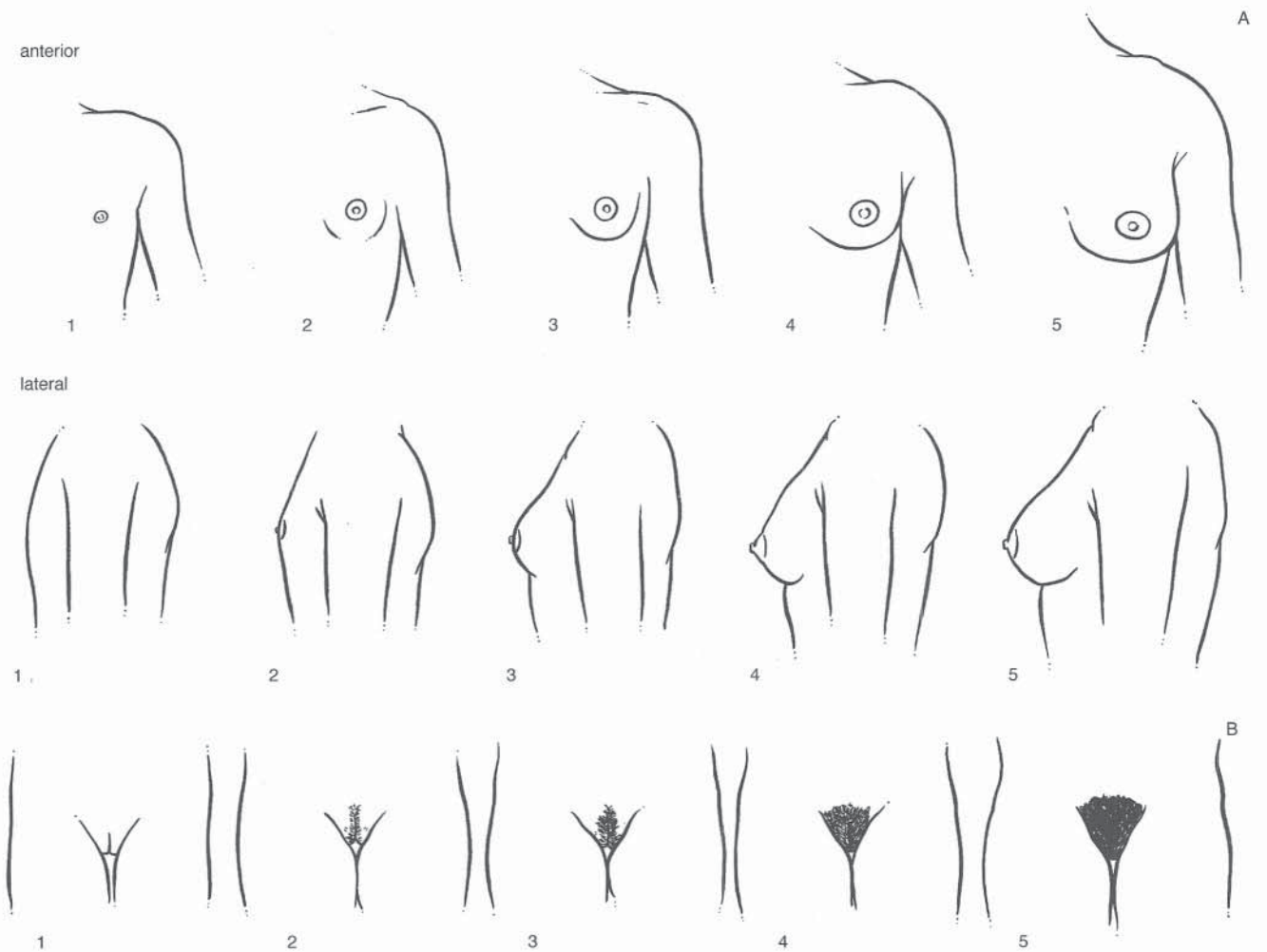

FIGURE 1–13 Tanner's stages of development of secondary sexual characteristics (female). **A,** Breast development; **B,** genital development.

heads above the plane of the body when supported in a prone position. By 6 months of age, the head should not lag when infants are pulled from a supine to a sitting position. Normally, infants will begin to roll over between 4 and 6 months of age and can sit with minimal external support at 6 to 7 months. They should be able to pull up to a standing position by holding on to furniture at 9 to 12 months and stand without support by 14 months.

The average milestones of development of locomotion are as follows: the infant should be able to crawl by 7 to 9 months of age, cruise and walk with assistance at 12 months, walk forward without support by 12 to 16 months, and run at 18 months of age.[1,2,11] Children should be able to ascend stairs with support by 18 months of age and without support by 2 years of age. They should be able to descend stairs with support around 3 years of age and without support by 4 years.

On gross inspection, the independent gait of the infant has a wide base, the hips and knees are hyperflexed, the arms are held in flexion, and the movements are abrupt. With maturation of the neuromuscular system, the width of the base gradually diminishes, the movements become smoother, reciprocal swing of the upper limbs begins, and step length and walking velocity increase.[13] The adult pattern of gait develops between 3 and 5 years of age.[14] A more complete description of normal pediatric gait patterns is provided in Chapter 5, Gait Analysis.

TABLE 1–1 **Developmental Milestones for Gross Motor Skills**

Age	Gross Motor Skills
1 mo	Minimal progress from newborn; may lift head up briefly when supported in prone position
2 mo	Able to maintain head in plane of body when prone; partial head control when pulled from supine to sitting position
3 mo	Can hold head above plane of body when prone
4 mo	Able to lift head and chest off bed with weight on forearms when prone
6 mo	Able to lift head and chest off bed with weight on hands; head does not lag when pulled from supine to sitting position; sits with support; head held steady when sitting; turns head side to side; rolls over; almost full weight on legs when held in standing position
9 mo	Sits without support, legs extended; sits "tailor fashion"—external rotation; sits with legs in internal rotation; pulls self to stand; stands with two-hand support; crawls
12 mo	Leans and recovers balance when sitting; walks with one-hand support
14 mo	Stands without support; walks forward without support; stoops and recovers balance
18 mo	Ascends stairs with two-hand support
2 yr	Ascends stairs without support, one foot at a time; runs forward; jumps in place; kicks ball forward
3 yr	Ascends stairs without support, foot over foot; descends stairs with support, one foot at a time; able to stand briefly on one foot; pedals tricycle
4 yr	Descends stairs without support, foot over foot; beginning to balance on one foot; hops on one foot; able to climb well
5 yr	Hops on one foot without support; skips one foot at a time; forward heel-toe walk
6 yr	Backward heel-toe walk; throws ball up and catches it with one hand

TABLE 1–2 **Developmental Milestones for Fine Motor Skills**

Age	Fine Motor Skills
3 mo	Symmetric head and arm posture in supine position; lip pressure on feeding; coordination of sucking and swallowing
6 mo	Purposefully reaches out and touches objects; palmar grasp of bottle or toy; involuntary release of bottle or toy; hand-to-mouth feeding
9 mo	Extended reach and grasp; uses fingers and thumb to grasp objects; releases object with flexed wrist; transfers object from hand to hand; can feed self cookies; can protrude tongue during feeding
12 mo	Attempts to stack one block on another (brings over and drops); hits two objects together; can voluntarily release object; rolls ball imitatively; puts round block into round hole; puts cube into container; can hold crayon and imitate scribbling; picks spoon up from table; chews cookies or toast; drooling controlled at all times; drinks milk from cup, if cup is held
18 mo	Builds three-block tower (1-inch cube); turns pages (two or three at a time); puts pegs into hole (1-inch diameter); pounds; hurls ball; points to nose, eyes, ears; drinks from cup (one- or two-handed); feeds self with spoon but messily
2 yr	Builds six-block tower; turns pages one at a time; throws bean bags; strings beads (1-inch); throws ball but inaccurately; feeds self semisolid food with spoon; drinks from cup or glass with one hand or straw; imitates vertical, horizontal, and circular writing strokes (but cannot initiate them)
3 yr	Builds nine-block tower; creases paper neatly; rides tricycle; feeds self with fork; tries to use scissors, but cannot follow line
4 yr	Throws ball overhand; copies cross when drawing
5 yr	Bounces ball and catches it; performs three simple directions in sequence; draws recognizable person; colors within 1-inch area; uses scissors, follows line
6 yr	Able to cut food with knife and eat with fork; copies printing (*A, B, C*)

FINE MOTOR SKILLS

The approximate ages at which children normally attain various fine motor skills are listed in Table 1–2. A child's exploration of the environment by touch and the development of manual skills should emerge in an orderly and sequential manner. At 3 months of age, infants can apply lip pressure and coordinate sucking and swallowing when feeding (the *sucking reflex* is present at birth in all normal full-term neonates but usually disappears at 3 to 4 months of age). By 6 months of age, children are able to feed themselves from hand to mouth. By 9 months, children can feed themselves food such as cookies. By 12 months of age, children can pick up a spoon from the table, chew cookies or toast, and drink milk from a cup if assisted. Between 12 and 18 months, they are able to feed themselves (messily) with a spoon and drink from a cup using one or two hands. By 24 months, they can feed themselves semisolid food with a spoon and drink holding the cup in one hand or using a straw.

Children should be able to purposefully grasp objects such as a bottle or toy rattle by 6 months of age. At 9 months of age, children use their fingers and thumb to grasp objects, and are able to transfer objects from one hand to the other. By 12 months, children's hand skills are such that they are

TABLE 1–3 **Developmental Milestones for Personal, Social, and Verbal Skills**

Age	Personal, Social, and Verbal Skills
3 mo	Smiles when spoken to; vocalizes without crying
4 mo	Turns head toward sound; recognizes mother
6 mo	Laughs and smiles spontaneously
10 mo	Responds to "no"; waves bye-bye; plays pat-a-cake; vocalizes *da-da* and *ma-ma* (nonspecific)
12 mo	Begins to show interest in picture books; recognizes familiar objects; starts cooperating with dressing (extends arm for sleeve); able to speak two or more words other than *da-da* or *ma-ma*
18 mo	Removes socks and shoes; vocabularly of 10 words, including names
2 yr	Uses three-word sentences; matches colors
3 yr	Unlaces and removes shoes; learns to lace shoes; takes off pants; dresses self with supervision; puts on shoes (not necessarily on correct foot); tries to wash and dry hands; knows age and sex
4 yr	Puts shoes on correct feet; laces shoes, but does not tie bow; dresses, knows back and front of clothes; manages buttons on self; washes and dries face; brushes and combs hair; brushes teeth; counts three objects correctly
5 yr	Dresses and undresses self completely (except for back fasteners); names four colors; names penny, nickel, dime; counts 10 objects correctly
6 yr	Buttons small buttons on shirt; ties bows on shoes; combs and brushes hair

able to hit two objects together, voluntarily release objects, manipulate and throw objects on the floor, and hold crayons and imitate scribbling. Between 18 and 24 months of age, their hand skills evolve to the point that they can build block towers, turn pages one at a time, and throw a ball (but inaccurately). Between 2 and 3 years of age, their writing skills evolve from imitating vertical, horizontal, and circular strokes to copying circles.

Ambidexterity (i.e., lack of hand preference) is normal during the first 18 to 24 months of age. If an infant demonstrates evidence of hand preference before this time, it may be due to some defect in the hand and arm *not* being used, and attention should be directed to that limb's status. This may be the first sign of spastic hemiplegia.

PERSONAL, SOCIAL, AND VERBAL SKILLS

The approximate ages at which children should normally acquire various personal, social, and verbal skills are provided in Table 1–3. At 2 to 3 months of age, infants smile when spoken to and vocalize without crying. By 4 months, children turn their head to sound and recognize their mother, and at 6 months, they are laughing and smiling. At 8 to 10 months, infants respond to "no." By 10 months, they wave bye-bye, play pat-a-cake, and say *da-da* and *ma-ma*. The sound *a, ba, da-da,* and *ma-ma* represent the earliest phase of speech and communication development, but the sounds do not have any specific meaning to the child at this stage. By 12 months of age, children should begin to show an interest in picture books and recognize familiar objects. At this age, they also start cooperating with dressing, such as extending their arms for sleeves. Between 12 to 15 months of age, children should be able to speak four or five words (other than *da-da* or *ma-ma*), and achieve a vocabulary of 10 words (including names) by 18 months. They should be able to speak three-word sentences by 24 months of age.

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