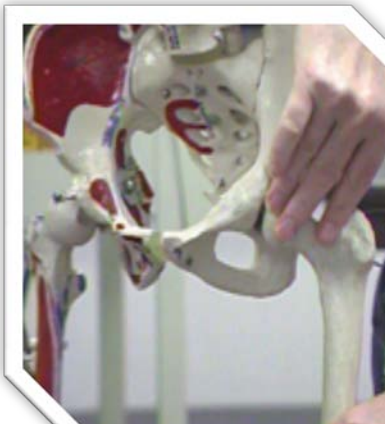
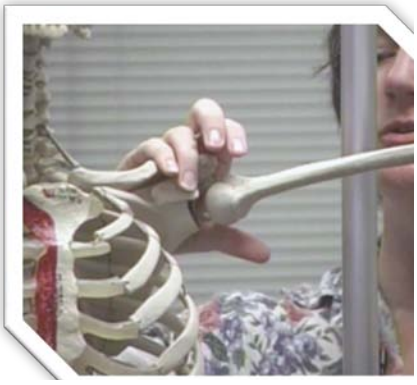
MOBILIZATION

FOR THE NEUROLOGICALLY INVOLVED CHILD

Assessment and Application Strategies For Pediatric PTs and OTs

Sandy Brooks-Scott M.S., PPT, PCS





clinician's view®

www.clinicians-view.com

Chapter I
Pathology and Resultant Immobility

"If change occurs while excess neurons exist, the excess neurons have a possibility of being maintained and reinforced. Unusual connections, functional or not will be the norm for the infant."

Mobility is a worthy goal. However, before it can be achieved in a child with neurological dysfunction, certain prerequisites must be in place: normal bony alignment; normal muscle strength, flexibility and endurance; a coordinating nervous system; an efficient cardiorespiratory system; and normal connective tissue flexibility. Immobility after initial neurological insult affects all these systems, making assessment and treatment of all systems interfering with efficient mobility a paramount goal of the therapist.

Neurological Damage—Original Insult

The motor result of the neurological insult is dependent upon the age, the location, and the extent of the insult (Brann 1988; Costello et al. 1988; Nelson 1988; Pape and Wigglesworth 1979). The most widely discussed reason for brain damage in the pre-, peri- or initial postnatal stages is a change in blood pressure, causing the vessels in the developing organ to hemorrhage or become ischemic (Pape and Wigglesworth 1979). Nelson (1988) notes that most infants who live through severe asphyxia at birth do not develop cerebral palsy or mental retardation. Brann (1988), in his discussion of the effects of acute total and prolonged partial asphyxia, clearly demonstrates that the neurological changes and motor outcomes vary depending on the acuteness, duration, and severity of the asphyxia.

Because a child will not have autoregulatory mechanisms to control blood pressure until 3 months of age, excessive heat loss, abnormal partial pressures of oxygen and carbon dioxide, or fluid imbalances can affect a newborn's blood pressure, producing ischemic hypoxia and neural damage. Hypoxia is a decrease in oxygen to the nerve cell, which can occur as a result of a hemorrhage or ischemic attack. Hemorrhage occurs when blood leaves the vascular system, drowning the nerve cells, and ischemia is a decrease in blood flow to the nerves. Either event decreases the oxygen available to the nerve cell, resulting in its death.

trauma or meningitis than in hypoxic events. Flaccidity may be a result of damage to the cerebellum or peripheral nerves and can be maintained or later overshadowed by spasticity; it should not be confused with muscle weakness. Flaccidity is a decrease in stiffness; conversely, muscle weakness is an inability to create tension sufficient to raise the body part against gravity and age-appropriate resistance. Spasticity is increased stiffness clinically identified as an increased resistance to high velocity muscle stretch. It is a result of neurological damage. Similar stiffness may be mimicked by muscle spasm, emotional state, and connective tissue tightness.

Taken together, the above factors all affect stiffness. Stiffness is a set of behaviors including muscle activation, response to stretch, kinematic patterns, conscious control, fiber patterns, and passive elastic properties of muscles and ligaments (Guiliani 1991). Neurological damage does not cause stiffness, yet stiffness can be affected by it. All factors contributing to stiffness must be ruled out before spasticity is implicated as the cause of the motor problem. Consequently, before movement anomalies can be linked to manifestations of spasticity, the role of the other systems' contributions to stiffness, including spasm, weakness, and connective tissue tightness, must be ruled out. Spasm, weakness, and connective tissue tightness are often sequelae of immobility frequently seen in infants and children with neurological damage.

Immobility and its Effects

Immobility is frequently more detrimental than the damage that causes the immobility in the first place, and it affects all tissues of the body (Kessler and Hertling 1983; Kottke 1966; Salter 1978). Within days of immobility, several physiological changes occur:

- bones lose density
- muscles atrophy and weaken
- synapses deteriorate
- cardiorespiratory inefficiency develops
- connective tissue tightens

Bones Lose Density

Immobility results in calcium loss in bone (Cornwall 1984). Abnormal stresses on weak bones from incorrect joint alignment may be responsible for some of the malformations frequently seen in children with cerebral palsy, such as foot deformities and hip dislocations (Bleck 1987; Cusick 1990). Immobility results in permanent deformity by maintaining infantile bone shape or allowing bones to twist as in some foot deformities or scoliosis (Badgley 1949; Beals 1969; Raney and Brashear 1971; Salter 1978).

Chapter 2
Principles of Mobilization

"To achieve normal joint play when there is a restriction secondary to particular connective tissue tightness, the therapist must consider grades of motion applied in an open-packed position in the direction dictated by the rule of convex and concave."

In the literature on the management of children with cerebral palsy, the focus has been on neurological approaches. No texts have discussed application of mobilization to the management of cerebral palsy. Before mobilization can be applied to the management of cerebral palsy, an overview of mobilization is necessary.

This chapter discusses techniques designed to stretch extra-articular structures of synovial joints. Key concepts to consider in the application of the techniques are joint play, grades of motion, close-packed or open-packed positions, and the rule of convex and concave.

Joint Play

Joint play is the term for the accessory movements that can be passively but not actively performed at the joint (Kessler and Hertling 1983; Maitland 1977) and that enable smooth gliding of joint surfaces. Joint play is achieved when the extra-articular connective tissue structures are flexible enough to allow normal roll and spin of the articular surfaces, a prerequisite for normal active range of motion. To achieve normal joint play, grades of motion are applied in open-pack positions in the direction determined by the rule of convex and concave.

Grades of Motion

Grades of motion are the passive rhythmic oscillations applied to a joint to increase its extra-articular connective tissue flexibility (Kessler and Hertling 1983; Maitland 1977). Choice of grade to use depends on the joint's irritability and degree of restriction. Four

grades of motion are defined (see Figure 2.1). Grades 1 and 2 decrease irritability in inflamed or painful joints, and Grades 3 and 4 increase flexibility in joints with extra-articular joint restrictions. Grades 3 and 4 are frequently used in patients with neurological impairment to increase the flexibility of joint structures that have tightened after immobility. Because these joints are seldom in acute trauma, grades 1 and 2 are used less frequently.

Close-Pack/Open-Pack Positions

In a joint's close-packed position, joint surfaces are maximally congruent; also, capsule and ligaments become twisted, causing the joint surfaces to approximate and lock so maximum stability is achieved (Kessler and Hertling 1983; Maitland 1977). Any other position is open-pack for that joint.

Table 2.1 lists the major joints and their close-packed positions. Notice that all the close-packed positions are positions in which the joint has a stability function (i.e., single limb stance is close-packed).

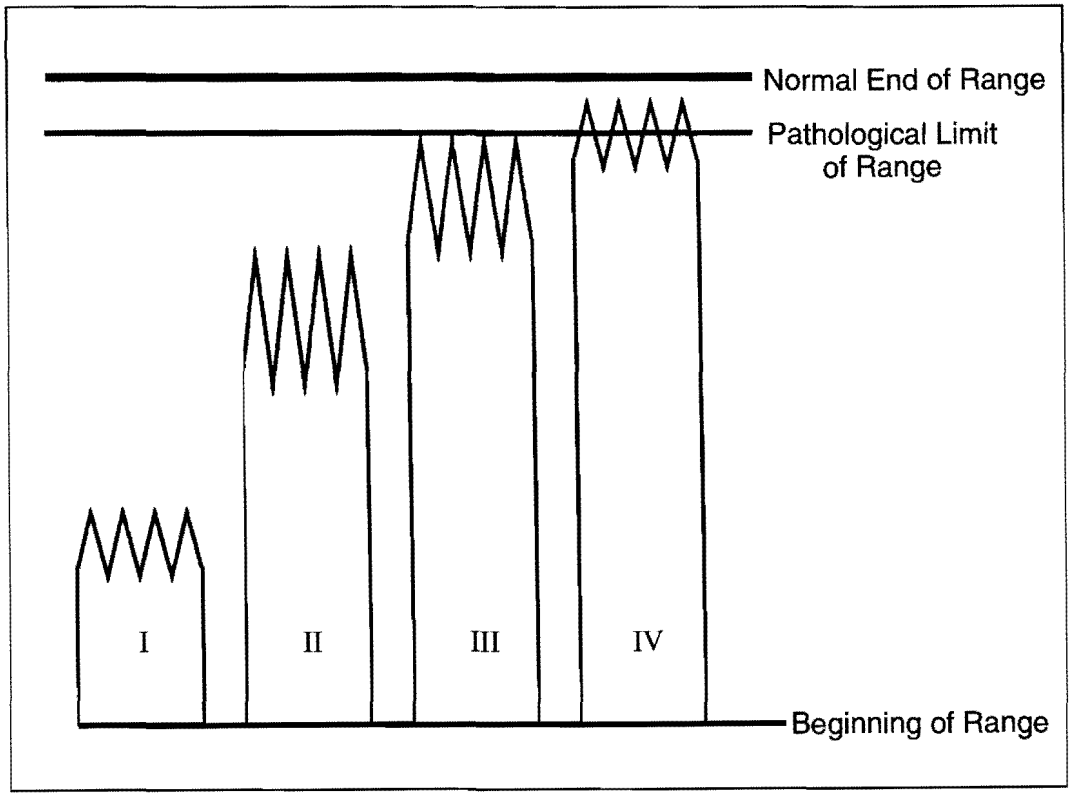


Figure 2.1. Grades of Motion

Table 2.1
Close-Pack Positions for the Joints

Joint	Close-Pack Position
Hip	Full extension with adduction, and internal rotation.
Knee	Full extension with external rotation.
Ankle	Full dorsiflexion for talocrural joint; supination for subtalor and midtarsal joints.
Shoulder	Maximal abduction and external rotation.
Elbow	Full extension/supination for humeroulnar joint; elbow flexion at 90° and supination at 5° for humeroradial joint.
Wrist	Full extension with radial deviation.

Rule of Convex and Concave

The rule of convex and concave determines the direction in which force is applied to achieve a desired range. Articular surfaces move relative to the shafts depending upon whether the convex or concave surface is stabilized or fixed. Hence, if the concave surface is stabilized (as the tibia in non-weightbearing dorsiflexion), the convex articular surface of the talus moves in the opposite direction of the shaft (body) of the talus. Conversely, if the convex talus is fixed (as in standing), the concave surface of the tibia moves in the same direction as the shaft of the tibia to achieve dorsiflexion. Figure 2.2 illustrates this concept. Applying this rule, the head of the talus must glide posteriorly relative to the tibia to achieve ankle dorsiflexion.

Table 2.2 summarizes the major movements used in mobilization for the neurologically impaired client.

Table 2.2
Common Mobilization Techniques for the Neurologically Impaired Child

Desired Motion	Direction of Force
Hip flexion	Femur glides posteriorly and inferiorly.
Hip extension	Femur glides anteriorly.
Hip abduction	Femur glides medially and inferiorly.
Knee extension	If in the last 15° of extension, tibia glides externally; if greater than the last 15° of extension, tibia glides anteriorly.
Knee flexion	If in the last 15° of extension, tibia glides internally; if greater than the last 15° on extension, the tibia glides posteriorly.
Ankle dorsiflexion	Talus glides posteriorly and the fibula and tibia separate at the mortise.
Shoulder flexion	Humerus glides inferiorly, clavicle depresses and rotates at the sternal articulation.
Shoulder abduction	Humerus glides inferiorly, clavicle depresses and rotates at the sternal articulation.
Supination	Head of the radius rotates on the ulna.
Wrist extension	Capitate glides palmarly on the scaphoid, the scaphoid glides dorsally on the lunate, then the scaphoid glides palmarly on the radius.

General Rules of Mobilization

The following are five general rules to observe while using mobilization techniques:

1. The patient must be relaxed.
2. The therapist must be relaxed.
3. One hand stabilizes a body part while the other hand mobilizes its articulating part.
4. The therapist considers the direction of movement, the velocity of movement, and the amplitude of movement.
5. One movement at a time, one joint at a time.

Indications and Contraindications

Joint mobilization is indicated when the extra-articular connective tissue abnormally restricts motion of that joint. For example, babies have a 60-degree hip flexion contracture at birth due to connective tissue tightness (Lee 1977). Many children with cerebral palsy also have a hip flexion contracture due to connective tissue tightness. Mobilization of the hip joint in infants is contraindicated because they have normal limitations and the ability to overcome them with their own oscillatory end-range movements when kicking. Mobilization would be indicated in the older child with cerebral palsy exhibiting abnormal range limitations interfering with function caused by extra-articular tissue tightness.

Contraindications fall into four categories:

1. Risk of fracture. The forces in mobilization can cause fractures in weak bones. Osteogenesis imperfecta or a history of pathological fractures is a contraindication to mobilization.
2. Joint inflammation. Stretching of articular tissue is contraindicated when the tissue itself is under stress such as the stretch from inflammation, as in acute juvenile rheumatoid arthritis.
3. Desired hypomobility. Extra-articular tissue stretching is contraindicated when fixation is required. Mobilization would be contraindicated at the subtalor joint following a triple arthrodesis in a child with cerebral palsy but may be indicated at the talocrural joint subsequent to the immobility from the casting for the surgery.
4. Hypermobility. Excessive mobility in a given direction at a specific joint is a contraindication to mobilization, but the techniques may be appropriate in a different direction at the same joint or in a related joint. For example, it is contraindicated to mobilize the glenohumeral joint in a child with cerebral palsy with a tendency to sublux the glenohumeral joint, but mobilization of the sternoclavicular joint may be indicated to increase shoulder girdle range of motion without stressing the glenohumeral joint.

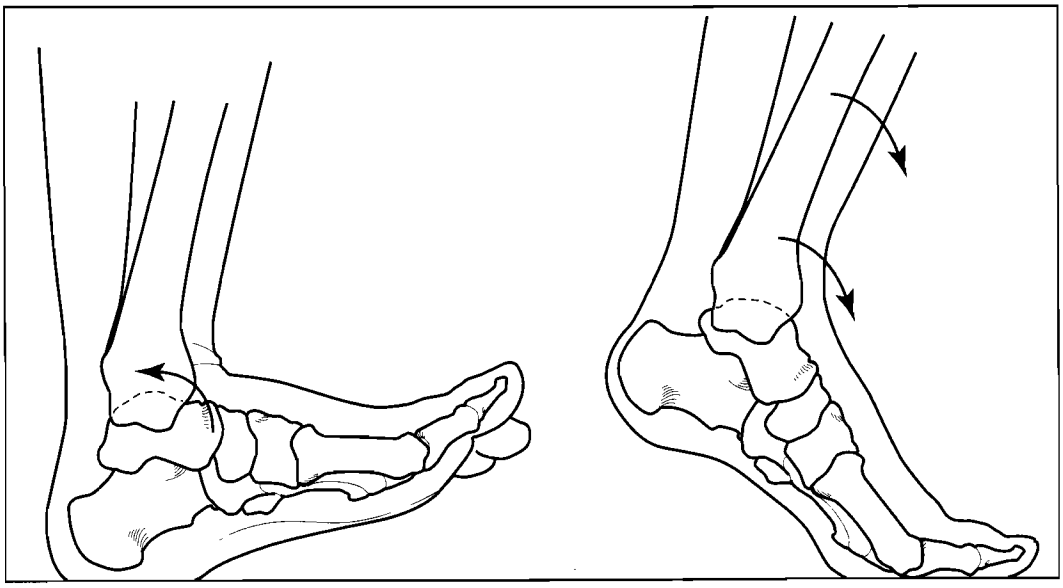


Figure 2.2. Rule of Convex and Concave

The proposed strength items have not been tested for reliability for muscle testing. They are frequently used informally in the clinic to document that children are "slightly better" after therapy or surgery because they can now perform these items. Because the items are used informally without a consistent pattern, this attempt to standardize terms and apply them clinically to children with cerebral palsy is intended to be a starting point for discussion and research. Until reliability and validity can be determined, clinical notation should define a muscle strength grade in terms of function (i.e., fair strength is the ability to move the part full range antigravity with no resistance).

Endurance

Muscular endurance can be a problem for children with neurological impairments. Children who can perform two to three repetitions of a muscle contraction but then begin to substitute other muscles may be showing poor muscular endurance. Functional mobility often requires frequent contractions. For example, if a normal child ambulates 150 steps per minute, the gastrocnemius unilaterally contracts 75 times in a minute. Now, if the child with cerebral palsy shows appropriate length and strength in the gastrocsoleous but still can only ambulate a few steps with appropriate push-off, the problem in carryover outside of therapy may be one of muscular endurance. Specific techniques to increase endurance must then be integrated into the therapeutic program to achieve functional carryover.

Neurological System

Neurological examinations assess the patient's ability to sense and process a stimulus. This information will give clues about the patient's neural damage and the particular stimuli most likely to elicit responses. A cranial nerve assessment can be critical in determining treatment options for children with cerebral palsy, because they often have multiple neurological deficits. To perform a cranial nerve assessment, gather together vials of different scents to test the olfactory nerve; a pencil for visual tracking; and a piece of cotton and a safety pin for the light touch and sharp/dull discrimination. See Table 3.1 for a summary of cranial nerves, their functions, and common deficits.

Table 3.1
Cranial Nerve Assessment

Nerve	Function	Deficits
Olfactory	Sense of smell	Loss of sense of smell (with accompanying decrease in the ability to taste)
Optic	Vision	Loss of vision
Oculomotor	Movement of eyeball	Ptosis, external stabismus, dilatation of pupil, loss of power of accommodation, and slight prominence of eyeball
Trochlear	Superior oblique muscle of eyeball	Cannot turn eye downward and outward. Eye twists inward, producing double vision
Trigeminal	Mastication and sensory nerve of head and face	Face paralyzed on one or both sides; diminished salivation and lachrymal activity; paralysis of lower jaw
Abducens	Focusing element of eye	Squinting, pupil contraction
Facial	Control of facial expression	Facial paralysis or spasms
Auditory	Hearing	Unilateral or complete deafness
Glossopharyngeal	Gag reflex	Increased risk of aspiration
Vagus	Controls motor function of breathing, voice, pharynx, esophagus, stomach, and heart	Difficulty breathing, coughing, swallowing, phonating
Accessory	Motor control of trapezoids and sternocleidomastoids	Difficulty with movement in cervical spine and sternoclavicular joint
Hypoglossal	Motor control of tongue	Difficulty with speech and swallowing

Other types of nervous system assessments include proprioception; sensory discrimination (such as stereognosis and two-point discrimination); motor planning; and cerebellar functioning and critical thinking. In-depth discussion of neurological assessment can be found in many texts and will not be discussed here.

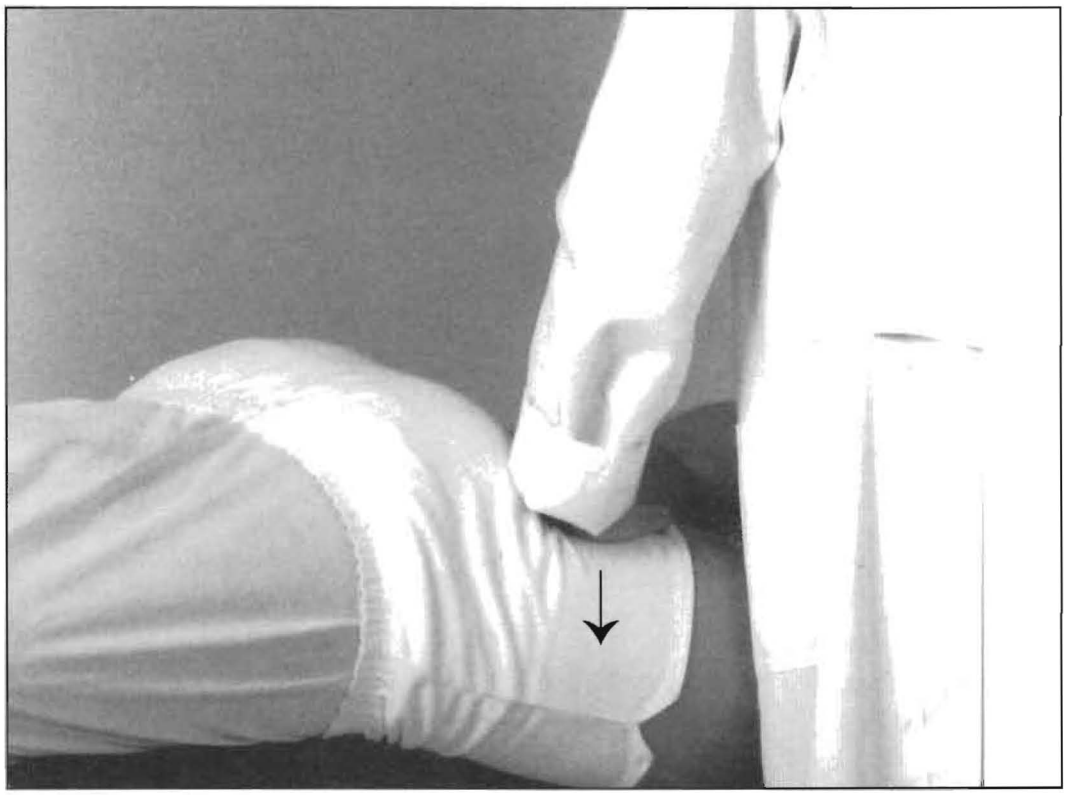


Figure 4.6. Anterior Glide of the Hip

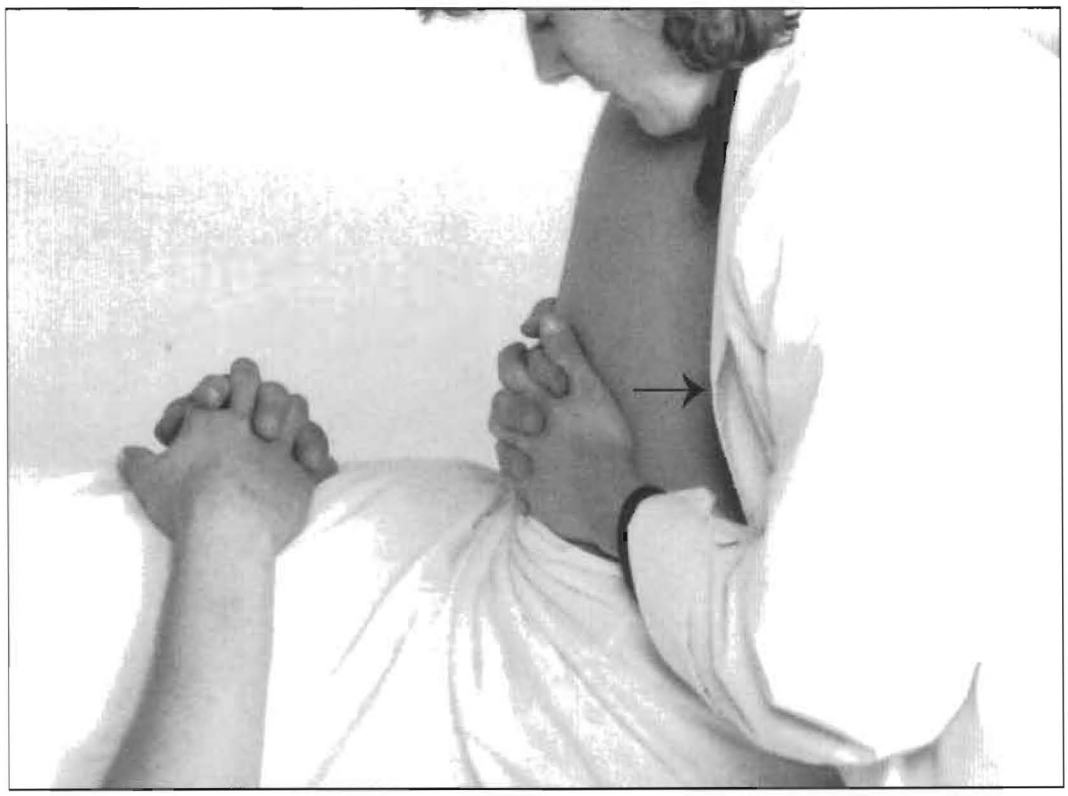


Figure 4.7. Inferior Glide

Chapter 5
The Knee

Children with cerebral palsy often have difficulty achieving full extension range because the rotary component of this locking mechanism is frequently missing. A child who cannot use the ligamentous knee-locking mechanism must rely on the bones as in genu recurvatum or the muscles as in flexed knee stance. Either strategy puts undue stress on the articular surfaces or the muscles.

The knee joint adjusts leg length during stance phase of gait and controls the excursion of the center of gravity over the base of support. It also responds to the positions of the hip and ankle-foot complex. Therefore, hip flexion contractures place excess stress on the femoral-tibial articulation, excess pressure on the patellar articulating surface, and excess demands on the strength of the quadriceps. Malalignment of the ankle-foot complex often stresses the knee more on one side than the other. All of these excess stresses force the knee to flex or hyperextend to control the center of gravity over the base of support.

Skeletal System

Bones of the knee joint are the femur, patella, and the tibia (Figure 5.1). The tibiofemoral and patellofemoral joints are maintained within the same capsule, but move very differently. Common variations in the bones include the tibiofemoral joint angle and tibial torsion.

The articulation of the femur and the tibia forms an angle known as physiologic valgus. The infant has no angle between these bones. Physiologic valgus at the knee forms as the femoral angle of inclination decreases, bringing the distal end of the femur in toward the midline. This change in relationship between the femur and the tibia has the effect of narrowing the base of support and decreasing the excursion of the center of gravity over the base of support in gait. Normal angle develops to between 165 and 170 degrees (increase in the angle is genu varum, decrease is genu valgum).

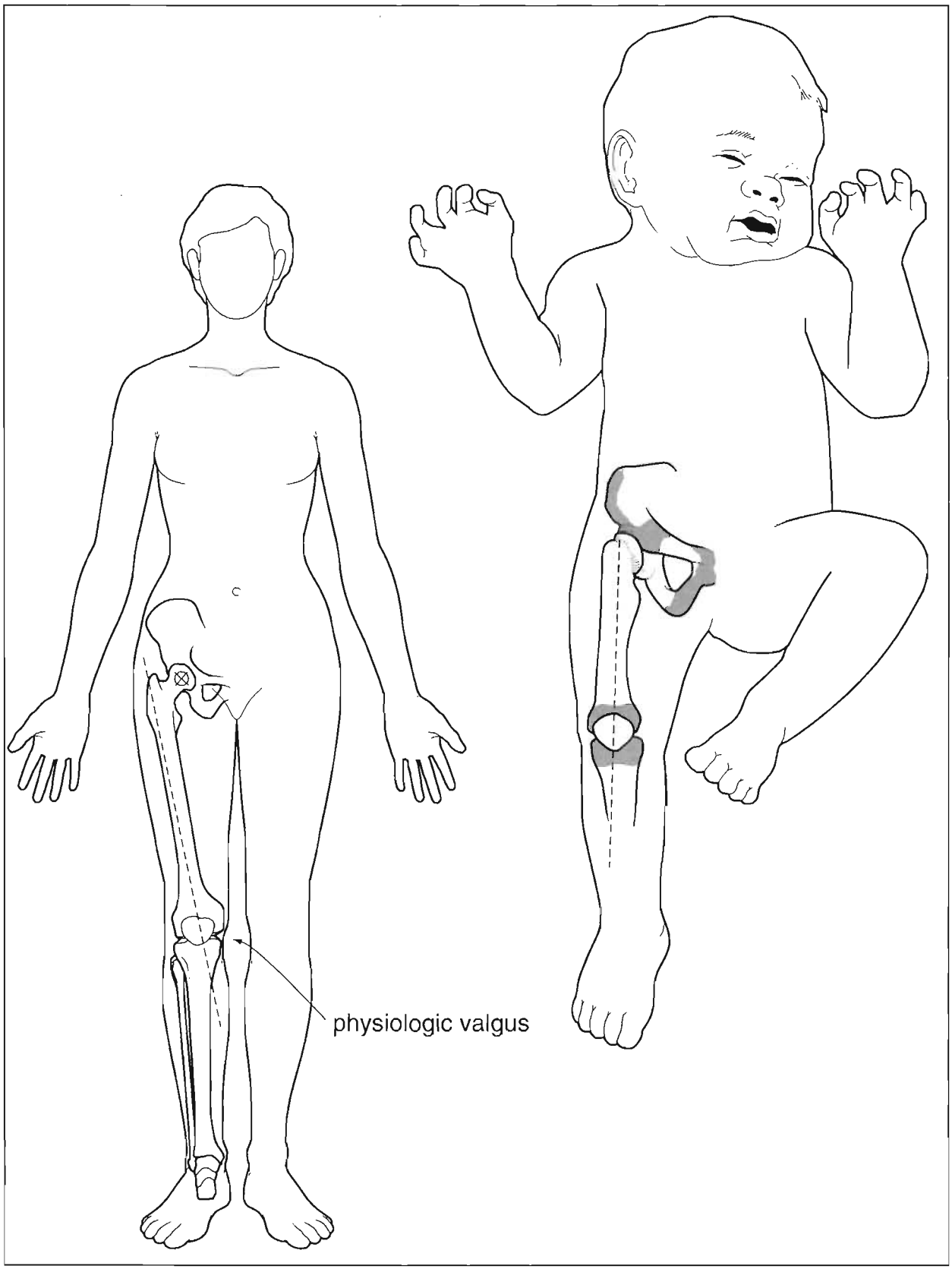


Figure 5.1. Knee Joint Skeletal System

Chapter 7
Shoulder

In children with cerebral palsy, limited mobility of The sternoclavicular and acromioclavicular joints produces characteristic limitations to range, predicatable motor problems and, often, hypermobility of the glenohumeral joint.

The shoulder girdle is a complex of the sternoclavicular, acromioclavicular, scapulothoracic, and glenohumoral joints.

Skeletal System

Bones involved in the shoulder girdle are the clavicle, scapula, sternum, and humerus (Figure 7.1); all have very shallow articulations and are highly dependent upon their ligamentous integrity for support.

Normal range of motion at the shoulder in children has not been well studied. However, the question of whether joint motion in the cardinal plane and in the plane of the scapula are the same has been addressed. In the 3-year-old, values for abduction of the glenohumoral joint in the frontal plane are 90 to 135 degrees, as opposed to values for abduction in the plane of the scapula of 107 to 115 degrees (Doody and Waterland 1970; Freedman and Munroe 1966). Neither of these values is anywhere near the often quoted norm of almost 170 degrees of abduction in the adult. Use caution when applying passive range to the infant.

Ligamentous System

Sternoclavicular Joint

The sternoclavicular joint is composed of the sternum and the clavicle. The ligaments are the anterior and posterior sternoclavicular ligaments and the costoclavicular and interclavicular ligaments. Figure 7.2 shows the anatomical relationship in the infant.

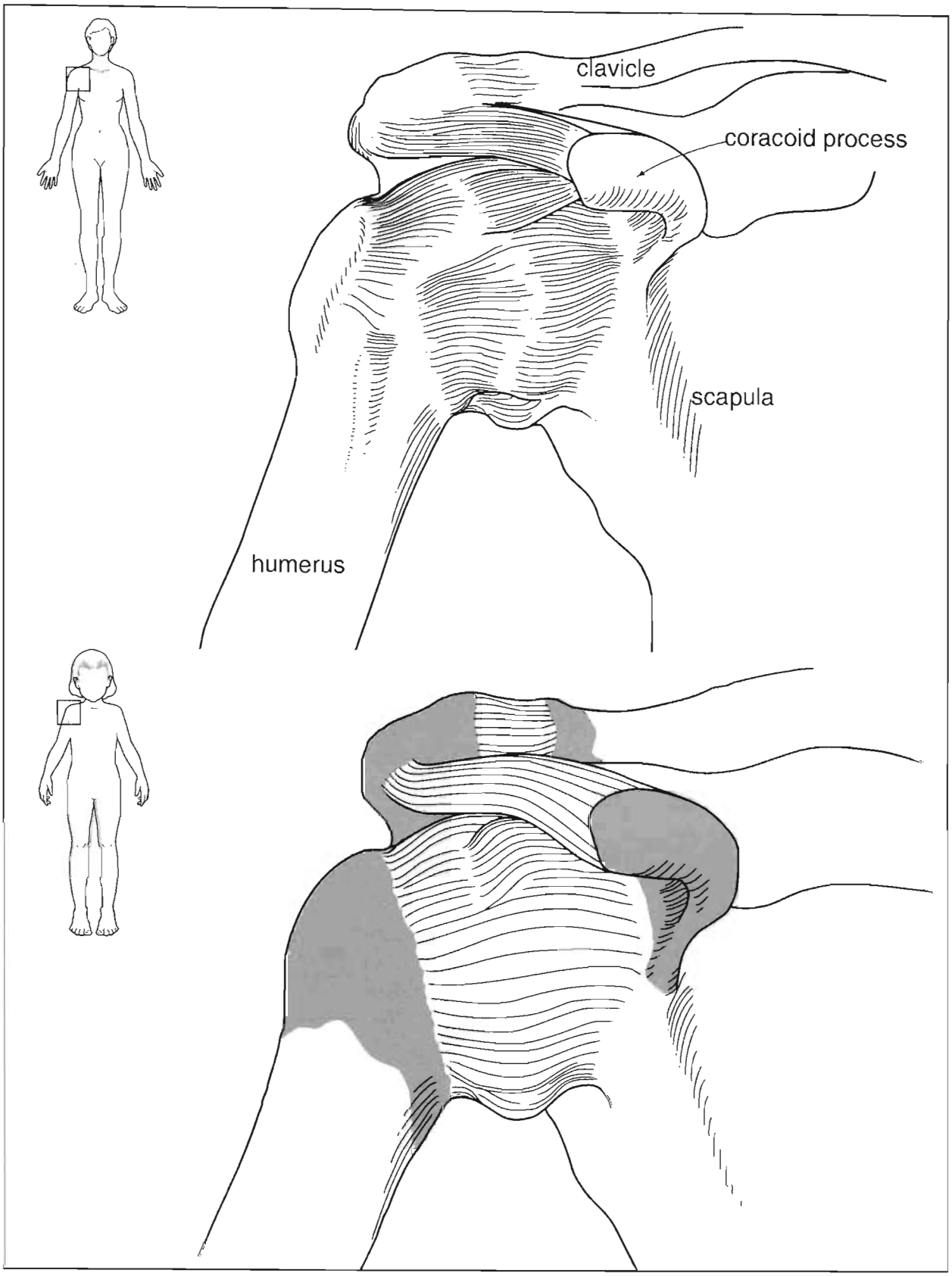


Figure 7.1. Shoulder Girdle

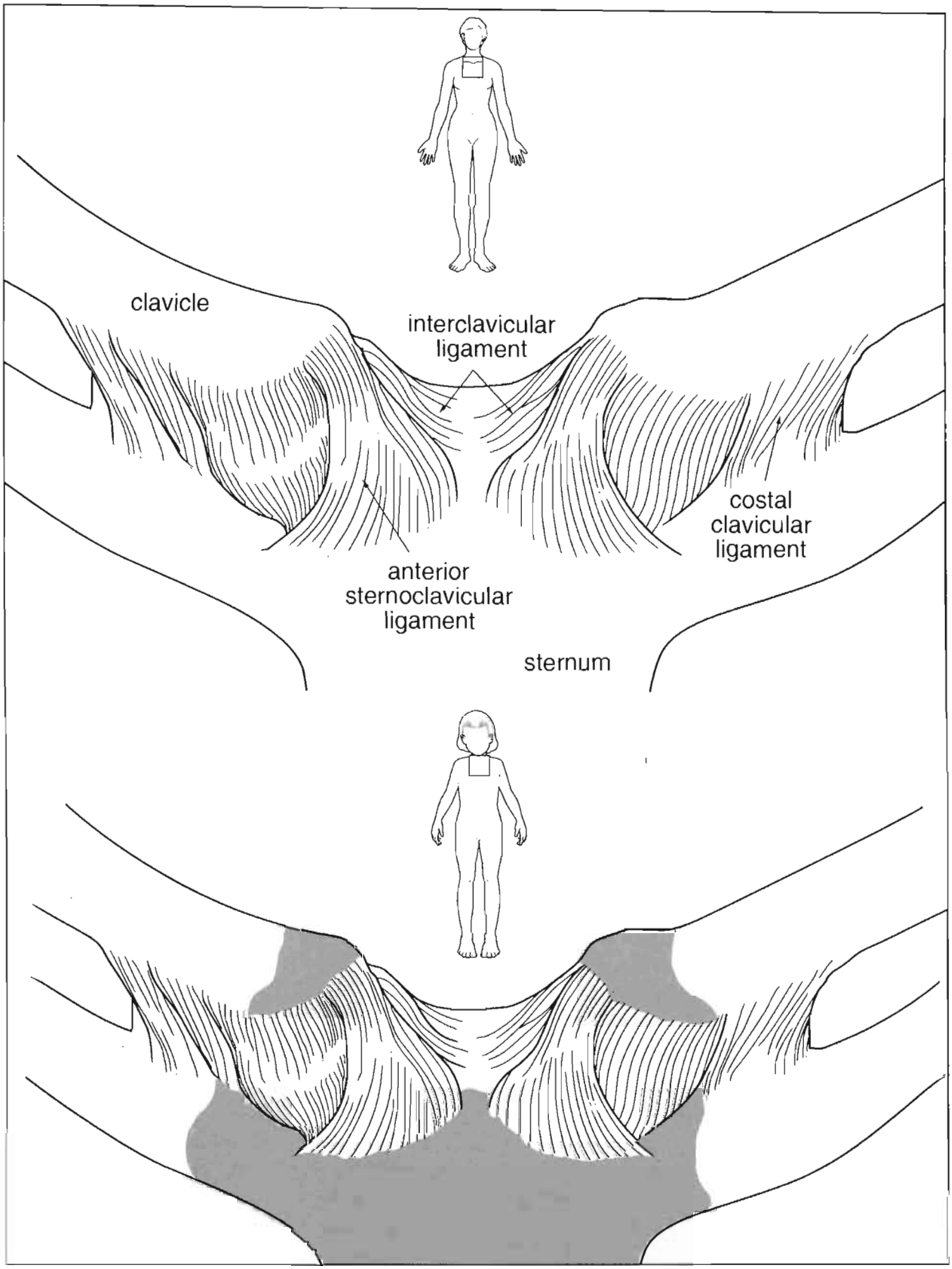


Figure 7.2. Sternoclavicular Ligaments

The capsular pattern of ligamentous tightness is a limitation of elevation and protraction of the distal end of the clavicle relative to the proximal end. Even though many children with cerebral palsy appear to have elevated and protracted shoulders, the distal end of the clavicle is not elevated or protracted relative to the proximal end. This apparent paradox is explained by the alignment of the clavicle relative to the sternum when the spine is kyphosed. Children with cerebral palsy appear to have elevated and protracted shoulders when the spine is kyphosed. Once the spine is extended, the clavicle is neutral relative to the sternum and the joint has little or no elevation and protraction—and both are critical for reach.

The sternoclavicular joint is the only bone connection between the upper extremity and the trunk. The motions available are clavicular elevation/depression, protraction/retraction, and rotation. The costoclavicular ligament provides the axis of motion for elevation and depression, as well as protraction and retraction. This ligament is located outside of the joint and results in a see-saw motion. Rotation occurs along the long axis and requires additional movement at the acromioclavicular joint.

Acromioclavicular Joint

The acromioclavicular joint is composed of the acromion of the scapula and the clavicle. The ligaments are the superior and inferior acromioclavicular and the coracoclavicular ligaments.

Close-packed position of the joint occurs during upward rotation and protraction of the scapula, as in reaching. In the adult, this joint contributes to shoulder elevation after 60 degrees and stops contributing motion between 90 and 120 degrees of elevation (Kessler and Hertling 1983). Because this joint is a fibrocartilagenous union until almost 2 years of age (Cailliet 1966), it is theoretically unable to contribute to the scapulohumeral rhythm in the child as it does in the adult. This may explain the more limited range of motion norms identified for children by Freedman and Munroe (1966) and Doody and Waterland (1970). It is possible then that total range of motion in the infant and child is markedly different and more limited than in the adult. Observation of normal infants does suggest that they do not show 170 degrees of shoulder abduction or flexion.

This joint maintains the relationship between the clavicle and the scapula in the early stages of elevation and allows additional range of scapular rotation in the latter stages of elevation. Motions available are scapular rotation, winging, and tipping. Scapular rotation occurs in an upward/downward direction during upper extremity elevation at the same time that the scapula glides over the thorax. Winging occurs when the vertebral border of the scapula rides perpendicular to the thorax. Tipping is the normal alignment of the flat scapula as it rides forward over the round thorax, as occurs in kyphosis. Tipping is frequently seen in children with cerebral palsy; winging is not.

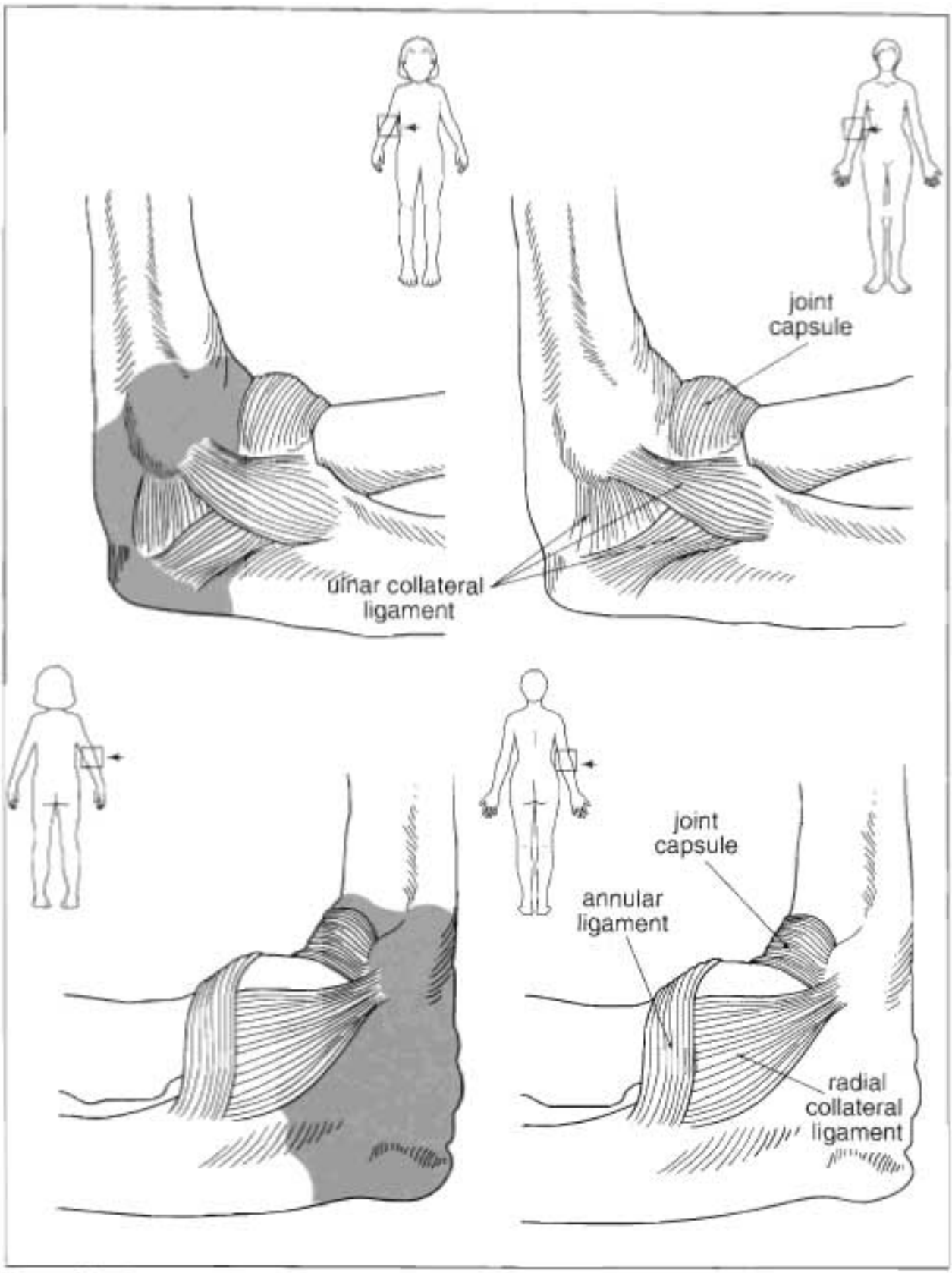


Figure 8.2. Elbow Ligaments

Muscular System

The biceps brachii is frequently implicated as the cause of elbow flexion and pronation contracture in children with cerebral palsy. However, the bicep is a supinator and a contracture occurs throughout the muscle's actions, so it cannot be the cause of the pronation component in the child with cerebral palsy. Lack of joint flexibility must also be ruled out as a contributing factor in the limited range of motion.

Table 8.2
Elbow Muscle Flexibility Testing for Children with Cerebral Palsy

Muscle Group	Testing Technique
Flexors	Stabilize the scapula and extend both the shoulder and the elbow.
Extensors	Stabilize the scapula and flex both the shoulder and the elbow.
Supinators	Stabilize the humerus and pronate the forearm.
Pronators	Stabilize the humerus and supinate the forearm.

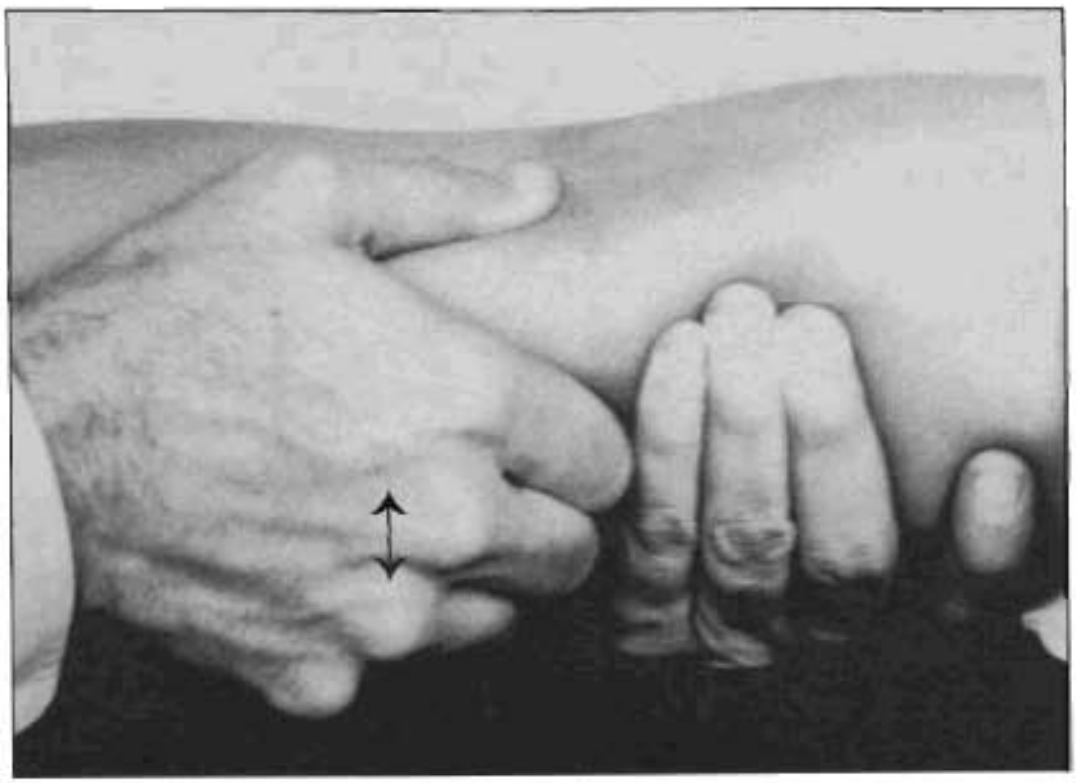


Figure 8.3. Anterior-Posterior Glide

Obtaining the range of motion for extension and supination is simple once the joint connective tissue is stretched. However, gaining strength in the new range is a far more difficult task, because very few functional activities involve full supination. Functional tasks tend to occur in pronation, or midway between supination and pronation. The child unable to actively supinate once the range has been obtained may need to begin strengthening with isometric contractions and work up to eccentric and concentric contractions. Isometric contractions while holding objects such as a lightweight paper cup and ice in the involved hand while the child pours water or juice into the cup, tend to be both functional and hold the child's interest. The amount the child can hold (the cup, the cup plus ice, the cup plus ice plus a little water) is an indication of the isometric strength of the muscle. Drinking the contents can be an immediate reward and will also decrease the resistance when necessary.

Table 8.3
Proposed Strength Criteria for Elbow Muscles

Strength Criteria	Flexors	Extensors	Pronators
Poor (movement with gravity eliminated)	Hand to mouth in prone.	Extends elbow along support in prone.	Supinate, pronate in dependent position.
Fair (Movement against gravity)	Hand to mouth in supine.	Reaches in prone.	Supinate, pronate with elbow flexed.
Good (Movement against gravity and some resistance)	Toy to mouth.	Reaches in prone while holding a toy.	Supinate and pronate with elbow flexed and toy in hand.
Normal (Age-appropriate resistance)	Lifts age-appropriate toys.	Reaches in prone while holding age-appropriate toy.	Reaches in prone while holding age-appropriate toy against age-appropriate resistance.
At 3 months	Attempts to bring hand to mouth	Thrusts arm in play	N.A.
At 6 months	Mouths toys	Elevates self by arms in prone	Turns hand in front of face
At 9 months	N.A.	N.A.	N.A.
At 12 months	Holds a ball	N.A.	Bangs spoon with supination
At 18 months	N.A.	Throws a ball	N.A.
At 24 months	N.A.	N.A.	N.A.
At 36 months	N.A.	N.A.	Pours

N.A. Not available. Unable to infer from standardized assessments.

Chapter 11
Skill Development

To achieve head up in prone, it appears that the normal infant must shift his or her head and oscillate weight backwards. This weight shift may provide the force necessary to increase the connective tissue flexibility for lumbar spine and hip extension.

The acquisition of gross and fine motor skills has been relatively well documented in such work as the Denver Developmental Scales, Gesell Scales, and Peabody Gross and Fine Motor Scales (Bailey 1993; Folio and Fewel 1983; Frankel 1973). However, scales such as the Denver were developed to identify early indicators of mental retardation, not motor control problems (Frankel 1973). This is disconcerting given the amount of therapy prescribed based on motor delays identified by these types of tests alone. The tests can document the delay but they cannot identify the cause of the delay. The therapy evaluation must determine if the delay is due to muscular, skeletal, or neurological factors, and if the delay is amenable to therapy.

Although some variability has been recorded in different scales, the general principle is one of orderly development of neural maturation causing skill acquisition. This principle has been challenged in several ways. First, the timing of skill appearance has changed in this culture since Gesell originally developed the scales, hence the need for revision. Second, it is well established that not all normal children display the same pattern of development. For example, not all non-neurologically involved children crawl before they walk (Bottos et al. 1989; Robson 1984). Third, different ethnic groups display differing rates of motor development (Malina 1988). Fourth, different nationalities display differing sequence and timing of motor milestones (Super 1976; Thornton 1992). An intact neuromusculoskeletal system and practice on a skill seems to be most important to the acquisition of the skill, not how early nor in what sequence the skill appears.

Integration for Skill Acquisition

This section focuses on the integration of neurological, orthopedic, and muscular systems that are prerequisites to motor skills performance.

The classical theories of motor development emphasize that the neurological connections must be present to express the skill. This is aptly illustrated by motor skill delays in the child with mental retardation lacking any other neuromotor problem. All the systems must be functioning correctly, however, for a child to express motor skills with the appropriate quality of movement characteristic of efficient function. For example, a child with spinal muscular atrophy may not practice pivot prone, and a child with arthrogryposis might never get to sit or crawl normally, yet both are neurologically intact.

Skill acquisition and performance have been related to myelination and synaptic maturation. However, skill acquisition and performance have not been related to the musculoskeletal prerequisites required to express the skill. This discussion focuses on the relationship between musculoskeletal prerequisites and skill. Infants gain range and strength on their own. To gain range, infants must stretch the connective tissue elements limiting that range. This is clearly seen in stretching hip connective tissue needed for the hip extension (Lee 1977). Infant movements are characteristically oscillatory and at the end of their available range. As the oscillations stretch the tissue, children continue oscillatory movements, now in a new range. The oscillatory movements at the end of joint range require repetitive contraction and relaxation of the muscles. Infants continue this pattern of oscillating near the end range, adding appropriate resistance to gain strength in the new range.

Children gain new range through oscillatory movements and add resistance to the oscillations to increase strength. Infants can increase resistance in two ways. First, an increase in the lever arm is an increase in resistance. As a child initially gains control for reach in prone, sitting, or standing, the arms are in high guard. That is, they are abducted from the body in the coronal plane, bringing the center of gravity over the base of support. As strength develops, muscular resistance increases by extending the elbow. Second, strength develops during play with weights, such as toys. An infant will pick up the rattle but not a teddy bear, and an older child will pick up a teddy bear but not a push toy. The weight of the toy is a measure of the resistance available to the muscle. Standard children's toys can be weighed and used as objective measures of strength in the clinical setting. Combining increased levers and weights provides strength in function, such as in reaching and throwing.

Pictorial Sequence of Development

The following pictorial sequence of development illustrates these points in a given child. The figures are illustrations of one normally developing child drawn from monthly photographs taken as she matured. A detailed examination of the illustrations suggests strength and range changes over time combined with neurological maturation are all necessary for a skill to appear.

Head Control

Head control in prone is one of the first skills to emerge. Lacey et al. (1985) observed 104 infants, 25 to 33 weeks gestational age. They identified a pattern of head side turning that decreased spinal extension; however, the central position of the head required more spinal extension. At 35 to 39 weeks post-conceptual age, the 11 infants with later motor handicap showed a persistence of decreased spinal extension.

Comparing Figure 11.1 (1-week-old, full-term child) and Figure 11.2 (the same child at 1 month), note the flexed spine with head to side consistent with the description of Lacey et al. (1985). Note that by 2 months (Figure 11.3), significant increases in lumbar spine and hip extension are evident. The hip extension changes are consistent with research on changes in hip range of motion previously reported. For the head to come up prone and keep the eyes level, the cervical spine is flexed. To bring the head up, the increased lumbar extension appears necessary. Figures 11.4 and 11.5 illustrate the continuing increase in lumbar extension through 11 months. Figure 11.4 shows a marked increase in the thoracolumbar junction but not a smooth curve throughout the lumbar spine. By 11 months (Figure 11.5), extension occurs throughout the lumbar spine.

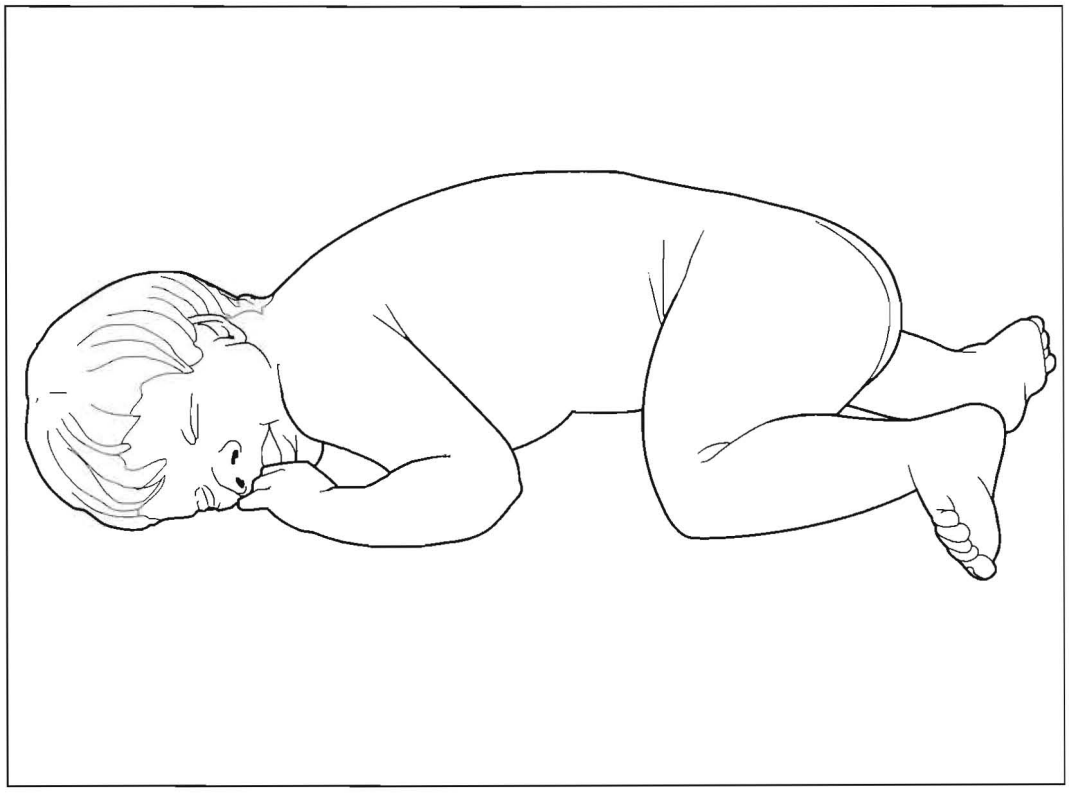


Figure 11.1. One-week-old with lumbar flexion

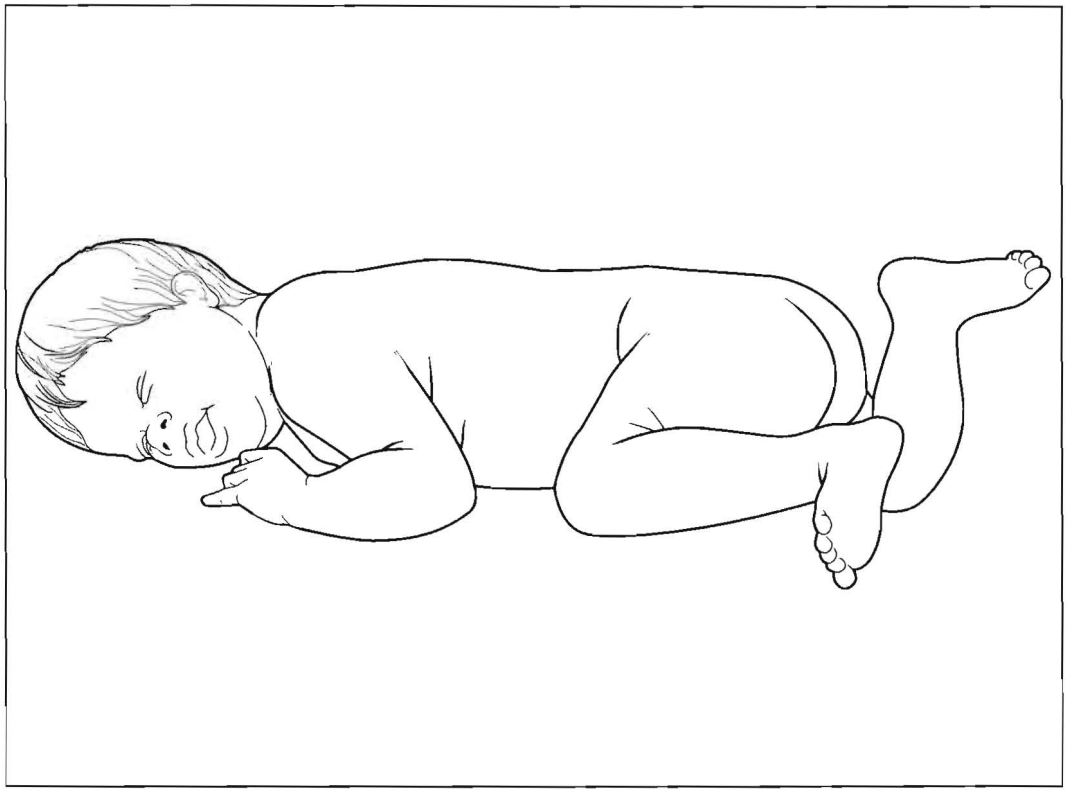


Figure 11.2. One-month-old with lumbar extension

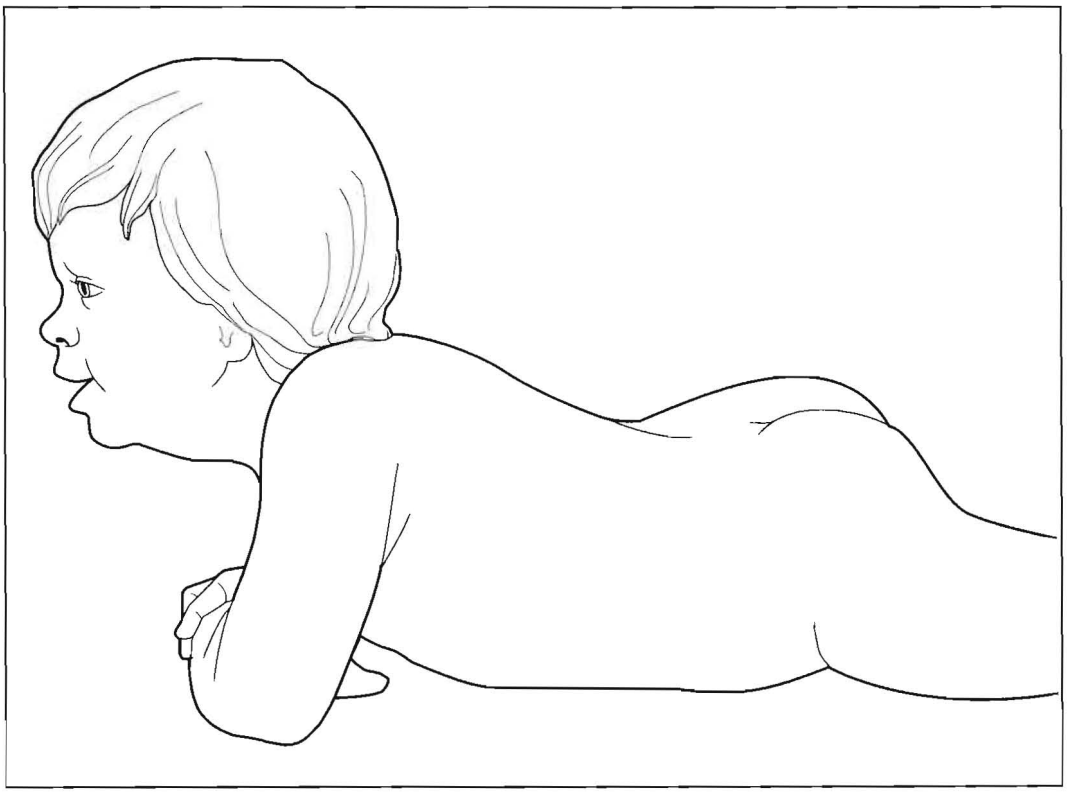


Figure 11.3. Two-month-old with lumbar extension

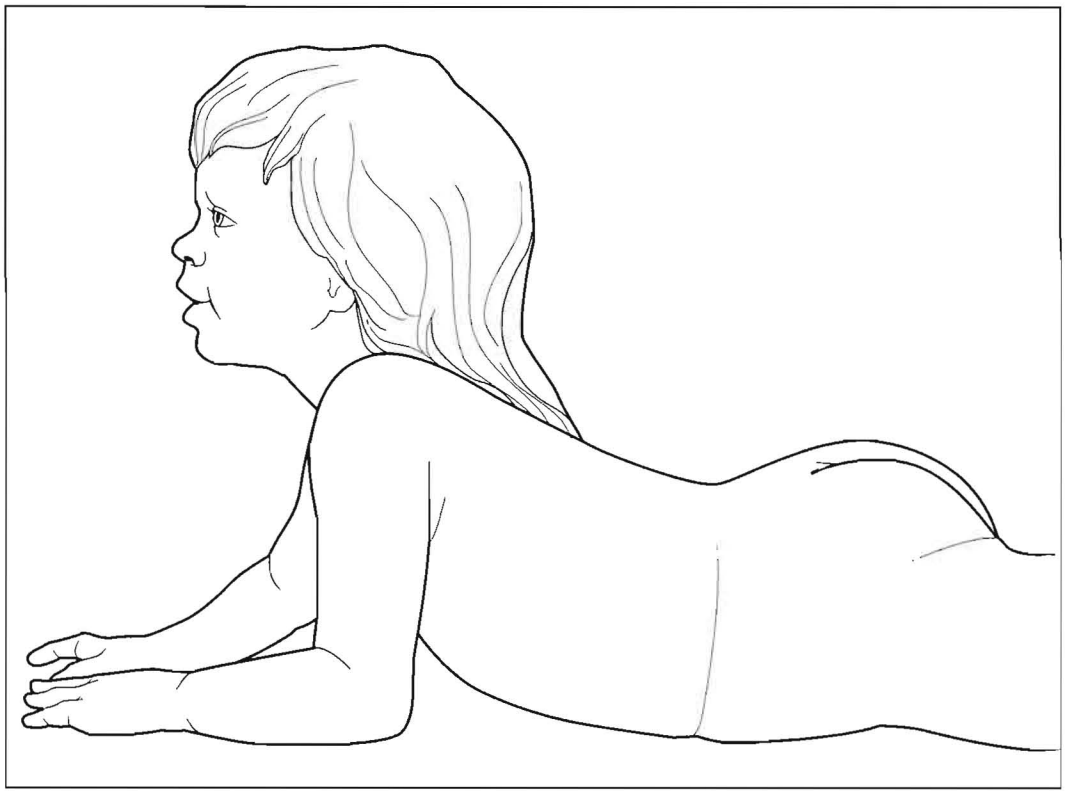


Figure 11.4. Nine-month-old with lumbar extension

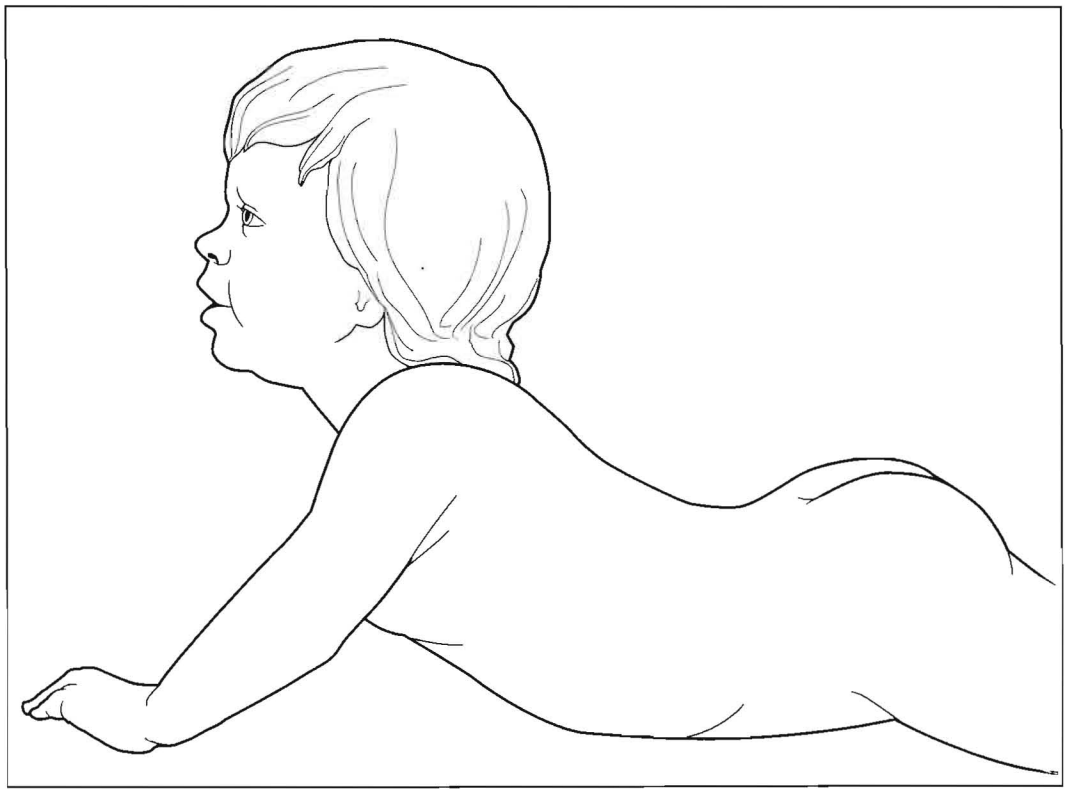


Figure 11.5. Eleven-month-old with lumbar extension

To achieve head up in prone, it appears that the normal infant must shift his or her head and oscillate weight backwards. This weight shift may provide the force necessary to increase the connective tissue flexibility for lumbar spine and hip extension. This in turn increases range and provides the repetition necessary to gain strength and influence neural stability. The child with neurological compromise does not appear to be able to change the range and strength for normal motor performance (Lacey et al. 1985, among others). Muscular weakness preventing the head to come to midline, or oscillate sufficiently while it is there, may lead to failure of the spine and hips to increase their range. This failure to increase range and subsequently strength in the range prevents appropriate joint mobility for movement of the center of gravity over the base of support in future skills. This failure to increase range to normal values often appears later as a contracture. Perhaps the contracture in older children with neurological damage did not develop, but was maintained from infancy. The hip contracture "normal" in the infant is "abnormal" in the older child with cerebral palsy.

Reach

Oscillation of the head and weight shift toward the posterior is a pattern repeated throughout normal development. Progressing from head up in prone described above, as the oscillations continue in neurologically intact children, swimming or pivot prone occurs. This brings the arms from the surface but keeps them near the body. Yet reaching out requires more range and strength through the shoulder girdle due to the increased length of the lever arm. Thelen et al. (1993) studied reaching in the infant and concluded that reaching appears between 12 and 22 weeks. Thelen notes that reaching appears when an infant can intentionally adjust force and compliance of the arm, often using muscle coactivation. These patterns are therefore consequences of the match between system dynamics and the task (Thelen et al. 1993). The natural dynamic of the system includes the available range and strength.

At birth, the arms cannot reach this high guard position in pivot prone, nor reach for objects. Range and strength must be increased for high guard in pivot prone or reaching. In the pictorial example explored here, initially the little girl had about 60 degrees of shoulder elevation (Figure 11.6). As the little girl increased her head up relative to prone, she continued to oscillate and shift her weight backward with the arms on the support. The child continues this oscillatory posterior weight shift across the sternoclavicular joints. Consistent with the function of the sternoclavicular joints, increasing joint range will allow the infant to raise the arm from its initial 60 degree (approximately) abduction and flexion to approximately 100 degrees necessary for prone on hands and reaching. She showed active shoulder range of less than 90 degrees at 1 month of age (Figure 11.7), progressing to slightly more than 90 degrees at 2 months (Figure 11.8). By 6 months, she can reach forward approximately 110 degrees (Figure 11.9). Note the normal side position of the scapula as she reaches. It is unclear when the full adult range of shoulder elevation is achieved. If the acromioclavicular joint is a fibrocartilagenous union until approximately 2 years of age, as some suggest (Cailliet 1966), it cannot contribute to "normal" scapulohumeral rhythm. Consequently, it is possible the adult norm of 170 degrees of flexion and

abduction is not achieved until after 2 years. This observation was verified by Freedman and Munroe (1966) and Doody and Waterland (1970). If it is accurate, then implications for passive range of motion exercises, placing baby prone over bolsters and wedges, and potential overstretching of the glenohumeral joint in children with cerebral palsy are obvious considerations.

Figure 11.6. Newborn with 60 degrees of active shoulder elevation