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23

Development of Locomotor Function and Its Importance in Clinical Medicine

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Learning Objectives

After reading this chapter, you should be able to understand:

- The role of agonist–antagonist muscle co-activation and functional joint centration
- The relationship between developmental kinesiology and muscle balance/imbalance
- The stages of neurodevelopment of upright posture
- The use of reflex locomotion methods techniques involving creeping, crawling, and rolling movements to facilitate muscle balance and joint centration
- The relationship of coordination between the abdominal wall and diaphragm for promoting spinal stability

Introduction

Two types of motor behavior result from the structure and function of the nervous system. One manifests itself by motor function as a result of motor learning. This consists of conditioned reflexes, which are formed by constantly repeated stimuli. The second is automatic learned motor functions, which are termed motor stereotypes.

The nervous system produces motor functions that appear in the same way from one generation to the next. These genetically determined factors of motor behavior are called motor patterns. Muscle function is encoded in motor patterns, which develop as the central nervous system (CNS) matures. Motor patterns, i.e., the reactions of the motor system to afferent stimulation, represent the programs of the CNS. The response to a given stimulus depends on the level of integration in the CNS. The reactions of specific stimuli described so far are at the spinal and brain stem level. This level of organization corresponds to phenomena such as the supporting reaction, the crossed extension reflex, gait automatism, segmental cutaneous motor reflexes, deep tonic neck reflexes, vestibular reflexes, etc. In addition to these reactions (programs), it is now possible to demonstrate motor patterns integrated above the brain stem level. These programs mature only in the course of postural ontogenesis.

If a 1-year-old is lifted by one arm and the leg of the same side from the supine position and held horizontal (Collis horizontal reaction), a characteristic motor response is obtained (Figure 23.1). This response, if repeated, is constant, with the child reacting in the same way each time. This response does not result from motor learning but will be the same in all children with a normal CNS. The type of response depends on postural function resulting from muscular co-activation, corresponding to the stage of maturity reached by the CNS.

Figure 23.1 The Collis horizontal reaction.

Motor patterns at this level of integration are neglected by clinicians and by neurophysiologists, despite their fundamental clinical significance. In this chapter we demonstrate that these motor functions, which though genetically determined, are controlled and integrated on a higher than brain stem level and can be explained by mechanisms of the ontogenesis of posture.

Central and Reflex Changes of Muscle Function

To fully appreciate muscular function it is necessary to describe, study, and understand not only its anatomy but also its function under the control of the CNS. It has been pointed out that muscle activity is the result of very complex reflex processes, which are better termed programs, because their nature is processing information by very complex and in many ways unknown physiological mechanisms. The relationship between receptors and effectors cannot be explained by a simple reflex pathway, but only by a program worked out by the CNS.

If there is disturbed activity of the CNS or of any other part of the human organism, including visceral organs, there will be repercussions in the somatic, i.e., muscular system. There are, however, only two types of response.

1. Inhibition, with signs of hypotonus, decreased activity and weakness.
2. Hypertonus, spasm, rigidity, and even spasticity.

In most cases, these changes affect only the contractile elements. However, they may affect connective tissue, resulting in shortening, or even contracture. In this case, the muscle cannot reach its full length. At a certain point contracture can change the alignment of joints the muscle is related to, even in the neutral position. Even when slowly stretched, the full range of movement cannot be reached (8).

Changes in muscular function, whether caused by hyperactivity or hypoactivity, can affect the whole muscle or group of muscles, or only a small part of it. If it is only a small localized lesion, it is called a trigger point (TrP). It consists of only a few muscle fibers with a decreased threshold to stimulation. In voluntary movement they contract first, but uneconomically. In the center of the TrP, the fibers are in a state of contraction, whereas at the periphery the fibers are distended and inhibited. This can be called intramuscular incoordination.

The muscle may not be weak in itself, but it may not function well because its attachment point is insufficiently fixed. A muscle must have a punctum fixum. Thus in resisted flexion of the wrist, the attachment point of the wrist flexors must be stabilized by the muscles that stabilize the elbow, and the elbow in turn by the shoulder girdle. In this way, stabilization of attachment points depends on a chain of muscles. Disturbed function of a muscle can therefore be caused by dysfunction of a far-distant muscle. As the shoulder girdle is stabilized by the abdominal muscles in the upright position, wrist flexion can be impaired by dysfunctional abdominal muscles. In this way, the condition of the abdominal muscles may change the quality of wrist flexion. This principle holds for specific muscular activity. It follows therefore that the functioning of any muscle is determined not only by its specific function but also by its stabilization. Insufficient stabilization is a very frequent cause of muscular dysfunction. Unfortunately, muscle function is usually examined without adequate regard to stabilization. This takes place automatically and unconsciously, programmed by the CNS. It is very important in treatment of disturbance of motor function to analyze the chain of muscles determining the stabilizing function.

The following characteristic features of these changes in function are:

1. They are interrelated, i.e., they are never isolated, but form chain reactions.
2. The dysfunctional chains are not at random, but follow definite rules.
3. Muscular dysfunction goes hand in hand with functional changes of joints, skin, fascia, periosteum, and even visceral organs.

Muscular Imbalance

There is clinical and experimental evidence that some muscles are inclined to inhibition (hypotonus, weakness, inactivity), and other muscle groups are likely to be hyperactive with a tendency to become short (2–4,6,7,9). This fact was already known. Janda, however, was the first who showed that the ensuing imbalance followed certain rules, which are sufficiently constant and characteristic to be called syndromes (the upper and lower crossed syndrome, the stratification syndrome) (see chapter 10).

A number of pathological conditions produce hypertonus and even contracture in some muscle groups and in other groups inhibition, ending up in atrophy. This is true, e.g., in organic lesions of the CNS. Those muscles that tend to develop spasm in acute poliomyelitis are the same as those that in the chronic stage of the disease produce contracture, and in patients with cerebral palsy (with signs of spasticity) cause spastic contracture. Their antagonists, however, are inhibited. AQ1

The same muscles that are likely to produce contracture and those that incline to inhibition in lesions of the CNS can be found to be hypertonic or weak respectively in disturbed posture.

Muscular Imbalance and Its Nature

The muscular system reacts according to certain rules. What, then, are the common features of muscles with a tendency to hypertonus, hyperactivity, and tightness, to spasticity, and even to spastic contracture in cerebral lesions? The same question can be asked about muscles tending to inhibition. In what function do these muscles differ?

The contemporary theory suggests that the two muscular systems have opposite characters. One basic feature stems from their function against gravity. Janda distinguishes tonic muscles with a tendency to shortness, and even contracture with a mainly postural function (3,4), hence the term postural muscles. It is, however, questionable which position (posture) is formative in the first place. Which position is decisive in opposing gravity? Janda considers gait to be the basic typical human motor activity (see chapter 10). He further explains that we stand on one leg during 85% of the time spent walking. He considers the muscles responsible for erect posture during a given stage of walking to be postural muscles in the true sense of the word (5,7).

Physiologists have shown that the two types of muscles differ in both function and structure. The same difference is also found in the nervous structures in control of these muscles, for it is the type of motor neurons that determine the type of muscle fiber. It is therefore better to speak of tonic and phasic motor units. Tonic motoneurons, i.e., small alpha motor cells, innervate red muscle fibers, whereas phasic motoneurons (large alpha cells) innervate white muscle fibers. In humans, both types of motor units are present in every muscle, in different proportions. Such muscles are “mixed.” According to the preponderance of one or the other type of motor units, tonic (postural) and phasic (kinetic) muscles can be distinguished. Contraction and decontraction is slower in tonic than in phasic motor units.

Having understood the functional and morphological difference between the two antagonistic muscular systems, this difference is particularly striking from the point of view of phylogenesis and ontogenesis. This also provides a more specific and effective approach for treatment of disturbances resulting from the functional antagonism of the two systems.

The Development of Muscle Function in Light of Postural Ontogenesis

It is common knowledge that unlike most animals, humans are immature at birth, both in function and even morphologically. The CNS maturates in the course of postnatal development, as does useful muscular function. The position of the joints, and posture, are the essential items of ontogenesis. This is to a great extent because of the stabilizing function of muscles acting interdependently. The specific bipedal erect posture matures during ontogenesis with trunk rotation and abduction and outward rotation of the arms. Thus, also, the development of joint position is determined by muscles responsible for coordinated stabilization of their attachment points.

The morphological development of the skeleton takes place at the same time (the shape of the hip joint, the plantar arch, spinal curvature, etc.) depending on the postural and stabilizing function of the "phasic" muscles, which are phylogenetically younger. Thus, intrauterine evolution continues in function and in morphology and is accomplished at the age of 4 years, when gross motor function has reached full maturity. This development can be illustrated at the shoulder blade. It does not stop at birth; during pregnancy, the shoulder blade begins to descend in a caudal direction, and if this does not take place, Sprengel deformity results.

Under normal conditions, CNS maturation continues at the shoulder blade after birth as the maturation of muscle function causes it to descend further. After the fourth week, the caudal part of the trapezius and the serratus anterior come into play. The stabilizing function of other muscles, in particular, of the abdominal muscles and even the diaphragm, is essential to facilitate outward rotation of the caudal angle of the shoulder blade, resulting in abduction of the arm to more than 90 degrees. This represents the most recent stage in the evolution of the scapulae's position.

In infantile lesions of the CNS, the muscles responsible for posture and stabilization do not function, and neither the descent nor outward rotation of the shoulder blade takes place. The shoulder blade remains in the neonatal position, i.e., elevated as a result of pull by the upper trapezius and the levator scapulae (Figure 23.2). This is also the case in bad posture because of incomplete maturation. Only humans can fix the shoulder blade to the thorax in a caudal and outward rotated position. This function matures only during postural ontogenesis after birth.

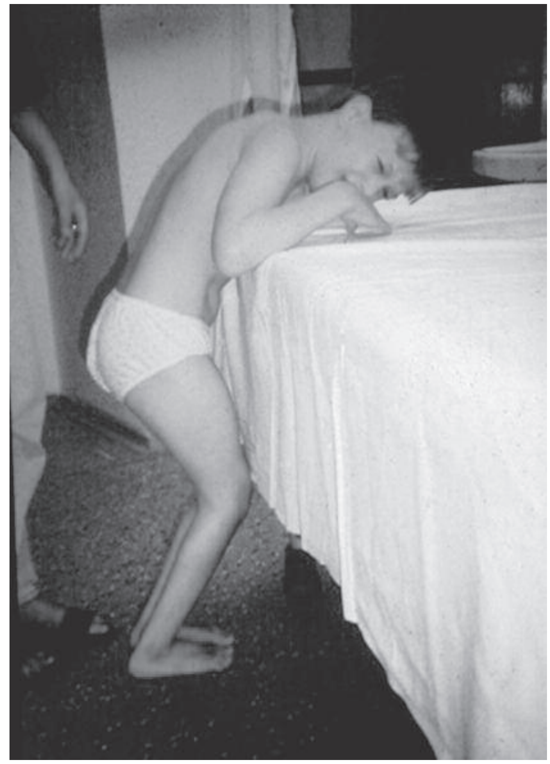

Figure 23.2 Child with spastic diparesis. The posture corresponds to the neonatal stage of development and morphological immaturity.

The muscles responsible for this position are very prone to inhibition, and similar disturbances can be observed in other parts of the human skeleton.

Not unlike posture, the position and stabilization of joints results from coordinated muscular activity under the control of the CNS. This follows logically from the development of some characteristic positions of the body (prone, supported on elbows, "oblique" sitting, standing erect), and also from the positions the joints take up in the course of primitive locomotion. Studying the separate phases of locomotion "frozen phases" Janda helps us to understand posture better and to infer joint position at each stage of motion (5,7). In the case of locomotion, on all fours we obtain the sum of momentary positions beginning with the starting position and reaching the opposite end position of side-bending, rotation, and anteflexion and retroflexion.

Postural Ontogenesis—Motor Programs

Muscular synergy develops during evolution, following patterns stored in the brain. The infant does not need to be taught how to lift his head, to grasp a toy, to turn around, or to move on all fours. All this occurs automatically in the course of maturation of the CNS by muscular coordination. These functions are genetically determined. Postural activity of the muscles comes into play automatically depending on optic orientation and the emotional needs of the child. This activity ensures active posture, i.e., all possible positions in the joints determined by their anatomical shape. Morphological development of the skeleton depends on postural function of the muscles. Understanding the kinesiology of postural development is essential for both the diagnosis and treatment of the locomotor system (10).

The Development of Functional Joint Centration

The position of joints is controlled from infancy (even during movement) by coordinated co-contraction of antagonists. It is also linked up with muscles providing joint stabilization. The co-activation pattern of antagonists develops between the fourth and sixth week of infancy. Well-balanced activity of antagonists guarantees well-centered joints. This depends only on a normally developed CNS. Any abnormality of the CNS causes abnormal joint position. This is very important for diagnosis, particularly in the early stage of development.

The concept of functional centration is essential to understand the relationship between joints and muscles. The terms "centration," "decentration," "subluxation," and "luxation" used mainly in orthopedics describe the morphological and/or pathological condition of joints. Functional centration, however, implies maximum load bearing, i.e., the best possible distribution of the load at the articular surfaces. In other words, it implies maximum contact of articular surfaces during each position in the course of movement.

A good example is the hip joint. If functional centration is to be maintained during flexion, there must be abduction and outward rotation at the same time. Thus, only maximal contact of the articular surfaces
AQ2 can be achieved. Under the same conditions the axis of rotation, too, is at the center of the joint cavity and of the femoral head. As flexion decreases, outward rotation and abduction decreases as well, and there is none in extension.

If hip movement is separated into individual stages, with each stage being correctly centered from one extreme to the opposite end position, a sum of "frozen" articular positions is obtained, i.e., of coupled flexion, rotation, and abduction. Maximum contact of the articular surfaces also produces maximum facilitation of muscle activity. Kabat's diagonal movements make excellent use of this principle.

The weight lifter can serve for illustration. He puts himself into a position in which the spinal column, the hip joints, the knees, etc. are loaded most favorably. His joints are centered during all the stages of weight lifting to bear the maximum load. In any other position the articular surfaces would be incongruent, risking tissue damage. This is an example of the balanced function of antagonists and goes hand-in-hand with well-balanced loading of the spinal column, its discs, and articulations.

The same principle of joint centration is adhered to during all the stages of postural ontogenesis because of balanced muscular activity. This principle holds for the spinal column because of the activity of the deep intrinsic back muscles, the deep neck flexors, and the abdominal muscles. Under their control, the optimum position of the individual segments is achieved in the sagittal plane. In this way, the most favorable loading of the intervertebral discs and the centration of intervertebral joints is achieved. It constitutes a motor program forming spinal curvatures in the sagittal plane. This postural program is completed during the fourth month. It is the posture we have seen in the weight lifter.

Further differentiation of muscle function from the fifth to the seventh month enables the child to achieve a well-centered posture, even during trunk rotation, having learned how to turn from prone to supine and back. A well-centered posture both in the sagittal plane and during rotation can be maintained only if the CNS develops normally. According to Vojta, this degree of maturity is never attained in 30% of children (1,11,13). In such children, faulty posture and muscular imbalance begin at an early stage of their development.

It must be particularly stressed that muscular synergy related to this model of evolution always depends on body posture as a whole and not that of a particular segment. Decentration of a single joint has its effect on the centration of all the other joints. The interrelation of all body segments is best demonstrated by Vojta's method of reflex locomotion. If stimulation is performed in a position of decentration, e.g., of the head, not a single joint will be correctly centered. In conclusion, correct centration of joints can be considered an important sign of normal function of the CNS.

Motor Programs During Individual Developmental Stages

During each stage, partial motor patterns mature representing the basic elements of adult motor behavior

The Neonatal Stage

During this stage of development, the posture of the infant is unbalanced (Figure 23.3). The point of gravity is in the sternal and umbilical region. In this unbalanced posture there is neither a differentiated function nor any point of support. The whole body rests on the surface. If prone, the child lays on one half of the body from the cheek to the chest as far as the umbilicus. The upper and the lower extremities are in flexion, unable
AQ3 to give any support. The same unbalanced posture can be seen with the baby supine (Figure 23.4).

This neonatal posture is given her in detail:

- The hand—the fingers are flexed and in ulnar flexion, there is also flexion at the wrist
- The elbow is in flexion and pronation
- The shoulder is protracted and in internal rotation
- The shoulder blade is elevated
- The spine is in flexion
- The pelvis is in anteversion
- The hip joint is in flexion and internal rotation
- The knees are flexed, the legs rotated outward
- The foot in plantar flexion

Figure 23.4 Posture at birth: supine.

In the neonatal period, the tonic muscular system is in complete control. As we have pointed out, all the anatomical structures of the skeleton at this stage are immature, too. This holds for the angle of anteversion and the colodiaphyseal angle of the femur, the plantar arch, the plateau of the tibia, leg rotation, and the horizontal position of the collar bones, etc. These are related to the formative influence of the postural function of the phasic muscular system: the abductors and outward rotators at the hip, the spinal extensors, the short extensors at the knee, the tibialis anterior, the peroneal muscles etc. Because no higher centers of nervous control are as yet functioning and the tonic system is in complete control, there is no postural balance and it is yet possible to elicit certain motor responses (programs), which are integrated at the spinal level of control.

The Suprapubic Reflex

On slight (not nociceptive) pressure at the upper edge of the symphysis extension and inward rotation at the hip, extension at the knee, plantar flexion of the feet, and fanning out of the toes takes place (Figure 23.5). This response is symmetrical on both lower extremities.

Figure 23.3 Posture at birth: prone.

Figure 23.5 Suprapubic reflex.

Support Reaction

The baby is held under the armpits and the soles of his feet are stimulated (Figure 23.6). The response is extension (support) of both lower extremities. If this reflex continues for some time, it can be mistaken for the infant attempting to stand

Automatic Gait

This reflex is elicited similarly to the previous one; however, in this case, only one sole is stimulated (Figure 23.7). Triple flexion of the opposite extremity takes place. In this reflex, the infant demonstrate a walking pattern on an involuntary basis.

The Crossed Extension Reflex

With the baby supine and the lower extremity flexed at the hip and knee, slight pressure is exerted against the knee in the direction of the hip joint (Figure 23.8). Extension and inward rotation at the hip, extension of the knee, plantar flexion of the foot, extension at the metatarsophalangeal, and flexion at the interphalangeal joints take place in the other lower extremity.

Figure 23.6 Support reaction.

Figure 23.7 Gait automatism.

Calcaneal (Heel) Reflex

The heel is tapped and the hip and knee are in a semi-flexed position (Figure 23.9). Extension of the knee and hip takes place.

In all the motor programs given, we find a reciprocal response of antagonists on stimulation, i.e., for

Figure 23.8 Crossed extension reflex.

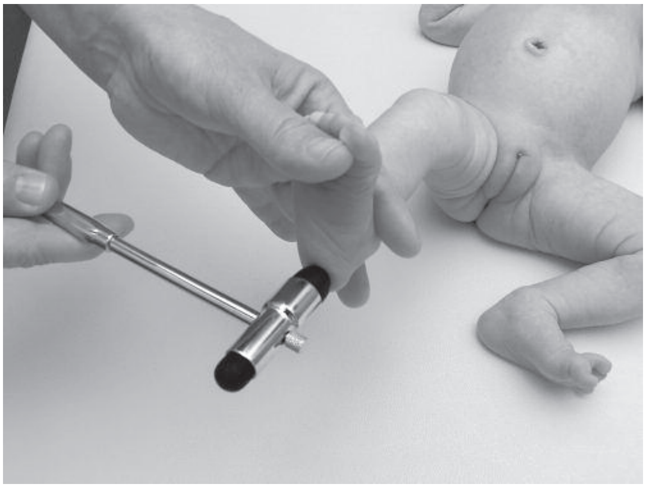

Figure 23.9 Heel reflex.

every reflex response of one muscle, its antagonist is inhibited.

The Fourth Through Sixth Week of Motor Development

Optic fixation appears between the fourth and sixth week and with it the infant's orientation in space. It begins to lift the head against gravity (Figure 23.10). In this way, the head is lifted beyond its base of support and supports itself on the forearms. The upper arms are no longer in a frontal plane, they move toward the sagittal plane by adduction and flexion at the shoulder. At the same time, the point of gravity moves in a caudal direction toward the symphysis, and anteflexion of the pelvis decreases. It must be stressed that lifting the head first is in no way an isolated movement but that this goes hand in hand with the upper extremity providing support to lift the thorax, changing in this way the entire body posture. This depends on precisely coordinated muscular function providing stabilization. This all-around change of posture is automatic; however, it depends on the child's mental development and is encoded in locomotor ontogenesis.

Higher levels of CNS control come into play when optic fixation is established. The characteristic features of this stage are:

1. The spinal motor patterns disappear or are hidden, i.e., the supporting reaction, the gait automatism, etc.
2. Muscular co-activation appears, resulting in a balanced activity by simultaneous action of

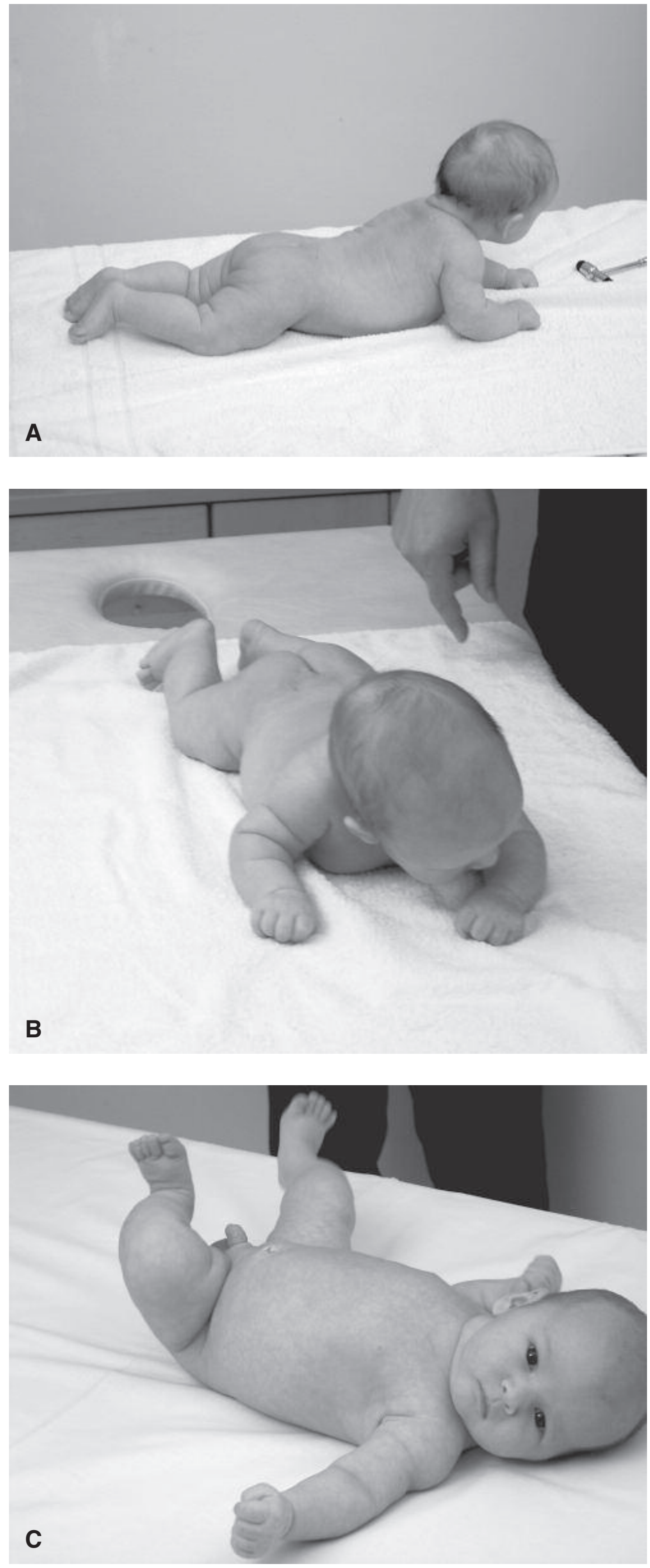

Figure 23.10 First stage of erect posture after optic orientation between 4 and 6 weeks (A–C).

antagonists and their mutual reciprocal facilitation and inhibition.

3. "Phasic muscles" begin to take part in the stabilization of posture. As a consequence, muscles with a tendency to weakness take part in the maintenance of posture as links of a chain. These muscles, as pointed out, are not true phasic muscles and, in view of their postural function, should be better-considered as phylogenetically and ontogenetically younger postural muscles. The most important phasic and tonic muscles are listed in Table 23.1.

The End of the First and the Beginning of the Second Trimenon

At 3.5 months, the first support base is defined and the points of support can be shown to be the elbows and the symphysis with the infant prone (Figure 23.11). If supine, the area of support is formed by the upper part of the gluteal muscles, the scapular region, and the linea nuchae (Figure 23.12). Posture is fully determined at this stage, controlled by the CNS. Spinal straightening, ensured by well-balanced activity of the deep extensors and flexors, can be observed starting at the occipital level and ending at

Table 23.1 Muscles With Predominately Phasic and Tonic Function

Tonic Muscles	Phasic Muscles
m. adductor policis	m. abductor pollicis brevis
m. flexor digiti minimi	m. opponens pollicis
m. interossei palmares	m. interossei dorsales
m. palmaris longus	m. extensor digiti minimi
m. flexor digitorum superficialis	
m. flexor digitorum profundus	m. extensor carpi radialis longus et brevis
m. flexor carpi ulnaris	m. extensor carpi ulnaris
m. flexor carpi radialis	m. extensor digitorum
	m. abductor pollicis longus
m. pronator teres	m. abductor pollis brevis
m. pronator quadratus	
m. biceps brachii caput breve	m. anconeus
m. brachioradialis	m. triceps brachii caput laterale et mediale
m. triceps brachii caput longum	m. teres minor
	m. infraspinatus
m. subscapularis	m. supraspinatus
m. pectoralis major	m. serratus anterior
m. pectoralis minor	m. deltoideus
m. teres major	m. biceps brachii caput longum
m. latissimus dorsi	m. trapezius—lower part
m. coracobrachialis	m. rhomboidei
m. trapezius hor.část	abdominal muscles
m. levator scapulae	extensors and outward rotators of the hip joint
	m. vastus med. et lat.
neck extensors	hipjoint abductores
m. sternocleidomastoideus	m. gastrocnemius
m. scaleni	peroneal muscles
m. quadratus lumborum	m. longus colli
	m. longus capitis
m. iliopsoas	m. rectus capitis ant.
m. rectus femoris	
hip joint adductors	
m. tensor fascie latae	
ischiocrural muscles	
m. soleus	
AQ4 foot adductors	

Figure 23.11 Posture when prone at 3.5 months.

sacrum. Equilibrium between the lower and upper fixators of the shoulder blade is established: in the course of the fourth month, stabilization of the spinal column in the sagittal plane matures. This forms the basis of the stepping forward (grasping) and support function of the extremities, which involves rotation of the spinal column. Maturity of the spine in the sagittal plane is also necessary for the grasping function of the upper extremity. Further development depends on this basic synergy. Turning over, sitting, standing, getting on all fours, and so on can be achieved only if there is stability in the sagittal plane. The spinal column thus provides the basis for stabilizing the muscles of the extremities, playing the role of a punctum fixum. If there is any abnormality, there will also be dysfunction at the extremities. This relationship is, however, reciprocal. Development in the sagittal plane that is not ideal can always be observed even later (during adulthood).

The muscular interplay described, very well-defined from the kinesiological point of view, is essential for erect posture. It represents a genetically fixed model, specific exclusively for the human species, and determines the formation of the characteristic spinal curvatures (kyphosis and lordosis) in the sagittal plane. It is very important that this model can be evoked by Vojta's method of reflex locomotion in the neonatal stage of development, at a time when the anatomical structures are not yet fully developed. This proves the genetically determined formative role of postural function.

Figure 23.12 Posture when supine at 3.5 months.

Motor Development From the Second Half of Trimenon 2

At age 4.5 months, the child is able to grasp an object when lying prone. The head, the upper extremity, and the shoulder are lifted against gravity. If the CNS functions normally, the spine and the extremity joints are in a centered position, and the support is of a triangular shape, formed by the elbow, the anterior superior iliac spine of one side, and the medial epicondyle of the femur of the opposite side (Figure 23.13). Thus, the support pattern of the lower extremity is partially formed. In this model of development, the fist is formed with radial flexion. At the same time, there is thumb flexion with abduction of the fingers. Lifting of the upper extremity prone is possible only if muscle pull of the opposite weight-bearing extremity is directed distally to the point of support.

At age 4.5 months, the child lying supine is able to lift his pelvis, supporting himself on the thoracolumbar junction, which is stabilized by muscular coactivation. This point of support enables the child to grasp an object situated above mid-line while supine. At this stage, the chest can also be asymmetrically stretched with the child supine. In this way, the lower shoulder becomes the point of support, which, too, is possible only if there is distal muscle pull. From this position, trunk rotation can follow with the spine straight, a function completed by the end of the sixth month. Two oblique muscle chains appear at this time. The first produces pelvic rotation in the direction of the supporting upper extremity.
Muscle contraction starts at the obliquus abdominis **AQ5**
internus on the side to which the chin is turned, pass-

Figure 23.13 Posture at 4.5 months: support based on the elbow, the anterior superior iliac spine of one side, and the medial epicondyle of the opposite knee.

ing by the transversus abdominis to the obliquus externus of the opposite side (Figure 23.14). The dorsal muscles take part in the co-activation synergy. The second oblique chain taking part synergistically in rotation is formed by the abdominal muscles with the pectoralis major and minor of both sides, producing rotation of the upper part of the trunk and straightening at the shoulder (Figure 23.15).

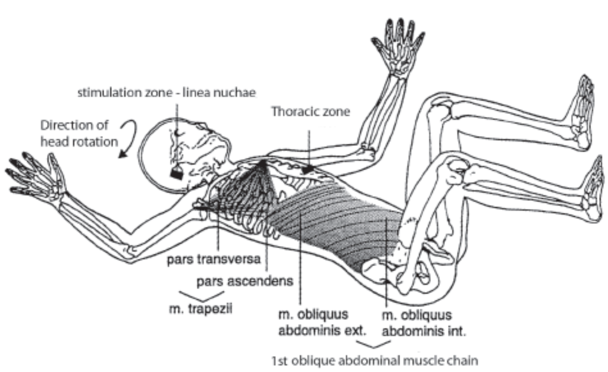

Figure 23.14 The first oblique muscle chain according to Vojta.

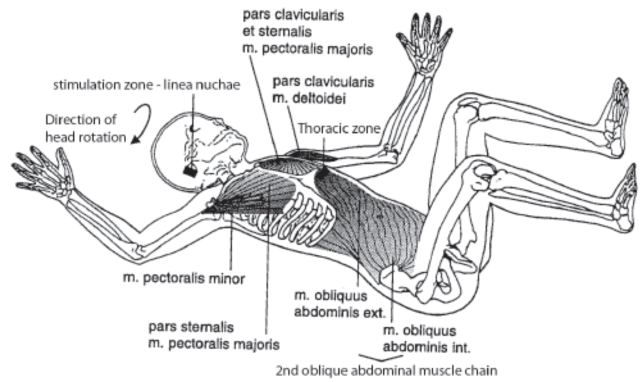

Figure 23.15 The second oblique muscle chain according to Vojta.

When turning over from supine to prone, one leg is supporting and the other is "swinging" (stepping forward). The arms behave in an analogous way. The reciprocal movement pattern has been finished, i.e.:

1. The supporting leg (which takes off) moves into inward rotation, adduction, and extension, and the other leg moves in external rotation, abduction, and flexion at the hip. The other articulations function analogically, i.e., their movement has a reciprocal pattern.
2. The muscles of the supporting leg exert a pull in a distal direction, i.e., "the punctum fixum" is distal and "the punctum mobile" is proximal. The muscles of the swinging (stepping forward) leg, however, have their punctum fixum proximal while the punctum mobile is distal.
3. Thus, muscle pull is differentiated at this stage of development, i.e., in the supporting leg (arm) the joint cavity moves against the head of the joint, whereas in the swinging leg (arm) the head moves against the joint cavity.

It is characteristic for locomotion during the fifth and sixth month that the supporting and swinging extremities are ipsilateral. Differentiated muscle function is established, by which is meant an opposite direction of muscle pull in swinging and supporting extremities. In stepping forward or grasping, the extremity muscles pull against a fixed point (punctum fixum) located proximally. The femoral and humeral heads move against the joint cavities. However, in the supporting extremities the situation is the opposite. In support function, the extremity muscles pull against a fixed point located distally. Now, the joint cavities move against the femoral or humeral heads.

We mean the direction of muscle pull, i.e., the location (proximal or distal) of the fixed point ("punctum **AQ6** fixum") against which the muscles pull and the movement of the joint head and cavity. The swinging (grasping) and the support extremity behave in the same way. The only difference is that the movement is reciprocal.

The oblique sitting position develops from both the prone and the supine position. The points of support are the gluteus medius and the hand. The grasping upper extremity is flexed at the shoulder at an angle above 120 degrees. Crawling on all fours develops from this position. The next step is for the child to stand up and walk toward the side. This is followed by true bipedal locomotion. After the age of 6 months, the supporting and swinging function of the arms and legs takes on a contralateral pattern. Thus, the "swinging" or grasping arm is on the side of the supporting leg and vice versa. The course of the movement of the stepping forward and the supporting extremity is the same. The difference is in the punctum fixum, which in the former is the joint cavity and in the latter the head of the femur. There are two basic models of the phasic movements. The stepping forward (grasping) and support function may be either contralateral or ipsilateral. This coordinated muscular activity is genetically programmed. It stabilizes the spinal column in the sagittal plane (fourth month) and later develops the function of swinging (stepping forward, grasping) and support. It forms the basis of our "motor subconsciousness." All joint positions result from muscular synergies maturing during early development. The range of movement depends not only on the anatomical structures but also on the muscles and muscular synergies performing the movement. Muscular synergies resulting in this model always depend on body posture, never that of a single segment. This functional goal explains the relationship between the anatomical structure of muscles and joints and their function.

Summary

Motor development in infancy is automatic, depending on optical orientation and the emotional needs of the child. It is genetically determined, developing the motor functions that form the basis of our automatic subconscious motor behavior. Two basic functions play a decisive role in this context:

1. The development of stabilization in the sagittal plane at the end of the fourth month. At this period, the muscular stabilizing function matures, enabling the spinal column to adopt ideal weight-bearing posture. If the CNS functions normally, the principles of neurophysiology and biomechanics must be in harmony. Stabilization in the sagittal plane forms the basis for every phasic movement.
2. The development of specific phasic movements. These are the swinging (stepping forward or grasping) function and the take off. They are closely related to the stabilizing function and develop at a precise date. Grasping takes place first from the side (third month), later from the mid-line (4.5 months), and finally across the mid-line (fifth to sixth months). The other extremity provides the function of support or take off.

Later in the development, the stepping forward (grasping) and support (take off) functions occur on contralateral sides. In other words, there are two models of stepping forward and support (taking off) functions:

1. Stepping forward and support (taking off) take place on the same side. (e.g., the left arm is moving forward and the leg is also stepping forward)
2. Stepping forward and support (taking off) take place on the contralateral side

Under normal conditions, both the stepping forward and support function take place according to a biomechanically ideal pattern when all the joints are functionally centered. This can be true only if there is normal maturation of the CNS.

Reflex Locomotion

Partial motor functions maturing in the course of postural development, such as postural stabilization in the sagittal plane, the swinging, and the support function (ipsilateral and later on opposite sides) can be evoked by reflex stimulation. This constitutes a new and fundamental principle that has changed our understanding of the motor system, i.e., its functional pathology controlled by the CNS.

It is possible to evoke partial movement patterns by innocuous pressure (pressure must be in the correct direction and vary in intensity) at stimulation points (Figure 23.16), which are points of support. Two types of complex responses result: reflex turning over (Figure 23.17) and reflex creeping (Figures 23.18 to 23.20) are both described by Vojta (12). They are general patterns in which the entire muscular system is involved in a well-defined coordinated way, and all levels of the CNS are involved. The movement evoked by stimulation involves the partial patterns described. Thus, in reflex turning over, we may observe partial movements according to the stage of development: lifting the legs over the table and keep-

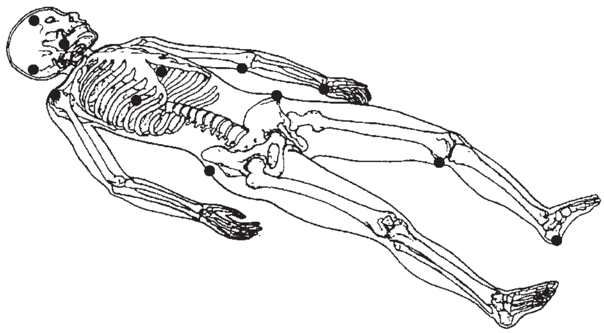

Figure 23.16 Stimulation zones.

ing them in triple flexion and abduction (fourth month), grasping over the midline (4.5 months), combined with turning to the side (fifth month), turning to prone position (sixth month), lying on the side using the elbow as a support (seventh month), oblique sitting position (eighth month), crawling on all fours (tenth month), walking sideways (twelfth month). These general patterns controlled by the CNS are constant and can be reproduced.

By stimulation of reflex zones in a given position, involuntary muscle activity is evoked, including the orofacial system. This response is constant and purposeful. The genetically programmed locomotor pattern is as follows:

1. By evoked muscle activity, the point of gravity is transferred and the body is supported automatically at given points. These points are genetically determined and represent structures that play an important role in upright posture. At these sites we find a great number of muscular and/or ligamentous attachment points rich in receptors. If stimulated, muscle activity is directed toward these points of support. The initial position in which stimulation takes place determines the zone of support. The automatic choice of the support point is made by stereognosis, i.e. by awareness of the point of contact and its position in space (making no use of vision), related to the body scheme. Therefore, no matter whether the body is lying on the side, supine, or prone, there will be the same response to the same stimulation, but the point of support will change.
2. The stabilizing system in the sagittal plane will be activated (fourth month). The spinal column, the thorax, and the shoulder blade automatically adopt the ideal position of maximum load bearing as the principles of neurophysiology and biomechanics are in harmony. The pattern of stabilization in the sagittal plane is the constant response to stimulation whether stimulation takes place when lying on the side, prone, or supine. Only the points of support are changed.
3. Stabilization of the spinal column is followed by the swinging (grasping) and support function of the extremities which is coupled with spinal rotation. The oblique abdominal muscles come into play. The choice of the ipsilateral or contralateral pattern of swinging (grasping) and the supporting extremity depends on the initial position. This, too, is automatic depending on head position and visual orientation. The mechanism of swinging (grasping) and mechanism of taking off is always identical, but in the opposite sense. On the swinging leg, we find:
   - The hip in flexion, external rotation, and abduction
   - The knee in flexion and external rotation
   - The foot in dorsal flexion and supination
   - On the grasping, upper extremity:
   - The shoulder in flexion, external rotation, abduction
   - The elbow in supination and slight flexion
   - The hand in extension, supination, and radial flexion

The supporting extremity moves in the opposite way. During the movement, all the joints are perfectly centered. The direction of muscular pull differs in the two patterns: in the swinging (grasping) extremity the punctum fixum is proximal and the punctum mobile distal; in the supporting limb, it is the reverse. In the former the head of the joint moves against the joint cavity, in the latter the joint cavity moves against the head. This model can be evoked throughout life, at every age. It differs, however, in the adult, because the response to stimulation is under the control of the cortex. In everybody, however, there will be changes in respiratory function that enhance the stabilization of the spinal column and the thorax, and also changes in muscle tonus, including those muscles that are not completely under the control of our will. To increase facilitation in addition to zone stimulation, we can also resist the locomotion movement (stepping forward) isometrically.

Postural Function of Phasic Muscles

The phasic muscles start their postural activity after the age of 6 weeks, as pointed out. As the CNS matures, these muscles play an increasingly important part in posture and its stabilization, and greatly influence the formation and shape of anatomical

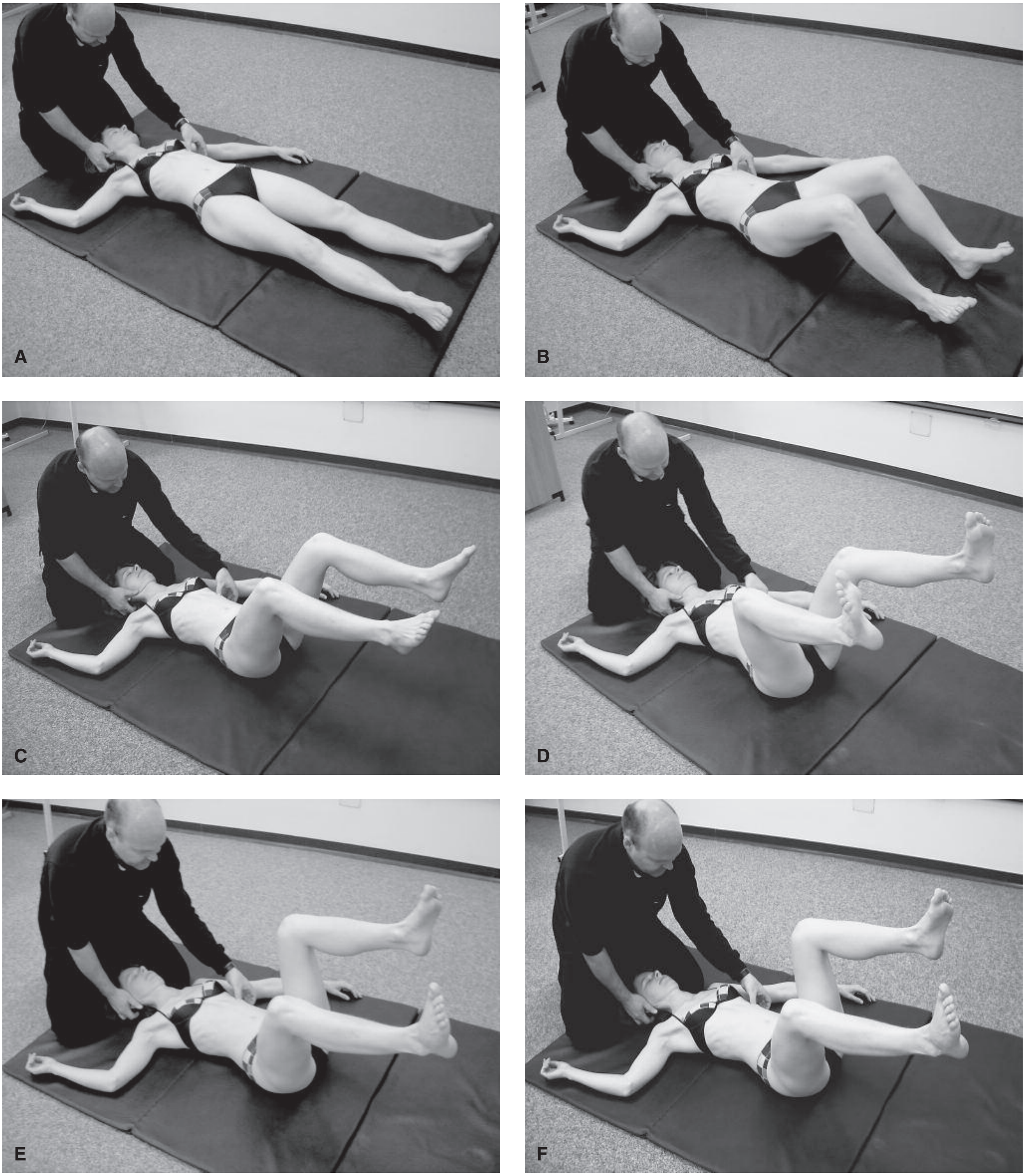

Figure 23.17 Reflex turning stimulation: supine (A–I).

structures. The development of postural function of the phasic muscles is completed by the age of 4 years, when the central motor control of gross mobility has matured. At this stage of development, the child can attain at each joint the opposite position to that of the infant at birth (Figure 23.21). This was earlier described for the shoulder blade and is further demonstrated on the entire upper extremity.

At birth, the position of the upper extremity is characterized by fingers in flexion and adduction, the wrist in ulnar and palmar flexion, the elbow in pronation and flexion, and the shoulder in protrac- 1 LINE

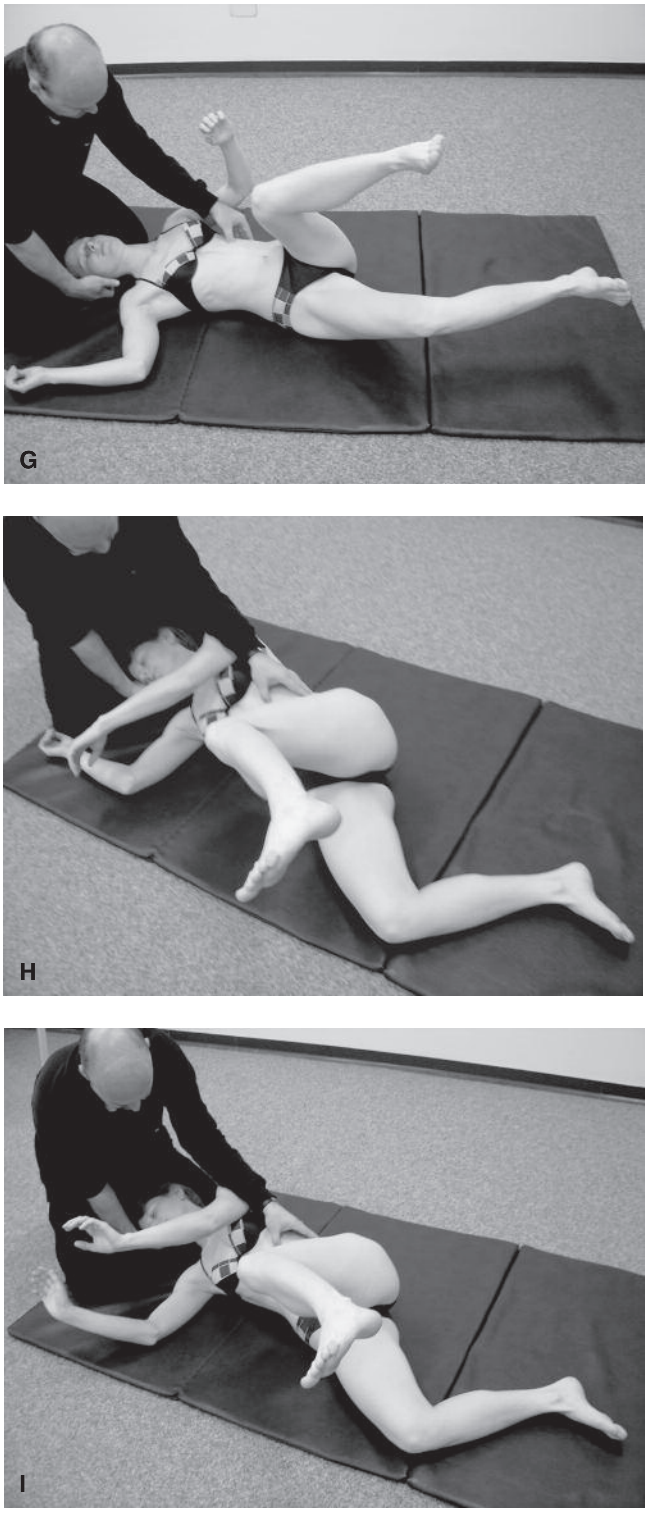

Figure 23.17 (*Continued*)

tion, adduction, and internal rotation. Posture is under the predominant influence of the phylogenetically older tonic system. At full postural maturity, the child can acquire a posture in which the fingers are extended and in abduction, the wrist in extension and radial flexion, the elbow in supination and exten-

LONG

Figure 23.18 Reflex creeping—basic position for stimulation.

sion, and the shoulder in depression, abduction, and external rotation (Figure 23.22 A–D and Figure 23.23 A and B). A similar development takes place in other body segments.

This posture is the youngest from the phylogenetic and ontogenetic point of view, and this also goes for its structure (no animal can attain a similar position with respect to the anatomical shape of the joints and even the muscles, responsible for posture). The muscles or their parts involved in posture are phylogenetically young in their postural function (active only in humans) and tend to become weak.

Tonic and Phasic Muscles—The Developmental Aspect

It is often expressed that tonic muscles are mainly concerned in posture ("postural muscles") and phasic muscles in movement ("kinetic muscles"). But both types have dual functions participating in both posture and movement.

Ontogenesis clearly shows that the decisive difference between the two systems consists in the timing of their development, i.e., at which period they are integrated into the postural function. Muscles with a tendency to weakness, i.e., the phasic muscles, come into play later; hence, they are younger with regard to their postural function. This postural function is also related to the developmentally youngest morphological structures. This system is not only young but also very fragile. The postural activity of phasic muscles goes hand in hand with central nervous control at a higher level of integration, compared to the neonatal period. It is of great clinical importance that at this higher level of integration a different interplay between different muscle systems are achieved than on the spinal or brain stem level. Motor programs at the spinal and

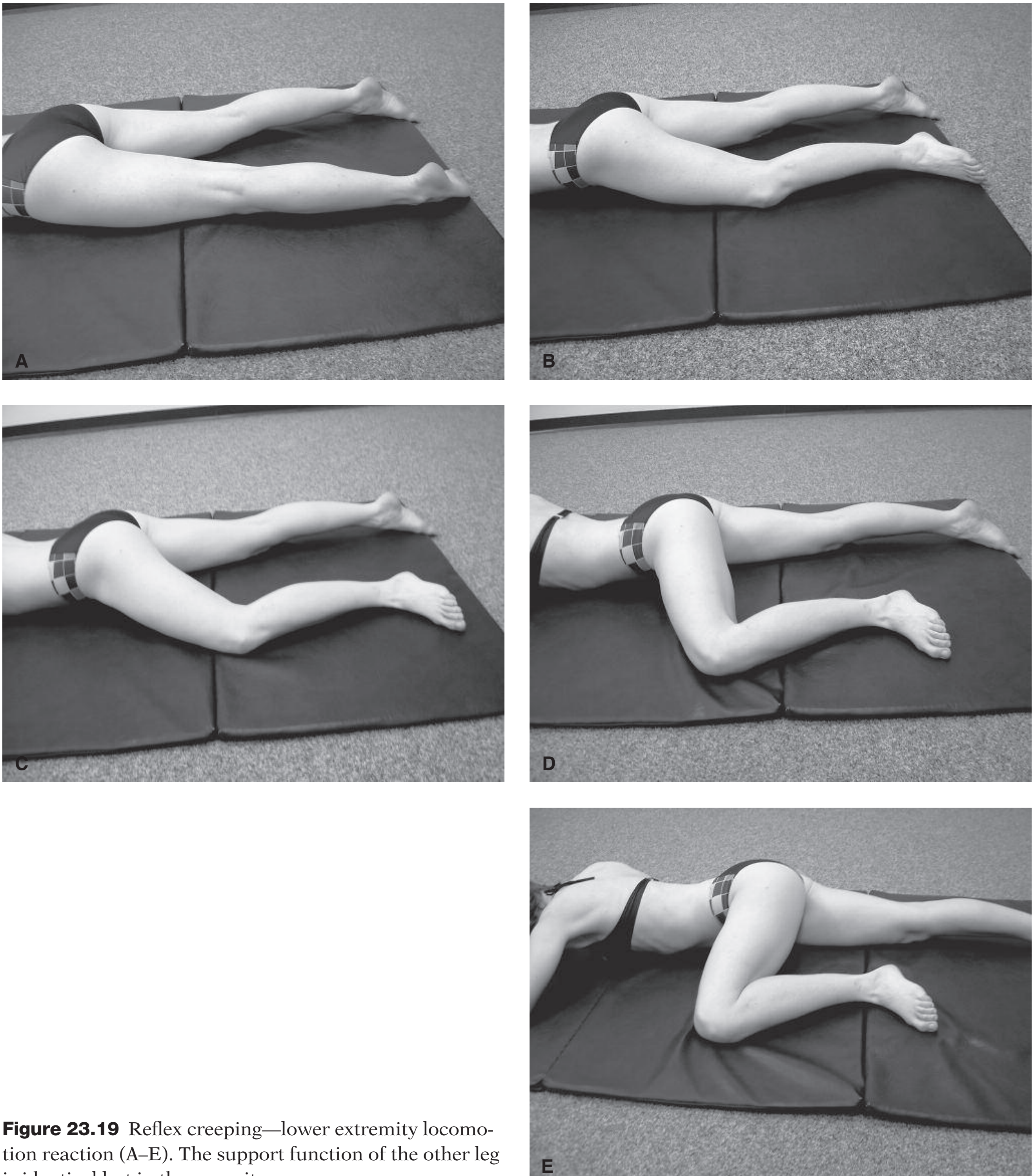

Figure 23.19 Reflex creeping—lower extremity locomotion reaction (A–E). The support function of the other leg is identical but in the opposite sense.

brain stem level function mainly by reciprocal inhibition of the antagonist (activation of the muscle causes inhibition of its antagonist), as can be seen from neonatal reflex activity. Co-activation patterns develop only as higher levels of integration mature. At the same time neonatal reflexes are inhibited.

Phasic muscles are involved in postural activity as a whole, as a system, and its activity automatically changes posture. The moment the deep neck flexors become activated (when between the fourth and sixth week the child lifts its head), all the other phasic muscles take part in postural function by

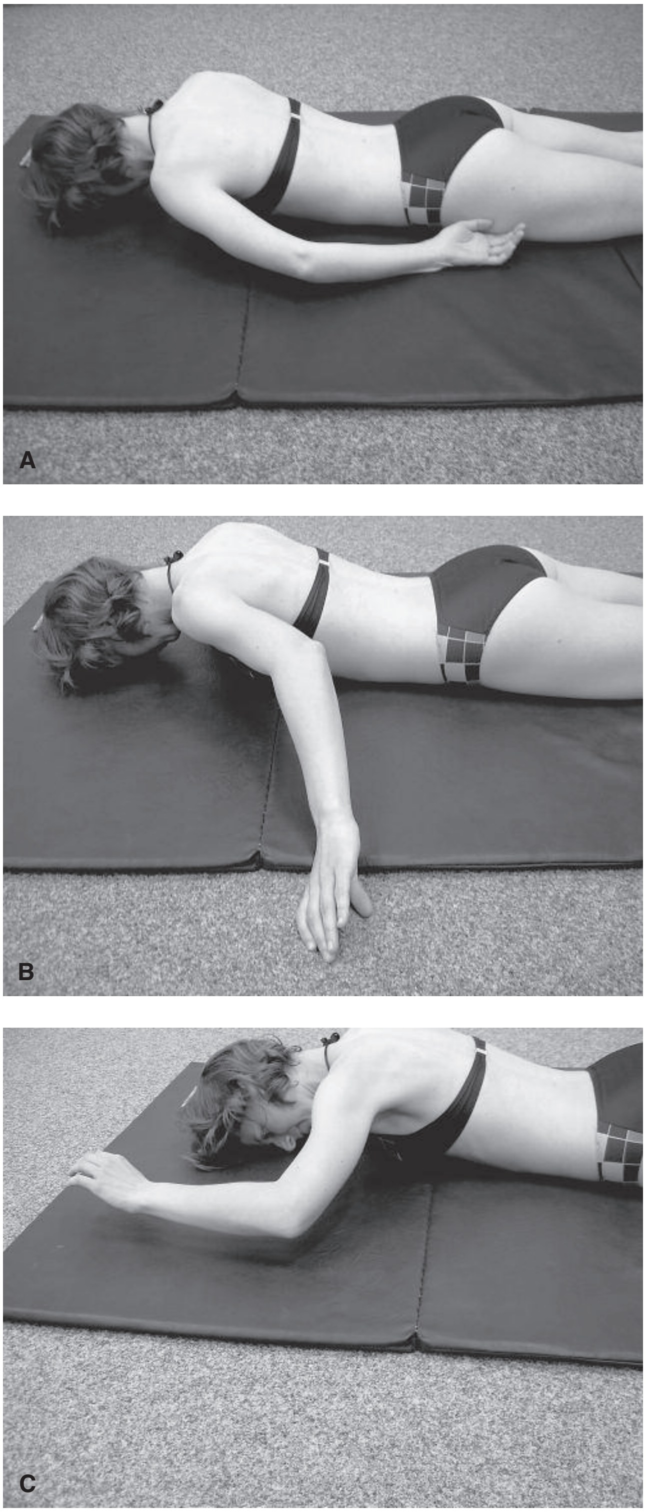

Figure 23.20 Reflex creeping—upper extremity locomotion reaction (A–C). The support function of the other arm is identical but in the opposite sense.

Figure 23.21 Posture reached at the age of 4 years.

means of their interacting attachments, including the external rotators and abductors of the hip joint, the external rotators and abductors of the shoulder, and the deep spinal extensors, the lower fixators of the shoulder blade, and other muscles of the same system. This represents a highly integrated global reflex stabilization function.

It can be shown that this program involves both the tonic and the phasic system as a whole and that the two cooperate in stabilizing posture by reflex action. If only a single phasic muscle is weak, not only is joint position automatically changed but also will inhibition irradiate into the entire system. Equilibrium between the two systems will change in favor of the tonic system. The tonic system predominates in stabilizing posture. By restoring the function of a single phasic muscle, however, inhibition of the entire tonic system will occur. If, e.g., we enhance the postural activity of the lower fixators of the shoulder blade, we lower the tension not only of their antagonists, i.e., the upper fixators of the shoulder blade, but also of tonic muscles at a distance, e.g., of the hamstrings (increasing the range of hip flexion). Resisting external rotation at the shoulders, extension at the elbow, supination, or

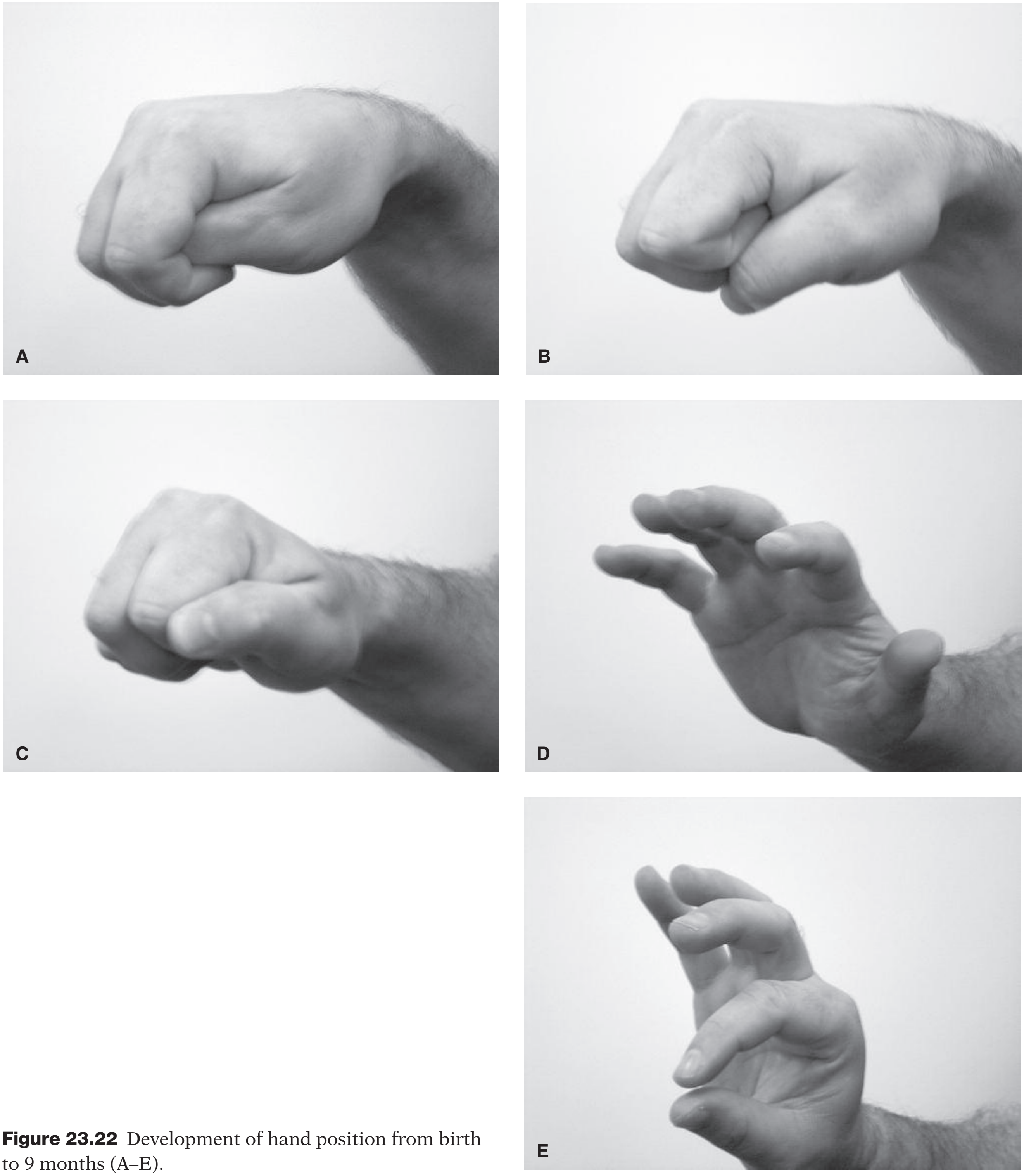

Figure 23.22 Development of hand position from birth to 9 months (A–E).

finger extension, not only will the antagonists of each muscle be inhibited but also will the tonic muscles be affected at a distance, e.g., the hamstrings may cause a change in the straight leg raising test. This higher level of integration results in new types of reflex relations, which can be established between muscles situated far apart. In this connection, the upper part of the trapezius (a tonic muscle) is an antagonist not only of the lower part of trapezius but also of the vastus medialis in the system of phasic muscles. Such reflex relations are established on a higher than brain stem level.

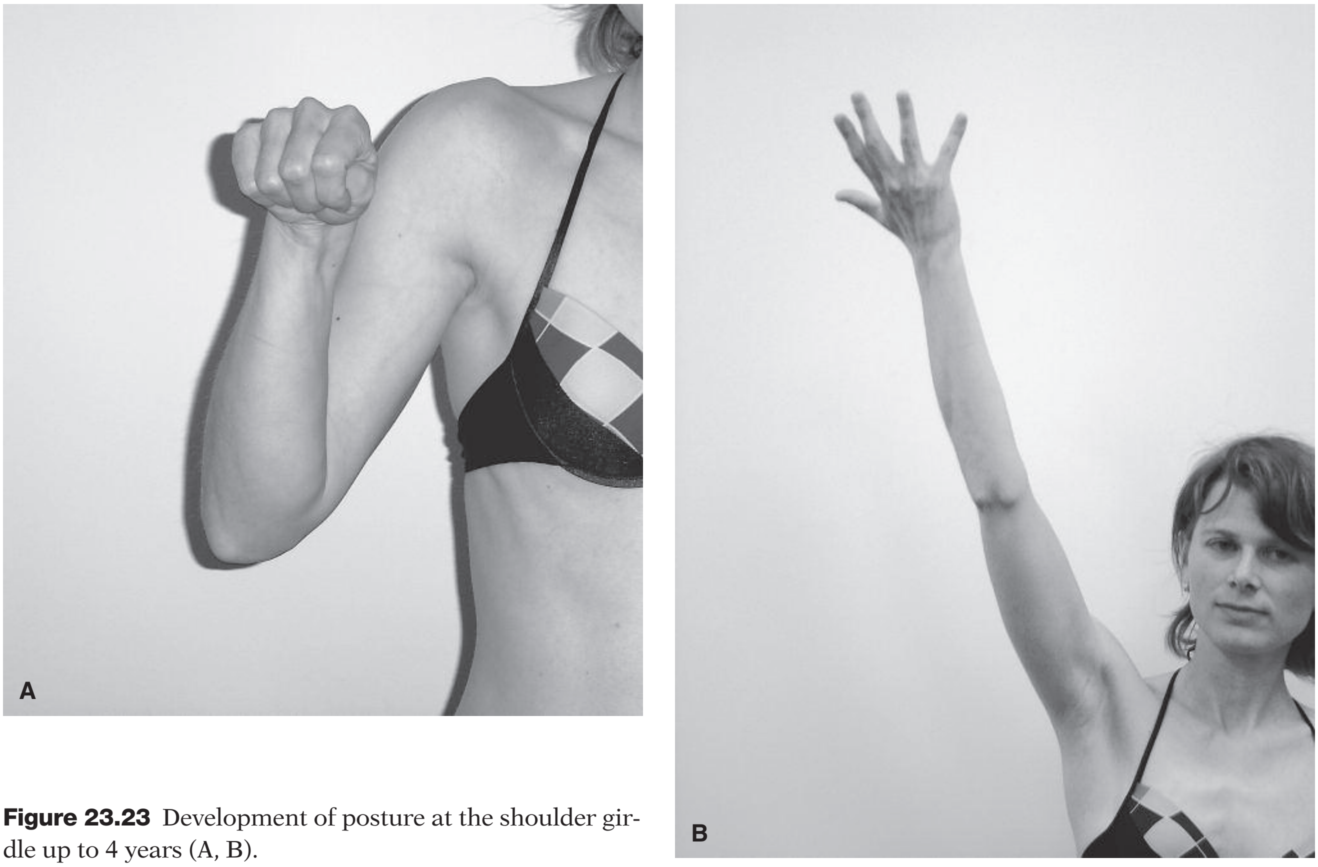

Figure 23.23 Development of posture at the shoulder girdle up to 4 years (A, B).

The Influence of Gravity on Function and Structure

The development of the postural function of phasic muscles is closely related to maturity or immaturity of the skeleton.

At birth, for example, the extremity abductors and outward rotators have no postural function. This can first be traced at the age of approximately 6 weeks. It not only changes posture but also influences anteversion and the colodiaphyseal angle of the femur. Insufficiency of the postural function of the abductors and external rotators results in anteversion and valgosity of the hip joint. The muscles necessary to attain the highest stage of morphological development are the middle and posterior part of the abductors and the outward rotators of the hip joint. These muscles belong to the phasic system with a tendency to inhibition.

Another example is the foot. The longitudinal axis of the calcaneus lies laterally because of the position of the talus at birth, and the heel is high because the calcaneus has not yet slipped under the talus. The calcaneus reaches this position underneath the talus thanks to the postural activity of the short muscles of the foot and the tibialis anterior, tibialis posterior, and the peroneal muscles. The shape of the longitudinal arch is not complete until the age of 4 years, i.e., when the postural function of all the pertinent muscles has been fully developed. In cerebral palsy the foot remains at the neonatal or even at an earlier stage, because the function of the muscles has failed to mature. The same is true in children with a central disturbance of coordination.

Thus, the phasic muscles determine the shape of most anatomical structures, including also the colodiaphyseal angle and the angle of anteversion at the hip joint, the plateau of the tibia, the transverse arch of the foot, the horizontal position and the torsion of the collar bones, the spinal curvatures, etc. Thus, a mature phasic muscle system ensures morphological maturity at the age of 4 years.

Phasic Muscles—Functional Insufficiency

Absent or faulty stabilizing postural function of phasic muscles not only causes faulty posture similar to that of patients affected by neonatal cerebral palsy but also causes typical changes in the skeleton: coxa valga antetorta, a kyphotic spinal column, an oblique tibial plateau, an insufficiently developed foot with valgosity, genua valga, and pelvic anteversion.

In almost 30% of the child population, there is some degree of faulty posture caused by dysfunction of the phasic muscles, which also affects the skeleton (1,11,13). Systematic weakness of the phasic muscles is also characteristic in old age, with insufficient extension of the spine, restricted elevation of the arms, faulty posture during trunk rotation, etc. The entire system tends to revert to an earlier neonatal postural model. Protective posture caused by joint pathology shows a similar pattern, as described by Cyriax, but was never explained. Here again we can see that pathological posture reverts to an earlier stage of development.

Developmental Kinesiology of Spinal Stabilization in the Sagittal Plane

The CNS program controlling the development of stabilized erect posture starts at the beginning of the second month. It is not restricted to the head and neck, but results in a change in the entire body posture. Spinal straightening, i.e., balanced co-activation of the muscles on the dorsal and ventral body aspect, is complete by the end of the fourth month. It is related to the first basis of support, i.e., for the prone position the triangle formed by the elbows and the symphysis, and for the supine by the glutei, the scapular region, and the linea nuchae (Figures 23.11 and 23.12).

At this stage of development, the foundations of stabilization of the spine in the sagittal plane are laid. Only on this basis can phasic movement be achieved. Any disturbance of stabilization will be evident in phasic movement. Stabilization in the sagittal plane, the prerequisite of physiological centered spinal posture, therefore requires:

1. The co-activation of the dorsal and ventral musculature. This is of crucial importance for physiological ("centered") posture, i.e., optimum static function. This applies in particular to the deep neck flexors and the abdominal muscles, and to the extensors of the spinal column on the dorsal aspect. Only this co-activation can achieve a centered position and provide optimum static function.
2. The cooperation of antagonistic muscles that are attached to the thorax and the shoulder blades. Both these anatomical structures transfer muscle pull to the spinal column. This applies particularly to the cooperation of the inferior serratus anterior and abdominal muscles, and, also, the scapular adductors and the pectoralis major.
3. The integration of the diaphragm into stabilization by respiration.

The muscles of the stabilization system function as a unit; they are interdependent. If one muscle is weak or overactive, this never remains isolated, affecting the static and dynamic function of the entire spine—the individual segments will be no longer in a centered position.

The Cervical and Upper Thoracic Region

Erect posture (centration) of the cervical spine develops after the age of 6 weeks. In an anatomic sense, the cervical spine ends at C7, but from a functional perspective it ends at T4, because the upper thoracic spine participates in flexion, extension, as well as in side bending and rotation of the head. This is borne out by the anatomy of the most important muscles that extend the cervical spine and originate in the mid thoracic region.

The extensors of the cervical spine are the m. semispinalis capitis cervicis, M. semispinalis capitis, m. splenius capitis, m. splenius cervicis, and m. longissimus AQ7 cervis et capitis. These muscles originate at T4, T5, and T6. At this stage of development, extension is further enhanced by the rhomboids and the middle and lower trapezius in cooperation with the serratus anterior, which serves as a punctum fixum for the spinal extensors. The serratus anterior, however, can fulfill its stabilizing function only if its attachment points are stabilized by the abdominal muscles.

Erect posture, i.e., correct centration of the cervical spine, is possible only if there is activity of the muscles on the ventral aspect, i.e., the longus colli and primarily the longus capitis, in addition to those on the dorsal aspect. These muscles also originate at the level of the upper thoracic spine and prevent reclination (i.e., back-bending) of the head and cervical hyperlordosis. The balanced co-activation of these muscles ensures correct centration and prevents overstrain of the sternocleidomastoids and the scaleni. In pathological cases, there is reclination of the head and flexion/extension takes place only at the cranio-cervical junction. When this occurs, normal development of the entire spinal column is impaired. Centration of the cervical spine also depends on the stabilizing function of the deep extensors of the mid thoracic spine. They provide the punctum fixum for the deep extensors of the cervical spine. Their weakness is accompanied by hyperlordosis, inhibition of the deep neck flexors. Activity of the deep neck flexors and extensors depends on stabilization of their attachment points, which in turn depend on a muscular chain. For instance, if the lumbar section of the diaphragm and the lateral section of the abdominal muscles do not function, forward-bending of the head occurs with substitution of the sternocleidomastoids for the deep neck flexors, with the result being a chin poke.

The Lower Thoracic and the Lumbar Spine

There is a similar close relationship between the function of the lumbar and lower thoracic spine as there is between the cervical and upper thoracic spine down to the mid thoracic region (T5). This results, too, from the anatomy of the relevant muscles. Erect posture of the thoracic and lumbar spine develops in close relation to the cervical spine. This is related to the anatomy the muscles. Straightening of the thoracic and lumbar spine is closely related to that of the cervical spine. Activity of the spinal extensors must be kept in balance by simultaneous activity of the abdominal muscles and the diaphragm, resulting in the correct centration of individual segments. The abdominal muscles with the diaphragm become involved in posture at the same stage of development as the deep extensors. Both the oblique abdominal muscles and the rectus originate from the lower ribs, beginning at T5. This anatomical and functional relationship enhances erect posture under the control of the CNS. If this stabilizing function is disturbed either by hyperfunction or hypofunction, the static function of the spine is compromised.

The interplay of the abdominal and back muscles with the diaphragm and the pelvic floor must be understood. At birth the diaphragm is still in an oblique position while the pelvic floor has no postural function, nor is there any postural synergy between the intrinsic back and the abdominal muscles. As the intrinsic back musculature comes into play, the spinal column straightens. The thorax with the ribs is stabilized by the caudal pull of the abdominal muscles. The ribs are steeper than in the newborn stage. Straightening up of the spine in concert with stabilizing activity in the abdominal muscles alters the punctum fixum for the attachments of the diaphragm, thus bringing the diaphragm into a horizontal position.

This is as specific for humans as is erect posture. Increased intra-abdominal pressure and decreased pelvic anteversion through the pull of the abdominal and gluteal muscles enable the pelvic floor to perform its postural function. The coordinated function of the diaphragm with the abdominal muscles is crucial for the anterior stabilization of the lumbar spine. Stability of these structures is decisive also for the thoracic and cervical spine because they form their punctum fixum. The postural function of the pelvic floor is brought about by increased intra-abdominal pressure and a change in pelvic anteversion by the activity of the abdominal muscles.

Postural Ontogenesis and the Function of the Diaphragm

If the CNS develops normally, the diaphragm will be the chief respiratory muscle. At the same time, it forms part of the co-activation pattern resulting in erect posture. These functions mean that posture exerts a great influence on respiration, and respiration on posture. As erect posture develops, the diaphragm finds its horizontal position at the end of the fourth month. If the diaphragm contracts, it flattens and is resisted by the abdominal wall. In coactivation with the abdominal muscles, it produces intra-abdominal pressure. This plays an important role in stabilizing the lumbar spine. Thus, the diaphragm not only is the main respiratory muscle but also stabilizes posture. Its activity depends also on the position of the spine and the thorax, which act as a punctum fixum. The inspiratory position of the chest together with thoracolumbar hyperlordosis impairs the activity of the diaphragm in all of its three sections. Activity of the lumbar section of the diaphragm is particularly impaired and the stabilizing co-activation of the abdominal muscles is lacking. Respiratory activity is transferred mainly to the thorax and via the auxiliary respiratory muscles to the cervical region. Under normal conditions, however, the diaphragm with the abdominal muscles and the spinal extensors stabilize the punctum fixum for the psoas at the thoracolumbar junction.

Muscular Imbalance in Disturbed Co-activation and Impaired Spinal Stabilization in the Sagittal Plane

The spinal column forms a fulcrum stabilizing muscles, which relate to the extremities, i.e., a punctum fixum. Faulty position of the spinal column is accompanied by functional imbalance of the muscles of the pelvic and shoulder girdle and the extremities. The reverse is also true.

Erect posture (sagittal plane function) is completed at an earlier stage than vertical stance. As pointed out, the postural model, i.e., well-balanced muscular coactivation resulting in optimum loading of the spine, is completed during the fourth month. At this early stage of development, the final basic posture is established. It remains unchanged even when the child stands up and during further postural development, but it adapts to the varying areas of support. A child with even a slight lesion of the CNS (approximately

30%) never reaches this ideal level of co-activation between the two functional systems (1,11,13). The posture of such children when standing is never truly erect. Generalized muscular imbalance caused by faulty development is the cause of future faulty posture. Hence, it requires treatment at this initial stage. Similar muscular imbalance need not, however, be caused by abnormal development, but by affections at a later stage, which result in reflex changes of a stereotypical character.

The muscles responsible for well-centered posture (the deep stabilizers) act as a functional unit. Hypofunction or hyperfunction of a single muscle never remains isolated but involves the entire complex by affecting the points of attachment. We therefore find that weakness of the pelvic floor is usually accompanied by weakness of the deep neck flexors and vice versa. This interrelation is very important for treatment. This functional unit is young from the phylogenetical standpoint.

Insufficiency of the deep flexors is characteristic for the cervical region. This results in head reclination with hyperextension of the lower cervical spine. The upper thoracic spine is in a forward-drawn position. Neck rotation is not proportional throughout the cervical spine and is therefore restricted. Fixation by the serratus is insufficient and therefore the rhomboids and the lower and middle trapezius cannot achieve erect posture in the cervical spine. The upper trapezius, the levator scapulae, sternocleidomastoids, and the scaleni predominate and function also as auxiliary inspiratory muscles.

Normally, co-activation of the abdominal wall, spinal extensors, and the diaphragm controls intra-abdominal pressure and centrates the low thoracic and lumbar spine. Weakness of the abdominal wall and insufficient intra-abdominal pressure result in permanent pelvic anteversion and increased lumbar lordosis. This is frequently accompanied by diastases of the abdominal muscles. Weakness of the abdominal wall not only induces hyperlordosis and pelvic anteversion but also prevents extension of the thoracic spine below T5. Lumbar lordosis thus ends in the low thoracic region, most frequently at the thoraco-lumbar junction, and kyphosis starts from this level. In the kyphotic segments there is no extension. The thorax is in an inspiratory position and there is obliquity of the diaphragm. The intercostal spaces do not widen at inhalation and the thorax is lifted as a whole. Thus, inhalation takes place by contraction of the auxiliary respiratory muscles. This condition goes hand-in-hand with weakness of the pelvic floor. At the same time there is disturbed co-activation of the serratus anterior and the lower trapezius, which normally straightens the thoracic spine and facilitates the transversus abdominis.

The mid thoracic spine, i.e., the transitional vertebra T5, plays a very important role both in ontogenesis and in pathogenesis. It represents the punctum fixum, from where the cervical spine straightens and where the most important postural muscles originate: the splenius cervicis and capitis, the longissimus capitis and the longus colli, and where the longigissimus thoracis is attached. The abdominal muscles also originate from the fifth rib. This is the level where the lumbar lordosis ends because of muscular co-activation.

In normal posture, T5 forms the apex of the thoracic kyphosis or the end of lumbar lordosis. Thus, the area from T4 to T6 is the region that functionally divides the upper and lower half of the human body.

Clinical examination of this section of the spine is particularly important. Only if there is well-balanced muscular activity in the entire motor system is it possible to straighten up below T5. It appears that almost every disturbance of muscle activity related to the spinal column as well as to the extremities will affect this region, keeping it in flexion, with kyphosis and movement restriction into extension below T5. The extent of this fixed kyphosis varies but can reach as far as to the thoraco-lumbar junction in some cases. Abnormality of the spine in the sagittal plane results from faulty activity of the oblique abdominal muscles. Thus, rotation of the spine, too, depends on stabilization of the spine in the sagittal plane.

Normal and Abnormal Kinesiology of Respiration: Its Relationship to Spinal Stabilization

Movement of the thorax plays an essential role in respiration. It is formed to comply with the movements of breathing. The muscles involved can be described as inspiratory and expiratory, and as main and auxiliary respiratory muscles. Auxiliary muscles come into play only when great effort is required or under pathological conditions.

During respiration the ribs are raised and lowered, moving around an axis starting at the head of the rib and ending at the transverso-costal joint, in a dorso-lateral direction. Torsion of the rib is most important for movement. There are three types of torsion:

1. Around the thorax
2. Along the lower edge of the rib (if placed on its edge on a table the rib touches it only at two points)
3. Twisting—at its dorsal end it is almost vertical, and in front oblique, pointing in a ventro-cranial direction.

Curvature of the ribs is important for the enlargement of the thoracic cavity. The joints between the ribs and the sternum have very tight capsules, allowing only slight movement. The ventral ends of the ribs are raised together with the sternum. In this way, the thoracic cavity widens in the sagittal plane. It should be noted that during inhalation the sternum should also move forward.

This is accompanied by rotation in the sternoclavicular joints. The clavicle does not move and the sternum rotates at the sternoclavicular joint. (The cavity at manubrium sterni moves against the articular head of the clavicula). The axis of the neck of the
AQ8 lower longest ribs (6–8) runs in a dorso-lateral direction, which makes the thoracic cavity widen in the frontal plane. This movement may be disturbed in pathological cases. The upper ribs move much less under normal conditions. If the development of the CNS is normal, the diaphragm is the main respiratory muscle, but it also stabilizes posture.

The diaphragm flattens and acts against the resistance of the abdominal wall. It controls intra-abdominal pressure in cooperation with the abdominal muscles and the pelvic floor, which are also important for stabilization. Its activity depends on the position of the spine and the thorax, which form a punctum fixum. If the thorax is in inhalation position with the sternum and the ribs raised, and the thoracolumbar junction in extension, then activity of the diaphragm is impaired in all its three sections. This particularly affects its lumbar section. Respiration is then limited to the thorax, which is pulled upward by the auxiliary muscles. The diaphragm and the abdominal muscles stabilize the thoracolumbar junction, providing a punctum fixum for the iliopsoas. In this way, physiological respiration stabilizes the lumbar spine. Examination of respiratory and stabilization function is therefore an essential part of examination and treatment of the locomotor system.

Examination of the Deep Stabilization System of the Spine in the Sagittal Plane

Disturbance of spinal stabilization is an important factor in back pain and other conditions. We have to bear in mind that any purposeful movement first requires spinal stabilization. Stabilization also plays an important role in compensation and normalization of dysfunction. Control of spinal stabilization is therefore a prerequisite for successful therapy.

Diagnostic Tests

1. Examination sitting erect or supine. We palpate below the last ribs at the lateral aspect of the abdominal wall. The patient is told to press against our hands, which press gently against the side of his abdominal muscles during exhalation, when his thorax is lowered. The spinal column must remain straight during examination; no spinal flexion should be observed.

Muscular activity at the waist is also palpated during inhalation. This test serves to examine to what extent the diaphragm is able to perform its stabilizing function (Figure 23.24A with the patient seated; Figure 23.24B with the patient supine).

Signs of Impairment The patient exerts minimal counterpressure or none at all. He may show some

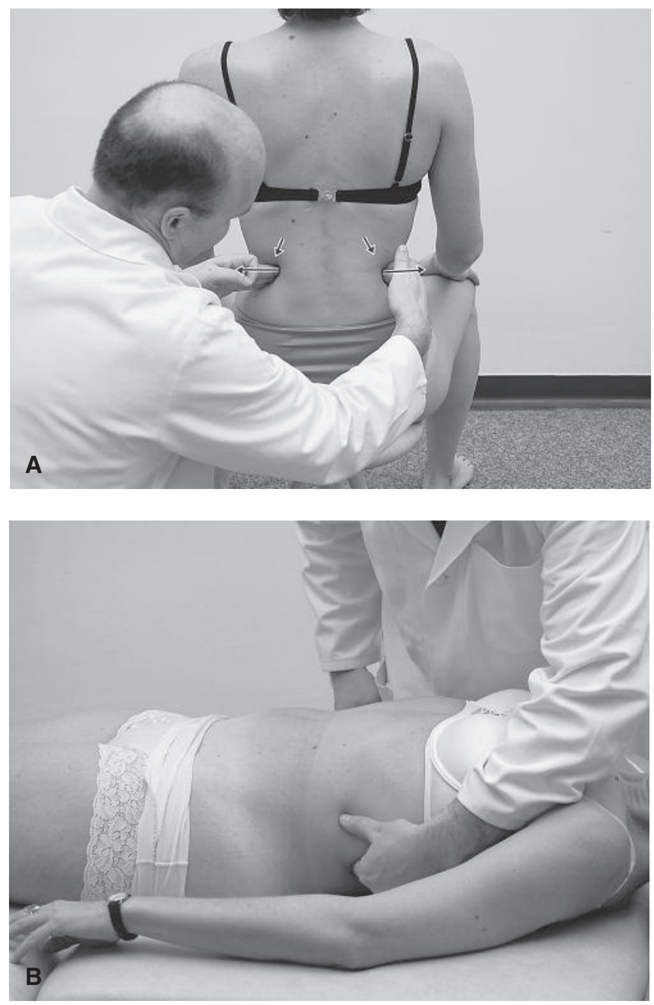

Figure 23.24 We ask the patient to press against our fingers: assessment of the patient's ability to activate the diaphragm (especially its lumbar part) together with the lateral parts of the abdominal muscles, with the ribs remaining in the caudal position. A: Examination with the patient sitting B: Examination with the patient lying supine.

activity during exhalation, but none during inhalation. Quite often he is not aware that he could activate those muscles. This shows lack of cooperation between the diaphragm and the lateral part of the abdominal muscles, creating an eccentric and finally isometric contraction. The pelvic floor also takes part in this muscular co-contraction, essential for the control of intra-abdominal pressure that stabilizes the lumbar spine from in front. The patient substitutes for this dysfunction by exaggerated activity of the rectus abdominis, particularly of its upper part, which is connected with the anterior paramedial part of the diaphragm, and by increased activity of the paravertebral muscles, especially at the T/L junction level. A patient unable to control the activity of the diaphragm in co-contraction with the lateral portion of his abdominal muscles is most likely to have low back pain. If this activity is asymmetrical at examination, disc herniation between L4/5 or L5/S1 is probable. Such a herniation can be asymptomatic; the patient does not have to have symptoms of spinal root irritation.

2. Examination supine with the legs extended or in slight flexion, followed by examination in the erect seated position. Supine, the patient exhales. With our palpating hands, we encourage the patient to move his thorax as far as possible with the sternum in a caudal direction (Figure 23.25). We hold the patient's chest in this expiratory (caudal) position and ask him to relax the abdominal wall completely. He is then asked to inhale while maintaining the caudal position of the thorax. With our hands we follow the movement of the sternum (we palpate the lower part of it) and the low false ribs (laterally from the medioclavicular line) (Figure 23.26). Inability to maintain the caudal position of the chest during inspiration indicates poor spinal stabilization; there is insufficient functional cooperation between the diaphragm and the abdominal wall. The patient cannot properly control intra-abdominal pressure. During the test we also check if the lateral aspect of the patient's abdominal wall protrudes below the last ribs. If this area bulges, it is a sign of good cooperation between the posterior part of the diaphragm (where eccentric contraction takes place) and the lateral group of abdominal muscles that also work eccentrically. This muscular cooperation is crucial for spinal stabilization.

With the patient seated, we palpate at the costal angle of the lower ribs (Figure 23.27) and follow rib movement during inhalation and exhalation. Under normal conditions, these ribs move in a lateral but not in a cranial direction; the caudal position is possible even during the inhalation. If the patient is in good control of his stabilizing functions, he should be able to perform this lateral rib movement even without breathing. He thus demonstrates his ability to control the lumbar section of his diaphragm. This is very important for the stabilization of the lumbar spine.

Signs of Impairment If the deep stabilizers are insufficient, the patient cannot control chest position during breathing. The initial position is cranial, i.e.,

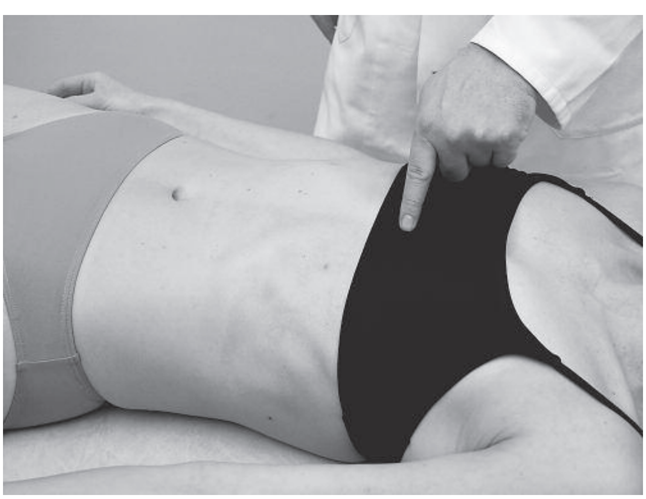

Figure 23.25 Assessment of the patient's ability to stabilize the chest during respiration. The sternal bone should reach the caudal position. The arrow indicates the direction of rib movement under physiological conditions.

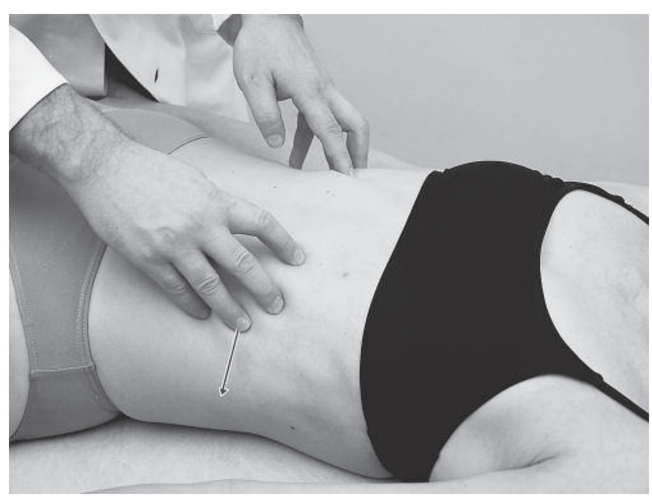

Figure 23.26 Palpatory assessment of false rib movement: the therapist notes whether the movement takes place in the cranial or lateral direction. The arrow indicates the direction of rib movement under physiological conditions.

Figure 23.27 Palpating the ribs at the angelus costae: assessment of lateral or cranial movement. The arrow indicates physiological, i.e., lateral movement of the ribs.

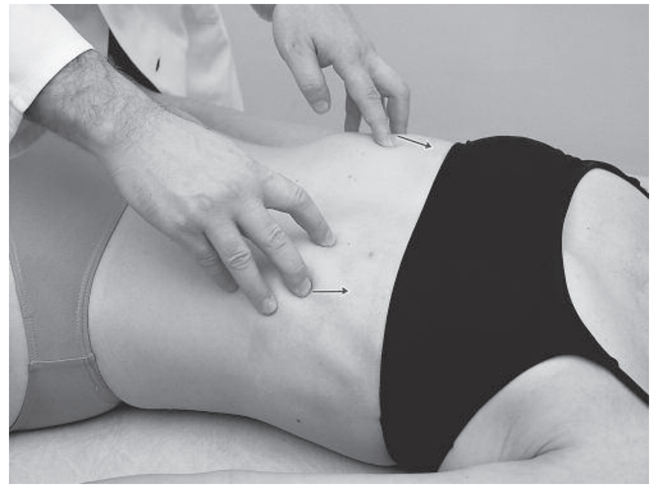

Figure 23.29 Movement of the ribs in a cranial direction is a sign of poor stabilization of the lumbar spine.

the inspiratory position of the chest. The axis connecting sternal and lumbar attachments of the diaphragm is oblique (normally it is horizontal). The lumbar attachment points are lower than the sternal. During inhalation the chest reaches an even more cranial position (Figure 23.28); its lower part does not widen and the axis becomes steeper. The patient cannot inhale while keeping his chest in a caudal position (Figure 23.29). By examination at the angelus costae during inhalation and exhalation, we observe cranio-caudal, but not lateral, movement. The intercostal spaces do not widen. By transmitting muscular activity, the thorax enhances stabilization. If,

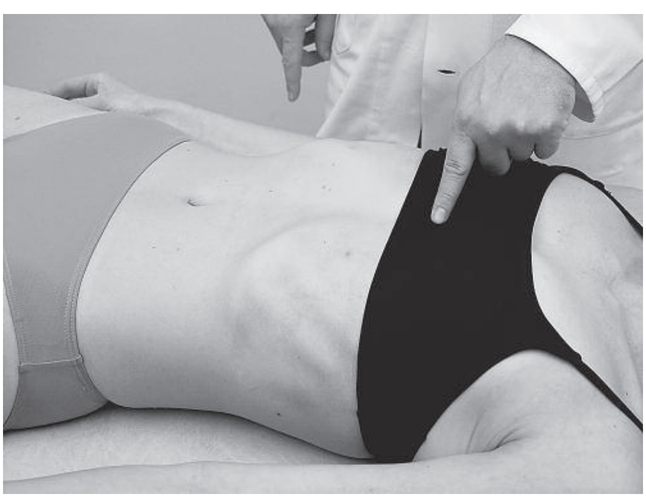

Figure 23.28 Movement of the sternum in a cranial direction. The patient is unable to maintain the caudal position of the chest and so cannot stabilize the lumbar spine from the front.

however, the thorax moves in a cranio-caudal direction during respiration, mainly by the activity of the auxiliary respiratory muscles, without stabilization in the transverse plane, there is no control of intra-abdominal pressure by the abdominal walls. Intra-abdominal pressure normally increases when we make any purposeful movement with our extremities.

3. Examination of the patient sitting erect with legs apart and hanging down freely. The patient flexes one hip against gravity or slight resistance and we assess to what extent he stabilizes the thoracolumbar spine. During hip flexion, the iliopsoas is activated and its point of origin must be stabilized. Under normal conditions, we assess the contraction of the muscles of the abdominal wall as abdominal pressure increases. It is important to observe the tension of the abdominal and the function of the paravertebral muscles (Figure 23.30).

Signs of Impairment Insufficient stabilization is evident in increased activity of the paravertebral muscles and of the rectus abdominis, mainly of its upper section. There is minimum activity of the lateral part of the abdominal wall palpated at the waist. Under such conditions, every contraction of the iliopsoas is performed with an insufficiently stabilized lumbar spine. There is increased tension in the paravertebral muscles and we may even find discrete lateral shift of the thoracolumbar junction toward the flexing leg during hip flexion (Figure 23.31).

4. The patient is supine with legs bent at the hips and knees at right angles in abduction and slight external rotation; the distance between the knees

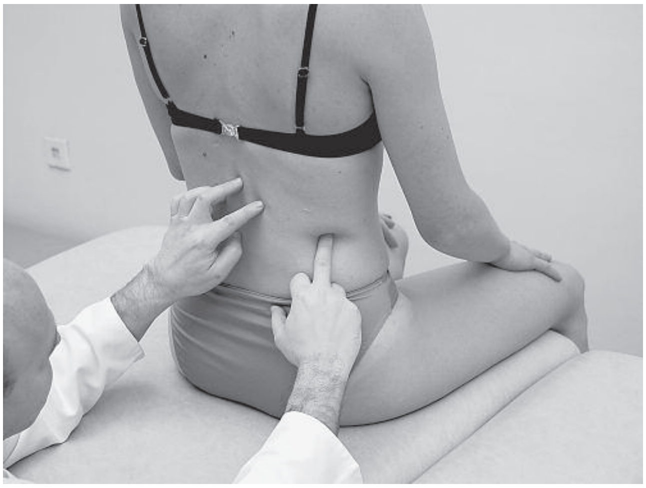

Figure 23.30 During examination, we palpate the T/L junction and lateral abdominal muscles below the lower ribs.

should be approximately the breadth of the shoulders. This is the correctly centered position from the functional point of view (Figure 23.32). The patient is told to support himself at the thoracolumbar region by the activity of the abdominal wall. This tests the quality of stabilization of the T/L junction by muscular activity and intra-abdominal pressure.

Signs of Impairment The first signs are revealed at the starting position. The rectus abdominis has a convex shape. Below the lower ribs, however, a concavity at the level of the costal angle can be noticed (Figure 23.33). At the caudal part of the lateral abdominal muscles on the side of the quadratus lumborum, the abdominal wall bulges because of muscular hypoactivity. Trying to straighten the thoracolumbar junction (for support) increases tension in the rectus abdominis and in the paravertebral muscles, with no activation of the lateral abdominal muscles (Figure 23.34). This is a sign of insufficient co-activation of the lumbar section of the diaphragm and the abdominal muscles, which is essential for stabilization of the lumbar spine. We also note whether there is diastases

Figure 23.31 If there is abnormality, we find lateral shift of the T/L junction, increased tension of the paravertebral muscles, and of the m. rectus abdominis, and poor stabilization of the lateral abdominal muscles.

Figure 23.32 The patient's posture corresponds to the developmental stage at which stabilization of the spine in the sagittal plane has been fully accomplished.

Figure 23.33 Insufficiency of the stabilization system results in hyperextension of the T/L junction; m. rectus abdominis predominates, and the chest is in a cranial position.

Figure 23.34 Any attempt to straighten the T/L junction results in hypertonus of the m. rectus abdominis and paravertebral muscles, whereas the lateral abdominal muscles remain hypoactive.

Figure 23.35 Evaluation of rib movement during trunk flexion. Movement in the lateral direction is pathological. Diastases of the rectus abdominis can frequently be observed

of the abdominal wall, which is another sign of insufficient stabilization. Diastases frequently increases if the patient tries to support himself at the thoracolumbar junction.

5. The patient supine with the arms along the body. The patient slowly bends his trunk. For examination, we palpate the rib movements. The lowest false ribs are palpated in the medioclavicular line and their movement is assessed.

Signs of Impairment When there is insufficient stabilization, the ribs deviate to the side and there is lateral bulging of the abdominal wall (Figure 23.35).

6. The patient is supine or standing erect. With the thorax in a caudal position, the patient lifts his arms. Activity at the thorax is assessed. If stabilization by the abdominal muscles is normal, the thorax should not be lifted during shoulder movement at full range (Figure 23.36)

Signs of Impairment When the patient lifts his arm, the thorax moves up as stabilization by the abdominal muscles is insufficient (Figure 23.37).

7. Examination with the patient supine with the legs extended. The patient slowly bends his head and neck. We assess the muscles performing the movement and those which stabilize their attachment points (Figure 23.38 A and B)

Signs of Impairment The patient moves with the head in a forward-drawn position because of exaggerated activity of the sternocleidomastoids and the scaleni. There is hyperactivity in suboccipital muscles and in spinal extensors. The lower ribs move in a lateral direction during the test and sometimes even cranially. The activity of the deep flexors is inhibited not only by their weakness (which may not be apparent) but also by the lack of attachment point stabilization.

8. Sitting erect. The patient is asked to straighten the cervical spine. The point of gravity of the head should move in a dorso-cranial direction (Brugger's erect seated position).

Figure 23.36 We assess chest position during shoulder flexion. Normally, the patient should maintain the caudal position of the chest throughout the whole movement.

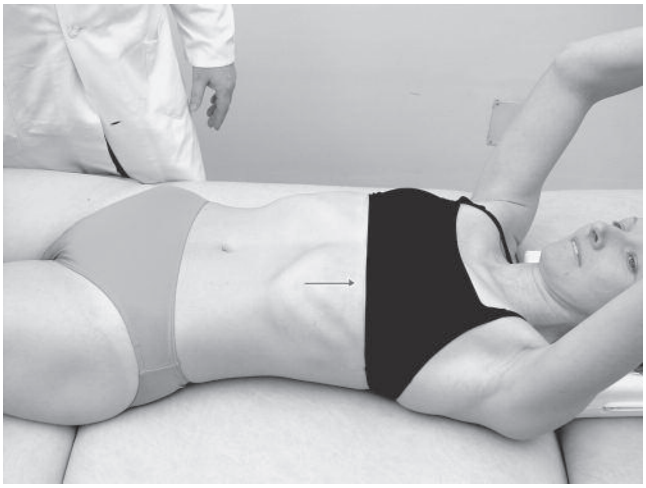

Figure 23.37 If there is poor muscular stabilization, the chest moves in a cranial direction during shoulder flexion.

Signs of Impairment In dysfunction, we frequently see that straightening up begins at the thoracolumbar region (as though the axis of rotation was there) (Figure 23.39A) or at the cervicothoracic junction, but not at T4/5, where it should start (Figure 23.39B). Extension of the mid thoracic spine is impaired. There is increased tension of the paravertebral muscles and of the adductors of the shoulder blade. Because extension of the mid and low thoracic spine is insufficient, the patient activates the sternocleidomastoid, the suprahyoid muscles, and the scalene when trying to straighten up segment T4/5. Stabilization of the thorax is insufficient. This insufficiency prevents the patient from being able to compensate adequately for stability challenges. Under such conditions all exercises will be useless.

9. The patient is prone and supports himself on his hands. The patient straightens his cervical and upper thoracic spine. Below T5, extension takes place from one vertebra to the next in succession. The shoulder blades remain abducted and in a caudal position. Straightening his arms, the patient pushes himself up and exhales. The patient moves to make the symphysis the main point of support

Signs of Impairment Insufficient extension of the mid thoracic spine and exaggerated extension of the thoraco-lumbar region. Tension in the paravertebral muscles greatly increases. The shoulder blades move together and upwards (Figure 23.40).

Treatment of Insufficient Stabilization of the Spine

There is controversy about whether we should strengthen the abdominal, back, or other muscles and whether to train proprioception by wobble boards, gymnastic balls, or other methods. However, it is too little realized that in the majority of cases we are unable to ensure the correct initial position essential for any type of exercise. There is then a lack of stabilization and the effectiveness of the exercise

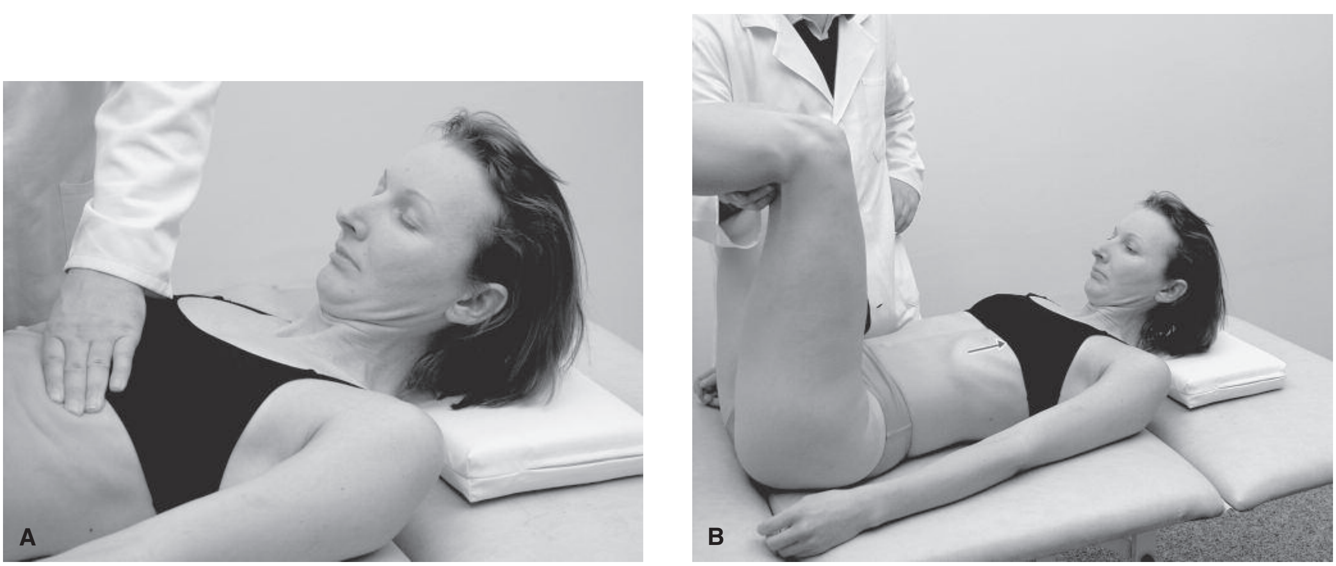

Figure 23.38 Flexion of the (C) spine is examined while the chest is fixed in a caudal position (A). Cranial movement of the chest prevents activation of the deep neck flexors (B).

Figure 23.39 Straightening up of the spine starts at the level of the T/L junction and either the chest moves cranially or the movement starts from the lower segments of the (C) spine (A). The patient cannot straighten the mid-thoracic spine (B).

Figure 23.40 During spinal extension, the thoracic spine does not straighten. Tonus in the paravertebral muscles increases and is maximal around the T/L junction. The patient cannot fix his shoulder blades in abduction and caudal position.

program is questionable. We should be aware that the chain of muscles required for any specific movement must be secured by stabilization of muscular attachment points.

Muscular coordination will greatly differ according to differences in stabilization. It is, for example, a great difference whether external rotation of the shoulder occurs with the shoulder blade stabilized by the trapezius or by the serratus anterior with the lateral abdominal muscles, or whether neck flexion takes place with the thorax in inhalation or exhalation. Stabilization results from the activity of a muscular chain that is not under the control of our will, nor do we know how to activate it deliberately. To make these muscles work, neither instruction nor explanation is effective. Reflex mechanisms or manual fixation are required to start with.

To be able to compensate for dysfunction, the patient must control spinal stabilization or else he will overburden the system. Every type of exercise, including sensory motor training or gym balls, depends on correct stabilization as a prerequisite of effective therapy.

There are three basic approaches to improving stability, depending on whether the case is acute or chronic, or whether our aim is prevention. It also depends on whether the patient is able to react adequately to our instructions or whether he cannot control his movements.

1. Reflex locomotion
2. Control of respiration
3. Treatment based on instruction and manual control of stabilization.

Making Use of Reflex Stimulation

Stimulating reflex zones activates muscles for a definite purpose. The spinal column, the shoulder blades, and the thorax are brought into an ideal position of maximum load bearing by the activated muscles. In this position, muscle pull is most favorable. The response to stimulation is constant: the thorax settles in a caudal position, respiration is without any cranial displacement of the sternum or ribs, the ribs move in a lateral direction, and the intervertebral spaces widen. The diaphragm contracts regularly in all its sections and arrives at the horizontal position. The abdominal muscles together with the serratus anterior provide fixation of the thorax and there is balanced activity of the rectus abdominis and the lateral abdominal muscles. The thoracic spine extends by the activity of the deep intrinsic muscles. The thoracolumbar junction is centered and stabilized by the activity of the diaphragm, the abdominal muscles, and the spinal extensors, so that the psoas can flex the hip joint. The accessory respiratory muscles relax by reflex action and the deep neck flexors are brought into postural activity. The shoulder blades move in a caudal direction and are fixed by the balanced activity of the serratus anterior and the adductors. In this way, the spinal column is stabilized in the sagittal plane as a prerequisite for the stepping forward and support functions. The response will be the same in any position in which we choose to stimulate. The intensity of the reflex response can be enhanced by resisting against the stimulated movement.

Reflex stimulation of the stabilizing function is indicated mainly in the chronic stage of locomotor disturbance in patients with little ability to form new motor stereotypes. It is an attempt to achieve better voluntary control of stabilization by reflex stimulation. Reflex stimulation is particularly useful in an adult who is not fully conscious (e.g., after trauma or after a stroke). We may thus influence postural tonus, provoke muscle activity, preventing spasticity and contracture. Reflex locomotion is helpful in patients in intensive care units unable to cooperate. It also helps in patients with lesions of the spinal cord, in particular in the early stages. Making use of inborn mechanisms, we are able to activate specifically the muscle chains responsible for respiration. This is important in patients with respiratory disturbances, because they are unable to control the respiratory muscles.

Treating Pathological Respiration

This has the greatest impact on intra-abdominal pressure regulation and spinal stabilization. The prerequisite for normal stabilization is that the thorax is in a position like during ontogenesis, or as a result of stimulation, i.e., with the sternum and the ribs in a caudal position. The sternum moves only in a ventro-dorsal (dorso-ventral) direction (not cranio-caudal), with the axis of movement being in the sternocostal and not in the acromioclavicular joints. The caudal position of the sternum and the ribs is essential for the eccentric contraction of the abdominal wall during inhalation. The diaphragm flattens and contracts in all its parts. Thus, the patient widens his abdomen not only anteriorly but also the lateral and lumbar part of the abdominal wall must also distend proportionally. The constant height of the sternum with the ribs in the sagittal plane is essential for a balanced activity of the abdominal, serratus anterior, and pectoral muscles. Respiratory movements are taught first with the patient supine (Figure 23.41),

Figure 23.41 We have to teach the patient how to breathe and maintain the caudal position of the chest. The chest must not be lifted. During inspiration the anterior and also the lateral and lumbar sections of the abdominal wall must distend.

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and only gradually in more demanding positions. The basic task is to teach the patient to breathe with the sternum in a caudal position, moving it only antero-posteriorly. The thorax must widen in the transversal plane. Only under such conditions can the diaphragm and the abdominal muscles fulfill their stabilizing function.

Patient's Voluntary Activity

The patient's voluntary activity is used in carefully chosen positions, fixed by the therapist, to control stability of transmission systems (e.g., the shoulder blade, the thorax). The aim is to teach the patient how to change the stabilization function. Some techniques and their modification are demonstrated.

AQ10 *The patient is supine, the legs are lifted with the hip and the knees flexed at right angles and abducted, the knees are approximately as far apart as the shoulders breadth and in slight external rotation. This is the position of functional joint centration and muscular facilitation. The sternum and the thorax are moved down first during exhalation under the therapist's manual control. The lower section of the thorax must widen. In this position, the patient is asked to support himself at the thoraco-lumbar junction, which forms a punctum fixum. Then he slightly lifts his buttocks, activating the abdominal muscles. He should not, however, draw in the pelvis. We fix the lower ribs from above with our hands at the level of the attachments of the lateral abdominal muscles to enhance their caudal position. In this way, the diaphragm and the lateral abdominal muscles are automatically brought into action. This can be felt at the waist (Figure 23.42).

Figure 23.42 Activation of the abdominal press with the diaphragm in the caudal position. We fix the patient's ribs and chest in a caudal position and ask him to support himself at the area of the T/L junction and slightly lift the buttocks up from the table.

Mistakes to be Avoided When slightly lifting the buttocks, the ribs must not be moved up by the activity of the rectus abdominis and the ventral section of the diaphragm. This is seen when the abdomen bulges in front, without contraction of the lateral abdominal muscles. It is also a mistake if retroversion of the pelvis occurs, as is adduction of the shoulder blades accompanied by increased activity of the paravertebral muscles.

*The patient is prone with hands clasped behind his head. In this position, care must be taken that the upper trapezius is relaxed. Support is given to the arms and shoulders to help the patient into extension. The patient is helped to fix the shoulder blades in a caudal position and abduction. Extension is most important in the mid-thoracic spine. In this position it is essential that the patient supports himself at the symphysis while his shoulder blades remain fixed. In this way, centration of the thoracolumbar region is achieved, and the lateral abdominal muscles and the lumbar part of the diaphragm are activated.

Mistakes to be Avoided The patient flexes the thoracic spine while seeking support at the symphysis. He adducts his shoulder blades.

*The patient is prone, supporting himself on his hands. He straightens the cervical and the upper thoracic spine. Below T5, the vertebrae move into extension one after the other, only into mid position, i.e., to achieve centration. The patient pushes himself up by pressing on his palms. The movement is to make the symphysis the point of support. In this position, maximum caudal movement of the thorax is attempted during exhalation. At this moment, the patient is told to exert pressure against our resistance underneath the costal angle of the lower ribs, i.e., at the laterodorsal aspect of the abdominal wall. Extension should not be greater than 45 degrees above horizontal (Figure 23.43).

Mistakes to be Avoided the patient adducts the shoulder blades. When contracting his abdominal muscles and the diaphragm, he increases flexion of the thoracic spine. The patient is unable to keep his thorax in a caudal position during the pushup.

Motor Patterns and Trigger Points

In addition to muscular imbalance between ontogenetically older and younger muscles, it is important to show the principles of chain reaction between muscles

Figure 23.43 The patient straightens the area of the mid thoracic spine while keeping his chest in a caudal position and activating the diaphragm and the deep abdominal muscles.

with local differences in tension, in particular muscles harboring trigger points (TrPs). We may assume that their origin is nociception. Their interconnection is by no means haphazard but follows rather strict rules. If we release one TrP, we obtain release in TrPs much further away. Localized changes in muscle tension will also affect joint function by changing the articular pattern. A TrP is never an isolated change in function. A number of authors have pointed out that TrPs are to some degree interconnected. The description of individual chains has so far been empirical, without neurophysiological explanation.

Here, too, developmental kinesiology has brought about a change. The existence of inborn motor patterns points the way for a new functional understanding. The development of posture shows that the highest level of control of inborn motor patterns is not at spinal or brain stem level, but above the latter. This, too, forms the basis of our motor behavior. Two patterns play an essential role in succession:

1. Spinal posture in the sagittal plane (which matures at the age of 3.5 months [Figures 23.11 and 23.12]).
2. The stepping forward and support function of the extremities in connection with trunk rotation.

These functions mature in succession during the motor development. Motor patterns can be seen in the course of the individual phases of the postural development. It is important that they are parts of the global locomotor pattern. This pattern is inhibited by the cerebral cortex but can be evoked by reflex mechanisms not only in children but also in adults.

The locomotor pattern is made up of purposeful joint movements from one extreme position to its opposite. If, for instance, we stimulate the reflex pattern of the hip joint, it starts in one leg in extension, adduction, and internal rotation, and it ends in flexion, abduction, and external rotation. In the other leg, the opposite reciprocal movement takes place at the same time, i.e., starts in flexion abduction and outward rotation and ends in extension, adduction, and internal rotation. At the forearm, the movement starts in maximum pronation and ends in supination (at the other arm it will be the reverse, i.e., from maximum supination into maximum pronation).

The wrist moves on the stepping forward side from flexion and ulnar deviation into extension and radial flexion (and it will be the reverse on the opposite side). The principle is the same for all joints. For each joint there is a well-determined movement as part of a motor pattern. The anatomical structure determines the biomechanically ideal joint movement. The neurophysiological and biomechanical principles make up the normal motor pattern. Each position the joint adopts in the course of the motor pattern may be called “frozen.” This is controlled by muscles that stabilize it (fixation by muscular attachments). The angle at which a joint is placed determines the activation of specific parts of the muscles that stabilize the joint in a given position at a given moment (Figure 23.44).

The role of the TrP is to immobilize the joint in certain positions or locomotor stages (“frozen positions”). The articular pattern is changed automatically as the joint is immobilized in that position or stage of movement. The TrP is found in the part of a muscle that stabilizes that particular locomotor stage or position. The angle at which we examine a joint activates different portions of the stabilizing muscle. In other words, when the joint is at a different angle it affects different sections of the stabilizing muscles. For example, in a given position of the arm only a specific section of the pectoralis muscle will respond. In addition there will be a chain of TrPs in muscles that stabilize the attachment points of this part of the pectoralis. They will be found in those fibers that are functionally connected with the fibers of the pectoralis harboring

Figure 23.44 The angle at which the articulation is positioned determines which parts of the muscles will be activated and which parts of the muscles providing stabilization will be activated.

the TrP. Thus, if the pectoralis muscle is active, its attachment point must be stabilized by other functionally related muscles. Other parts of the abdominal muscles, of the adductors (retractors), of the shoulder blade, and also of the adductors and abductors of the hip, etc., must be activated if the angle of arm abduction is changed. Attachment point stabilization automatically occurs under the control of the CNS. Every joint position is stabilized during movement by muscle function.

Chains of TrPs can therefore be explained by the synergy of stabilizing muscles or their parts that correspond to a specific position or stage of movement ("frozen position") of the locomotor pattern. Reflex changes like TrPs are never isolated. They require immobilization of a certain position by a chain of stabilizing muscles. Thus, if we find a TrP in the pectineus, another will be found in the corresponding part of its antagonist, i.e., in the posterior part of the gluteus medius, and also in the corresponding part of the pectoralis, with an attachment point at the fifth rib, in the upper part of the subscapularis, and in the adductors of the shoulder blade, with attachment points at the T5/6 level, etc.

Principles of Examination and Correction of Pathological Articular Patterns

The basis for examination and treatment of disturbed function is the function of muscles and joints determined by a program under central control. The principles are as follows:

1. First, we try to make the joint move according to its pre-programmed pattern. For this, it is important to know the pattern of locomotion which is most favorable with regard to its mechanism. Therefore, the joint is examined under dynamic, not static, conditions. Because examination is passive, no resistance should be felt close to the neutral point of the joint. If there is abnormality, this pattern is changed. We feel some resistance and normal movement is substituted in a characteristic way, like a detour, with the movement not being smooth, as though a certain phase has had to be left out. This "derailment" is very characteristic.

   If we examine the segment L5-S1, passive flexion is produced at the hip joint, with the patient lying on the side, rotating at the same time the pelvis and trunk, which corresponds to the stepping-forward pattern (Figure 23.45). At the stage when the segment L5-S1 comes into play, i.e., at the end of the stepping-forward stage, we sense resistance and a change (substitution) of the movement pattern. This is felt like resistance, producing a lateral deviation of the pelvis. This deviation is a very sensitive sign of a movement restriction in segment L5-S1.
2. Correct positioning plays a key role in therapy. For this, we have to find the phase of the motor pattern in which resistance has been found at examination. This position has to be fixed; then, we have to overcome the resistance, the patho-

Figure 23.45 Mobilization of the lumbar spine making use of the stepping-forward function of the leg. During mobilization, our fixation must prevent incorrect substitution patterns.

logical substitution, by manual contact and complete the full range of the locomotor pattern. By mobilization, we prevent the joint moving in an abnormal way by using our hands. Thus, we obtain the effect of mobilization, i.e., normal joint pattern including joint play. If, for example, we mobilize the segment L5-S1, we position this segment to make it move in the pattern of stepping forward (Figure 23.46). By manual fixation, we prevent lateral movement of the pelvis (i.e., substitution) and move on into flexion. We do not mobilize by a movement of joint facet translation, but only by correcting the movement that is part of the normal pattern. This principle can be applied to joints in general.

Another possible way to correct articular patterns is by specific activation of muscles. We first take up the slack in a joint and the patient makes a "stepping-forward movement" with his leg, against resistance. The patient is required to exert only minimum resistance. In this way, muscular stabilization is obtained, securing the segment to be mobilized. By resisting the stepping-forward pattern, we change the muscle tension at the segment we intend to mobilize, including the deep stabilizers, which are not under the control of the patient's will (Figure 23.47). This effect can also be produced by stimulation of specific zones. Stimulation has to be performed in the position in which the slack of the joint to be treated has been taken up (Figure 23.48). Muscle facilitation takes place automatically. In this way, muscle tension is normalized and mobilization takes place.

Figure 23.47 After taking up the slack in the segment, we want to mobilize we resist the stepping-forward function of the leg (supination, extension, and radial duction). The force developed by the patient should only be minimal.

■ CONCLUSION

An attempt has been made to integrate the principles of developmental kinesiology with those of both neurophysiology and biomechanics. They comprise basic motor functions that form the basis of a diagnostic and therapeutic system. This principle is universal. Most techniques apply the principles of the developmental program, in particular of precise joint centration, of balanced muscular stabilization, and even of restoring proprioception.

The development of human erect posture helps us to understand chain reactions of functional lesions of the motor system. Without understanding the anatomical and functional, co-contraction of muscles would be meaningless.

Figure 23.46 Mobilization of the segment without making use of movement patterns.

Figure 23.48 After taking up the slack in the segment to be mobilized, we stimulate the appropriate zones.

Developmental kinesiology of course plays a key role in the assessment of early development in infancy and in the detection of even the slightest motor lesion in the earliest stages when therapy is most effective.

Developmental kinesiology enables us also to assess the prognosis of children with cerebral palsy. It is even possible to assess the relation between what has been achieved by treatment and what could have been achieved under optimum conditions. It is therefore possible to assess the effectiveness of rehabilitation.

Audit Process
Self-Check of the Chapter's Learning Objectives

- What are the chief landmarks in neurodevelopment of the upright posture that an infant/child achieves from ages 1 month to 4 years?
- How would you position a patient in the supine position to perform reflex locomotion in rolling?
- How would you position a patient prone to perform reflex locomotion in creeping?
- How can you test and train coordination of the abdominal wall and diaphragm?

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