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Pediatric Orthopedics

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Preface

This work was undertaken upon the invitation of its publisher and begun with interest and great personal involvement that have never faltered. Now that its manuscript is complete, I must seize the occasion of this prefatory statement to answer the reader's natural question: Why was it done?

I began with the perhaps-simplistic idea of providing a detailed technical presentation of surgical treatment of disorders of the neuromuscular and skeletal systems in children. I intended to write primarily for the orthopedic surgeon but I hoped also to interest physicians and surgeons of other specialties involved in the care of children.

I had no sooner set out on what proved a long and tortuous path than I began to appreciate that one cannot describe the techniques of surgery without considering also the biological principles of surgery, the dynamics of trauma, and the rationale for surgical intervention. That rationale is itself dependent upon knowledge of neuromuscular physiology and of the biomechanics of motion. One cannot speak of the management of disorder or of the amelioration of congenital defect without understanding disease process and the genesis of musculoskeletal anomaly. The surgeon who operates well performs not only with skill but also with reason; and that reason rests upon a diagnostic acumen fortified by physical examination, pathology, radiology and accurate classification. Similarly, the evaluation of surgery cannot be set out without attention to its possible complications and its aftercare.

On reflection, I realize the project I have undertaken is more ambitious than I had originally envisioned. And so I have written a long and complex book. Its very length and complexity must mean occasional omission and even error. I have tried to guard against them by citing for each important statement significant findings from the vast literature of pediatric orthopedics; but the opinions I have expressed concerning preferred methods of treatment and surgical procedure arise from personal experience and from the privilege of having learned and worked at fine teaching centers.

In another and perhaps more important way I have departed from original intent. I decided to omit chapters on the hand and on orthotics and prosthetics in the conviction that these highly individual subjects should be treated intensively and thoroughly in separate monographs.

I wish to express gratitude to John Dusseau, Editor of the W. B. Saunders Company, for the confidence he invested in me. Without his support, advice, and encouragement, this work would have been impossible.

I wish to express thanks also to the Trust Under Will of Helen Fay Hunter–Crippled Children's Fund, and to Mr. Carl A. Pfau and the Harris Trust and Savings Bank Trustees for their generous support.

The kind indulgence of the Board of Directors of Children's Memorial Hospital in allowing me the necessary time to complete this work is greatly appreciated. I also wish to thank certain of my professional colleagues and members of the orthopedic staff for their sincere cooperation during preparation of this manuscript.

With the exception of a few that have been reproduced from other works, the illustrations and operative plates are all original. The majority represent the superb artistry of Mr. Ernest Beck, to whom I am greatly indebted. I also wish to thank medical artists Wesley Bloom, Jean McConnell, Diane Nelson, and Laurel Schaubert. The diligent work of Miss Helen Silver and Mr. John Kelley of the Photography Department, Children's Memorial Hospital, must be particularly acknowledged.

The entire staff of W. B. Saunders Company, particularly Miss Ruth Barker and Mr. Raymond Kersey, are to be commended for their meticulous work during the preparation and production of the printed book.

Finally, I wish to thank Miss Eleanor Lynn Schreiner, who, in her role as my personal editor, has prepared and finalized the entire manuscript as it has been written during the past four years. Without her assistance and meticulous attention to clarity, this task would have been difficult, if not impossible, to achieve. For her unselfish dedication I shall always be grateful.

I shall conclude in the hope that if the reader learns as much from reading as the writer has from writing this monograph, its attendant trouble and trial will have been amply repaid in the better care of children.

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1. Introduction

Definition and Scope of Orthopedics

Orthopedics is a branch of medicine and surgery that deals with the preservation and restoration of function of the skeletal and neuromuscular systems. Although the skeleton per se is primarily concerned with the form of the body and its motion, it may be affected by many metabolic and other systemic diseases.

The components of the neuromusculoskeletal system are closely interwoven in their function. Action in one causes a response in the other. For example, many deformities of the skeletal system arise from muscular paralysis in diseases in which the nervous system is the primary area of pathologic change, such as poliomyelitis. During the years of growth, the normal function of muscles is essential to the development of skeletal contours. Abnormalities of muscle function can disturb growth and cause deformities of the bones. Muscles, in turn, respond to diseases of the skeleton. In the instance of an inflamed joint, for example, the muscles that motivate the area respond by a reflex mechanism, a so-called involuntary muscle spasm, to prevent motion in the painful joint. The muscles antagonistic to those in muscle spasm rapidly develop atrophy. If the muscles in spasm are left in their shortened position for a long period of time, they develop myostatic contracture—permanent shortening of the muscle length. This is seen particularly when there is associated imbalance of muscle strength or when factors that increase fibrosis are present.

The term "orthopaedy" is derived from two Greek words, *orthos*, meaning "straight, upright, or free from deformity," and *paidos*, "a child." It was originally used by Nicholas André, in 1741, as the title of a treatise—*L'Orthopédie, ou l'Art de prévenir et de corriger dans les enfants les déformités du corps*.[3] André taught orthopedics as a branch of preventive medicine rather than of surgery. In modern surgical days, one constantly needs to be reminded that "prevention is always better than cure."

Although the name *orthopedics* is only about 230 years old, the diseases of the neuromusculoskeletal system have always been among the major concerns of mankind. The early background of orthopedics is that of surgery and of medicine. All varieties of bone disease existed in prehistoric times, as evidenced by findings in thousands of skeletons unearthed from the caves of Dawn Men of Europe, Asia, and North Africa. Osteomyelitis, bone tumors, arthritis, and others are easily recognized. Fractures were common, and some of them were healed in good alignment. On a portal of Hirkouf's tomb, there is a carving, executed in 2830 B.C., showing the earliest known record of the use of a crutch. A textbook picture of what may well be the residuals of poliomyelitic paralysis is that of an Egyptian prince of the Eighteenth Dynasty with his right lower extremity atrophied and shortened, and the foot in equinus. Surgical operations on bones in prehistoric times are well documented, as skeletons are often well preserved.[5]

Hippocrates gave great attention to the musculoskeletal system; over 40 per cent of the *Corpus Hippocrates* is concerned with it.[22] The diagnosis and treatment of fractures and dislocations were quite well discussed. Traction, splints, and bandages were used. Clubfoot and congenital dislocation of the hip were well known.

The first hospital to specialize in musculoskeletal diseases was founded by Venel, in 1790, at Orbe, Switzerland. It was devoted primarily to the care of tuberculosis and congenital deformities. This was rapidly followed by construction of a number of such hospitals in Europe. In the United States, the first orthopedic hospital was the Good Samaritan, founded in Boston, by Buckminster Brown, in 1861. In the same year, Lewis Sayre became the first professor of orthopedics in the United States. Appointed to Bellevue Medical College, he organized an orthopedic dispensary at Bellevue Hospital in New York.

Initially, orthopedic surgeons were concerned with disorders of the musculoskeletal system that were of nontraumatic origin, particularly those of the child. During World War I, however, it became evident that the new techniques that they had developed were equally important for the management of disabilities and deformities resulting from trauma, and since then, it has become customary to consider all affections of the skeletal and neuromuscular systems as being one field of medicine. Orthopedics is now a broad surgical and medical specialty, interlocking with general surgery, neurosurgery, plastic surgery, vascular surgery, and many aspects of general medicine and pediatrics.

Diagnosis in Neuromusculoskeletal Disorders

THE ORTHOPEDIC HISTORY

A clinical history skillfully obtained and properly analyzed often holds the key to diagnosis. Many misdiagnoses are due to incomplete or inaccurate histories.

There are certain special problems, however, in taking the history of an infant or a child. First, the child is unable to describe precisely his own subjective symptoms and their temporal relationship. A child's recollection of past events is poor; he tends to live in the present and the future. Though one is compelled to turn to the parents for narration of a sequential history, one should not, however, neglect the child's observations entirely, as a child can often describe his symptoms in a delightfully refreshing and naïve manner, which may be of some historical value relative to his own illness. Second, cooperation is often poor. Patience, kindness, time, and a smile on the examiner's face are essential to ensure a relaxed atmosphere. The physician should conduct the examination in such a manner that it is pleasant for the child and for the anxious parents. Both father and mother should be interrogated whenever possible. One should encourage the parents to relate the problems in their own language. It is essential to convey interest, understanding, and sympathy. An impression of haste should be avoided.

While taking the history, the physician should evaluate the patient as a whole, the reactions of both the child and the parents to his disease and his handicaps, and his relationship to his parents and siblings. A friendly and courteous attitude, the centering of all attention on the patient, accurate and tactful wording of questions—all are important in developing a proper patient-parent-physician relationship.

The orthopedic history, like all clinical histories, usually begins with certain statistical data, which include the child's name, sex, date and place of birth, both father's and mother's names, and the name of the referring doctor, his address, and phone number. These data are usually obtained by the nurse or secretary.

Next, the *presenting complaint* is recorded. Common complaints pertaining to the musculoskeletal system are deformity, limp, localized or generalized weakness, swelling, pain, and stiffness of joints. Since the musculoskeletal system is concerned with support and locomotion, many of the symptoms arising from it are brought about by physical stress and motion; interrogation should establish this relation of symptoms to physical activity. The chronological occurrence of the presenting complaint with its exact date and mode of onset should be determined. Questions concerning severity, disability, factors aggravating or alleviating symptoms, and previous treatment should be noted. If there is any history of injury, details of the alleged trauma should be investigated to determine its etiologic significance. Once the foregoing information has been obtained, the physician should determine the time of onset, in terms of the life history of the patient, by taking what may be called *developmental history.*

Prenatal History

During the first trimester of pregnancy, embryogenesis and organogenesis proceed at a maximal rate. Any unusual incident during this period may be of clinical significance. Was there any history of vaginal bleeding to indicate threatened abortion? Were there any infections? The deleterious effects of maternal rubella during the first months of pregnancy with consequent cataract, deafness, heart disease, mental retardation, and seizures is well established. Syphilis, toxemia, and diabetes mellitus in the mother are also associated with a high incidence of abnormalities in the newborn. Is there any history of excessive radiation to the fetus or ingestion of toxic substances and medicines such as the tranquilizer thalidomide? Was there an accident in which the abdominal wall was struck, or in which there was excessive blood loss with critical lowering of the blood pressure?

Fetal movements are usually felt by the mother between the fourth and fifth months of pregnancy. A history of feebleness or absence of fetal movements may be of importance in arthrogryposis multiplex congenita or Werdnig-Hoffmann disease.

Birth History

Information should be obtained as to length of pregnancy, birth weight, birth length, and duration of labor. What was the presentation? Certain conditions, such as congenital dislocation of the hip and congenital muscular torticollis are more frequent in breech deliveries. Was onset of labor spontaneous or induced? Did the mother receive an analgesic or other medications during labor and how long before delivery? Was obstetric anesthesia general, block, or none?

The condition of the infant during the neonatal period should be determined. This is particularly important in children with brain damage and birth defects. What was the appearance and color of the newborn when first seen by the parents? How many minutes did it take for the infant's first breath and first cry? Was there any cyanosis? Were there any respiratory problems? Was the infant resuscitated? Was there any jaundice, and if present, when was it first noted and when did it disappear? Was any exchange transfusion given? Were there any neonatal convulsions? Was the muscle tone normal, flaccid, or rigid? Was there any opisthotonus? Was the child in an incubator? Did he receive oxygen? Was sucking or feeding normal, feeble, or absent? Did he have to be tube-fed? What was the nature of the cry? Was there any asymmetry of the face or the extremities? When was the infant discharged from the hospital? Did he go home with his mother? Were there any injuries or evidence of trauma? Were there any obvious deformities of the limbs?

Next, milestones of development for posture, locomotion, manipulation, activities of daily living, social development, and speech are determined. When did the infant lift his head, roll, crawl, sit, stand, pull himself to standing position, walk, run, ascend or descend stairs, and hop on one foot without support?

The examiner should habitually inquire about details of development of function of the upper extremity. When did the infant hold a bottle, reach for and grasp a toy, transfer objects from hand to hand? When did he offer his arm for coat or foot for socks, feed himself with spoon or fork, pull off or put on clothes? Ambidexterity, i.e., lack of hand preference, is normal during the first two years of life. When an infant demonstrates an unequivocal hand preference before this time some defect in the use of the other hand should be suspected; this may be the first sign of spastic hemiplegia. Exploration of environment by touch and the development of manual skills emerge in an orderly and sequential manner.

Equally important as evidence of the functional adequacy of the neuromusculoskeletal system is the general responsiveness of the infant to parents and objects in the environment. At two months of age an infant smiles when spoken to and vocalizes; at four months he turns his head to sound and recognizes his mother; at eight months he responds to "no"; at ten months he waves bye-bye, plays pat-a-cake, and says da-da and ma-ma. The sounds *a*, *ba*, *da-da*, and *ma-ma* represent the earliest phase of development of the articulatory process and of communication; however, they are without specific word meaning at this stage.

An interest in picture books and recognition of familiar objects begins at the age of 12 months; the child achieves a vocabulary of four to five words at 15 months, and three-word sentences at 24 months. Levels of motor development are presented in Table 1–7 in the appendix to this chapter.

A systemic review and a family history complete the orthopedic anamnesis.

THE ORTHOPEDIC EXAMINATION

Orthopedic diagnosis requires not only an evaluation of the neuromusculoskeletal system, but also a complete general physical examination.

The orthopedic examination usually follows a definite order unless the symptoms or status of the patient indicate deviation from it. It is imperative to pay scrupulous attention to minute details. The patient is stripped of all clothing and draped to expose the body in use. Normal body measurements are shown in Tables 1–1 and 1–2 and the accompanying Graphs 1–1 and 1–2 in the Appendix to Chapter 1.

Stance and Posture

The first step is inspection of the body as a whole and as a mechanical unit in action. If the child is ambulatory, he is asked to stand, and his natural standing posture and body outlines are observed from the back, front, and side. Are there any obvious defects of the spine or deformities of the extremities? Is there exaggeration or diminution of the normal physiologic anteroposterior curves of the dorsal and lumbar spine? What is the pelvic inclination? Are the shoulders carried behind the pelvis in the lateral view? What is the position of the head, scapulae, shoulders, gluteal and popliteal creases? Are the iliac crests level? Are the shoulders balanced over the pelvis? Is there deviation of the trunk to one side? (A plumb line held over the center of the occiput or over the spinous process of the seventh cervical vertebra should pass through the intergluteal cleft.) Is there any scoliosis? Is one hip more prominent than the other? How is the symmetry of the flank creases? If scoliosis is present, the degree and direction of rotation of the involved vertebrae can best be demonstrated by asking the child to bend forward for inspection of his spine from the back. In a structural curve, rotation of the vertebral body is to the convexity of lateral angulation; in a functional curve, it is to the concave side. Is there muscle spasm in the paravertebral

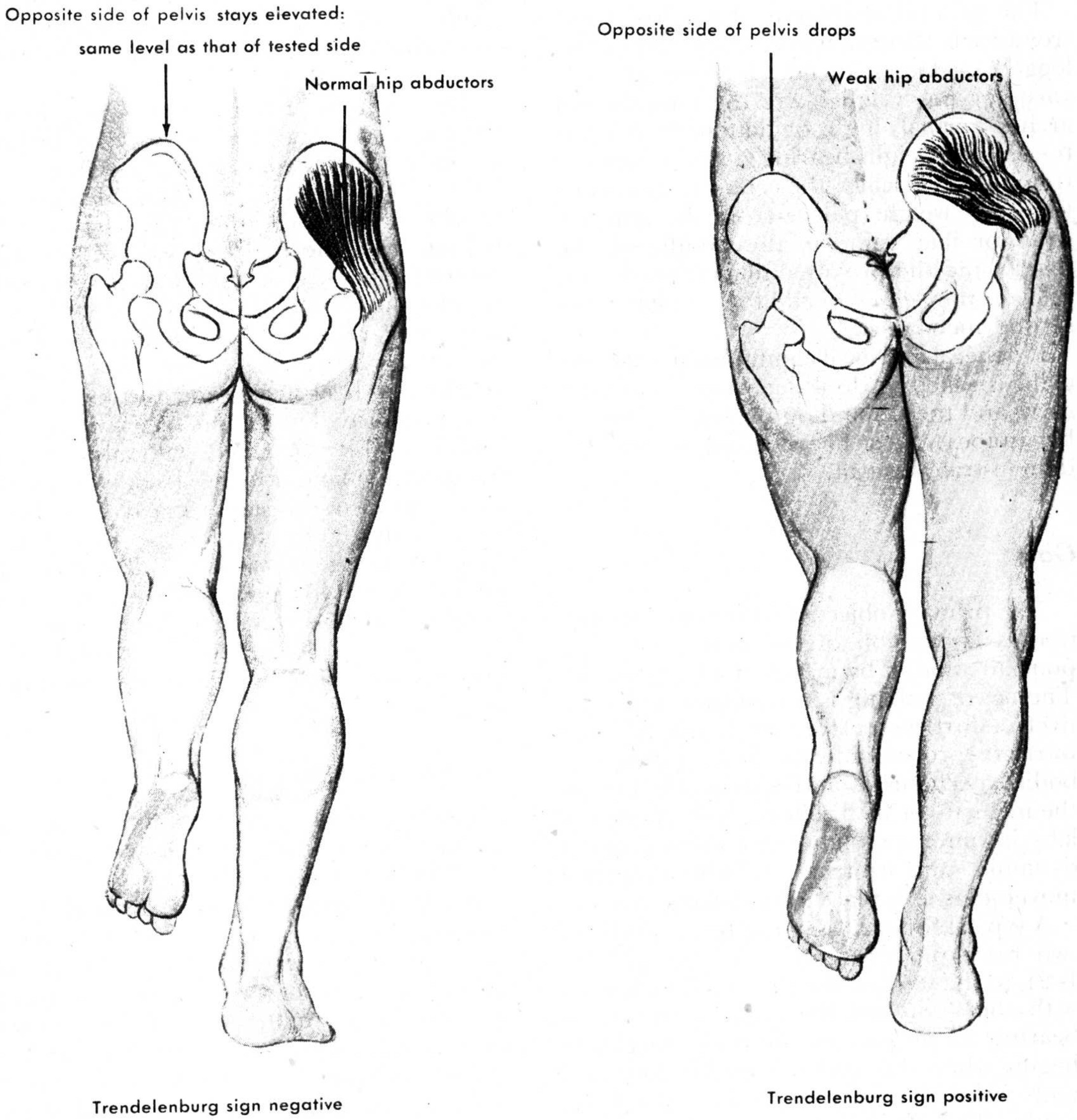

FIGURE 1–1. Trendelenburg test.

(Adapted from von Lanz, T., and Wachsmuth, W.: Praktische Anatomie. Berlin, Julius Springer, 1938, p. 167.)

muscles? Is there limitation of motion of the vertebral column on forward flexion, extension, lateral bending, and rotation? A Trendelenburg test is performed by asking the patient to stand first on one leg and then on the other. Normally, when a person stands on one leg, the contralateral side of the pelvis is elevated with the contraction of the strong ipsilateral hip abductor muscles. When the opposite side of the pelvis drops (a positive Trendelenburg sign) it indicates weakness of the hip abductor muscles (Fig. 1-1).

The general alignment of the lower extremities is also evaluated. Is the child bowlegged or knock-kneed? Is there any pes varus or pes valgus? Are the longitudinal arches normal, high, or flattened? What is the line of weight-bearing in the lower extremities? Normally, the center of gravity of the body weight passes from the anterior superior iliac spine to the middle of the patella and the proximal tibial tubercle and falls on the center of the foot, which is the second metatarsal.

If general and local conditions permit, the child is asked to do a deep knee bend, return, and then, standing on one leg, rise to his tiptoes. Next he is asked to walk to demonstrate his gait.

Gait

The primary objective of human locomotion is translation of the body from one point to another by means of a bipedal gait. The act of walking is a rhythmic and relatively effortless performance, but it is an intricate process affected by a number of bodily mechanisms and is dependent upon the integrity of such reflexes as the postural, labyrinthine, and righting. Locomotion is a dynamic performance in which certain movements take place in a regular sequence.

A typical forward step can be divided into two basic phases—stance and swing (Fig. 1-2). In the *stance phase,* the foot is in contact with the floor and the lower extremity is bearing all or part of the body weight. It begins when the heel strikes the floor and ends when the toe rises at the end of the stride. The stance phase may be further subdivided into three parts: heel-strike, mid-stance, and push-off. In the *swing phase,* the foot is not touching the floor and the body weight is borne by the opposite leg. It begins when the toe leaves the floor and ends when the forward swing of the leg ceases. The swing phase can also be subdivided into three parts: acceleration, swing-through, and deceleration.

Gait may be described as an interplay between loss and recovery of balance with constant shifting of the center of gravity of the body. When one pushes forward with his weight-bearing limb, the center of gravity of his body shifts forward, and he tends to fall forward, only to be stopped by the swinging leg, which arrives in its new position just in time.

The location of the center of gravity of the adult body has been estimated to be just anterior to the second sacral vertebra—at a level that is about 55 per cent of the total height of the individual.[43] In the normal human gait, the pathway followed by the center of gravity of the body is a smooth regular curve moving up and down in the vertical plane with an average rise and fall of about 1.8 inches. The low point is reached at heel-strike, and the high point at mid-stance. The center of gravity of the body is also displaced laterally in the horizontal plane during locomotion; the total side-to-side distance traveled is about 1.75 inches. The motion is toward the weight-bearing extremity, reaching its lateral limit in mid-stance. When the vertical and horizontal motions of the center of gravity of the body are combined, they are found to describe a "double sinusoidal curve."

DETERMINANTS OF GAIT

The six basic determinants of gait as defined by Saunders, Inman, and Eberhart in 1953 are as follows:[43]

Pelvic Rotation. In normal level locomotion, the pelvis rotates alternately to the right and to the left, relative to the line of progression. As the swinging lower extremity moves forward, the pelvis rotates forward on that side. The magnitude of rotation is about 4 degrees on each side of the central axis, or a total of approximately 8 degrees. Since the pelvis is rigid, the rotation actually occurs at the hip joint, which passes from internal to external rotation during

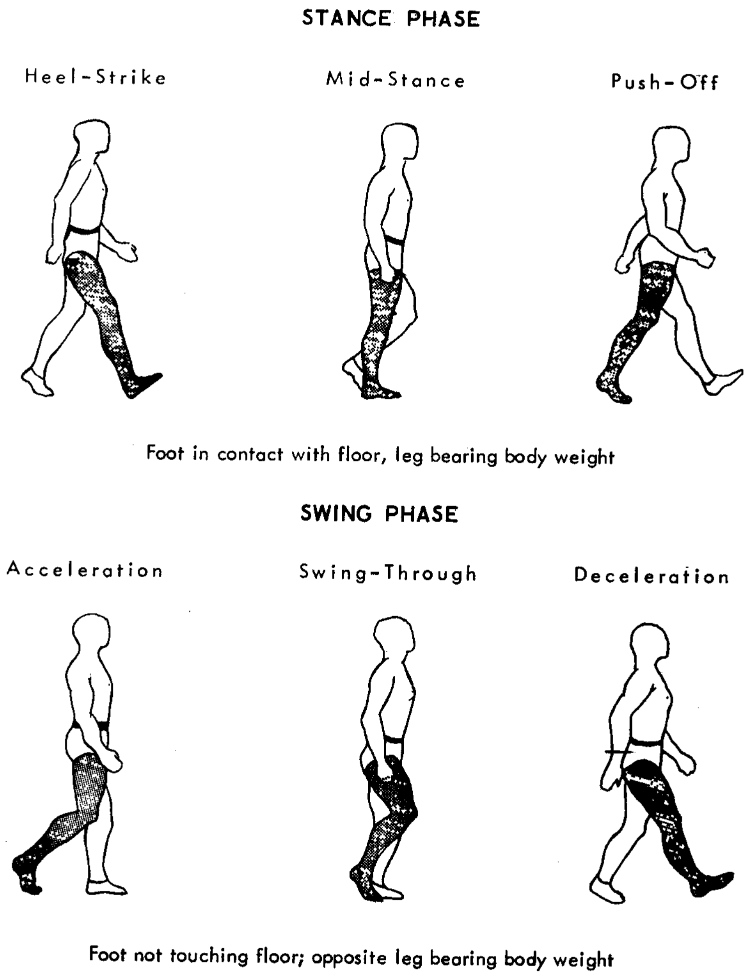

FIGURE 1–2. Analysis of a single forward step.

(Redrawn from Anderson, M. H., Bray, J. J., and Hennessy, C. A.: Prosthetic Principles—Above Knee Amputations. Springfield, Ill., Charles C Thomas, 1960, p. 32.)

the stance phase. This has the effect of flattening the arc of the pathway of the center of gravity by elevating the extremities of the arc. The stride is lengthened without increasing the drop of the center of gravity at the instant of heel-strike. In this way, the expenditure of energy in locomotion is greatly reduced.

Pelvic Tilt. The pelvis also tilts during normal locomotion, listing downward in relation to the horizontal plane on the side opposite to that of the weight-bearing limb (positive Trendelenburg sign). The angular displacement occurs at the hip joint and is, on the average, 5 degrees. To permit pelvic tilt, the knee joint of the non-weight-bearing extremity must flex to allow toe clearance for the swing-through of that limb. Pelvic tilt causes the center of gravity to lower by approximately half. By cutting the vertical displacement of the center of gravity in half and by shortening the pendulum of the limb by knee flexion in the swing phase, energy is saved.

Knee Flexion in the Stance Phase. The supporting lower extremity enters the stance phase at heel-strike with the knee in full extension, after which the knee joint immediately begins to flex until the foot is flat on the ground. The average degree of knee flexion at this time is 15 degrees. Shortly after mid-stance, the knee joint passes into extension once more, and this is immediately followed by the terminal flexion of the knee, beginning simultaneously with heel-rise as the limb is carried into the swing phase. This period of the stance phase in which the knee is first locked in extension, unlocked by flexion, and again locked in extension prior to its final flexion is referred to as the period of "double knee lock."

"Walking over" a flexed knee results in reduction of vertical displacment of the center of gravity as the body weight is carried forward over the stance leg, again conserving energy.

It is apparent from the foregoing discussion that pelvic rotation, pelvic tilt, and knee flexion in stance—all three determinants—flatten the arc through which the center of gravity of the body is translated. Pelvic tilt and knee flexion act to depress the summit of the arc; whereas pelvic rotation elevates the extremities of the arc.

Foot and Ankle Motion. The motions of the foot, ankle, and knee are intimately related in smoothing out the pathway of the center of gravity in the plane of progression. At heel-strike, the foot is dorsiflexed and the knee joint is fully extended. Next, rapid plantar flexion of the foot takes place, with the ankle moving forward over the heel. The foot remains flat on the floor until the heel starts rising just before push-off. As the heel rises from the floor, the ankle moves in a second arc over a center located approximately at the ball of the forefoot. These motions of the foot and ankle smooth out the path of the center of gravity when coupled with knee motion, which thus acts as the fifth determinant of gait.

Knee Motion. The knee flexes just after heel-strike as the ankle is rising and again at push-off when the ankle is rising the second time. The foot-ankle and knee motions are combined in such a manner that the ankle rise is largely cancelled out by the knee flexion.

Lateral Displacement of the Pelvis. As the weight of the body is being shifted from the right lower extremity to the left lower extremity, the pelvis moves laterally in the horizontal plane. If the two extremities were parallel to one another, the necessary shift would be half the interval between the axis of the hip joints, approximately 3 inches. The tibiofemoral angle with relative adduction of the hip reduces the horizontal displacement to about $1\frac{3}{4}$ inches so that it approximates that of vertical displacement.

Exaggerations in the range of any one of these six basic determinants of locomotion are compensated for by reductions in another. The interaction of the six determinants of gait results in a smooth pathway for the forward displacement of the center of gravity of the body.

MUSCLE ACTION IN GAIT

A source of energy is required for locomotion. The initial energy to start, accelerate, and decelerate the leg segments is supplied by muscle action. Other factors that enter into the cycle are momentum and gravity.

Electromyographic studies of muscle action during gait have shown that muscles act over very short periods and that, during long intervals in the cycle, the extremity is propelled forward solely by its own momentum. In general, the muscles of the lower limb are used to stabilize, accelerate, or decelerate the extremity.

During normal locomotion, major muscle activity starts in the last 10 per cent of swing—the deceleration part of the swing phase—with the hamstrings, erector spinae, pretibials, hip adductors and abductors, gluteus maximus, and quadriceps all being brought into play in that order (Fig. 1-3). All these muscles have reached the peak of their activity and are subsiding at heel-strike—that is, before the end of the first 10 per cent of the stance phase. Only the calf muscles do not act at this time. The calf

FIGURE 1-3. Muscle action during gait.

(Adapted from Anderson, M. H., Bray, J. J., and Hennessy, C. A., Prosthetic Principles—Above Knee Amputations. Springfield, Ill., Charles C Thomas, 1960, p. 32.)

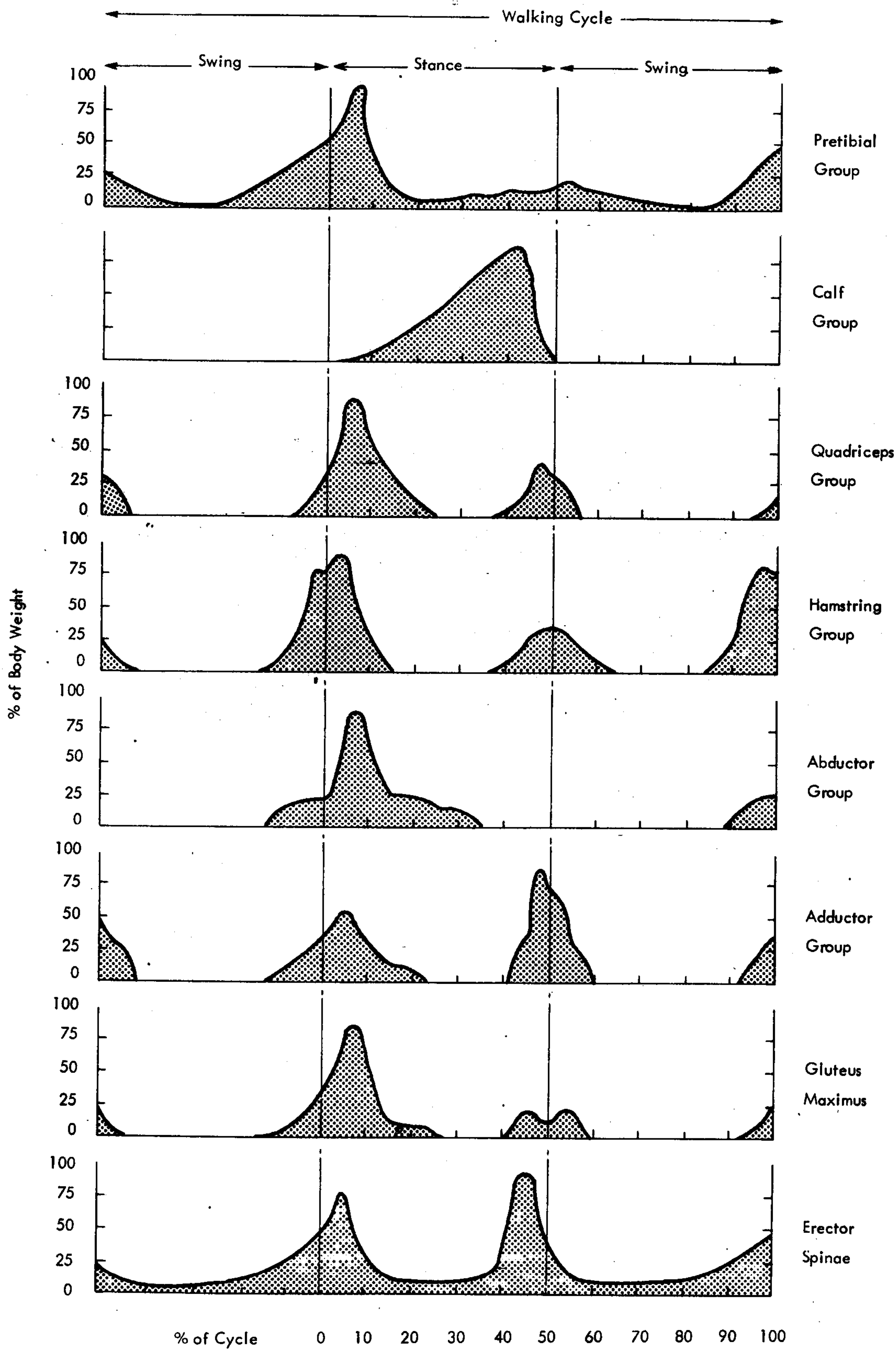

FIGURE 1–3. ***Muscle action during gait.*** *See opposite page for credit.*