3 Functional Anatomy

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Introduction

Anatomy is the study of the physical structures within the human body. The skeleton provides a stable foundation, and muscles attach by way of bony origins and insertions that cross and influence the angle of the joints. Knowledge of the nervous system provides us with a practical understanding of muscular control both to the tendon excursion and muscle mobility. The interrelatedness of the skeleton, muscle, and nervous systems provides an understanding of how the body works during a simple task to overall performance in daily activities, simply due to the functional anatomy. Knowledge of these systems, interrelationships, and how they affect the efficacy and efficiency of movement will facilitate therapeutic interventions that lead to improved client outcomes.

The principles of functional anatomy begin with the ability to understand the components in each of the three systems. Knowledge of skeletal support, muscle orientation and location, and muscle tone influences any given action. The interaction of the neuromusculoskeletal systems is important to analyze the parts of the body systems that explain observable postures. The concept of the unconscious and compensatory mechanics of the body to overall performance is a prerequisite to the goal of improved functioning. Sound knowledge of anatomical systems and the understanding, applying, and analyzing of their interrelationship during movement is a primary directive to addressing movement dysfunction. Ultimately, in practice, the functional anatomy is an important factor in grading the success of our clients' task performance.

The focus of this chapter is to introduce a sophisticated yet understandable method of neuromusculoskeletal assessment. The recall of anatomy as an identifiable detail is mainly at the lower level of the learning hierarchy. The ability to evaluate and analyze the body systems requires looking at component anatomy and then distinguishing between limitations of the parts to the whole of functional movement. There are conditions that may appear to be limited to a single part of the body (e.g., swan neck, zigzag deformity of the wrist and fingers, rounded shoulders) yet over time this initial change may contribute to changes both proximally and distally. The sections of this chapter are divided into body parts. The local aspect of muscle balance is described in each section and then combined to the analysis of the whole in movement. Then learning progression of analysis to synthesis will be summarized in the last part of this chapter using case studies. These common clinical scenarios will illustrate abnormal deviations or faults in postural mechanics resulting from tissue imbalance that will provide examples for quick screens of the functional anatomy. The analysis of the interrelationships of systems that affect the body's ability to perform are those against-gravity movements that incorporate upper limb movements within the advanced skills of functional mobility.

Key concepts of functional anatomy are normal postural mechanics, structural components of alignment, principles of muscle function, posture and body alignment (systems interdependence), and the influences of postural deviation on body position.

Standard Postural Mechanics

There are observable muscle behaviors that influence our posture and purposeful movements, also termed functional anatomy. Essential distinctions should be made between the anatomical characteristic of body positions, both at the initial static position of a kinematic event and then the return to our neuromuscularskeletal equilibrium of balance.[1] **Static posture** is the stationary position held against gravity, whereas **dynamic posture** refers to a series of positions that continuously changes during movement and function. Both postures require equilibrium of the muscle system and are observed during relaxation, standing, sitting, or lying down.[1]

Functional anatomy, defined by postural kinematic expressions, is fundamentally based on a predictable design. The gross structure, knowledge of muscle fiber alignment, location, and the origins and insertions of human anatomy references will assist in understanding the natural tone and potential forces of a specific muscle. Standard postural mechanics work in harmony and are observed when the antagonist, agonist, and synergistic coordination of our body mechanics perform in an efficient and effective manner.

If the observed initial position of the body differs from the known standard, well-balanced posture, the therapist can assume there is potentially altered kinematics. Studies have found that there is a relationship between altered posture and musculoskeletal disorders.[2] The therapist's knowledge of the neuromusculoskeletal anatomy is paramount to identifying the specifics of the constraints and resultant soft tissue changes. Furthermore, an identified structural abnormality can be the cause or result of movement dysfunction and pain. For example, in the forward head, rounded shoulders (FHRS) position, which differs from the standard position of balanced posture, this starting position of altered anatomy can create the potential for proximal and distal disruptions in the kinematic chain of movement. During reach, the changes in joint orientation due to the core malalignment will add kinematic mechanical stress to structures, such as the acromioclavicular joint or to the muscles that originate on the lateral epicondyle.[2]

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If the starting position of the body differs from the zero position of balance, the altered anatomy will create a disrupted kinematic chain of movement that adds stress to areas, such as the acromioclavicular joint or the muscles that originate on the lateral epicondyles.

Structural Components of Alignment

Bones, Ligaments, and Joints

Bones are responsible for the rigidity and structure of the entire foundation. The joint anatomy is designed to allow transmission of muscle force, at rest and during motion. Understanding joint structure contributes to the overall whole of functional anatomy and posture configuration. Bone-to-bone connection creates the joint. The bone segments within the joint move in relation to each other. The configuration of the bony surfaces dictates the degree of freedom of a joint and creates a type of movement hinge.

Most joints allow freedom of movement from one to three planes as the bony segments move in relationship to each other. Usually, one segment is stable while the other moves in relation to the base. As the joint moves, there can be more than one contributing articulation that influence the overall pattern of movement. For example, the shoulder girdle comprises the glenohumeral joint with scapulohumeral, sternohumeral, and clavicohumeral articulations.[3] The control and stability of the joint's axis of rotation directly relates to the articular orientation of the all of the structures. Without the rules for joint stability, the simplest movement can become weakened by the loss of mechanical advantage at any given point along the kinematic chain. This is seen in a joint dislocation, degeneration, and in segmental bone fractures, whereby the movement is not guided, and irregular angulations are observed. Conversely, if the segments of bone are not congruent and there is altered space that changes the axis of movement, the extrinsic muscle pull can be offset, and functional movement will present with distorted mechanics that are dysfunctional and not optimal. In the occupation-based profile, the client will describe various levels of adaptation, usually not from the changes in specific movement or those of unconscious motoric compensations, but to the description of pain or loss of meaningful activity.

Throughout the body, there are many axes of rotation. In the upper limb, there are flexion–extension, abduction–adduction, internal–external, radial–ulnar, and pronation–supination axes. The wrist has two, the elbow joint has one at the ulnohumeral joint axis, and the glenohumeral joint is a ball-and-socket joint with three axes of rotation. The relationships of joint axes have a normal presentation of balance that is predictable and can be assessed at rest and during movement.

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Joint pathologies can be observed, and should be palpated, at rest and during movements.

An altered configuration of the joint's soft tissue matrix or bony constructs lead to the joint's failure to glide and can result in various types of joint collapses and deformities.[3] With joint laxity, the axis shifts in the direction of the weakened and degraded tissue. Frequently, this is seen with attritional changes of the glenohumeral joint where the anterior capsuloligaments are weakened and attenuated. A shift in the joint axis results in tension changes in the anterior and posterior capsule and over time contributes to the formation of adhesions. Instability and adhesive phenomena are due to many types of disease manifestations. All will eventually involve the soft tissue structures of the intrinsic and extrinsic muscles that will lose the internal balance of the bony articular surface and ligamentous stability. The loss of joint stability will allow muscle to pull the articulated bone unopposed and contribute to deformity.[4]

Nervous System

The peripheral, central, and autonomic nervous systems all combine to form one internal communication system for sensing and responding to internal and external stimuli.[5] The motor and sensory functions for the upper limb come from the cervical and brachial plexus. Most nerves have an efferent motor and afferent sensory fibers arranged in bundles of axons. Layers of dense connective tissues called the epineurium, perineurium, and endoneurium protect the axons. Each layer has a unique role to support the innermost structures of the nerve, modulate compressive and tensile forces, and allow gliding between nerve fascicles and the surrounding anatomical structures.[6] Electrical impulses are rapidly conducted by way of the nodes of Ranvier along a neural pathway, which originates at the spinal cord and brainstem and terminates in the fingers and toes. Due to the continuous nature and physiology of the peripheral nervous system, motions at a distal site, such as the wrist joint, increase the strain at the cord level of the brachial plexus. Similarly, contralateral flexion of the cervical spine increases the strain in the cords of the brachial plexus and three major nerves in the arm.[5] Under tension, the neural tissue may have difficulty conducting electrical impulses, ensuring adequate blood supply, and providing adequate axonal transport, especially during movement.[6]

The complex role of the nervous system in muscular activity is to keep the body in balance. What is found in the nerve-to-muscle connections is a synchronous muscular harmony that is performed by the receptor Golgi tendon organs and the muscle spindles. These two proprioceptors are in or near muscles. Their function is to record and respond to muscle tension and changes in muscle length. They are responsible for muscle inhibition of the agonist and facilitation of the antagonist.[4] This complex feedback system from sensory receptors up to the spinal cord, to the central nervous system and back, contributes to the movement components that produce both planned and reflexive movement patterns.

The nervous system is the control center for our muscle equilibrium at rest and during motion. The complexity of the system controls muscles in isolation or in synergistic groups. Anatomical knowledge of specific locations of nerves from the spinal cord to the periphery, or at the synaptic junction of skeletal muscle, helps us understand the type of changes that occur within the musculoskeletal anatomy.

Muscles

Muscles work in groups and patterns of movement. Individual muscles have lengthening, contractile, excitable, and recoil characteristics. **Contractility** allows a muscle to shorten with force, to lengthen passively, and to move. **Excitability** allows a muscle to respond to a stimulus and to maintain chemical potentials across its cell membranes. **Extensibility** allows a muscle to be stretched, repeatedly and considerably, as needed, without being damaged. **Elasticity** allows a muscle to return to its normal length after being stretched or shortened. The result of a muscle function is an application of force. For example, a coordinated neuromuscular event occurs during the conscious decision to make a fist. The wrist extensors and flexors stabilize the wrist in approximately 35 degrees of extension, the extrinsic extensor digitorum communis (EDC) elongates into a full extensible position as the antagonist muscle, and simultaneously the extrinsic flexor digitorum profundus (FDP) and flexor digitorum superficialis (FDS) contract in their role as agonist muscles. The balanced self-selected position of 25 to 35 degrees of wrist extension and 7 degrees of ulnar deviation was found to produce optimal grip strength.[7] The coordinated muscle contractions of the wrist assist in the differentiation of tendon glide that allows terminal distal joint flexion. Simultaneously, contraction of the intrinsic lumbrical and interossei muscles increase metacarpal joint flexion, stabilize and control the joint, and allow the digits to converge into a tucked position within the palm.[4] The characteristics of the musculotendinous structures that contribute to muscle balance are located in Box 3.1. In summary, the principles of muscle function allow coordinated effort to improve both strength and flexibility of the isolated muscle and those muscles in groups.

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The wrist position is the key to changing the tension placed on the extrinsic fingers and thumb musculotendinous units.

BOX 3.1 Musculotendinous Characteristics That Contribute to Balance

1. The resting length of a muscle is the relationship and proportional stretch to the fully contracted muscle fiber.
2. At rest and even during sleep, there is a tendency of the muscle to contract and resist lengthening. This principle is influenced by the central nervous system and the intrinsic muscle structure, and by definition is our muscle tone.
3. Ordinary normal range of motion at rest or during movement is influenced by the variability of length and pull of all of our contributing anatomy due to antagonist lengthening as well as synergistic coordination.
4. Gravity and the need for skeletal stability will change the resting muscle tone and therefore change distal joint position.
5. Length and cross-section of a muscle leads to predictable excursion and levels of muscle elasticity.
6. A muscle crossing multiple joints will provide a composite excursion; a proximal joint stability is necessary for increased distal joint mobility.
7. Passive joint mobility is without influence of soft tissue elastic characteristics.
8. Muscle balance is involuntary, and over time the resting length can change or be changed by an altered axis. As the joint moves, these altered forces create imbalances and lead to deformity.

Posture: Body Alignment

Functional anatomy, defined by postural kinematic expressions, is fundamentally based on a stable, predictable design. This composite of body position is called **standard posture**. During observation, the skeletal conformation is observed and analyzed by envisioning the underlying bone positions. By knowing the preset configuration, or default design, you can visually construct the muscle anatomy and its contribution to posture. The gross structure, knowledge of muscle fiber alignment, location, and the origins and insertions of the human anatomy assist in understanding the natural tone and potential force of a specific muscle.

Skeletal alignment is observed and analyzed by envisioning the underlying interplay of the neuromusculoskeletal system. Postural configurations as a whole are the positions that are caused by changes in an isolated joint or by multiple joints. The shortened and lengthened muscle orientations are primary or secondary contributions to the observed posture. Many different conditions can cause these noted structural changes.

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Shortened muscles are not stronger muscles.

The neutral resting balance of our anatomy is the state of default or the **zero position** of the body.[3] The zero position is different from the anatomical position of the body. It represents the standard resting balance position where the upper limbs align themselves in space against gravity, where movement ceases, and where relative loads are removed. In the zero position, the upper limbs are positioned in the midrange of

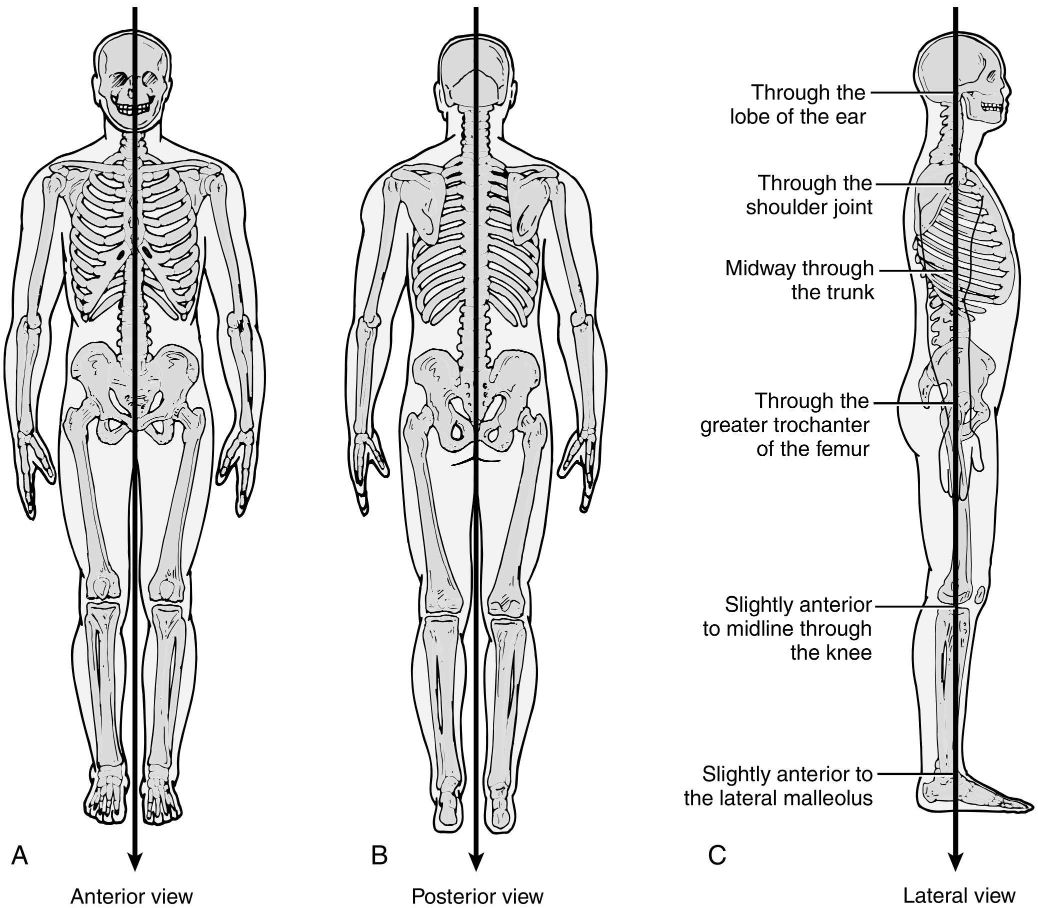

FIG. 3.1 The zero position of the body from the sagittal and coronal planes. (A) Anterior view. (B) Posterior view. (C) Lateral view. (Modified from Cameron MH, Monroe LG. *Physical Rehabilitation: Evidence-Based Examination, Evaluation, and Intervention.* St Louis, MO: Saunders Elsevier; 2007.)

glenohumeral and forearm rotation, the wrist is positioned in approximately 10 degrees of extension, and the finger joints are positioned in approximately 45 degrees of flexion. Abnormal changes in functional anatomy cannot be understood without knowledge of the standard resting balance position. Fig. 3.1 illustrates zero position.

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The position of the hand in relation to the zero position tells you about the functional anatomy of the scapula and suggests the orientation of the scapula and its relative position on the thorax.

The upper limb returns to this default resting position, or zero position, in most static body postures. It is an assumed position of joint alignment where the tone of muscle activity is minimal, where the origins and insertions are in a "resting" position, and where the tension of the joint is in a relaxed ligamentous balance. The residual muscle tone at rest is the muscle contraction in response to the gravitational pull. Importantly, the resting position and resultant tone of the upper limb may be different in different postures (e.g., sitting, supine, prone) due to the contributions from the base of support and the gravitational pull and subsequent tilt of the pelvis and or scapula.

Muscle tone is defined as the continuous and passive-partial contraction of the muscle or the muscle's resistance to passive stretch during the resting state.[4] The joint angles and lines of muscle tension that are produced, as well as the whole conformation of the body, are indications as to how synergistic muscles and nervous system are performing. Typically, the points of reference are anatomical landmarks and are observed in two body planes. The **coronal plane** is vertical and divides the body into anterior and posterior halves.[3] From the coronal plane we draw a linear plumb line, or line of gravity (LOG), that forms an **axis of reference.** From the lateral view of the client, the alignment of the ear, shoulder, lateral elbow, posterior hip, anterior knee, and lateral malleolus are body landmarks that are located close to, if not directly within, the axis of reference. From the axis you can observe the flexion, extension, anterior, and posterior adaptations of the body. Similarly, the **sagittal plane** is vertical and divides the body into right and left halves.[3] Postures viewed from all sides include obvious body markers, such as head position, shoulder height and glenoid orientation, clavicle angle, scapular position, antecubital fossa (i.e., carrying angle/orientation), hand orientation, and hip height. Fig. 3.1A and B illustrates the body in the sagittal plane and provides the anterior and posterior views of the body. Fig. 3.1C illustrates the body in the coronal plane and provides a lateral view of the body with a clear view of the arm orientation.

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The scapula tilts (anteriorly, posteriorly, upwardly or downwardly). The scapular tilt changes the orientation of the limb at rest and contributes to acquired functional range of motion.

A functional anatomy screen is performed by envisioning key markers of anatomical landmarks, and bone segments, as they create altered angles in contrast to those described in the zero position. The altered angles can change the overall height or distance between parts and present with a segment line of movement from the vertical or horizontal "zero" position. The differences in these angles or projections are used to hypothesize the influence of the associated muscle function. To understand postural forces of human anatomy and to utilize these concepts in practice, we need to apply the normal orientation of the ideal skeleton and muscle alignment at rest and during movement. These "normal" default postures can then be compared to the client who has compensatory adaptation and restrictions in anatomical structures.

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An understanding of normal anatomy and the ideal positions of balance is essential to recognize the imbalances in your client's neuromusculoskeletal anatomy.

The skeletal system of the body and upper limb can be mapped to determine the standard default state of zero position. **Mapping** is a visual technique of drawing, using the design and angles of the body that creates a picture of alignment. An imaginary overlay of the skeleton on the conformation of the body creates the approximate location of the joints and bone segments. Positions of mapping are in the planes of movement. The body's coronal and sagittal planes produce the lines of reference in static and dynamic body postures. The front and back views of the body allow the best view of symmetry.

These structures assist in recognizing important landmarks. **Landmarks** are structures that identify a feature other than a joint. Examples of landmarks are the ear, forehead creases, palm and nail positions, the carry angle space, web spaces, and skin folds in the back and digital creases. An example of important landmarks as seen in Fig. 3.1 is the space between the arm and body. Fig. 3.2 identifies the mapping specific to the hand. Important landmarks for the hand are nail positions, the space between the index and thumb, the cascading flexion of the fingers, the mass of the thenar eminence, and the prominence of the ulnar head.

Once the position of the joint articulation and landmarks are identified, the **segments**, or lines drawn between articular surfaces, are identified. The design is then analyzed using the expected functional anatomy as the reference point for identifying imbalances that can contribute to pain, weakness, and restrictions in movement.

The use of the two anatomical planes, axes of reference, and mapping techniques serve as a functional anatomy screening tool that allows the therapist to compare the ideal postural alignment to that of the assumed posture of the client. The deviation from the ideal can range from slight to severe and will guide the evaluator in understanding the problems associated with joint and muscle functions. This tool can identify at a local level (joint) and global level (body posture) the differences in the contributing anatomy misalignment.[8,9] The shortened muscles (e.g., antagonist weakness, joint pain, proximal etiology) may have contributed to the observed posture or joint position that of greater deviation of flexion, extension, lateral rotation. Recognizing these postural fluctuations allows therapists to describe the contributory neuromuscular events and address the functional anatomy in their therapeutic interventions.

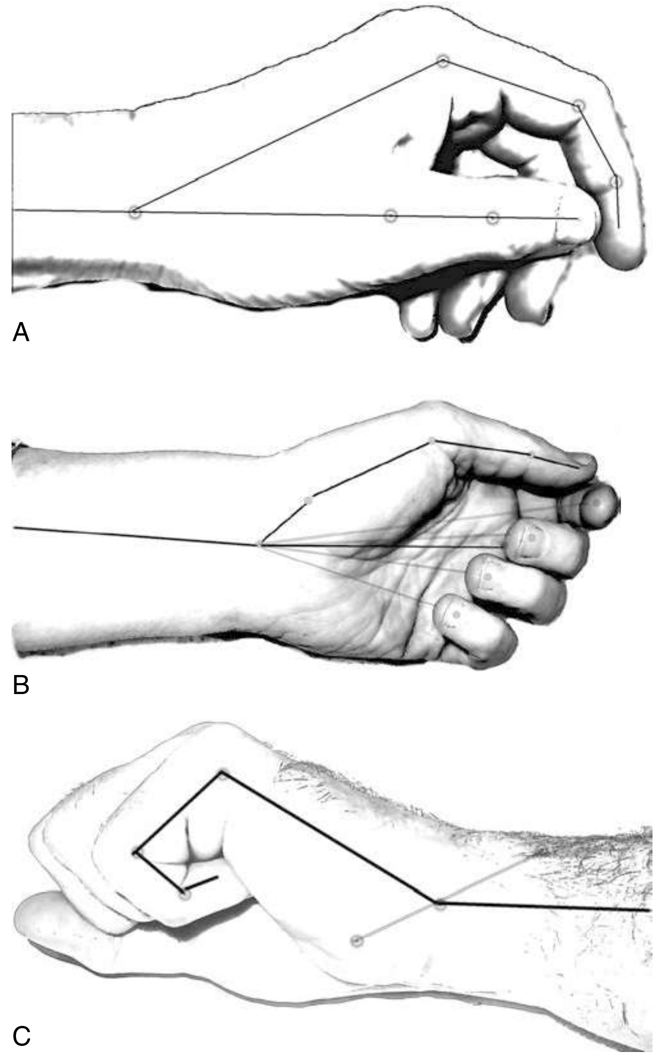

FIG. 3.2 Mapping of the hand at rest in a (A) radial view pronated position, (B) neutral forearm position, and (C) ulnar view pronated position. (From Donatelli RA. *Orthopaedic Physical Therapy.* 4th ed. St Louis, MO: Churchill Livingstone Elsevier; 2010.)

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With practice, the therapist performing anatomical mapping will find that this process can be envisioned, looking at the client's conformation, using the feet, knee, hip, shoulder, and ear landmarks as key visual markers and comparing them to the normal resting alignment.

Influences of Postural Deviation on the Body Position

Human systems as a whole perform like a living machine, and operate under the same physical laws and principles of all inanimate structures. These laws and principles describe how the relatively efficient levers, pulleys and wheel-axle mechanics in the human body machine convert energy to work. Energy from the position of the body is called stored or potential energy. The energy that is the result of motion is called kinetic energy. This energy is the body's capacity and potential to do the desired movement. Once performed, the actions of the body and on the body have a potential consequence.

Force is any action or influence that moves the body or influences the movement of the body. Gravity, the weight of the body, and friction on those structures that work against it, are external forces. The body's structure, namely the neuromusculoskeletal system, also generates internal forces as it overcomes the demands of gravity and loads.[10] The transmission of these forces is transferred from one part to another. The external and internal forces of muscle contraction, ligamentous restraint, and bony support are important to mention because if no internal forces were acting to counteract external forces, the body machine would be rendered noneffective. These forces influence how the body behaves as a whole, either with efficiency of movement that is proficient or as motoric compensatory adaptation that is weakened and painful. To complete an activity, the body components of the musculoskeletal systems change position in space and time due to the requirements for execution of that movement. The requirements are those actions needed to perform the desired actions for independence.

The forces are directed by internal and external demands, those generated by or as a result of an action. The body machine becomes efficient by accomplishing the transference of forces from one place to another, changing directions, increasing the magnitude of a force, or increasing the distance or speed of a force.[13] To perform efficiently, the machine has to overcome friction and the stress of loads in every action.[4] The laws of movement mechanics help in understanding the postural effect of strain and stress on the body during all body positions and actions. For the purpose of this chapter, the understanding of functional anatomy includes the interrelationships of systems, the forces that act on the body structures and the biomechanics of that motion. These are the factors contributing to our client's functional complaints.

Force is a cause (push or pull) that produces or changes the acceleration of a body.[4] The forces defined for our purposes are those that cause stress to the musculoskeletal system, which includes those of the bones, joints, and soft tissue. Body postures are attempts to move as efficiently as possible in order to successfully complete desired tasks. Importantly, the external forces of gravity continually act on all body structures. The ever-changing center of gravity is the concentrated point about which all parts balance each other and produce musculoskeletal changes down the kinematic chain. During postural changes for stability and mobility that occur with movement, the lengthening and shortening of our neuromuscular structures work against gravity to maintain the body in the best erect and stable position. The effect of internal and external forces on a body changes the mechanical balance and center of gravity. Efficient mechanical balance is based on a stable distribution of its weight throughout the entirety of the movement. In summary, proper alignment during activity is based on the body's ability to support and adjust the weight of the gravitational pull using the functional anatomy of muscle contraction and relaxation.

Internal mechanical stresses (i.e., tensile, compressive, shearing, torsion, and bending), if they are persistent, can result in changes to the neuromusculoskeletal form. The changes in form are seen in the muscle builder or performance worker who has overdevelopment of muscle, known as chronic hypertonicity. The muscle *strain* changes the shape, volume, or both in a body as the result of excessive and/or sustained stress. Other changes to form that alter the pattern of movement are observed with the imbalance of the antagonist due to atrophy. The muscle properties change in elasticity, flexibility, and suppleness with the inability to reach the full range of motion, to return to its original shape, and to recover from distortion even when the stress has been removed.

Local changes at a joint can be observed when muscle atrophy occurs following nerve injury or complete denervation to a muscle or muscle group. The balanced equilibrium at the joint will be lost as the unopposed muscle contracts without an antagonist and alters the joint's position. A joint imbalance may be the primary contributor to a joint contracture and/or may be part of the chain of kinematic changes resulting in dysfunction. The observed deformity is accentuated when forces are applied. Functional movements that include the external forces of acceleration and gravity will generate a reaction to neuromuscular relationships. External and internal forces that create balance or imbalance subsequently result in alignment or misalignment.

A broader picture of the more global effect of skeletal changes is observed with postural variations in the normal curves of the spine. The postural variation can be seen in different combinations. The faulty posture can sit alone as a primary problem or be the contributor to secondary distal and/or proximal kinematic compensations. Faulty core postures influence distal kinematics of the upper limb and compound the internal and external stress of our movements. Thoracic flexion (kyphosis), rounded shoulder forward head (RSFH), scoliosis, and lumbar extension (lordosis) are examples of faulty postures that occur when the spine and scapular line of movement increase their distance from the line of gravity. Each of these postures presents with shortening and lengthening of corresponding muscles with elongation, weakness, shortening and/or ineffectual strengthening of the functional anatomy.[12,13]

Next, a review of the anatomical systems will be discussed in further detail including the characteristics associated with bones, joints, ligaments, muscles, tendons, and the neurovascular systems of the upper limb as well as their contribution to posture and the mechanics of movement. Each body region will be discussed with information to identify and qualify the changes that occur within the functional anatomy.

Hand, Wrist, Forearm, and Elbow

Postural deviations that are due to disease can be seen in the hands of persons with rheumatoid or osteoarthritis. The anatomical structural changes that occur over time are observed with metacarpophalangeal (MP) joint subluxation and swan neck deformities. A common MP joint change occurs when the most proximal phalanx segment tilts palmary toward the volar plate, descending and subluxing the joint. What is observed at rest is the prominent head of the metacarpal. The internal forces from muscle contractions are transmitted through the altered joint axis and changes in the moment arm of the tendon. In this example, the extensor digitorum communis tendon becomes a flexor of the finger MP joint. The change in the axis of rotation alters not only the forces applied to the MP joint but also the kinematic chain of all joints that the muscle-tendon unit controls. The anatomical redirection of the long tendon at the MP joint, in conjunction with significant joint changes, presents with a zigzag pattern of the fingers with proximal interphalangeal (PIP) joint hyperextension and distal interphalangeal (DIP) flexion joint postures. These changes in the anatomy and kinematics result in a functional loss to extend the digits for grasp. As the condition progresses, the zigzag deformity produces a locking PIP joint hyperextension posture that restricts digital flexion for all tasks.

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The kinematic chain of mobility is controlled and primarily influenced proximally.

Attritional changes at a joint may be due to ligament laxity or disease of the articular surface as found in the carpometacarpal (CMC) joint of the thumb.[14] The excessive movement during functional use causes bone surface erosions and ligament laxity. Laxity of the stabilizing deep anterior oblique ligament (DAOL), called the beak ligament, causes the joint to sublux in a radial and palmar direction. Over time, the degenerative thumb CMC joint exhibits changes in appearance as seen with a prominent ledge that extends from the radial side of the base of the thumb. The loss of joint stability changes the characteristic of the surrounding muscular anatomy. The abductor pollicis brevis weakens and the adductor pollicis muscle contracts, unopposed. The thumb CMC joint is drawn into adduction and rotational supination.[4] The imbalance of the thumb intrinsic muscles changes the axis of rotation, decreasing the transmission of flexion forces across the metacarpal joint, and moves the resting position of the MP joint from a flexed posture to extension. Over time, the metacarpal joint hyperextends as the mechanical advantage from the extensor pollicis brevis (EPB) muscle further aggravates the adductor pull on the CMC joint and the increasing severity of the contracture. The interphalangeal (IP) joint compensates for loss of metacarpal joint flexion and overly flexes to produce a functional tip pinch. The cascading events are self-perpetuating as the normal joint forces become pathological. The specific pattern of use changes the functional patterns of pinch.

The anatomy of the arthritic thumb presents with imbalances, principally at the CMC joint level, with bone erosions and capsular instability that contribute to the distal joint changes at rest and during dynamic loads.[14] Fig. 3.3 illustrates the mapping of a normal and pathological CMC joint. The dots estimate the joint location, the stars are the landmarks, and the dashes are the bone segments. The disparities between the two thumbs are clear. The line of movement has changed from a resting flexed posture to a zigzag presentation. Compared to the normal thumb, imbalances in the pathological thumb are identified by three visible landmarks; increased nail rotation, MP joint hyperextension, and a protuberance at the CMC joint caused by the subluxing metacarpal.

The function of the collateral ligaments in the human body is to provide joint stability while functional activities occur within

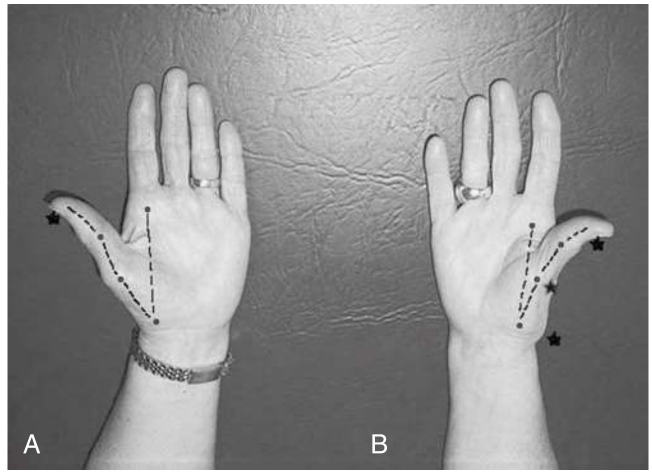

FIG. 3.3 Mapping of a (A) normal and (B) pathological carpometacarpal joint of the thumb. (Photo Lori DeMott.)

multiple planes of movement. Fig. 3.4 provides the ligamentous system of the wrist. The palmar wrist ligaments provide support between the carpal bones. The dorsal wrist ligaments provide support between the carpal bones and the radius. The palmar radioscapholunate ligament provides support for the radius, the scaphoid, and the lunate. The triangular fibrocartilage complex (TFCC) provides support between the carpal bones, the ulna, and the distal radial-ulnar joint. Each of the supporting structures is important in stabilizing the wrist in extreme ranges of wrist extension, flexion, radial deviation, and ulnar deviation.[8] Not only does stability of the joint affect mobility, but without adequate support on the ulnar border of the wrist, the amount of pinch strength on the radial side can be diminished.

Several imbalances of the wrist can occur from pathology. In the case of a displaced and angulated metacarpal fracture, the skeletal length changes and the shortened foundations can limit the ability of the extensor tendon to bring the MP joints into full extension. This is an important function in initiating grasp for large objects, placing the hand into pockets, and for the fine manipulation of using a keyboard. Injuries to the wrist ligaments themselves have stabilizing effects that redirect the pull and balance of the long extrinsic tendons. This is seen in clients with distal radioulnar joint (DRUJ) instability. During forearm pronation, the ulna migrates dorsally and a prominent ulnar styloid is observed. The CMC joint of the small finger demonstrates mild changes but an obvious collapse proximally creates a visual fovea, or depression. The extensor carpi ulnaris (ECU) tendon that inserts onto the fifth metacarpal now becomes inefficient and loses its ability to stabilize the metacarpal into extension during active grasp. The hand changes its appearance as the arch of the small metacarpal joint ascends and over time the entire hand radially deviates during grasp and pinch tasks. The ligaments by virtue of disease and overload from an altered axis will eventually cascade into instability and joint collapse. Fig. 3.5A and B, maps the expected imbalances from the same client with ligamentous instability associated with a classical malunion of a distal radius fracture. In Fig. 3.5A, shortening of the radius and carpal collapse demonstrates the radial bias of the wrist. Landmarks can be observed with increased prominence of the ulnar styloid. In Fig. 3.5B, the proximal elevation of the fifth metacarpal can be seen as a result of ulnocarpal ligament laxity. This instability results in the disruption of the distal transverse arch. Also, you will

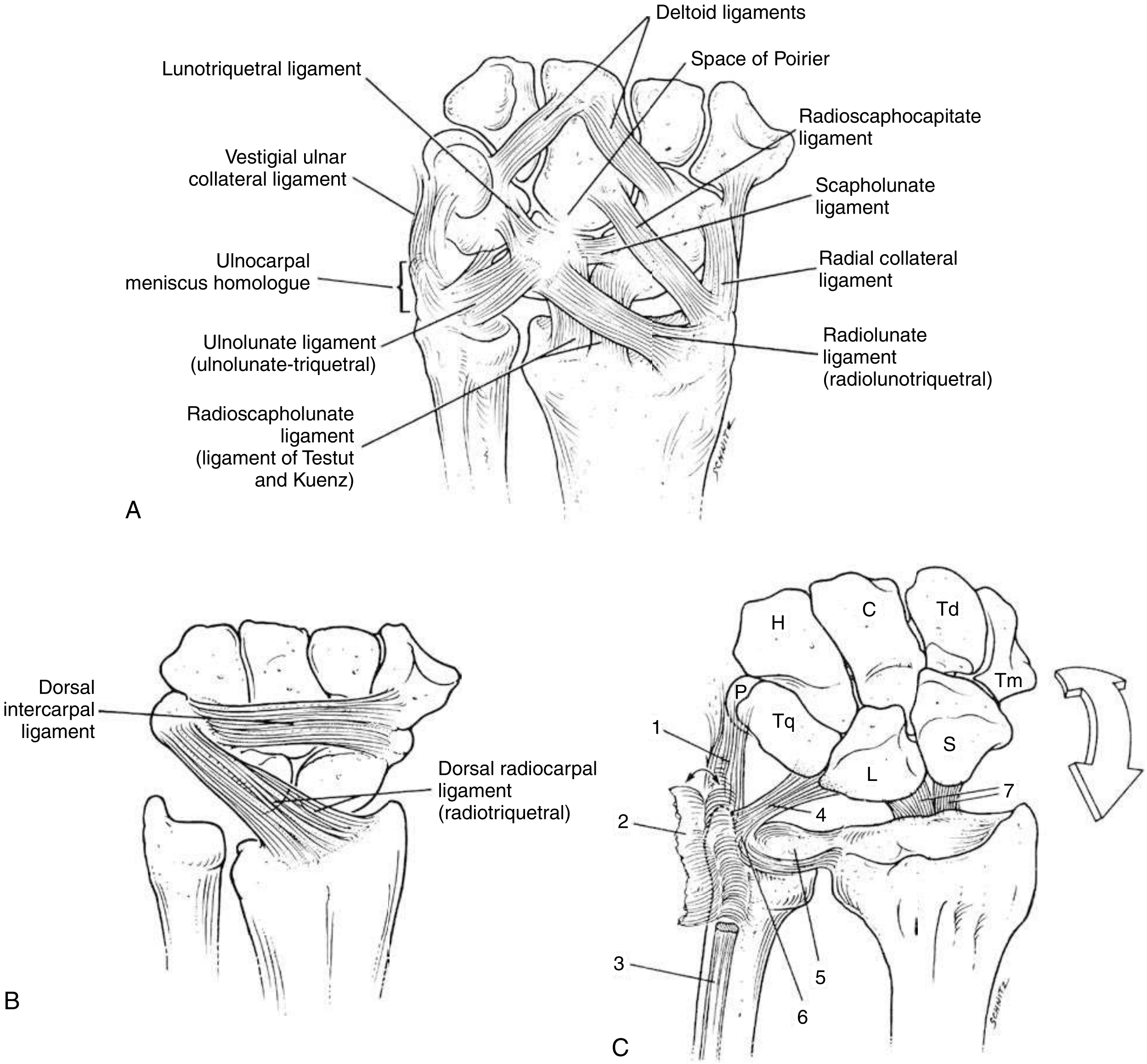

FIG. 3.4 Ligamentous anatomy of the wrist. (A) Palmar wrist ligaments. (B) Dorsal wrist ligaments. (C) Dorsal view of the flexed wrist, including the triangular fibrocartilage. 1, Ulnar collateral ligament; 2, retinacular sheath; 3, tendon of extensor carpi ulnaris; 4, ulnolunate ligament; 5, triangular fibrocartilage, 6, ulnocarpal meniscus homologue; 7, palmar radioscaphoid lunate ligament; C, capitate; H, hamate; L, lunate; P, pisiform; S, scaphoid; Td, trapezoid; Tm, trapezium; . (From Fess EE, Gettle K, Phillips C, et al. *Hand and Upper Extremity Splinting: Principles and Methods.* 3rd ed. St Louis, MO: Mosby; 2005.)

see an atrophied hypothenar eminence and a pronounced extensor digitorum minimi, which assists with wrist extension. Other landmarks can be observed with abnormal depression from the metacarpal angle and prominence of the ulnar styloid; both are indicative of possible subluxation of the wrist carpus and DRUJ imbalance.

The ligamentous structures in the fingers differ considerably from those of the wrist. Fig. 3.6 reviews the supporting structures of the finger MP and PIP joints. The design of the collateral ligament is to ensure lateral support. When the MP joint is flexed, the collateral ligament lengthens to accommodate the movement and stabilize the joint. Similarly, slack in the collateral ligament occurs when the MP joint is fully extended. In addition to the lateral support of a joint, volar reinforcement is provided through strong membranous connections with the collateral ligament. The palmar (also called volar) plates are slack in flexion but become taut when the joint is extended, thus protecting the joint from hyperextension stresses or dislocations. Common postural changes for ligamentous instability of the fingers may include swan neck deformity of the digits. In the static and dynamic postures of the PIP joint, the palmar support attenuates over time and the lateral bands slide dorsal to the joint axis with the resulting PIP hyperextension posture.

As expected, the thumb has ligamentous supports at the IP joint, the MP joint, and the CMC joint. Of particular interest are the radial and ulnar collateral ligaments (RCLs/UCLs) of the MP joint. Fig. 3.7 illustrates the importance of this strong band of tissue in supporting pinch, especially for tip

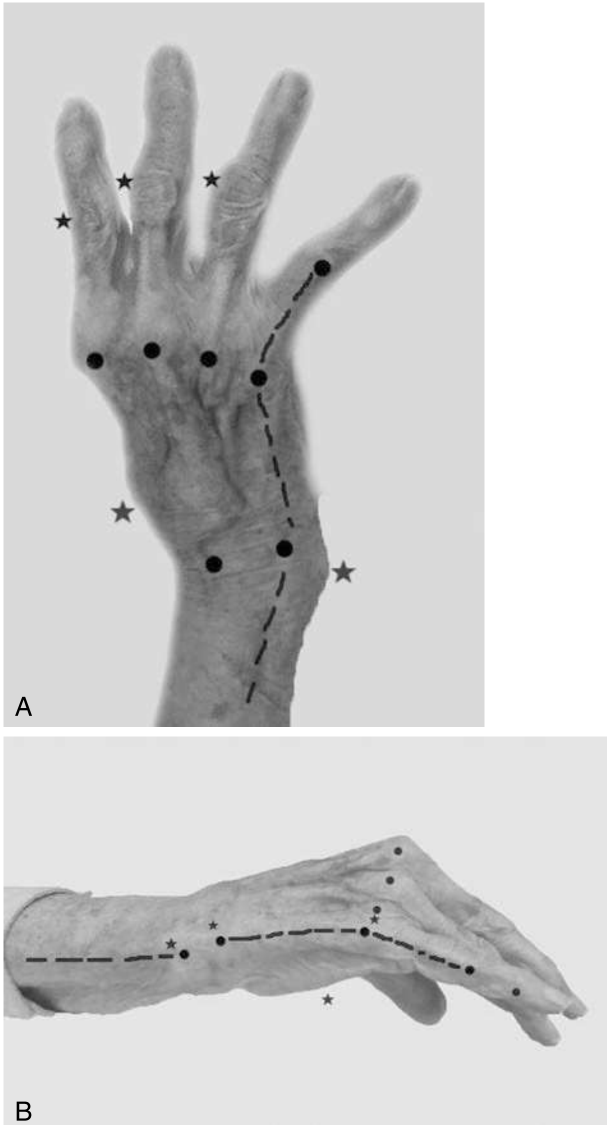

FIG. 3.5 A,B Mapping of the expected distal imbalances from ligamentous instability of the radiocarpal, ulnocarpal, and distal radioulnar joints. (From Sahrmann SA: *Movement system impairment syndromes of the extremities, cervical and thoracic spines: considerations for acute and long-term management*, St. Louis, 2011, Elsevier Mosby.)

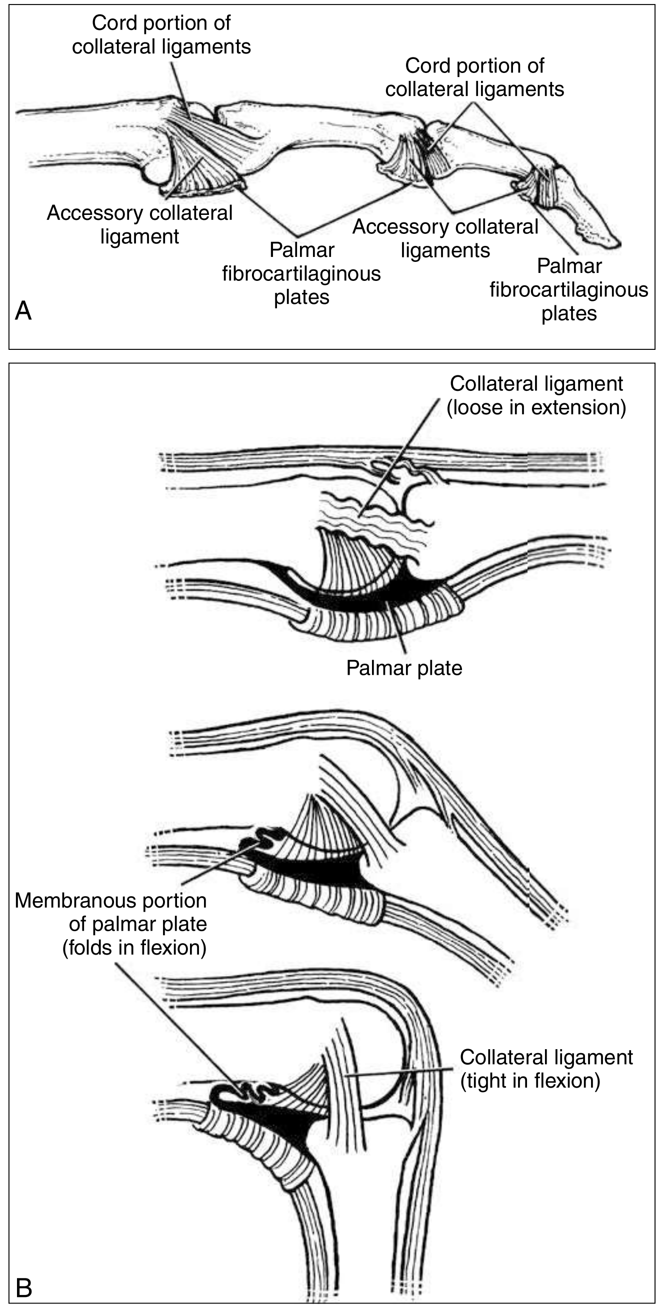

FIG. 3.6 (A) Ligamentous structures of the finger joints. (B) At the metacarpal joint level, the collateral ligaments are loose in exertion but tighten in flexion.(A, From Fess EE, Gettle K, Phillips C, et al. *Hand and Upper Extremity Splinting: Principles and Methods.* 3rd ed. St Louis, MO: Mosby; 2005; B, modified from Wynn-Parry CB. Rehabilitation of the hand. In: Fess EE, Gettle K, Phillips C, et al. *Hand and Upper Extremity Splinting: Principles and Methods.* 3rd ed. St Louis, MO: Mosby; 2005.)

and lateral pinches. Common postural imbalances can be seen with ligamentous instability when loading the joint through tip pinch. Observational mapping of unstable bilateral RCLs at rest shows increased angulation of the MP joints of the thumb, supination of the thumb nail, and loss of muscle mass in the thenar eminences (Fig. 3.7A). Similar changes can be seen with observational mapping of an unstable UCL with pinch to include radial deviation of the MP joint and rotation of the thumb nail (Fig. 3.7B).

Proper balance of the musculotendinous structures that originate from the lateral and medial epicondyles is necessary for positioning the hand in tasks away from the body. Actions of elbow extension and flexion, forearm rotation, wrist extension and flexion and some finger extension and flexion are controlled by these musculotendinous structures. Due to the length of these tissues, their actions cross as many as five joints and can influence reaching and positioning of the hand. Static or dynamic muscle imbalances can lead to pathological joint stresses, muscle weakness, and ultimate limitations in functional reach and grasp patterns.

Even though all of the muscles that originate from the lateral epicondyle are innervated by the radial nerve, a different picture of function can be obtained when observing their influence on multijoint, simultaneous movements. Table 3.1 provides a listing

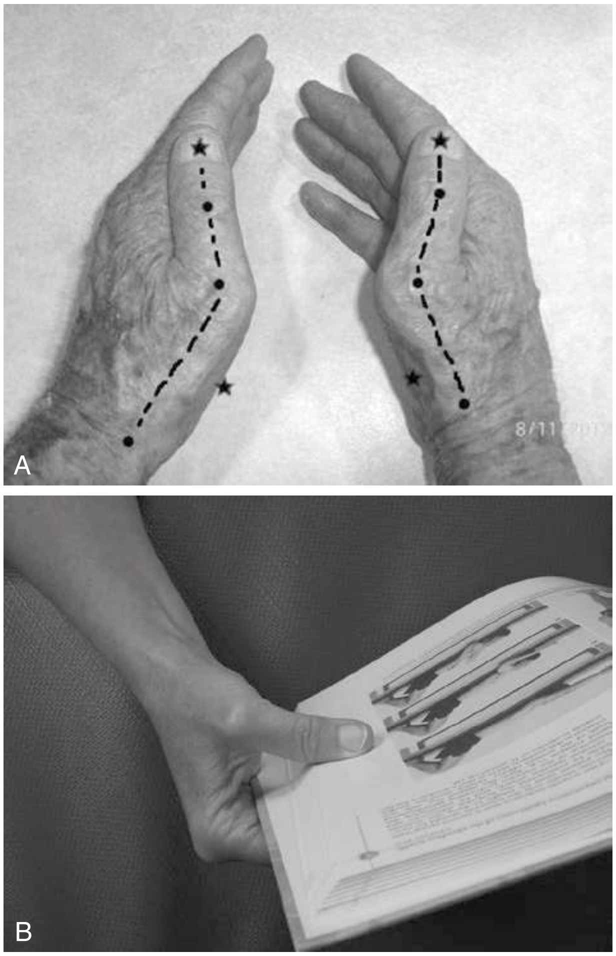

FIG. 3.7 Unstable thumb MP joint collateral ligaments in static and dynamic postures. (A) Bilateral unstable radial collateral ligaments at rest and (B) unstable ulnar collateral ligament with movement. (Martin Dunitz Ltd., 2001.)

of the eight muscles, their origin, and their action.[3] It is easy to recognize that many of these muscles cross the elbow, the forearm, the wrist, and in some cases the fingers. In order to ensure full joint motion, pliability of the muscles and connective tissues, and strength testing individual or groups of muscles that originate from the lateral epicondyle can be useful. When testing range of motion of the wrist and hand, the position of the elbow and the forearm should be considered. For example, full passive stretch of the longest musculoskeletal structure originating on the lateral epicondyle, the EDC muscle, is obtained with elbow extension, forearm pronation, wrist flexion, and full finger flexion.

In discussing the muscles that originate from the medial epicondyle, a similar picture of function also can be obtained. Table 3.2 provides a listing of the five muscles, their origin, and their action.[3] In this case, all of the muscles are innervated by the median nerve, with the exception of one, the flexor carpi ulnaris, which is supplied by the ulnar nerve. In spite of the differences in nerve innervations, the same principles for extensibility of these muscles can apply as was suggested for the muscles originating from the lateral epicondyle. For example, full passive stretch of the longest musculoskeletal structure originating on the medial epicondyle, the FDS muscle, is obtained with elbow extension, forearm supination, wrist extension, and full finger extension.

A functional anatomy screen of the muscles that originate from the lateral and medial epicondyles is essential to determine deviations from normal posture of the wrist and hand. At rest, imbalances cause unopposed muscles from the lateral epicondyle to change the positions of the upper arm joints. In standing or sitting positions the client will present with subtle increases in the **carrying angle of the elbow**, the palm of the hand facing forward, the wrist in radial deviation, and the MP joints of the fingers in slight hyperextension. Similarly, the extrinsic flexor bias of the muscles from the medial epicondyle at rest can be observed with the back of the hand more prominent and the wrist in ulnar deviation. During movement, the client may have difficulty reaching in every plane of movement and may present with a more pronounced posture defect when carrying increased loads. Exaggerated movements of trunk flexion and glenohumeral rotation compensate for limitations in extensibility of the elbow extensors and wrist deviators.

Functional anatomy screening can be utilized to assess muscle adaptations that occur with acute and chronic nerve injury. Changes in muscle balance, and ultimately postures at rest and during movement, develop in response to pain. Symptoms of nerve pain can be reported within the cutaneous distribution or throughout the entire peripheral distribution from an injury to the nerve root. Unconsciously, the nerve response to injury is to limit the stretch and excursion that occurs with joint movement. The muscles of the upper limb limit the arc of motion by contracting the corresponding joint. An example can be seen in clients with an ulnar nerve injury. The shoulder, elbow, and wrist joints will limit tension and stress to that nerve by holding the joint in a position to limit and prevent stretch or nerve excursion. Neural tension increases with elbow flexion greater than 90 degrees and intrafascicular pressure intensifies with shoulder abduction, forearm supination, and wrist extension. The neuromuscular system will prevent this undesirable painful posture by controlling joint motion in a cohesive manner. A functional anatomy screen for the composite joints of the upper limb will find the arm bias of elbow flexion is short of 90 degrees, forearm movements range from neutral to pronation, and the wrist is flexed. If additional tension occurs, as when the client's head laterally flexes to the opposite side, the shoulder girdle and elbow may change position to accommodate proximal nerve glide without increasing neural tension. Measures are needed to decrease the pain and the neuromuscular response during intervention. Immobilization may be necessary, but overlooking the effects of pain reduction through postural modifications may lead to an undesirable response of joint and muscle adaptation.

In nerve injuries with a severe degree of conduction loss of both sensory and motor fascicules, a functional anatomy screening uses a more conventional assessment of imbalance. Frequently, manual muscle tests are performed by evaluating synergistic action of muscle groups, such as wrist extensors or finger flexors as a group. In reality, manual muscle testing can be a valuable tool in viewing muscle balance from other perspectives. Unrecognized impairments of the upper limb can be discovered due to imbalances created from a condition such as peripheral neuropathy.

The findings of a manual muscle test can be more sensitive when selecting muscles innervated by various nerve distributions. For example, Fig. 3.8A provides the distribution of the muscles associated with the radial nerve. It is important to note that more than finger and wrist extension can be involved, especially with trauma to the nerve proximal to the elbow in the midhumeral or

TABLE 3.1 Muscles Originating From the Lateral Epicondyle

Muscle	Origin	Action	Position for Full Musculotendinous Flexibility
Anconeus	Lateral and posterior surfaces of proximal half of body of humerus and lateral intermuscular septum	Extends the elbow	Elbow flexion, forearm pronation
Brachioradialis	Proximal two-thirds of lateral supracondylar ridge of humerus and lateral intermuscular septum	Flexes the elbow, assists with pronating and supinating the forearm	Elbow extension, forearm pronation or supination
Supinator	Lateral epicondyle of humerus, RCL of elbow joint, annular ligament of radius, and supinator crest of ulna	Supinates the forearm	Elbow extension, forearm pronation
Extensor carpi radialis longus	Distal one-third of lateral supracondylar ridge of humerus and lateral intermuscular septum	Extends the wrist in a radial direction, assists with elbow flexion	Elbow extension, forearm pronation, wrist flexion in an ulnar direction
Extensor carpi radialis brevis	Lateral epicondyle of humerus, RCL of elbow, and deep antebrachial fossa	Extends the wrist, assists with wrist radial deviation	Elbow extension, forearm pronation, wrist flexion
Extensor carpi ulnaris	Lateral epicondyle of humerus, aponeurosis from posterior border of ulna, and deep antebrachial fossa	Extends the wrist in an ulnar direction	Elbow extension, forearm pronation, wrist flexion in a radial direction
Extensor digitorum communis	Lateral epicondyle of humerus and deep antebrachial fossa	Extends the MP joints of the second through fifth digits; in conjunction with the lumbricals and interossei, extends the PIP joints of the second through fifth digits; assists with abduction of the index, ring, and small fingers; and assists with extension of the wrist in a radial direction	Elbow extension; forearm pronation; wrist flexion; and MP, PIP, and DIP flexion of the fingers
Extensor digitorum minimi	Lateral epicondyles of humerus and deep antebrachial fossa	Extends the MP joint of the small finger; in conjunction with the lumbricals and interossei, extends the PIP joint of the small finger; assists with abduction of the small finger	Elbow extension; forearm pronation; wrist flexion; and MP, PIP, and DIP flexion of the small finger

DIP, Distal interphalangeal; *MP,* metacarpophalangeal; *PIP,* proximal interphalangeal; *RCL,* radial collateral ligament.

TABLE 3.2 Muscles Originating From the Medial Epicondyle

Muscle	Origin	Action	Position for Full Musculotendinous Flexibility
Pronator teres	Medial epicondyle of humerus, common flexor tendon, and deep antebrachial fascia	Pronates the forearm, assists with elbow flexion	Elbow extension, forearm supination
Flexor carpi radialis	Common flexor tendon of medial epicondyle of humerus and deep antebrachial fascia	Flexes the wrist in a radial direction; may assist with pronation of the forearm and elbow flexion	Elbow extension, forearm supination, wrist extension in an ulnar direction
Flexor carpi ulnaris	Common flexor tendon of medial epicondyle of humerus	Flexes the wrist in an ulnar direction; may assist with elbow flexion	Elbow extension, forearm supination, wrist extension in a radial direction
Palmaris longus	Common flexor tendon of medial epicondyle of humerus and deep antebrachial fascia	Tenses the palmar fascia, flexes the wrist, and may assist with elbow flexion	Elbow extension, forearm supination, wrist extension
Flexor digitorum superficialis	Common flexor tendon of medial epicondyle of humerus, UCL of elbow, and deep antebrachial fascia	Flexes the PIP joints of the second through fifth digits; assists with MP and wrist flexion	Elbow extension; forearm supination; wrist extension; and MP, PIP, and DIP extension of the fingers

DIP, Distal interphalangeal; *MP,* metacarpophalangeal; *PIP,* proximal interphalangeal; *UCL,* ulnar collateral ligament.