Chapter 7

Postural Restoration: A Tri-Planar Asymmetrical Framework for Understanding, Assessing, and Treating Scoliosis and Other Spinal Dysfunctions

Susan Henning, Lisa C. Mangino and Jean Massé

Additional information is available at the end of the chapter

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Abstract

Current medical practice does not recognize the influence of innate, physiological, human asymmetry on scoliosis and other postural disorders. Interventions meant to correct these conditions are commonly based on symmetrical models of appearance and do not take into account asymmetric organ weight distribution, asymmetries of respiratory mechanics, and dominant movement patterns that are reinforced in daily functional activities. A model of innate, human asymmetry derived from the theoretical framework of the Postural Restoration Institute® (PRI) explicitly describes the physiological, biomechanical, and respiratory components of human asymmetry. This model is important because it gives an accurate baseline for understanding predisposing factors for the development of postural disorders, which, without intervention, will likely progress to structural dysfunction. Clinical tests to evaluate tri-planar musculoskeletal relationships and function, developed by PRI, are based on this asymmetric model. These tests are valuable for assessing patient's status in the context of human asymmetry and in guiding appropriate exercise prescription and progression. Balancing musculoskeletal asymmetry is the aim of PRI treatment. Restoration of relative balance decreases pain, restores improved alignment, and strengthens appropriate muscle function. It can also halt the progression of dysfunction and improve respiration, quality of life, and appearance. PRI's extensive body of targeted exercise progressions are highly effective due to their basis in the tri-planar asymmetric human model.

Keywords: human physiological asymmetry, spinal disorders, scoliosis, neutral posture, right-side dominance, muscle chain activity, biomechanical model of scoliosis, sagittal plane dysfunction, hyper lumbar lordosis, scoliosis specific exercises, postural restoration, etiology of scoliosis, kyphosis, respiratory mechanics, postural disorders

1. Introduction

Recognition of inherent physiological asymmetry has not yet been applied to the understanding, assessment, or treatment of scoliosis or other spinal and postural disorders. Even without an accurate baseline model of human form and function, interventions to correct dysfunction can be successful; however, while a local dysfunction may be rectified, the underlying biomechanical imbalance will persist as will the musculoskeletal strategies developed to compensate for the imbalance.

The Postural Restoration Institute® (PRI) methodology is a theoretical framework, which describes a model of universal human anatomical and physiological asymmetry. This unique model provides a new baseline for understanding common postures, movement patterns, and respiratory mechanics, which generate from our asymmetrical bias. It also explains the factors that support human right-side dominance. While human asymmetry can be understood as a positive factor that facilitates movement, overuse or misuse of the dominant muscle pattern will promote progressive imbalance within the body and will likely result in dysfunction. The treatment goal for dysfunction resulting from musculoskeletal imbalance needs to be restoration of the baseline in which there is relative balance between the dominant and nondominant muscle patterns [1–4].

Scoliosis is an example of a tri-planar, biomechanical dysfunction. In its most common form (90% of the cases), right thoracic convexity and left lumbar convexity [5–7], it exemplifies the extreme progression of normal human asymmetry according to the PRI model, which will be described in this chapter. Other postural disorders such as kyphosis and lordosis, exhibiting primary sagittal plane dysfunction, also belong to the spectrum of disorders developing from unbalanced human asymmetry. These conditions result in musculoskeletal stress, subsequent structural damage, loss of efficiency in movement and in respiratory function, as well as in a diminished quality of life.

This chapter introduces the fundamental concepts of PRI's theoretical framework and its baseline model. It will then describe how PRI's clinical tests can more accurately evaluate a patient's status by taking into account the inherent human asymmetry. These tests guide exercise prescription and treatment progression. Some examples of exercises used in the treatment of scoliosis have been selected to demonstrate activity progression from supported target muscle isolation, to complex, unsupported, multiple muscle integration, all with a major emphasis on respiration. Three case studies are presented here to illustrate this process. Many similarities exist between PRI rehabilitation concepts and exercises and the well-known Schroth methodology [8, 9].

2. Fundamental PRI concepts

The following fundamental concepts provide a new perspective on effective restorative techniques for treating scoliosis, other spinal dysfunctions, and postural disorders. The concepts explain the PRI baseline model of innate human asymmetry. Each is discussed in detail in this chapter: (1) human asymmetry arises from our innate anatomy and physiology and exerts significant influence on human posture and movement. (2) Ideal or neutral posture results from relative musculoskeletal balance of our asymmetrically organized body. (3) Anatomical and physiological asymmetries evident in the respiratory system are powerful contributors to our biomechanical function. (4) Right-side dominance is the functional result of physiological asymmetry. (5) The movement of the respiratory diaphragm and the pelvic diaphragm (pelvic floor muscles) is synchronized during breathing. The pelvis is a primary structure that facilitates gait. The synergistic activity of these two diaphragms links respiration and gait. (6) Gait requires integrated muscle activity, different on two sides of the body, in order to stay erect on one leg as the other advances the body through space. In the context of human asymmetry, right-side stance phase and left-side swing phase will be most competent. (7) Biomechanical dysfunction begins in the sagittal plane.

2.1. Innate physiological human asymmetry

Studies of many aspects of human asymmetry abound in the literature [10–15]. Much of this fascinating material is beyond the scope of this chapter. However, asymmetries of the internal organization of the body, organ weight distribution, muscle mass, and muscle attachments are all factors that contribute significantly to human asymmetrical posture and movement patterns. For example, the heart and its vessels share the left upper quadrant with two lobes of the lung. The right upper quadrant is less full, housing three lung lobes. The weight of the heart is offset by the large, heavy liver, which sits—lower than the heart—in the right lower quadrant [14]. This weight distribution and placement difference facilitates a gravitational shift of the body onto the right lower extremity, thereby promoting right stance. The left lower quadrant is less weighty because of the small spleen and usually empty stomach [1–4] (see **Figure 1**).

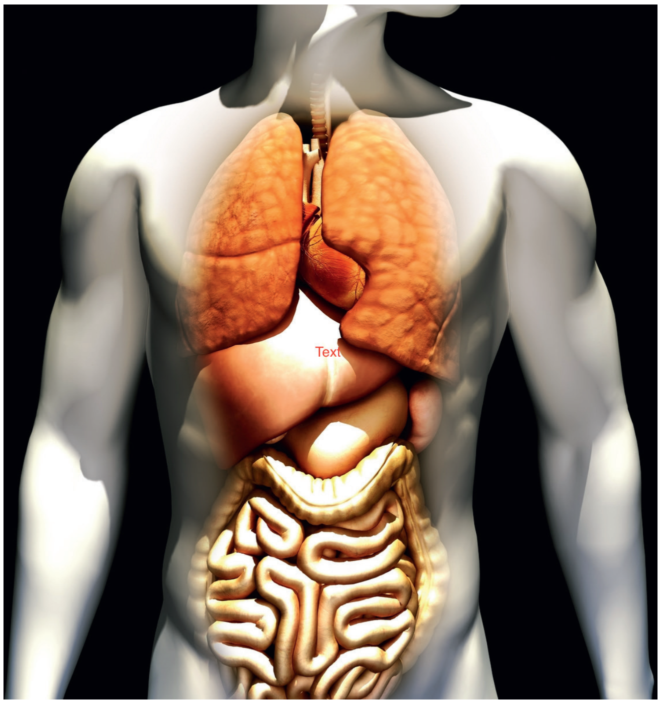


Figure 1. Asymmetrical organ distribution. Scottff72 copyright 123RF.com

The upper and lower quadrants are separated by the respiratory diaphragm, a unique muscle that spans the internal dimension of the body. The diaphragm is comprised of a stronger, larger, and better-supported right leaflet, and a smaller, less efficient, left leaflet. The diaphragm's respiratory mechanics exert a powerful asymmetrical influence on the torso. The crura of the right leaflet, which inserts onto three lumbar vertebrae L1–3, is also stronger and thicker than the left crura, which inserts on only two lumbar vertebrae L1, 2 [16] (see **Figure 2**). This distribution exerts a right rotational influence on the lumbar spine, orienting it to the right. Articulation of the lumbar spine with the sacrum orients the sacrum to the right. Strong ligaments bonding the sacrum to the pelvis effect right rotation of the pelvis as well. This right rotational orientation of the lower spine and pelvis is enhanced by the gravitational shift of the body over the right leg due to the weight of the liver on the right side of the body [1–4].

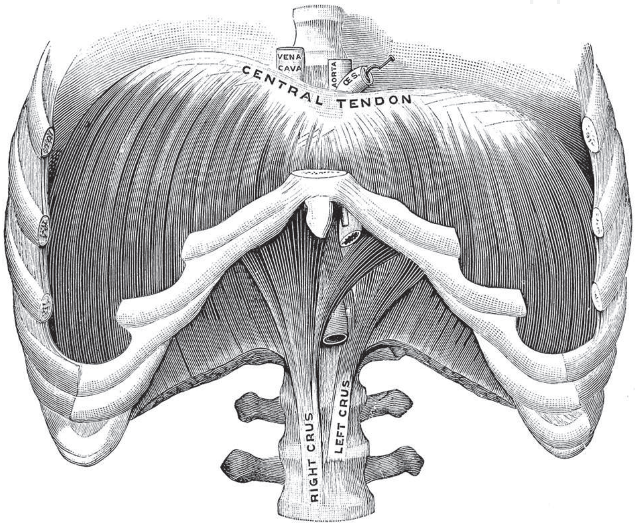


Figure 2. Diaphragm with crura. Florida Center for Instructional Technology copyright 2004–2017.

Asymmetry facilitates movement. In a balanced system, asymmetry is a positive, vitalizing force. In the human body, loss of balanced musculoskeletal function precipitates and reinforces overuse of dominant postures and patterns because of the underlying structural bias toward right stance, influenced by organ placement, weight distribution, and muscle attachment. Habit and repetition perpetuate and reinforce dysfunction. Innate physiological human asymmetry may well be a factor in the onset and development of scoliosis and other postural disorders.

2.2. Neutral posture reflects relative musculoskeletal balance

Webster's New World Medical Dictionary defines "neutral posture" as the stance that is attained when the "joints are not bent and the spine is aligned and not twisted" [17]. Neutral posture gives rise to the concept of "ideal posture" in which the alignment of body segments involves a minimal amount of stress and strain and which is conducive to maximal efficiency in use of the body [18, 19]. Ideal posture is critical for proper respiratory action [20]. When the body is in its ideal or neutral alignment, diaphragmatic respiratory mechanics are optimized [16].

Due to physiological asymmetry, a neutral posture does not imply strict symmetry; rather, it describes a position of relative structural balance and a readiness for movement in any direction. Loss of relative musculoskeletal balance reflects persistence of a structural bias resulting from habitual, repetitive muscle activity. For example, hyper lumbar lordosis is a frequently seen, sagittal plane, postural disorder. Positional alignment of the ribcage and pelvis has become imbalanced. The lumbar paraspinals have shortened and tightened, and the abdominal muscles have become overlengthened and weak [19, 21]. Neither of these muscle groups exists in their neutral or rest position. The neutral position of a muscle is equivalent to physiological rest [19]. With hyper lumbar lordosis, all future movements will initiate from this unbalanced basis of the skeleton (ribcage and pelvis) now supported and reinforced by adaptive muscle imbalance. Movement into any direction will require compensation by other muscles or will not be accomplished. Compensatory muscle activity is less efficient, energy demands increase, and stress accumulates on poorly aligned joints. Restoration of musculoskeletal balance would address these multiple issues [1–4].

Respiration is a key component of posture [22–27]. Our ability to breathe efficiently affects all aspects of our daily function and our endurance for activity. Through its anatomic attachments, the position and functional efficiency of the respiratory diaphragm is highly dependent on musculoskeletal posture as well as on tonic muscular activity [23]. The average person takes 21,000 breaths per day [28] with the respiratory diaphragm as a key muscle of respiration [22, 25]. Thus, the respiratory pattern is powerful in its contributions to posture. Efficient respiratory mechanics are dependent on neutral body position and muscle function [16].

When the diaphragm is compromised, it not only causes inefficient breathing patterns but also becomes a key contributor to the persistence and progression of postural disorders, including hyper lumbar lordosis, [29] kyphosis, forward head posture [20], and changes in ribcage symmetry [9, 16] as seen in scoliosis.

2.3. Asymmetries of respiration

The influence of the respiratory system is significant and often underlies or is complicit with scoliosis and other postural disorders. Understanding the mechanisms of breathing and how the loss of diaphragmatic competency can precipitate biomechanical dysfunction is not sufficiently appreciated in most current rehabilitation practices. Since the ability to exchange air is crucial to life, the respiratory system is a core motivator for muscle activity to insure adequate oxygenation. Within the respiratory system, the diaphragm is considered the primary muscle of respiration; however, there are numerous accessory muscles of respiration to assist when supplemental ventilation is needed. For instance, running places higher oxygen demands on the body to support a higher level of physical exertion. The accessory muscles of respiration are designed to accommodate such needs. Loss of diaphragmatic effectiveness due to postural or biomechanical dysfunction will result in pathological, compensatory accessory muscle recruitment [30].

The respiratory diaphragm is centrally located in our asymmetrically organized trunk. It is highly asymmetrical in form, in muscle attachment, and in function. Most importantly, it is uniquely positioned to directly influence every aspect of the postural, skeletal, and muscular core, and it influences the position and function of all other body systems [31]. The respiratory diaphragm is comprised of two muscles: a right and left hemidiaphragm [32], each with its own central tendon and each innervated by a right and left phrenic nerve, respectively [16].

Together, these two muscles span the internal dimension of the body just below the lungs. They insert on the xiphoid process, on the inner surfaces of ribs 7–12, and on the anterior aspect of the spine. The right leaflet is larger in diameter, it has a thicker and larger central tendon, its dome is higher, and it is better supported than the left by the liver beneath it and by strong right eccentric abdominal activity [31]. The right crura anchors to L1–3 on the right, the left crura to L1, 2 on the left [16]. The diaphragm leaflets also insert into the fascia overlying quadratus lumborum and to the psoas muscles via the arcuate ligaments, creating a strong functional linkage between these muscles. The superior strength, position, and function of the right hemidiaphragm supports and is supported by the physiological right orientation via right stance [1–4] (see **Figure 3A**).

The respiratory "Zone of Apposition" (ZOA) is the region of interface between the hemidiaphragm and the inner surface of ribs 7–12 [16, 33]. Apposition refers to multiple layers of muscles with differing fiber orientation lying adjacent to one another. The ZOA facilitates inhalation by generating tension between the muscle layers, which promotes external rotation of the ribs, complementing the action of the external intercostals. As the central tendons contract and descend, the hemidiaphragms displace caudally while the ribcage expands and externally rotates. The ZOA diminishes in volume with this activity. Simultaneously, the abdominal viscera are displaced caudally enabling lung expansion [16, 33] (see **Figure 3B**). Exhalation reverses this process. Shortening of the internal intercostals and of the lateral abdominal musculature reduces ribcage dimension. The hemidiaphragms relax and recoil upward returning to their domed configurations. Then, in a position of potential energy, the hemidiaphragms are ready to piston down again, thereby creating a vacuum, which will draw air into the lungs. Additionally, the diminished volume of the pleural cavity aids in expelling depleted air from the lungs [16, 33] (see **Figure 3B**).

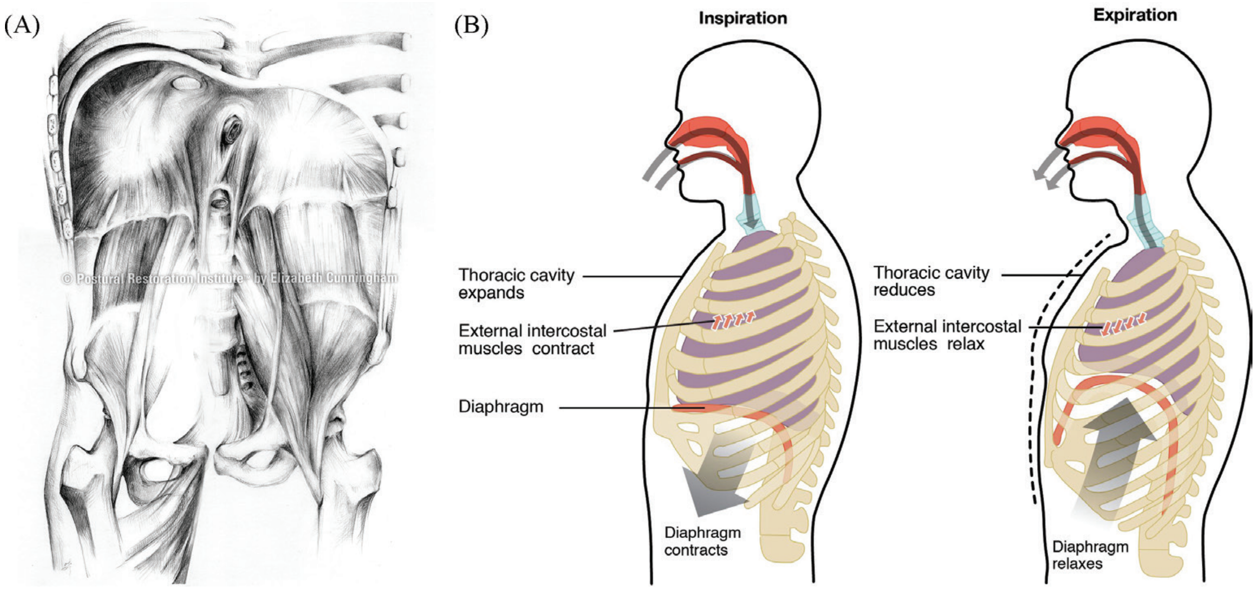


Figure 3. (A) Functional relationship of diaphragm, psoas, quadratus lumborum, and right stance illustration created by Elizabeth Noble for the PRI copyright. Used with permission from the PRI. Copyright 2017, www.posturalrestoration.com. (B) Respiratory mechanics of inspiration and expiration. www.wikimedia.org

Application of these respiratory mechanics to the biomechanical model of innate human asymmetry gives a more realistic understanding of our functional baseline. The three layers of lateral abdominals: transverse abdominis, internal, and external obliques, taken together, insert cephalically on the costal cartilage of ribs 5–12 and caudally on the ipsilateral iliac crest. These lateral abdominal muscles link the ribcage and pelvis, and they are critical components of posture and respiration [25, 26]. As described previously, shifting of weight to the right leg and orientation of the lumbar spine and pelvis to the right result in anterior rotation of the left hemipelvis. When the left hemipelvis is chronically anteriorly rotated, these lateral abdominal fibers will be adaptively overlengthened and weak. (In some cases, the right hemipelvis will also rotate anteriorly to avoid the strain of this asymmetry, resulting in bilateral compensatory and pathologic anterior pelvic rotation). The weakened, lateral abdominal muscles cannot maintain balance between the anterior ribcage and the pelvis. Without the anchoring action of the lateral abdominals, the anterior ribcage migrates further into elevation and external rotation mimicking thoracic position on inhalation [1–4].

This positioning has consequences for respiratory mechanics. When the left ribcage is in a chronic state of inhalation (expanded ribcage), the diaphragm is obligatorily in its descended state of inhalation as well. This chronic positioning limits diaphragmatic ascension on exhalation, thereby reducing the left ZOA. Consequently, the diaphragm loses its effectiveness for inspiration. Additionally, as the left anterior ribcage elevates, the diaphragm's domed configuration decreases and its fibers take on a more flattened, diagonal orientation, elevated anteriorly, resulting in further loss of the left ZOA. In this altered state, when the diaphragm contracts, it pulls the lumbar spine forward and reinforces anterior ribcage elevation. Having lost efficiency as a respiratory muscle, the diaphragm now functions more as a postural extensor muscle promoting progressive lumbar lordosis [29] (see **Figure 4**). Left anterior ribcage flares are commonly seen clinically and are exaggerated in patients with scoliosis. These flares indicate hyperinflation of the left lung due to insufficiency of the left lateral abdominals.

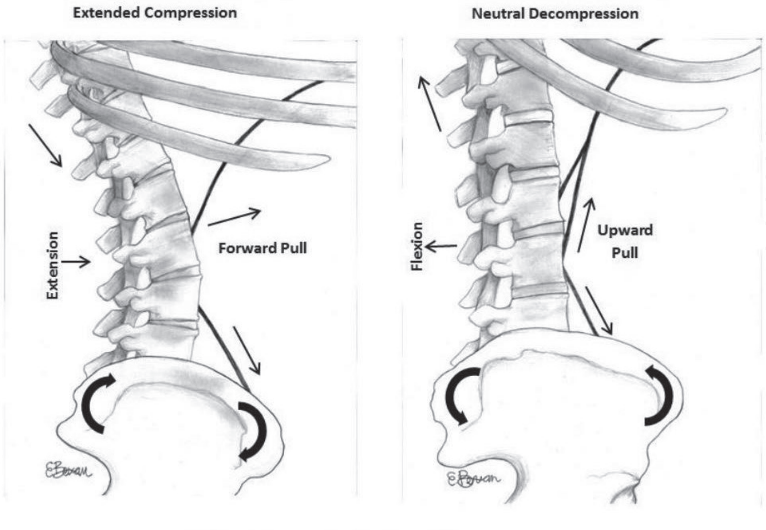


Illustration by Erica Bevan for James Anderson

Figure 4. Positional consequences for respiratory mechanics. Illustration by Erica Bevin for James Anderson and the PRI. Copyright 2017 PRI®.

The right hemipelvis configuration is opposite relative to the left; it is posteriorly rotated. The right lateral abdominals are better positioned to exhale, but are more restrictive to inhale. Compensatory strategies to maximize breathing capacity in order to meet respiratory need will then rely on the accessory muscles of respiration, including the psoas, paraspinals, muscles of the upper back, chest, and anterior neck. With these compensatory changes in breathing mechanics, left anterior ribcage flares and right anterior ribcage restriction may progress along this diagonal trajectory, resulting in the common scoliosis pattern of right posterior ribcage prominence and left posterior ribcage concavity [1–4] (see **Figure 5A** and **B**).

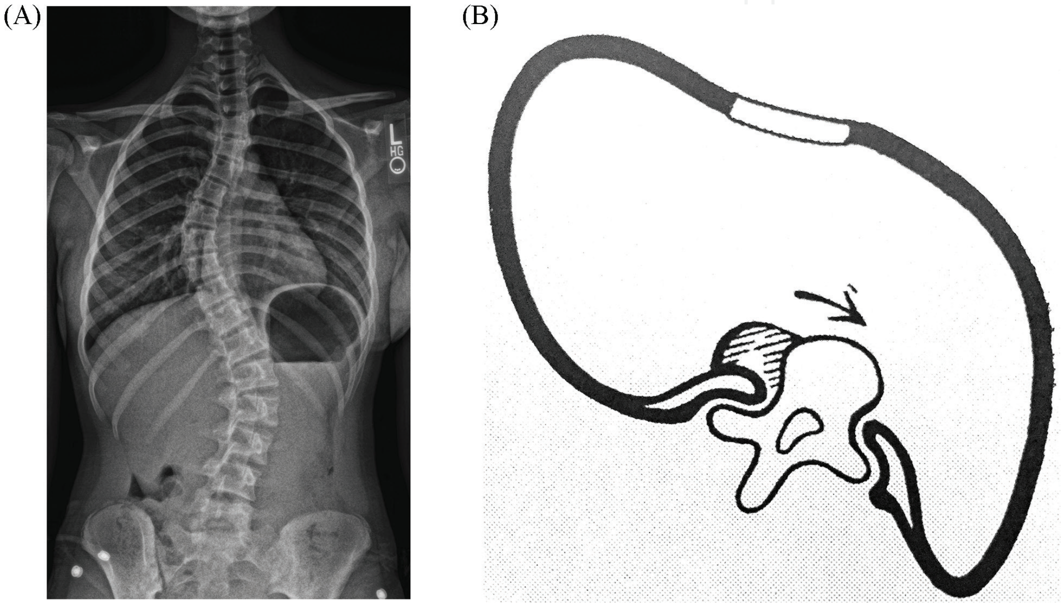


Figure 5. (A) EOS of common scoliosis pattern used with permission. (B) Common costal deformity in scoliosis used with permission from The Martindale Press, Three Dimensional Treatment for Scoliosis, 2007 by Lehnert-Schroth, C.

2.4. Right-side dominance, the functional result of physiological asymmetry

Humans almost universally exhibit right-dominant postural and movement patterns resulting from physiological asymmetry. Preferential standing on the right leg and increased breathing efficiency of the right hemidiaphragm are major contributors to this fundamental bias. Additionally, 90% of the population is right-handed, a defining characteristic of humans [11, 15]. Use of the right upper extremity for manipulative and reach activity dates far back in human history and has been correlated with early human brain asymmetrical development [11]. Right arm swing accompanies right stance phase of gait and coordinates with left leg swing-through. Right arm swing, consistent with right reach activity, promotes left trunk rotation to balance lumbar spine and pelvis right orientation, present in right unilateral stance. However, it is important to emphasize that handedness does not define side dominance [34]. Left-right asymmetry is a fundamental, ancient characteristic of animal development present in the earliest large multicellular organisms according to fossil records [14, 34]. Strong right-hand preference for manipulative and expressive tasks is thought to correspond to the emergence of language. These developments occurred with cerebral cortical lateralization at a much later date [11, 13, 35] and differ from inherent left-right organism asymmetry [34].

2.5. Synchronicity of respiration and gait

During breathing, the thoracic diaphragm and the pelvic diaphragm (pelvic floor muscles) function synergistically, linking gait and respiration [4, 36]. Internal obliques and transverse abdominis muscles are key participants in this process. Acting as a force couple, these lateral abdominals assist the hamstring's postural activity to maintain a neutral pelvis position as they simultaneously assist ribcage position and motion [25, 26, 31, 37]. Concurrently, lateral abdominal and hamstring lengths are determined by pelvic position due to their respective pelvic insertions.

When the thoracic diaphragm descends for inhalation, the abdominal muscles and the muscles of the pelvic floor *eccentrically* lengthen to allow for visceral displacement caudally [16]. As the abdominal muscles elongate, the ribcage expands and externally rotates, and the pelvic crest migrates forward into anterior rotation, abduction, and external rotation, while the ischial tuberosities approximate, allowing the pelvic floor to descend. The femur remains oriented anteriorly to keep the feet in a forward trajectory. Relative to the acetabulum, the femur is in an externally rotated *unlocked* position, described as "Acetabular Femoral External Rotation" (AFER), which facilitates the swing phase of gait [1–4] (see **Figure 6**).

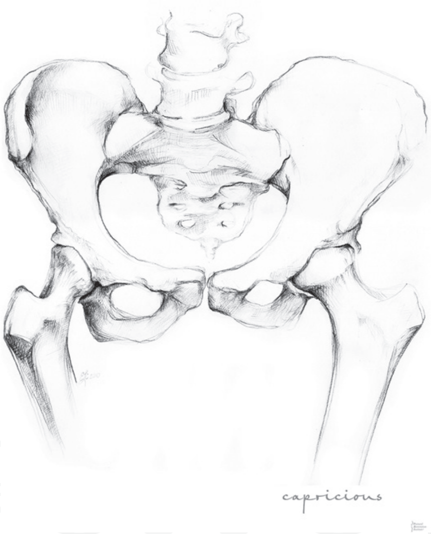


Figure 6. Frontal view of left AFER and right AFIR illustration created by Elizabeth Noble for the PRI copyright. Used with permission from the PRI®. Copyright 2017, www.posturalrestoration.com

Active exhalation relies on *concentric* activation of the internal obliques and transverse abdominis muscles to assist ribcage contraction, internal rotation, and thoracic diaphragmatic ascension. As the lateral abdominals shorten, they assist posterior rotation, adduction, and internal rotation of the pelvis. This pelvic position assists ascension of the pelvic floor as the ischial tuberosities move laterally as pelvic crests move medially [4, 25, 26]. The two diaphragms coordinate their pistoning activity, moving as a unit cephalically on exhalation and caudally on inhalation. While the pelvis rotates posteriorly with adduction and internal rotation, the stance leg maintains its forward orientation. The now internally rotated configuration of femur to acetabulum, described as "Acetabular Femoral Internal Rotation" (AFIR), *stabilizes* the hip joint (see **Figure 6**). Muscles of the hip—hamstrings, adductors, and gluteals—synchronize with lateral abdominals to stabilize the pelvis [1–4].

These functional relationships occur during gait. Gait is a highly complex movement task, which requires multisystem coordination and integration. Visual-vestibular, somatosensory, respiratory, and cardiovascular systems all give input and guidance [38]. Biomechanically, the challenge is to stay upright as the body advances through space balanced over one limb. When one side is in stance phase of gait, the contralateral side is in swing phase. The opposite arm and leg swing forward together (see **Figure 7**). This reciprocal extremity activity balances the torso around a vertical axis and assures nonstressful upright balance. In stance phase, the pelvis and lumbar spine are rotated toward the stance leg. The trunk is rotated opposite to the stance leg at or above the upper aspect of the diaphragm and is side bent ipsilaterally due to ipsilateral forward arm swing and ribcage kinematics [39]. This configuration mechanically supports shortening of the stance leg side abdominals, further assisting ribcage contraction and diaphragmatic ascension. Efficient gait requires the right and left sides of the body to be relatively equally competent in both stance and swing phases of gait. Gait is the best measure of balanced, biomechanical asymmetry [2].

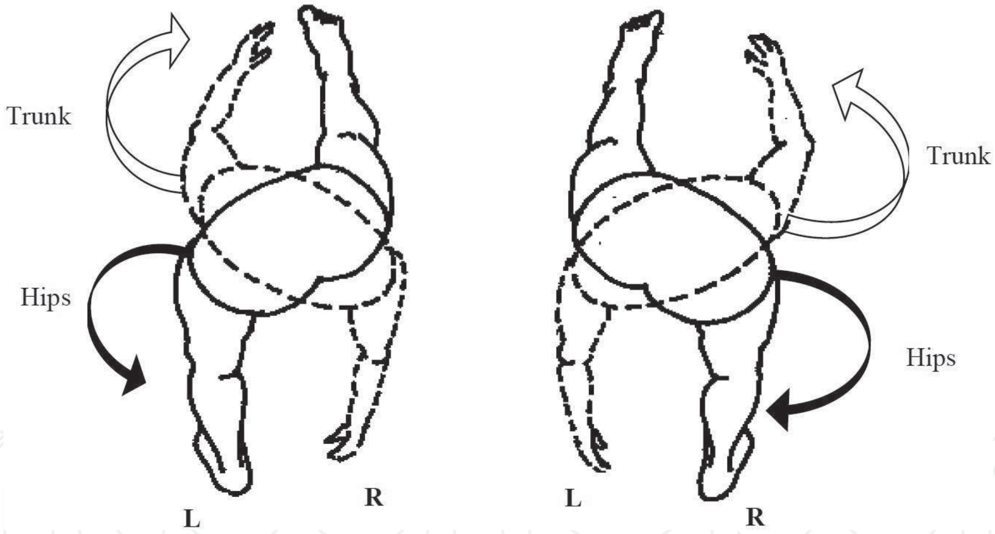


Figure 7. Alternating reciprocal gait viewed from above used with permission from the Postural Restoration Institute®. Copyright 2017, www.posturalrestoration.com

However, anatomical and physiological asymmetry biases the body toward greater competency in right stance. When musculoskeletal function is not relatively balanced, the left side does not achieve full stance phase of gait or full exhalation phase of respiration, and the right side will likely not achieve effective swing phase of gait or efficient inhalation phase of respiration. The daily repetitive nature of these basic activities of life reinforces and strengthens unbalanced asymmetrical function. Without intervention, the unequal stresses placed on musculoskeletal elements will likely progress to structural changes.

2.6. Muscle chain activity of the right-side dominant pattern

The development of muscle compensation follows a predictable pattern based on the model of human right-side dominance. Interventions to restore balance to a dysfunctional system will be maximally effective if the underlying baseline is understood and accounted for in the intervention. To this end, PRI describes muscle patterns based on a right-side dominant model. These patterns identify polyarticular muscle chains within the body, defined as a series of muscles, which overlap one another having fibers in the same direction and spanning multiple joints and thereby working synergistically together [2].

The anterior interior chain (AIC) governs the pelvis, lumbar spine, and lower extremities (see **Figure 8A**). It is so named because it is comprised of muscles located anterior to the spine and situated within the abdominal cavity. Muscles of the AIC are active during swing phase of gait (see **Figure 8B**). Swing phase of gait corresponds to the left nondominant muscle bias. The left-side pattern is, therefore, exemplified by the body's configuration during swing phase of gait.

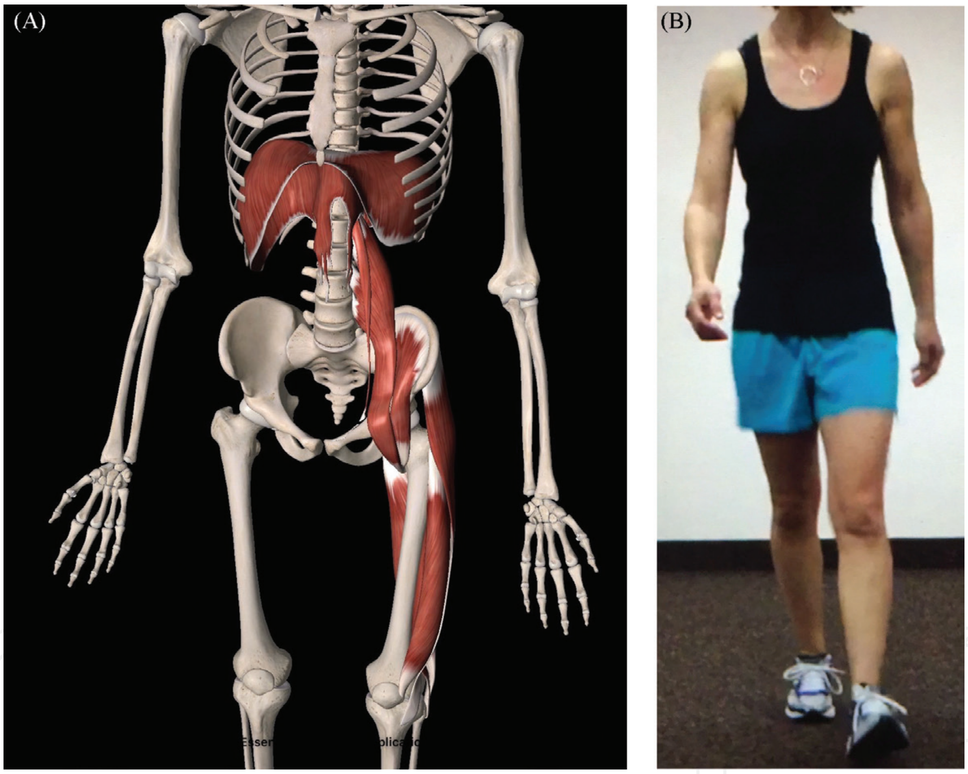


Figure 8. (A) Muscles of the left anterior interior chain. Copyright—3D4 medical modified with permission by the Postural Restoration Institute®. (B) Left anterior, interior chain in left swing phase of gait.

The biomechanical elements are already familiar from earlier description: the lumbar spine, sacrum, and pelvis orient to the right. The left hemipelvis rotates anteriorly, abducts and externally rotates, facilitating muscles that promote left swing through. These AIC muscles include the left diaphragm, the left psoas major, the left iliacus, the left tensor fasciae latae, the left biceps femoris, and the left vastus lateralis. Simultaneously, the left anterior ribcage elevates and externally rotates as the left diaphragm flattens into an inhalation position. The left lumbar spine is pulled forward and downward by the psoas and forward and upward by the diaphragm, resulting in increased lumbar lordosis [3] (see **Figure 4**).

This is the normal swing through configuration. However, when body neutrality is lost, the left AIC pattern remains tonically active. Persistence of the left swing through pattern interferes with full recruitment of its opposite, the muscles of left stance [31]. Consequently, left stance performance is weakened and less stable. Left AIC patterning thereby reinforces right-side dominance that is neurologically encoded as the new normal posture. Biomechanical strategies to compensate for this maladaptive left stance phase often involve overuse of the right lower extremity and/or malpositioning and stress of the left lower extremity joints. The right AIC muscle chain is not constrained by underlying positional insufficiency, and it supports right stance well. However, the efficiency of right swing through may be limited due to left-side instability during left stance as well as due to persistent overactivity of the right adductors and lateral abdominals.

The upper trunk muscle chain described by PRI is named the "Brachial Chain" (BC) (see **Figure 9A**). The BC balances rotational forces generated by the AIC by counterrotating the spine and ribcage to a forward direction. A right BC pattern complements the left AIC pattern by promoting left thoracic rotation (see **Figure 9B**). Counterrotation takes place in the approximate region of T7–9 [1]. The respiratory diaphragm inserts on the inner surfaces of ribs T7–12 and to the anterior aspect of vertebrae L1–3 on the right and L1,2 on the left. In its normal, exhalatory rest position, the dome of the diaphragm is at about T8. Therefore, the trunk could be considered to be the portion of the torso above the diaphragm. This counterrotation of the trunk is accompanied by ipsilateral side bend due to ipsilateral forward arm swing and to ribcage kinematics [39].

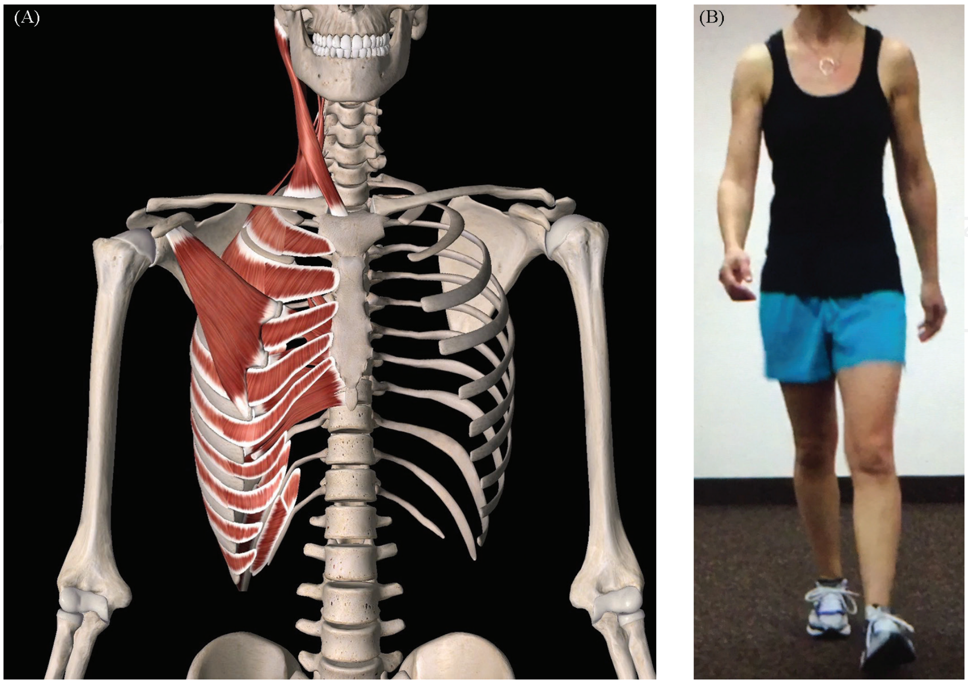


Figure 9. (A) Muscle of the right brachial chain. Copyright—3D4 medical modified with permission by the Postural Restoration Institute®. (B) Right brachial chain in left swing phase of gait.

Right arm reach is facilitated by this configuration. As the mid and upper trunk turn leftward, opposite to the right rotation of the lumbar spine and pelvis, ribcage kinematics re-form the shape of the ribcage and its muscular attachments. Left trunk rotation results in right ribcage approximation and internal rotation, and left ribcage expansion and external rotation [39]. This configuration encourages airflow from inhalation to the already-expanded left ribcage and lung while decreasing airflow to the right internally rotated approximated side. Muscles of the BC supporting right ribcage internal rotation include the right triangularis sterni, right sternocleidomastoid, right scalenes, right pectoralis minor and right intercostals, and also muscles of the right pharynx and anterior neck.

The "left AIC, right BC" pattern can be understood as the normal configuration of one half of the gait cycle, i.e., right stance. A *right* AIC, *left* BC pattern would reflect the other half of the gait cycle, i.e., left stance (see **Figure 10**). Human physiological asymmetry and right-side dominance predispose the body for greater right competency. Although left-side function will never be as efficient as the right, left stance can achieve near-equal stability with musculoskeletal balance or body neutrality.

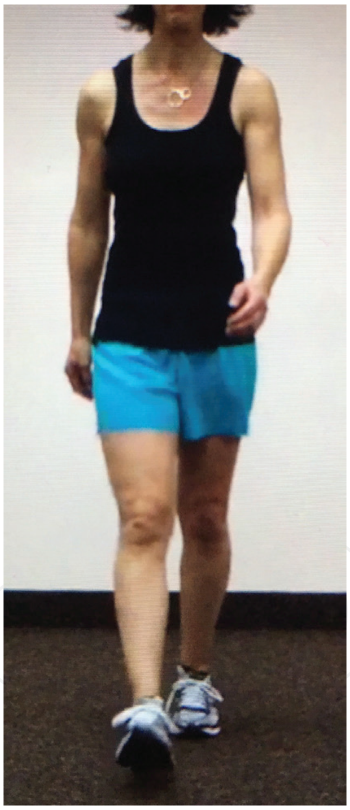


Figure 10. Right swing phase of gait illustrating the right anterior interior chain and left brachial chain.

This Left AIC, right BC pattern explains the biomechanics predisposing the development of a right thoracic, left lumbar spinal curvature, which describes 90% of curves [5–7] (see **Figure 11A**). The left AIC, right BC pattern underlies all human posture and movement (see **Figure 11B**). While different circumstances may result in different pathological compensations, generating a variety of stresses and/or structural changes, this innate human asymmetrical bias will be present [1–4].

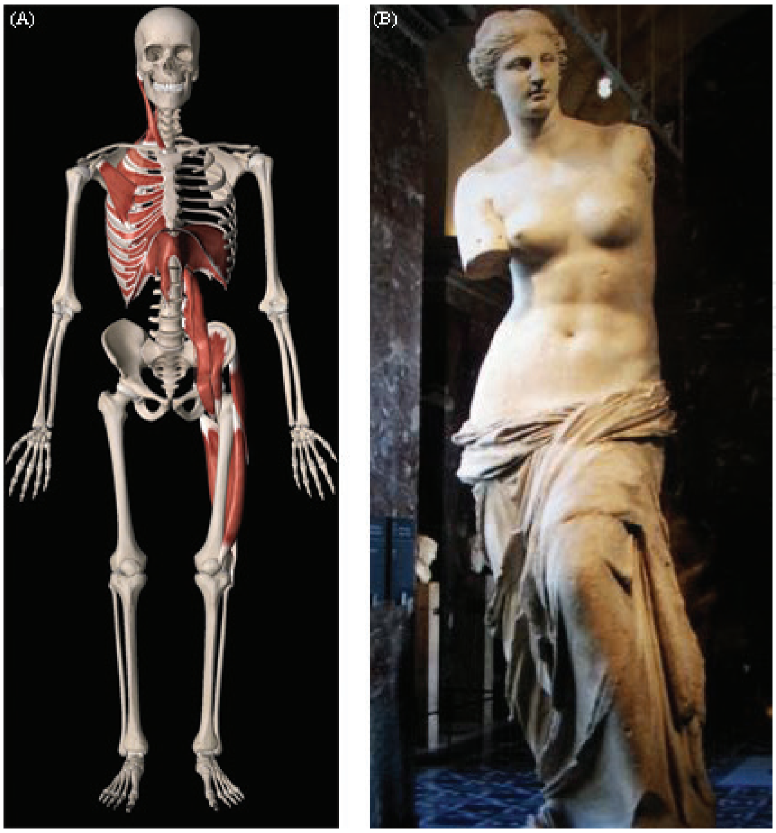


Figure 11. (A) Muscles of the left anterior interior chain and right brachial chain. Copyright—3D4 medical modified with permission by the Postural Restoration Institute®. (B) A classic example of a Left AIC, right BC pattern.

2.7. Biomechanical dysfunction begins in the sagittal plane

The sagittal alignment of the pelvis and ribcage affects muscle length and strength throughout the body. With any activity, the positional relationships of the structures and of the muscles that attach to them change. However, when the body is at rest, the ribcage and pelvis should be in a relative sagittal neutral position with muscle groups at their resting length. In an alternating reciprocal activity such as gait, there should be a moment of relative sagittal plane neutrality as weight shifts from one side to the other.

When this relative state of neutrality is no longer possible due to overactive right-dominant patterning, the left AIC, right BC pattern takes precedence. The left hemipelvis chronically positioned in swing phase of gait is anteriorly rotated. The spine balances this forward momentum with backward tilting as tonic, shortened paraspinal muscles take on the responsibility of keeping the spine erect. The left psoas and iliacus muscles adaptively shorten as the left transverse abdominis and internal oblique muscles are stretched between their insertions on the anterior lower ribs and the now more distal iliac crest. The left anterior ribcage flares, further weakening the overstretched left lateral abdominal muscles. With diminished opposition to left diaphragm recoil, because of lengthened abdominals and a loss of ZOA, the fibers of the left diaphragm orient more vertically, and the diaphragm assumes a greater role as a back extensor muscle than as a respiratory muscle. Its directional pull on the spine is forward and upward, while the psoas pulls the spine forward and downwards. The action of these two muscle groups encourages an exaggerated lumbar lordosis, reinforced by the lumbar paraspinals [16] (see **Figure 4**).

Exaggerated lordosis in the sagittal plane precedes a cascade of compensatory muscle and respiratory activity, as the brain encodes alternative strategies for continuing upright function. Further sagittal plane dysfunction follows, for example, the development of thoracic kyphosis to rebalance weight distribution over the pelvis. Another common strategy is the development of thoracic lordosis with reversal of the cervical spine to assist inhalation as cervical respiratory accessory muscle use increases to support the inefficient diaphragm position. According to the Hueter-Volkmann Law, epiphyseal bony growth is inhibited by compression and facilitated by tractioning [40]. In a young spine, exaggerated lordosis compressing the posterior vertebral segments would facilitate the development of relative anterior spinal overgrowth (RASO). This sagittal plane flattening of the thoracic kyphosis is an acknowledged precursor of scoliosis [41, 42].

Human physiological asymmetry expressed as right-side dominance via the left AIC, right BC pattern, demonstrates biomechanical challenges to maintaining neutrality of the pelvis and ribcage in the sagittal plane. Other factors contributing to loss of neutrality may include prolonged static positioning, especially sitting, hypermobility especially when participating in extreme sports or dance, and impaired somatosensory input. In the absence of pathology, right stance is a common default stance position. Respiration and gait will reinforce imbalance once neutrality is lost.

3. PRI tests to evaluate tri-planar musculoskeletal relationship and function

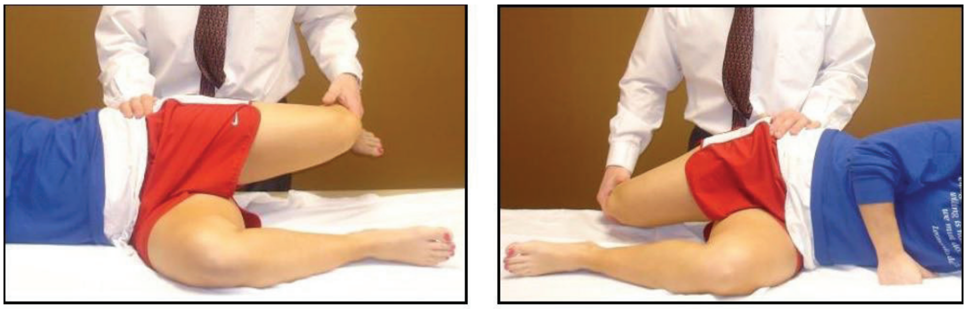
Taking into account the universal predisposition for human left AIC, right BC patterning, PRI tests accurately assess structural relationships such as sagittal plane position of the hemipelvis and ribcage and rotational orientation of the lumbar, thoracic, and cervical spines. Other palpatory tests reveal the patients' ability or inability to expand both apical lungs fields and both posterior mediastinal spaces. Initial testing exposes underlying patterning based on the left AIC, right BC model. Therefore, patients who exhibit typical findings for these patterns are not in a neutral state. It has to be understood that results from any further testing of range of motion, or strength, including core strength, would be based on their compensatory strategies. Deviation from predictable configuration implicates pathological compensation.

Neutral posture is defined by an alignment of body segments involving minimal amount of stress and strain and which is conducive to maximal efficiency in use of the body. It also optimizes diaphragmatic respiration. The neutral position of a muscle is equivalent to physiological rest [19]. This equates with musculoskeletal relative balance in a body, which is physiologically and functionally asymmetric. It is, therefore, imperative to first restore this neutrality. Once accomplished, further testing will give accurate information about weaknesses or restrictions in joints limiting appropriate frontal plane and transverse plane balance and function. Only with the restoration of musculoskeletal neutrality can appropriate, compensatory-free strengthening be initiated.

Over 25 PRI tests are available for initial assessment and to guide exercise progression as the patient progresses toward functional strength, respiratory competence, and upright alternating reciprocal activity. During treatment, the PRI tests are often applied before and after therapeutic exercise to determine its effectiveness, to reveal weakness or improvements in strength, and to further guide appropriate exercise progression. Three basic tests are described below.

3.1. The adduction drop test (ADT)

This is an example of a positional test for hemipelvic position in the sagittal plane. This side-lying test position facilitates a neutral hemipelvic position by flexing the hips and knees, thereby taking potential overstretch off the hamstring muscles. If the hemipelvis is in its neutral range, the ipsilateral femoral head will align with the acetabular groove allowing the femur to achieve full passive adduction as it is lowered by the clinician. If the hemipelvis is anteriorly rotated despite the test position of bent hips and knees, the femoral neck will impinge on the acetabular rim. The femur will not achieve full passive adduction (see **Figure 12**).



**Positive* *Negative*

Figure 12. Adduction drop test used with permission from the Postural Restoration Institute®. Copyright 2017, www.posturalrestoration.com

3.2. The humeral glenoid internal rotation test (HGIR)

This positional test assesses ribcage alignment. The posterior ribcage, as the foundation for the scapulae, determines scapular position and glenoid orientation, and therefore, humeral-glenoid mechanics. In the supine, bent knees test position, the humeral head is abducted to 90°, the elbow is flexed to 90°, and the forearm is pronated. Neutral alignment of the hemiribcage will allow full passive humeral internal rotation within the glenoid fossa. If the ribs of the anterior ribcage are internally rotated and the intercostals adaptively shortened, the apical chest wall will exhibit restriction and limited expansion with inhalation. The scapula is pulled forward by pectoralis minor and positioned in a state of upward rotation, abduction, internal rotation, and protraction. Consequently, the humeral head is now in external rotation relative to the glenoid fossa. Passive internal rotation of the humerus will result in impingement on the glenoid fossa and the range of motion will be limited (see **Figure 13**).

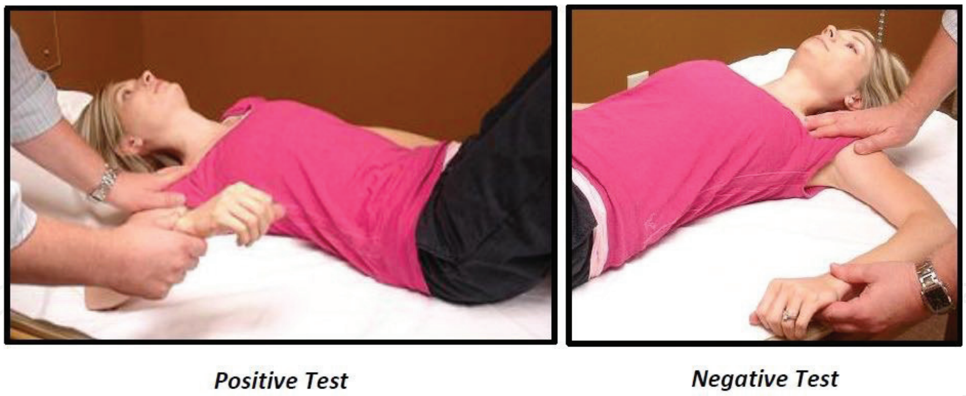


Figure 13. Humeral glenoid internal rotation test used with permission from the Postural Restoration Institute®. Copyright 2017, www.posturalrestoration.com

3.3. Trunk rotation test (TRT)

This test assesses the integrity of the right iliolumbar ligament and the stability of the lumbopelvic junction. In patients with scoliosis, it is used to classify curve patterns. A "nonpathological" curve indicates this ligament is intact and the pelvis moves with the lumbar spine. A "pathological-compensatory" curve refers to an overstretching of the ligament, allowing the pelvis to move opposite to the lumbar spine and indicating laxity of this lumbopelvic stabilizing ligament. The nonpathological curvature is similar to the Schroth Barcelona[1] 3 curve or non 3-non 4; the pathological-compensatory curve is similar to the 4 curve or thoracolumbar curve. A positive TRT corresponds to countertilts identified by X-ray.

The test position is supine with knees bent and with ankles together. As the bent legs are passively rotated to one side, the clinician monitors the contralateral lower ribcage feeling for a movement of the ribcage away from the supporting surface. The beginning of ribcage movement indicates that the pelvis has reached its end of range and the spine is beginning to assist the rotation. Because the ribs articulate with the spine, the initiation of spinal rotation can be palpated. The range of motion is recorded and compared with motion to the other side (see **Figure 14**).

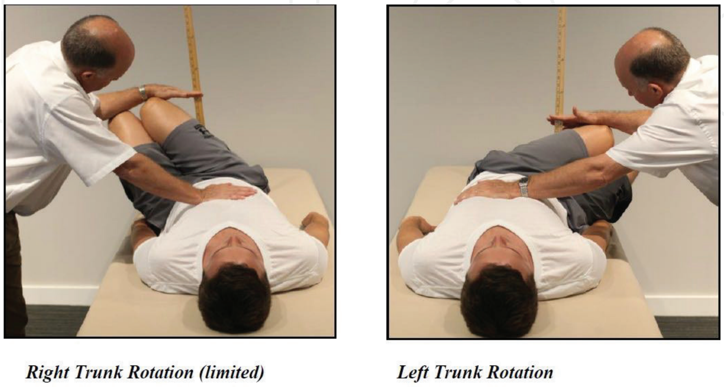


Figure 14. Trunk rotation test used with permission from the Postural Restoration Institute®. Copyright 2017, www.posturalrestoration.com

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[1] C2 certified.

Findings from this test must be correlated with the ADT for accurate assessment. If the ADT demonstrates a bilaterally neutral pelvic position, the rotational range to right and left should be equal. If the ADT reveals left or bilateral anterior pelvic rotation, the legs should have a greater range of motion to the right. The rationale for this test assumes a right-side dominant pattern unless the ADT demonstrates neutral balance. In a right-side dominant person, the lumbar spine will be right-oriented; therefore, the legs will appear to turn further to the right. If the legs move farther to the left, it indicates that the right iliolumbar ligament is compromised and does not maintain lumbopelvic stability.

These few examples give an idea of how the findings from PRI clinical tests correlate with one another to give an understanding of the patient's position and biomechanical function. These physiological details are otherwise hard to assess and factor into treatment protocols.

4. Exercise progressions for restoration of musculoskeletal balance

Exercises, termed "nonmanual techniques" in PRI, are powerful tools for proprioception and physiological transformation for patients with scoliosis of all ages. Based on the model of right-side dominance due to human asymmetry, and taking into consideration the patient's unique configuration and function revealed by the evaluation tests, exercises are carefully chosen to most appropriately meet the tri-planar needs of that patient. Some of the greatest similarities between the methodology of Schroth Barcelona and PRI are in the application of exercises. Both place emphasis on exercise position, breath, and stabilization in the corrected tri-planar position [8, 9].

Exercise progression begins in fully supported positions to isolate and recruit underused or misused muscles. Supported positions are also favored for the introduction of multimuscle integration. When the patient demonstrates competence in activating correct muscle chain activity while supported, challenge is intensified by progression to more upright activities. Repetition of challenging positions, held through multiple breathing cycles, promotes proprioceptive familiarity with new alignment and stabilization in new muscle patterns. Increased self-awareness and more precise muscle and breath control enable the patient to self-correct in activities of daily living. Achieving true alternating, reciprocal movement, as required in gait, is a final challenge.

4.1. Repositioning for sagittal plane neutrality

The PRI protocols begin with establishing the patient's ability to achieve sagittal plane neutral position of the pelvis and the ribcage. As previously described, this means that in a position of rest, their musculoskeletal system is in a state of relative muscle balance following a "repositioning" activity. Sagittal plane repositioning is most easily achieved in supported positions. Gravity is thereby eliminated and underused muscles can be positionally isolated and challenged.

Recruitment of the hamstring muscles is the most common starting point for repositioning exercises. The hamstring muscles insert proximally on the ischial tuberosity and distally on the medial tibial condyle and on the head of the fibula and the lateral tibial condyle. When the pelvis tilts anteriorly, the ischial tuberosity moves proximally and away from the tibia, resulting in overlengthening and weakening of the hamstring complex. Consequently, this powerful muscle group is unable to perform its postural function of stabilizing the pelvis, especially during stance phase of gait. Assessing ADT or another relevant test, prior to and following the activity, demonstrates whether that activity was helpful in restoring correct hamstring length and neutral pelvic alignment. If so, it is useful to ask the patient to stand and describe their body sensation to assure a definitive, proprioceptive experience of difference. Some patients, especially people with hypermobility, have difficulty noticing subtle differences. Others notice new sensations: "I feel lighter, taller, more weight on my heels."

The skill of sensing, i.e., the ability to focus attention on subtle sensations, is a potent tool for reshaping one's alignment from within. These sensations include awareness of the ground, of the body's orientation in space, internal structural relationship, and subtle changes in muscle tone. Most empowering is the ability to achieve expansion of targeted thoracic regions on inhalation.

4.2. Balancing the frontal plane

As the patient becomes stronger and more proficient at maintaining sagittal plane ribcage and pelvic alignment via hamstring and lateral abdominal integration, work begins on balancing muscles of the frontal plane. The pelvis and hips are key components. For example, in the stance phase of gait, the femur should be internally rotated relative to the acetabulum to insure stability. The right leg is typically better positioned to achieve stable stance. The pelvis is typically oriented right, positioning the right femur in stance and the left femur in swing phase of gait. Muscle chain activity supporting left stance is weak. Exercise progressions to recruit, strengthen, and integrate the left nondominant muscle chain are initiated. Target muscles to promote frontal plane balance include, but are not limited to the left adductor, the left anterior gluteus medius, the right gluteus maximus, and right serratus anterior.

Frontal plane exercise progressions often begin with sidelying to assist isolation, strengthening, and neural encoding of underused muscles. More upright positions challenge the patient's ability to maintain sagittal control with the addition of appropriate abduction and adduction movements. Exercise complexity and challenge increases as isolated muscles are integrated together in activities that require frontal plane muscle chain activity. Isolated left nondominant muscles are gradually integrated together in increasingly complex and challenging exercises in the frontal plane.

Muscle inhibition is another powerful technique utilized by PRI to rebalance patterned systems. Recruitment of an antagonist to an overactive muscle will neurologically inhibit that muscle's firing. Overactive and overused muscles are inhibited by the exercise position as well as by the action of the exercise.

4.3. Restoring the transverse plane (via the left zone of apposition)

As we see in right-side dominant posture and in almost every patient with scoliosis, irrespective of curve pattern, the left anterior ribcage is prominent and flared. The anterior left lateral abdominals are lengthened and weak, and the right abdominals are often restricted anteriorly. The left diaphragm is maintained in a position of inhalation. Activities to restore and to achieve greater left diaphragm respiratory effectiveness require a neutral pelvis and relative frontal plane balance. Mobilizing muscles to promote left anterior ribcage internal rotation targets left internal obliques and transverse abdominis. Right and left lower trapezius, left serratus anterior, and right subscapularis are important muscle chain agonists.

Retraining of alternate, reciprocal, upright gait is the ultimate goal. Balanced asymmetry in gait requires sagittal core strength to maintain neutrality of the pelvis and ribcage, with frontal plane competence to achieve *left* AFIR in stance phase and *right* AFER in swing phase, and the ability of the left diaphragm to fully exhale and the right to fully inhale. This exemplifies normalized function of the nondominant *right* AIC (see **Figure 10**). Although not all patients can achieve full-balanced asymmetry, especially in the presence of structural change, balancing triplanar muscle activity will enhance functionality, improve respiration, and in most cases, halt curve progression.

4.4. Examples of exercises

90-90 Hip Lift with Right Arm Reach and Balloon: This is one of the several versions of sagittal plane repositioning activities. In this activity, the patient is able to stabilize the pelvis in a neutral position, via bilateral, isometric hamstring activation, making it easier for many patients to achieve control. The addition of a balloon in any activity will promote active resistance to exhalation and concentric contraction of internal obliques and transverse abdominals. Right reaching in this activity further promotes left abdominal shortening and helps the patient to sense desired left posterior pelvic rotation (see **Figure 15**).

Figure 15. *90–90 hip lift with right arm reach and balloon* used with permission from the Postural Restoration Institute®. Copyright 2017, www.posturalrestoration.com

All Four Belly Lift Walk: This activity offers greater sensory awareness of position through 4 points of contact with the ground as well as movement against gravity. The patient is asked to “reach” during synchronized breathing with both hands and heels as they “walk” their feet forward, keeping knees bent. This promotes improved thoracic positioning through activation of internal obliques and transverse abdominals as well as diaphragmatic expansion and elongation of the thorax, while paraspinals are inhibited. Ankle dorsiflexion required for posterior weight shifting is an additional valuable component of this activity (see **Figure 16**).

Figure 16. *All four belly lift walk* used with permission from the Postural Restoration Institute®. Copyright 2017, www.posturalrestoration.com

Left Sidelying, Left Flexed Femoral Acetabular Adduction with Right Lowered Extended Femoral Acetabular Abduction: This frontal plane sidelying exercise is a progression following the acquisition of sagittal plane neutral pelvic position. The sidelying position offers support and sensory reference to help the patient find and recruit the proper muscles. Activation of the left hip adductor helps to maintain sagittal plane neutral pelvic position. The left lateral abdominals are concomitantly activated with a right lower extremity reach to correct the left lumbar scoliosis in the frontal plane. The sidelying position offers gravitational resistance to right hip abduction, strengthening the right gluteus medius and maximus in the corrected position (see **Figure 17**).

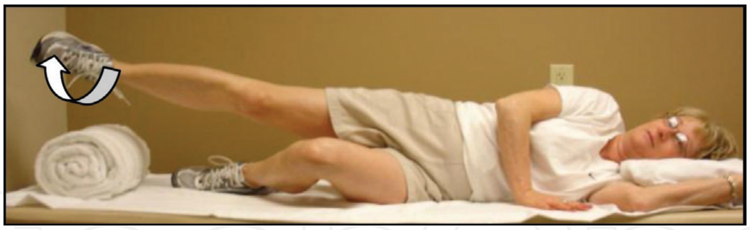

Figure 17. *Left sidelying, left flexed femoral acetabular adduction with right lowered extended femoral acetabular abduction* used with permission from the Postural Restoration Institute®. Copyright 2017, www.posturalrestoration.com

Right Sidelying Right Apical Expansion with Left Femoral Acetabular Internal Rotation (AFIR): A higher-level challenge for control of a right thoracic curvature is presented in this activity. The loaded right arm facilitates right scapular depression and retraction of the thoracic prominence toward the midline with beneficial elongation of the right lumbar spine. The left reach promotes right trunk rotation and left posterior mediastinal expansion. The pelvic position further encourages the corrective left lateral abdominals, left acetabular femoral adduction, and internal rotation (AFIR) with right acetabular femoral abduction and external rotation (AFER). Without sufficient right thoracic control, this activity can result in patients “dropping into” their thoracic curve, making this an advanced activity (see **Figure 18**).

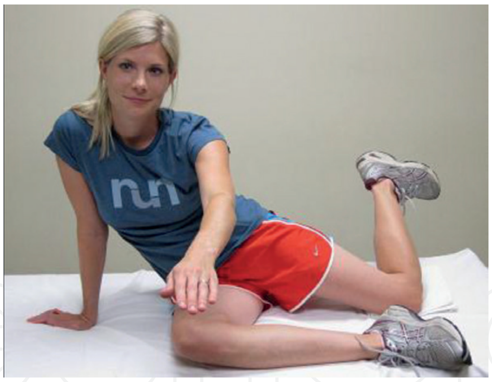

Figure 18. *Right Sidelying Right Apical Expansion with Left Femoral Acetabular Internal Rotation (AFIR)* used with permission from the Postural Restoration Institute®. Copyright 2017, www.posturalrestoration.com

Standing Supported Left Acetabular Femoral Internal Rotation (AFIR) with Right Femoral Acetabular Abduction: This frontal plane, upright, supported activity is a natural progression of a left sidelying program. For patients with left lumbar scoliosis, activation of left internal obliques and transverse abdominals creates a stabilizing triplanar force on the lumbar spine, a region clinically associated with instability in these patients. Frontal plane control of the pelvis is highlighted as the patient attempts to abduct their right leg and maintain triplanar pelvic corrections. Bringing this familiar frontal plane challenge to the upright position allows the patient to carry over sensations and control established in left sidelying to a more functional integration of postural correction (see **Figure 19**).

Figure 19. *Standing supported left acetabular femoral internal rotation (AFIR) with right femoral* used with permission from the Postural Restoration Institute®. Copyright 2017, www.posturalrestoration.com

Four Point Gait with Mediastinum Expansion: Efficient gait requires the pelvis to move over the stance limb with the trunk counterrotating. Patients with scoliosis are commonly challenged during left stance due to limited left pelvic rotation and right trunk counterrotation. The use of walking poles is an effective method to achieve "all 4" sensory awareness of the ground when upright. The patient is guided into a movement pattern for left pelvic orientation over the left stance limb as they simultaneously expand the left posterior mediastinum via left arm reach as they advance the left pole, promoting right trunk counterrotation (see **Figure 20**).

Figure 20. *Four-point gait with mediastinum expansion* used with permission from the Postural Restoration Institute®. Copyright 2017, www.posturalrestoration.com

Seated, Supported Left Acetabular Femoral Internal Rotation (AFIR) with Right Psoas and Iliacus and Right Femoral Acetabular External Rotation (AFER): In scoliosis, spinal compression is problematic because it increases spinal torsion. Sitting is likely the most common posture associated with increased spinal compression. Effective seated postural corrections are, therefore, an important skill requiring advanced, tri-planar control of the pelvis and thorax. This advanced, integrated activity positions the pelvis in left rotation with counterrotation of the thoracic spine into right trunk rotation. The lengthened right psoas is shortened and strengthened in its role as a hip flexor (see **Figure 21**).

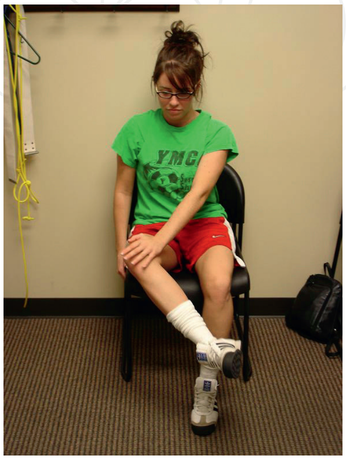

Figure 21. *Seated, supported left acetabular femoral internal rotation (AFIR) with right Psoas and iliacus and right femoral acetabular external rotation* (AFER) used with permission from the Postural Restoration Institute®. Copyright 2017, www.posturalrestoration.com

5. Case studies

5.1. Case 1

History: MD is a very active, extremely flexible, 9-year-old girl. She is passionate about ballet. She reports right hip pain and limited motion with some dance moves. Her shoulders occasionally "pop out of joint." Her mother reports numerous falls. MD was diagnosed with left thoracolumbar scoliosis at age 8, with a Cobb angle of 13°. Her doctor recommended to "wait and see." One year later, at age 9, the Cobb angle had increased to 27°. Again, her doctor recommended to "wait and see." MD's mother decided to seek conservative treatment.

Initial evaluation findings: Observation—general laxity, swayback, forward head posture, restless, constantly moving into different end-range extension positioning. Standing posture—stands on left leg, left knee hyperextension, left hip shifted to left, left pelvis positioned in swing phase (AFER), right knee bent, minimal right weight bearing. Unilateral stance—left leg 20 s, right leg 6 s. Bilateral stance (equal weight bearing)—10 s, then reverts to left stance. Forward bend—¼ range of motion, no lumbar reversal, states "my back will break." Seated hip rotation—internal: right 59°, left 45°, external: right 45°, left 45°. Spirometry (FEV)—average of three trials 1173 cc (age norm 1550 cc), weak exhale. Gait—extreme lumbar lordosis, bilateral Trendelenburg. Unable to maintain test position for ADT due to restlessness.

5.1.1. Clinical reasoning and treatment progression

MD being hypermobile demonstrated the common finding of decreased proprioception. In her physiological attempts to feel stable, she resorted to end-range positioning via hyperextension. In the sagittal plane, this lordotic posturing caused anterior pelvic rotation and anterior ribcage elevation. Chronic anterior ribcage elevation decreased diaphragmatic efficiency and resulted in the diaphragm acting as a postural extensor muscle. Due to chronic pelvic anterior rotation and overuse of her right leg, especially in dance class, right hip impingement developed. MD shifted off the right leg to avoid impingement pain. This became a strong pattern, and she could no longer maintain bilateral stance. To balance her left-sided shift, her spine migrated right. She remained in hyperextension.

Treatment began with a practice of bilateral and right stance. This was pain-free, but very challenging. *Sagittal plane*: repositioning was introduced at the second visit via the *All Four's Belly Lift Walk* (see **Figure 16**). This activity inhibited the tight paraspinals while shortening and strengthening lateral abdominals. Over the next few visits 90/90 *Hip Lift* activities were added to inhibit the paraspinal muscles in a supported position while isolating the hamstring muscles to establish pelvic neutrality. A balloon blow was added to 90/90 *Hip Lift* to increase recruitment of lateral abdominals while in a pelvic neutral position (see **Figure 15**). A sitting exercise with back supported, balloon blow, and left arm reach was added to challenge her in a more upright position. MD also practiced sitting in a chair blowing out through a straw to help her learn how to breathe diaphragmatically.

Frontal plane: Left AFIR was introduced with a hip hinge standing activity that simultaneously facilitated left posterior mediastinal (concavity) expansion.

The lateral spinal curve was eliminated in five physical therapy sessions of 1 hour each, over a 3-month period by addressing sagittal plane and respiratory dysfunction. MD's mother helped her with daily exercises. Due to her extreme hypermobility, MD is continuing physical therapy check-ins at 3–6-month intervals to maintain alignment, to stabilize, and strengthen her structure and to assure a neutral baseline. Scoliosis has not recurred. She continues her intensive ballet.

Summary: At age 9, when MD began PT, no spinal structural changes were evident, and there was no countertilt. However, her curve had progressed over a year, at Risser 0, from 13° to 27° with a rapid growth period ahead of her. Without intervention, structural change and curve progression were inevitable. This case highlights the importance of early detection and treatment. In the US, the current medical approach to juvenile and adolescent scoliosis is "wait and see." Once exaggerated curvatures in sagittal or frontal planes progress to structural change, rehabilitation is significantly more challenging and often less successful.

5.2. Case 2

History: RM is a 12-year-old female who was diagnosed with scoliosis at age 11. Her X-rays showed a right thoracic, left lumbar PRI nonpatho curve pattern, measuring 28° from T6–T12, and 21° curve from T12–L4. Her sagittal view film showed 52.4° of lumbar lordosis and 42° of thoracic kyphosis. She was told by her physician to "wait and see" and return 6 months later. New X-rays revealed progression to 38° from T6–T12 and 26° from T12–L4. She was still a Risser 0 and had not yet started menses. She was fitted for a Boston Brace, which she wore for 16–20 hours a day, for about 2½ years weaning to nights only at the beginning of her freshman year of high school and continuing. RM is an athlete playing basketball, tennis, and ultimate frisbee and more recently, doing yoga. She spends the summers at a 6-week sleep-away camp and travels internationally with her family.

Initial evaluation findings: Her starting height was 5′3″. It is speculated that she had a growth spurt from time of diagnosis over the 6-month period in which her curve progressed by roughly 10°. Standing posture—anterior pelvis, knee hyperextension left greater than right, the right medial border of scapula more prominent with the right scapula being rounded forward, protracted, and slightly elevated, her right hip is higher and shifted slightly to the right. In the sagittal view, her weight is shifted anteriorly toward her toes. Gait—arm swing was greater on the left than right, right shoulder is higher, and she lacks knee flexion at the loading response bilaterally. Her upper body stays stiff and her pelvis moves in the frontal plane more than in the transverse plane. Forward bend—visible left lumbar curve with slightly elevated right rib cage. Spirometry (FEV)—2200 cc, (age norm – 2150 cc.) Scoliometer—5° rotation to the right in mid-thoracic spine, 4° rotation to the left in mid-lumbar spine.

Clinical testing: PRI testing—*ADT* indicated left anterior hemipelvis rotation, right hemipelvis neutral position (see **Figure 12**). *HGIR* indicated bilateral ribcage elevation and external rotation, left greater than right (see **Figure 13**). *TRT*—knees go farther to the left, indicating suspected iliolumbar ligament laxity (see **Figure 14**). Both *Right Apical Chest Wall Expansion* and *Left Posterior Mediastinum (left thoracic concavity) Expansion* were limited. *Single limb stance for 60 s*—more stable in right stance, and trunk is more symmetrical in right stance than left stance. In left stance, her hip and pelvis are shifted anteriorly. Her favorite position is to stand on her right leg with her left leg crossed in front, her right hip out to the side with her right hand propping on her right hip. She was *pain-free*.

5.2.1. Treatment progression and clinical reasoning

Postural awareness and behavior changed during activities of daily living—she lightened her backpack and began to use a waist strap to redistribute weight to her pelvis from her spine. We encouraged her to sense her heels and improve standing posture. We incorporated spinal precautions (hip hinge instead of spinal flexion) due to relative anterior spinal overgrowth (RASO) and encouraged corrective postures for studying and lounging (i.e., avoiding prone on elbows and sitting in her curve pattern).

Sagittal plane: Supported supine activities to reposition pelvis were initiated by concomitant strengthening of hamstrings and lateral abdominals focusing on exhalation to bring her rib cage down anteriorly, restoring her respiratory zone of apposition. A left hip shift bias was used to help anchor her left femoral-pelvic position with her left lateral abdominals as in the *90/90 Hip Lift with Right Arm Reach and Balloon* (see **Figure 15**). Improved sagittal plane position was maintained throughout her program while addressing other planes of correction and progressing positional challenges against gravity.

Frontal plane: Exercises focusing on balancing left lumbar curve were implemented in left sidelying with a right leg reach, and by PRI left-side plank activities to lengthen her right lateral abdominals and shorten/strengthen the left. Her right thoracic curve was addressed with left sidelying activities to allow gravity to assist with centralization, as well as with positioning and muscle activation to direct air for right apical and left thoracic concavity expansion. Right upper extremity retraction/shoulder extension in external rotation was implemented to help activate her right low and middle trapezius to help reposition her right scapula toward the midline. Position was progressed from sidelying to sitting to standing. Examples of these PRI nonmanual techniques are *the Left Sidelying Left Flexed Femoral Acetabular Adduction with Right Lowered Extended Femoral Acetabular Abduction* (see **Figure 17**), and the *Standing Supported Left Acetabular Femoral Internal Rotation (AFIR) with Right Femoral Acetabular Abduction* (see **Figure 19**).

Transverse plane: Once the left respiratory zone of apposition was achieved to anchor left anterior rib flare, activities to strengthen right low trapezius and triceps were used to assist with thoracic spine derotation and rib cage balancing. Likewise, right iliacus and psoas were used for lumbar spine derotation in sitting and standing. The left serratus anterior and low trapezius were activated concomitantly to bring the left rib cage posteriorly (to expand the left thoracic concavity). Exercises were progressed from supine to seated to supported standing to freestanding, followed by the addition of resistance (dynamic stabilization) in standing for strengthening and maintenance of this correction.

Final Clinical Findings: Height—5′6 & 5/8″ (2½ years later, almost 4″ of growth), X-rays - right thoracic: T5–T12 = 35°, left lumbar: T12–L4 = 29.1°, Risser 4. Menses began summer of 2016. Her growth has stabilized, and we are hopeful to prevent progression requiring surgical correction/fixation. Spirometry (FEV)—2700 cc, which is age-appropriate. Single limb stance—more symmetrical and balanced on each leg with good observable pelvofemoral position bilaterally.

Summary: Working with teenagers can be challenging as well as rewarding due their very busy lives and neurodevelopmental immaturity to realize consequences. When trying to prevent curve progression, over a long period of time during growth, the process can become repetitive and laborious and it is easy for an adolescent to lose belief and/or motivation in the process. School and extracurricular activities can override exercise programs, especially if the patient has no pain. However, RM was diligent with her program and was able to implement concepts of correction and to perform challenging exercises while away at summer camp. Her case is an excellent example of the possibility to hold a curve that began to rapidly progress (10° in 6 months), with a starting point >25°, during a period of growth. She was able to avoid the need for surgical correction and now has a "tool bag" of exercises and positions she can use to thwart potential discomfort, as well as to maintain balanced asymmetry, throughout her lifetime. At recent follow-up, she proudly offered that she has less pain than her peers and teammates following exercise classes and games "because I now know how to take care of my spine!"

5.3. Case 3

History: JP is a 66-year-old female with primary complaint of loss of upright function for the past 10 years due to debilitating left leg sciatica. JP was able to stand and/or walk for only 10 min at a time, and this was greatly affecting her ability to participate in her choir practice and in her ability to play actively with her grandson. The patient was diagnosed with scoliosis as a teenager but was not offered any intervention. X-rays reveal right thoracic convexity between T2 and T11 (apex T8) with a Cobb angle of 26°. There is a larger, left lumbar convexity between T11 and L4 (apex L2) with a Cobb angle of 51° and clear evidence of rotary instability with moderate lateral listhesis of L4 on L5.

5.3.1. Initial evaluation findings

Standing posture—anterior translation of the pelvis. There is a notable, fixed left thoracolumbar kyphosis deformity and an associated left trunk imbalance with a right pelvic orientation in the frontal and transverse planes. JP is noted to have a flat thoracic spine and anterior rib flares bilaterally. Gait—elevated thorax with no appreciable right arm swing, the pelvis remains right-oriented throughout right and left stance phases. Clinical tests—*ADT* (see **Figure 12**) reveals the right hemipelvis is in neutral position and the left hemipelvis in anterior rotation. *HGIR* (see **Figure 13**) reveals restriction of right glenoid-humeral internal rotation due to restrictions of right apical chest expansion with elevation and external rotation of the left anterior ribcage. Palpation reveals limited expansion for both the right *Apical Chest Expansion Test* and the left *Posterior Mediastinum Expansion* Test. Spirometry (FEV) measures were 2100 cc, 1800 cc, and 1800 cc, respectively, over three trials consistent with hyperinflation and likely reduced FEV for age and gender (norms for 65-year-old woman, 2160 cc). *Functional outcome measure*—Roland

Morris Self-Report Low Back Pain Disability Questionnaire (RMDQ) was 9/24 or 37.5% self-report disability.

5.3.2. Treatment progression and clinical reasoning

Sagittal: Treatment began with sagittal plane control of pelvis and thorax to improve critical respiratory core muscle control. JP started in hooklying and supine 90–90 postures to begin activities like supine 90–90 with balloon blowing versions (see **Figure 15**). Once postural testing indicated adequate sagittal plane control, she moved to a left sidelying program.

Frontal: For this patient, the left sidelying position was felt to be best to help her begin to control frontal and transverse plane forces particularly in the region of her left lower lumbar spine, which were the most likely source of her debilitating sciatica. As JP gained control of the left abdominal wall in left sidelying and to obtain a ZOA, she began to integrate that control with combined muscular efforts culminating in left acetabular femoral internal rotation as with *Left Sidelying Left Flexed Femoral Acetabular Adduction with Right Lowered Extended Femoral Acetabular Abduction* (see **Figure 17**). JP was severely challenged with kinesthetic awareness of muscle activation and "carry over" to alternative postures. In her case, it was very helpful to have her stand up after a left sidelying activity to try to reproduce the same movement pattern in upright—her most challenging posture. Adding activities like *Standing Supported Left Acetabular Femoral Internal Rotation with Right Femoral Acetabular Abduction* (see **Figure 19**) were, therefore, quite a good challenge for improved upright control.

Transverse and alternating, reciprocating movement: As JP demonstrated further capacity for trunk control with left acetabular femoral internal rotation, we added challenges to coordinate with right trunk rotation as with gait. The use of walking poles was tremendously helpful for this patient to help with her balance, core muscle activation, kinesthetic sense of the ground and weight shifting, as well as to offer additional support for spinal elongation, a critical element in scoliosis treatment. Activities depicted like Four Point Gait with Mediastinal Expansion were further developed (see **Figure 20**).

Summary: Over the course of her last few visits (21 visits total), JP was consistently reporting dramatic and steady improvement in her function. She was playing with her grandson more than 2 hours at a time and able to stand through 3-hour choir rehearsals. Her walking progression was up to 34 min. The last RMDQ score was 3/24 or 12.5% self-report disability. All physical therapy goals were met. She was highly compliant and motivated throughout the course of her care, which no doubt, contributed to her strong outcomes.

6. Conclusion

The theoretical framework of PRI and its model of innate human asymmetry provides the clinician valuable insight into the development and progression of scoliosis and other spinal dysfunctions. This framework has the potential to redefine how clinicians evaluate and treat these conditions.

It is our experience that early detection and treatment of scoliosis and other postural disorders makes a significant difference to the success of intervention. For instance, a functional disorder resulting from an asymmetrical dominant pattern can more easily be rebalanced than one that has evolved into structural pathology. In the US, the medical approach to juvenile and adolescent scoliosis is commonly "wait and see." The PRI model recommends simple tests of balance and respiration in young people to identify those at risk. Early introduction of exercises to reestablish balanced asymmetry may effectively reduce the need for long-term rehab or surgery.

Patients of all ages and magnitude of spinal deformity can benefit from the PRI approach. Reestablishing neutrality, learning to balance tri-planar muscle activity, and optimizing respiration are among the life-long benefits of working on these exercises. Self-awareness engendered in this process is additionally empowering for many patients.

Clinical results of the application of PRI methodology have been compelling. We would like to encourage research on the many aspects of this new, innovative framework.

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Author details

Susan Henning*, Lisa C. Mangino and Jean Massé

*Address all correspondence to: myadvancephysicaltherapy@gmail.com

Advance Physical Therapy, Chapel Hill, NC, USA

PRI certified and Schroth Barcelona certified

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