

19. Clinical aspects of the sacroiliac joint in walking

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INTRODUCTION

Walking as an exercise for enhanced physical fitness has many positive attributes (Rippe et al 1986). If pursued at a rapid pace, the aerobic conditioning capacity is almost as great as in jogging and running, but with less risk of injury and progressive degenerative joint disease of the lower extremities. In addition to cardiovascular conditioning, walking provides biomechanical exercise for the total musculoskeletal system, including the upper and lower extremities and the trunk and pelvis. To be biomechanically efficient, the gait should be cross-patterned, with alternating arm swing and leg movement, and as symmetrical as possible. Walking has many advantages. It can be done in many places by anyone with appropriate shock-absorbing shoes and the available time. The American Medical Association's council on scientific affairs has stated, 'walking is a most convenient and adaptable form of exercise' (Dan 1988). In the presence of lower back and lower extremity pain, walking is frequently an activity that contributes to the patient's pain and disability. In those patients, it is an appropriate therapeutic goal to establish the maximal biomechanical capacity for symmetrical gait within the musculoskeletal system.

Lower back pain with or without lower extremity radiation is a frequent patient presentation to the health-care delivery system. It constitutes 25% of worker's compensation claims but consumes 80% of worker's compensation costs. It presents a major diagnostic challenge to health-care practitioners. Between 60 and 80% of cases defy specific diagnosis and are classified as idiopathic (Kirkaldy-Willis & Hill 1979).

The role of the sacroiliac joint (SIJ) in lower back and lower extremity pain has recently gained more attention and understanding. The anatomy, radiology and other imaging studies, and the pathology of the joint have been extensively reviewed by Bellamy et al (1983). This excellent review does not deal with the dysfunctional biomechanics of the sacroiliac (SI) mechanism viewed by many practitioners as being highly significant in back pain patients. These authors do, however, note that a discrepancy in leg length of 1.0 cm or more causes torsion to occur in the pelvic girdle, resulting in changes in the sacrum and pubis that frequently result in SI pain. It is further pointed out that the most reliable clinical sign of instability of the SIJ is disruption at the symphysis pubis, resulting in increased mobility when alternately weight-bearing on either leg.

The SIJ was eloquently reviewed from the perspective of the anatomy, biomechanics, and structural diagnosis by Beal (1982). This excellent review concluded that the motion at the SIJ was highly variable and of small quantity, and that there were marked variations in the anatomy of the joint surface. Beal also concluded that structural diagnosis of SIJ dysfunction required high-level skill in testing joint motion, analysing tissue texture, and assessing asymmetry of pelvic landmarks. Great care must be used in this process to differentiate accurately between normal and abnormal mobility.

ANATOMY

The anatomy of the lower back and pelvis has been covered in previous chapters and has been eloquently reviewed by Alderink (1991). There

are certain features of the anatomy that relate to the biomechanics of gait which need to be highlighted.

Conceptually, the junction of the lower extremity and the trunk can be viewed as being at the two SIJs with the two innominates functioning as lower extremity bones. Gracovetsky (see Chapter 20) has demonstrated that an individual with no lower extremities can perform a classic cross-pattern walking cycle with the ground contact being the two ischial tuberosities. The SIJs have two major components: a ventrally placed synovial joint and an extensive dorsal ligamentous component. The articular surfaces of the SIJ have extensive elevations and depressions (Vleeming et al 1990a, Weisl 1954), with a central depression on the sacral side. The sacral concavity and iliac convexity, and other elevations and depressions, increasingly develop over time (Bowen & Cassidy 1981). The contour of the joint begins to develop its uneven articular surfaces during the second and third decades. Well into the seventh decade, there is continued movement, but the interdigitating groves of the joint are better developed. It is interesting to note that the age of the greatest incidence of disabling back pain, the third and fourth decades, is a time at which the joint is well formed and quite mobile, yet is frequently dysfunctional. In childhood and early adolescence, the joint is not well formed, glides quite easily and is apparently not frequently involved in restricted dysfunction. In one's fifties, the joint begins to have less flexibility, and increased interdigitation of the opposing joint surfaces results in reduced mobility. Disabling mechanical back pain is less common in this age. The SIJs have the capacity for rotation and translation determined in large measure by the joint shape and ligamentous attachments. The axis of rotation varies considerably between individuals, and the combined rotation and translation that occur contributes to ligamentous tension which would absorb energy, and result in the concept that the SIJs function as shock-absorbing structures (Wilder et al 1980).

The ligamentous portion of the SIJ is extensive and has several significant relationships. The anterior SI ligament is quite thin and can basically be viewed as the anterior extension of the capsule

of the synovial portion of the joint. The ilio-lumbar ligaments from the transverse processes of L4 and L5 not only attach to the iliac crest, but also have extensions that blend caudally with the anterior SI ligaments. The posterior SI ligaments are extensive and multilayered. The deepest component is extremely short and horizontally oriented. As the layers become more superficial, they result in the vertical portion of the posterior SI ligament, which blends into the sacrotuberous ligament ultimately becoming continuous with the hamstring fascia of the posterior thigh. The SIJ and its ligamentous components are extensively innervated from the lower lumbar and upper sacral roots.

There are no muscle prime movers for motion of the SIJ. The bony pelvic ring responds to mass action of muscles from the trunk above and the lower extremities below. The piriformis muscle is as close to a prime mover as exists. It takes origin from the anterior surface of S2, 3, and 4, and traverses the sciatic notch to insert into the greater trochanter of the femur. Its primary action is external rotation and abduction of the femur. There is some question of the possibility of the muscle functioning as an internal rotator if the hip joint is flexed beyond 90°. The piriformis is a muscle that becomes easily facilitated, resulting in shortness and tightness. Asymmetric length and tone of the piriformis is a frequent clinical finding in the presence of SI dysfunction.

The abdominal musculature attaches to the iliac crest and inguinal ligament, with the rectus abdominis muscle attaching directly to the pubis. The adductor group of the medial thigh attaches to the inferior ramus of the pubis. Muscle imbalance between the abdominals above, particularly the rectus abdominis, and the adductors below appears to contribute to the persistence of dysfunction at the symphysis pubis.

The psoas major muscle links the thoracolumbar junction and lumbar vertebra with the hip joint while passing over the anterior aspect of the SIJ. The quadratus lumborum links the twelfth rib with the lumbar vertebra and the iliac crest. These two trunk muscles can be viewed as lower extremity muscles in that they influence function of the innominate bones as well as the femur through the hip joint. Imbalance of right

and left can significantly influence the participation of the innominate bone in the walking cycle.

Lower extremity muscles that influence pelvic function in addition to the adductors are the gluteals, hamstrings, and quadriceps groups. The rectus femoris muscle of the anterior thigh is a two-joint muscle, attaching proximally to the anterior inferior iliac spine of the innominate and distally to the tibia; when dysfunctional, this muscle becomes facilitated, short, and tight. The other three components of the quadriceps group are one-joint muscles, which, when dysfunctional, become inhibited. Shortness and tightness of the rectus femoris is frequently associated with tightness of the psoas muscle and can restrict the anterior capsule of the hip joint. The gluteus minimus and medius are hip abductors and weak internal rotators. The gluteus maximus is primarily a hip extensor. The glutei when dysfunctional become inhibited and result in weakness. A major problem in the gait results from tightness of the psoas and rectus femoris anteriorly and weakness of the glutei posteriorly. The hamstring group links the ischial tuberosity of the innominate with the lower extremity. The biceps femoris attaches distally to the head of the fibula and responds to altered functional capacity of the lower portion of the lower extremity, particularly ankle mechanics. The proximal tibiofibular articulation becomes dysfunctional in the presence of biomechanical fault of the foot and ankle. Good foot, ankle, and knee mechanics are all essential components of normal gait. It can be seen that there is an extensive and continuous linkage of myofascial elements from the foot through the thoracolumbar junction that can influence SI motion, both normal and dysfunctional.

Other muscles that relate to the osseous pelvis are those in the pelvic and urogenital diaphragms. While they appear to have little function in the mechanics of pelvic girdle mobility, they respond to alteration in pelvic girdle function with imbalance and contribute to symptoms relative to the lower urinary, genital, and rectal viscera. Urgency, frequency, dysuria, and dyspareunia are frequently associated with dysfunction at the symphysis pubis.

BIOMECHANICS

The motions within the pelvic girdle can be viewed from the perspective of the symphysis pubis, one innominate in relation to one side of the sacrum, and the sacrum between the two innominates. Each motion contributes a small component to overall pelvic mobility during gait.

Movement at the symphysis pubis consists of two components. There is a superior-to-inferior translatory movement that occurs during one-legged standing (Chamberlain 1930). Normally, the right and left pubic bone is found in the same relationship to the horizontal plane. On prolonged one-legged standing, the ipsilateral pube moves cephalward. This should return to normal on standing on the opposite leg or on prolonged two-legged standing. Habitual one-legged standing results in muscle imbalance between the abdominals above and the adductors below, restricting the pubic bone in aberrant relationship with its fellow. This dysfunctional relationship interferes with the other major motion available at the symphysis pubis.

The symphysis serves as the axis of rotation for the alternating anterior and posterior rotation of the right and left innominate bones (Pitkin & Pheasant 1936). These authors used an inclinometer method for evaluating motion within the pelvis and described the alternating anterior and posterior rotation of the innominates. They felt that the sacrum responded with bilateral bending and rotation as coupled movements in response to ilial movement. The introduction of Kirschner wires into both innominates was used to assess the relative mobility of one innominate to the other (Colachis et al 1963). Nine test positions were used, and the relative movement was measured. These authors concluded that there were angular and parallel movements in addition to rotation, and that mobility was not about a fixed mechanical axis. The greatest movement demonstrated was in forward bending while standing. Studies of fresh cadavers monitoring load displacement behavior showed differences in the axis of rotation from one specimen to another (Miller et al 1987). Torsion was the cause of the greatest number of single joints to fail. There was a difference when one or both ilia were fixed:

when both ilia were fixed motion was small; with only one ilium fixed, mobility was greater and appeared to simulate behavior during a one-legged stance in vivo. The methodology did not allow for measurement of all coupled movements.

Lavignolle et al (1983) used radiographic photogrammetric methodology in cadavers and in vivo, measuring the right and left innominate bones in relation to the sacrum and to each other. The sacrum was fixed to reduce the influence of mobility at the lumbar spine and lumbosacral junction. The exact axes of rotation varied between subjects but were found to be in a relatively constant area and basically in the oblique direction. These authors refuted older studies that described motion in an antero-posterior axis. The amplitude of movement varied by subject but rotation averaged 10–12°, with translation of up to 6 mm in young adults.

One of the earliest studies assessing sacral motion in relation to the innominate was performed by Strachan et al (1938), who studied sacral movement induced by movement through the lumbar spine with one innominate being fixed. They demonstrated coupled side-bending and rotation to opposite sides in most specimens. The coupling seemed to vary depending upon how the motion was introduced through the lumbar spine and may have been biased by the unilateral preparation. Subsequent studies have usually identified that coupling of side-bending and rotation is to opposite sides. A report by Stevens (1992) eloquently described side-bending and axial rotation of the sacrum. Utilizing a goniometric measurement technique in both the standing and seated positions, he demonstrated coupled behavior of side-bending and rotation to opposite sides in neutral and extended posture. In the forward-bent posture, sacral side-bending and rotation occurred in the same direction. He further demonstrated coupled side-bending and rotation to the opposite side in the upper lumbar segments, and side-bending and rotation to the same side at the lumbosacral junction. Asymmetric movement was identified in symptomatic patients. The restriction was reversible by manual treatment, resulting in restored normal range of motion.

The contour of the SIJ with ridges and depressions has high friction coefficients and influences the amount of mobility available (Vleeming et al 1990b). Dorman (1994) postulated that, during gait, the SIJ has a clutch function, with bracing on the stance side resulting in close-packing of the joint and allowing loose-packing of the contralateral SIJ for mobility through the swing phase. The SI ligaments were viewed as essential components in this process, and compromise of the ligamentous structures might lead to symptoms, including pain and occasional falls. Vleeming et al (1995) described both form and force closure of the SI mechanism, providing a self-locking mechanism for stability and mobility. Form closure depends on the shape of the SIJs, their contours, and the associated friction. Ligamentous tension and muscle behavior are essential for stability of the SI mechanism. These authors link the behavior of myofascial elements of the trunk with those of the lower extremity as part of normal SI integrated function. Gracovetsky (1995) links motion of the pelvis and spine during gait with functions of lower extremity and trunk muscles in transferring energy to activate the 'spinal engine'.

These studies, and many others, have demonstrated the difficulty of identifying all the motions available within the pelvic girdle complex. Suffice it to say, one can conclude that there is normal anterior and posterior rotation of the two innominates associated with an axis through the symphysis pubis. In addition to this motion of one innominate with the contralateral one, there is also a repeating anterior and posterior rotational movement available of one innominate on one side of the sacrum. This has some axis posterior in the pelvis. The sacrum has a primary motion of nutation and counternutation, with some accompanying translation around a variable transverse axis. Since asymmetry between the right and left SIJs is the rule rather than the exception, asymmetry of this nutation and counternutation movement can be expected. The sacrum also has the capacity of side-bending and rotating between the two innominates. This coupled motion appears to be primarily to opposite sides. The coupling of lumbar side-bending and rotation with sacral side-bending and rotation

is less clear. This is the result of the lumbar spine having the capability of side-bending and rotation to opposite sides in the upper levels, and side-bending and rotation to the same side at L5. All of these motions, resulting from multiple muscle activities, are essential for symmetrical gait.

GAIT

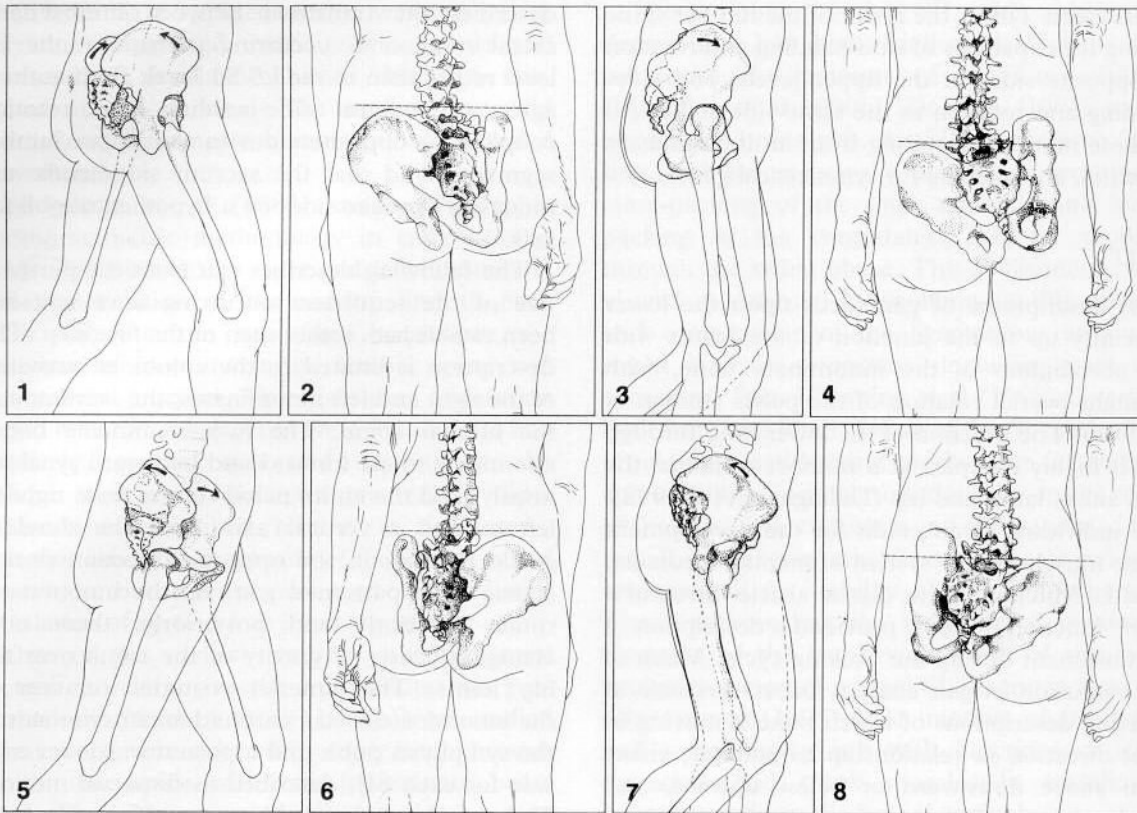
Most descriptions of gait focus upon the lower extremity up to the junction of the femur with the acetabulum of the innominate bone, with resultant overall rotation of the pelvis (Inman et al 1981). The function of the lower limb through gait is highly complex at a number of joints: the foot, ankle, knee, and hip (Dillingham et al 1992). The individual given credit for the development of the muscle energy system of manual medicine, Fred L. Mitchell, in his classic article 'Structural pelvic function' (1965), provided a description of SI movement during the walking cycle. Much of the confusion in gait analysis occurs because of differing descriptions of which bone is moving in what direction in relationship to another, either from above downward or below upward, and whether it is the first step or one that is continuous in the cycle. It has been shown that the whole pelvis will rotate in three-dimensional space with one leg at heel strike and the other at toe-off (Schmidt et al 1995). Schmidt et al's study concluded that there was substantial angular movement at the SIJs but it did not describe the function of the sacrum during the change from right to left straddled positions.

Lee (1989) eloquently describes the kinetics and kinematics of the sacrum, lumbar spine, innominates, and hip joints. Her description of the gait is congruent with Mitchell's, with the exception of the related side-bending and rotational behavior of the lumbar spine on the sacrum. Mitchell described the lumbar spine as having coupled side-bending and rotation to opposite sides as far down as the lumbosacral junction. He viewed that the sacrum would always rotate and side-bend to the opposite side of the lumbar spine. Lee's description is slightly different. She describes the L5 segment as side-bending and rotating to the same side, in agreement with research available since the time of Mitchell. She

describes the transition between lumbar and sacral rotation as occurring perhaps at the L4 level rather than at the L5/S1 level. Both authors agree on neutral side-bending and rotation coupling to opposite sides in the upper lumbar segments, and that the sacrum side-bends and rotates to opposite sides on a hypothetical oblique axis.

The following describes gait from the perspective of the sequences occurring once gait has been established, rather than of the first step. The description is limited to the combined activities of the right and left innominates, the sacrum, and the lumbar spine. The two innominate bones alternately rotate forward and backward synchronously, and the entire pelvis rotates from right to left around a vertical axis, with the shoulder girdle rotating in the opposite direction during classic cross-patterned gait. As the innominates rotate anteriorly and posteriorly, there is a changing center of gravity of the trunk over the hip joints. This anterior-posterior rotation of the innominates occurs around an anterior axis at the symphysis pubis and a posterior axis on each side for each SIJ, described as iliosacral motion. The sacrum appears to move alternately in a 'wobbling' fashion, with side-bending and rotation coupled to opposite sides and following the induced pelvic rotation. The lumbar spine will side-bend and rotate to opposite sides in an alternating fashion.

At the time of right heel strike and left toe-off, the right innominate is rotated posteriorly and the left innominate anteriorly to the maximum (Fig. 19.1). The sacrum is level and the lumbar spine straight, and both face toward the left due to maximal pelvic rotation to the left (Fig. 19.2). During the right stance phase, the right innominate is rotating anteriorly and the left posteriorly (Fig. 19.3). At right midstance, there is maximal loading of the right hip and SIJ, and the sacrum between the innominates is rotating to the right, side-bending left, and moving into (anterior) nutational movement at the left sacral base. The lumbar spine is side-bent right and rotated left (Fig. 19.4). At left heel strike, the left innominate starts its anterior rotation, and as the right leg enters the swing phase, it begins to rotate posteriorly (Fig. 19.5). At this point, the sacrum has



Figs 19.1–19.8 Combined activities of right and left innominates, sacrum, and spine during walking.

Figs 19.1 and 19.2 At right heel strike. (**Fig. 19.1**) Right innominate has rotated in a posterior and left innominate in an anterior direction. (**Fig. 19.2**) Anterior surface of sacrum is rotated to left and superior surface is level, while spine is straight but rotated to the left. **Figs 19.3 and 19.4** At right midstance. (**Fig. 19.3**) Right leg is straight and innominate is rotating anteriorly. (**Fig. 19.4**) Sacrum has rotated right and side-bent left, while lumbar spine has side-bent right and rotated left. **Figs 19.5 and 19.6** At left heel strike. (**Fig. 19.5**) Left innominate begins rotation anteriorly; after toe-off, right innominate begins rotation posteriorly. (**Fig. 19.6**) Sacrum is level but with anterior surface rotated to right. Spine, although straight, is also rotated to the right, as is lower trunk. **Figs 19.7 and 19.8** At left leg stance. (**Fig. 19.7**) Left innominate is high and left leg straight. (**Fig. 19.8**) Sacrum has rotated to left and side-bent right, while lumbar spine has side-bent left and rotated right. (Reproduced with permission from Greenman 1990.)

returned to being level between the two innominates, the lumbar spine is straight, and the pelvis is rotated to the right (**Fig. 19.6**). During the stance phase on the left, the right innominate continues its posterior rotation during the swing phase and the sacrum now rotates to the left, side-bends right, and (anteriorly) nutates at the right sacral base (left-on-left sacral torsion). The lumbar spine is side-bent to the left and rotated right (**Fig. 19.8**). From there the cycle is repeated. With each succeeding step, each innominate alternately rotates anterior and posteriorly, the sacrum moves from right-on-right to left-on-left anterior torsion, and the lumbar spine side-bends

left and rotates right, and then side-bends right and rotates left. Regardless of the coupling at L5, it is clear that the upper lumbar segments and sacrum behave as described.

It is readily apparent that normal gait requires maximum symmetric movement of all of the lumbar vertebra, the two SIJs, and the symphysis pubis. This complex total body movement also requires maximal functional length and strength of the paired muscle groups of the lower extremity and trunk. Instability of the SIJs can have major consequences on gait. Strain of the joint can affect the osteoarticular ligamentous system (form closure), particularly with traumatic laxity of the

strong posterior SI ligaments and of the myofascial system (force closure), with loss of muscle balance and control of the trunk and lower extremities (Lee 1995). Prolotherapy to strengthen the ligamentous structures of the SI region has been shown to improve the energy efficiency of a patient during walking (Dorman et al 1995). Manipulation of the lower back and pelvic region has been found to improve the symmetry of gait post treatment (Robinson et al 1987).

CONCLUSIONS

1. This discussion has been based upon current research knowledge available. Much more research needs to be done, particularly motion analysis of these complex motions in vivo.

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A non-invasive method has yet to be developed and implemented.

2. It is apparent that normal gait is important for all patients, particularly those with lower back and lower extremity pain syndromes. The skilled clinician should assess the total musculoskeletal system for integrated function during gait.

3. The treating practitioner, whether employing surgical or non-operative care interventions, should have as a therapeutic outcome the maximal gait symmetry allowed by the anatomy.

4. The patient needs to be aware of his or her responsibility in exercising with appropriate stretching, strengthening, and motor control activities, to maintain a symmetric gait as so many of the activities of daily living revolve around it.

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