# Function of the Lumbosacroiliac Complex as a Self-Compensating Force Couple with a Variable, Force-Dependent Transverse Axis: A Theoretical Analysis

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*The dense ligamentous structures surrounding the sacroiliac joints preclude free movement in the joints, yet some movement persists into old age. The nature of movement and function of the sacroiliac joints is obscure. I hypothesize that these joints function as part of the lumbosacroiliac complex, end act as self-compensating force-couples to balance forces of gravity, weight-loading, Inertia, rotation, acceleration and deceleration. These forces are accommodated in variations in tensile ligamentous stress that is translated into compressive forces in the sacroiliac joints, which increases friction and stability, and allows increased weight-loading without shearing. This also allows storage of energy in the form of in- creased tensile ligamentous stress without injury to the joint. The joints appear to have both a transverse and an oblique axis, the location of which is dependent upon the moment of the applied forces, which may vary and change the location and direction of the axis. Dysfunction may occur with an anterior displacement of the line of gravity if anterior pelvic support fails to maintain self-bracing and friction. The resulting lesion may mimic disc dysfunction or give the impression of a multifactorial etiology and prevents normal function of the force couple.*

The purpose of this article is to suggest that the lumbosacroiliac complex functions as a self-compensating force couple that accommodates, mitigates, balances, stores and. redirects various forces affecting tile pelvis and its principal ligaments. This mechanical couple may have a force-dependent, variable trans verse axis. Certain basic mechanical engineering principles will be defined and their possible relationship to the function of this complex will be described. Both normal and probable pathological forces will be discussed and related to clinical findings.

In mechanics, a couple is described as two equal and parallel forces acting in opposite directions and resulting in a pure moment (Fig. 1).

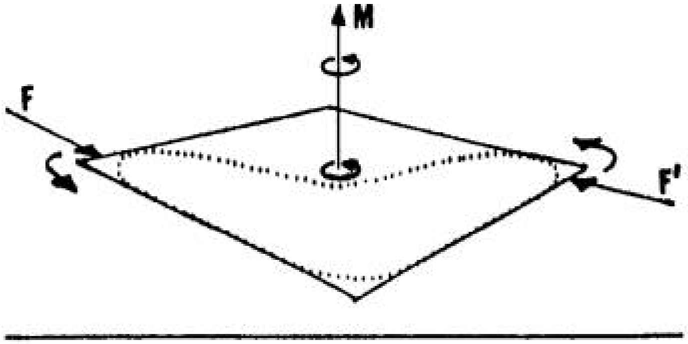

Fig. 1. Two equal and parallel forces (F and F') acting on a structure tend to cause rotation about an axis (M).

A moment is a vector quantity and is defined as the tendency to cause rotation about an axis. A vector quantity is any quantity that can be entirely defined by its magnitude and direction. The most common vector quantities in mechanics are linear velocity, linear acceleration, angular acceleration, linear momentum, angular momentum, the rate of change of momentum, force and moment of force. The moment of force about an axis in the product of the force and the perpendicular distance between the line of the force and the axis (Fig. 2).

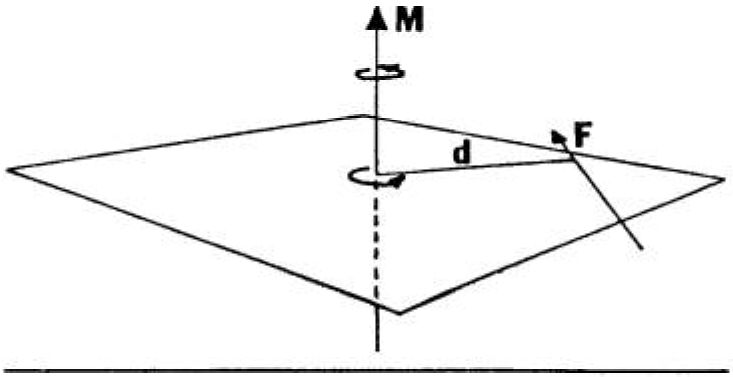

Fig. 2. The moment of force (M) is the product of the distance (d) and the force (F).

This can be expressed as M = Fd. Any combination of forces that has a resultant force of zero and which causes a moment about some point can be replaced by a couple. The size of the moment depends on the location of the point about which the moment is taken, whereas a couple will have the same magnitude regardless of the reference point.

Another mechanical principle that may affect this complex is damping.

Damping is a restraint or arrest of vibration or oscillation attributed to frictional resistance that occurs between two solid contacting surfaces.

### Ligamentous Influence

The sacroiliac joint has a tendency to rotate that is markedly restricted by its shape and by a system of dense ligaments. A basic understanding of the interaction and function of these ligaments under various conditions is essential to the analysis of pelvic mechanics and pathomechanics. When moving from a supine to an erect posture the sacrum rides more deeply between the innominate bones as the superincumbent weight is loaded onto it and transferred to the ilia principally through the posterior interosseous ligaments. These ligaments function under a tensile loading and the sacroiliac joints are essentially non-weight bearing. These joints become profoundly unstable with the removal of the posterior interosseous ligaments [1].

In the normal standing posture the posterior interosseous ligaments can sustain a wide range of loading without pelvic or sacral deformation even after the elimination of the sacrotuberous and sacrospinous ligaments [1].

Vertebral loading on the sacral promontory causes the sacrum to incline ventrally (nutation) increasing tensile stress on the posterior interosseous ligaments. This causes a tendency for the caudal end of the sac- rum to move posteriorly causing a counter-balancing tensile stress on the sacrotuberous and sacrospinous ligaments, creating a force couple and a tendency to rotate around a transverse axis perpendicular to the force couple (Fig. 3).

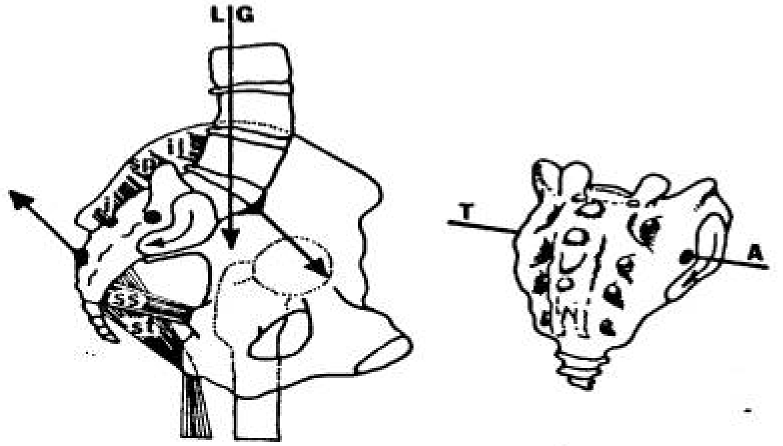

Fig. 3. Ligamentous tensile stress at the sacroiliac joint on a stabilized pelvis, independent of the ground reaction force vector through the acetabular axis. As the superincumbent weight through the line of gravity (LG) places a gravitational tensile stress on the posterior interosseous ligament (i-il) that results in a counter-gravitational tensile stress on the sacrotuberous (st) and sacrospinous (ss) ligaments causing a force-dependent transverse axis perpendicular to these opposing tensile forces.

If these forces are balanced bi laterally on the sacrum then a transverse axis is established through the sacrum, but not necessarily through the joints. This transverse axis would be force dependent, but may not be anatomically dependent. The existence of a force-dependent transverse axis of rotation could explain the difficulty in locating a precise anatomically dependent transverse axis, especially considering the diverse anatomical manifestations of the sacroiliac joints.

The movement with loading (nutation) and unloading (contranutation) of the sacroiliac joints is influenced by the ground reaction force vector which may cause the innominates to rotate anteriorly or posteriorly around an acetabular axis (if the subject is standing) or over the ischial tuberosities (if the subject is seated) depending upon the location of the line of gravity. Thus, depending on the forces involved and with different postures and movement in the same individual, this force dependent transverse axis may vary in its location.

Increased loading of the ventrally inclined sacrum increases tension in the posterior interosseous ligaments and the sacrotuberous and sacrospinous ligaments.

The balance of forces through the sacroiliac joint is further assisted by the biceps femoris acting through the sacrotuberous ligament and (among others) the piriformis and the lower fibers of the gluteus maximus acting to prevent further posterior movement of the sacrum. To further insure stability of the sacroiliac joint, the angular orientation of the ligamentous fibers cause a movement of the ilia toward the sacrum on the axis created by the moment which draws the opposing surfaces of the sacroiliac joints tightly together (Fig. 4), increasing friction and protecting the joint from shearing with increased weight- loading.

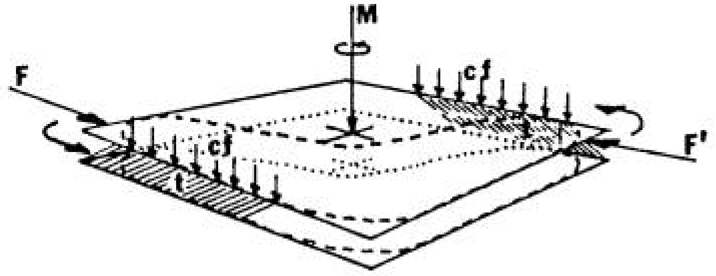

Fig. 4. A diagramatic representation. As the forces F and F' tend to rotate the superior structure around a force-dependent axis (M), the rotational force creates a tensile stress on the tethering ligamentous attachment to the lower structure (t) and results in a compressive force (cf) between them. If the angle of the force at F or F' is changed then the location of the axis will be changed. If these forces are reversed then compression is decreased. Without the application of these forces (F and F') there can be no transverse axis of rotation.

The sacrum then rides more deeply between the ilia and the posterior superior lilac spines approximate. Posterior rotation of the innominate bones around a transverse axis through the acetabula would further tense these ligaments and increase friction and load transmitting capabilities, but would not be expected to cause the innominates to move further posteriorly on the sacrum. This was described by Grant [2] as an automatic locking mechanism and by Vleeming and his associates [3] as a self-bracing mechanism. As this mechanism appears to be very strong and effectively limits further motion posteriorly of the innominates on the sacrum, we can probably conclude that the sacroiliac joint is not susceptible to injury through minor trauma with posterior rotation of the innominates on the sacrum.

I hypothesize that with increasing ventral inclination of the sacrum (nutation) the various ligaments are tensed sequentially beginning cephalad with the shortly posterior sacroiliac ligament (the interosseous ligaments are already weight-loaded), the inferior band of the iliolumbar ligament and followed by the superior band of the iliolumbar ligament. Caudally, the posterior movement of the sacrum is probably first resisted by tensing of the sacrospinous ligament followed by tensing of the sacrotuberous ligament. This will probably first increase tightness and friction in the sacroiliac joint at the S-1 level, then at the S-2 level and finally at the S-3 level. The lowest level is probably subject to the least friction. Friction may also be higher at the margin of the sacroiliac joint nearest the transverse axis.

Dorsal inclination of the sacrum (contra-nutation) with extension of the spine is blocked anatomically by the broad sacral surface of the S-1 segment of the ventral horn moving posteriorly against the ilial surface which changes angulation at the S-3 segment of the dorsal horn and blocks the distal sacrum as it moves ventrally. We can also expect decreased tension on the sacrotuberous, sacrospinous, short posterior and iliolumbar ligaments, and a decrease of friction and self-bracing with a slight opening of the joints centrally. This movement would appear to be accompanied by and increased with an anterior rotation of the innominate bones on the sacrum, however, in the standing position, Russek[4] demonstrated that extension of the spine caused the line of gravity to shift posteriorly to the ground reaction force vector through the acetabula so as to cause the innominate bones to rotate downward posteriorly and upward anteriorly around the acetabular axis, decreasing the lumbosacral angle. Thus, the posterior innominate rotation that occurs as a result of extension appears to tense the sacrotuberous ligaments and increase friction and self- bracing, limiting sacral inclination dorsally and results in flexion of the lower lumbar segments (Fig. 5).

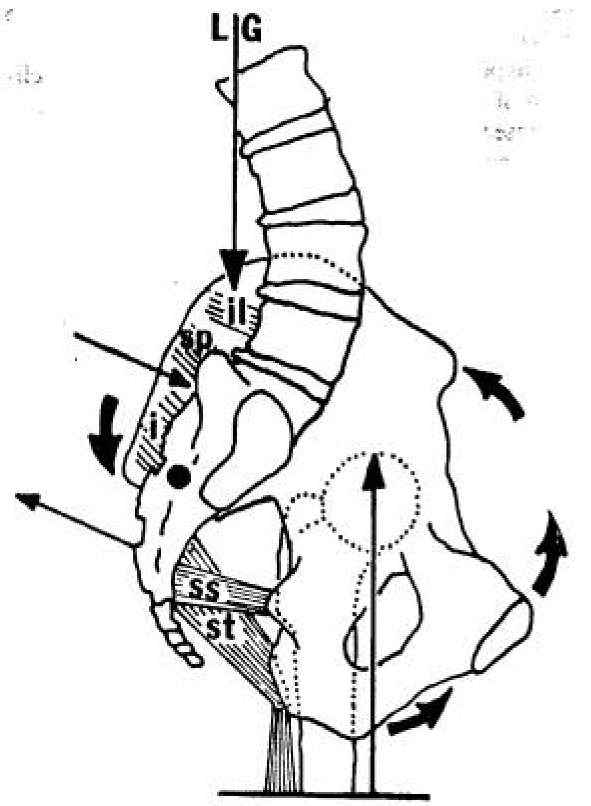

**Fig. 5.** When the superincumbent weight moves posteriorly with extension, the line of gravity (LG) moves posteriorly causing a posterior rotation of the innominate bones on an acetabular axis at the ground reaction force vector, creating an increased tensile stress on the sacrotuberous (st) and sacrospinous (ss) ligaments with an increase in self-bracing. As the sacrum moves dorsally with (but not on) the innominate bones, the angle of applied tensile forces is changed, altering the location of the transverse axis of rotation near the sacroiliac joint.

During ambulation the sacroiliac joint on the side of initial impact self-braces while the contralateral joint is released from self-bracing in an action that releases energy stored in tensed ligaments and fascia, facilitating the forward movement of the trailing leg and decreasing the energy demands of ambulation [5]. Deceleration of the pelvis with impact loading results in a deceleration of the upper trunk with a straightening and recovery of the spinal curves [6]. This rhythmic sacrocranial vertebral oscillation occurs with the in- nominate on the side of initial impact in slight posterior rotation and self-braced, and the other is slight anterior rotation not self-braced at which time the sacrum appears to move on the innominates on an oblique axis [5]. I speculate that the counter-rotation of the trunk opens the S-1 segment posteriorly on the self- braced side creating an oblique axis with the S-3 segment of the sacroiliac joint on the contralateral side (Fig. 6) and that this oscillation is damped by high coefficient of friction of these joints.

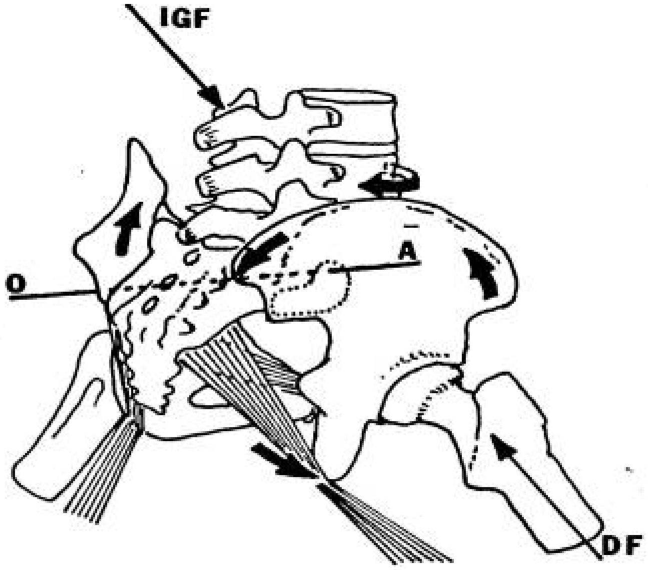

Fig. 6. On the side of initial impact, the deceleration force (DF) increases self-bracing to accommodate the transfer of the superincumbent weight, which is increased by the inertial-gravitational force (IGF). Counter-rotation diminishes the intensity of the weight-transfer force. During counter-rotation the spine undergoes a rhythmic segmental deceleration and recovery in the sagittal plane with each step and the sacrum oscillates on a force-dependent oblique axis (OA).

## Pathomechanics

Low back pain most commonly occurs during a transition from an erect posture to a trunk forward posture (or reverse), while lifting, bending or lowering. As the superincumbent weight moves anteriorly, the line of gravity moves anteriorly to the acetabula creating a force in anterior rotation of the innominate bones around the acetabula, which has a tendency to loosen the sacrotuberous and sacrospinous ligaments, decreasing self-bracing and friction. As this occurs a number of muscles function to maintain the balance of forces on the lumbosacroiliac complex. The biceps femoris acts on the distal sacrum through its tendinous origin in the sacrotuberous ligament as does the gluteus maximus through its sacral origin. Probably the most critical support necessary to maintain self-bracing when leaning forward is a strong voluntary contraction by the abdominal muscles to lift the anterior pelvis (Fig. 7).

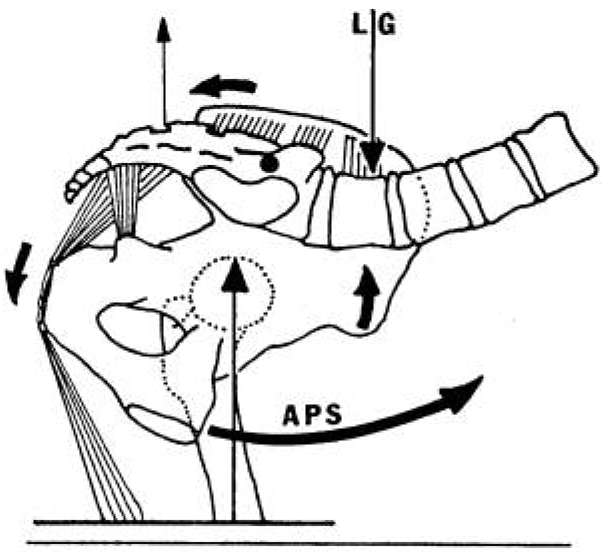

Fig. 7. In forward flexion of the trunk, the line of gravity (LG) is anterior to the acetabula and creates a tendency for the innominates to rotate anteriorly. This must be countered by strong anterior pelvic support (APS) to maintain self-bracing and balance forces through the lumbosacroiliac complex.

As the abdominal muscles are relaxed when standing [7] and do not automatically contract when leaning forward, they frequently fail to provide adequate" anterior pelvic support in the transition to and from the trunk-forward position. Failure to voluntarily contract a strong abdominal muscle group or inability to contract a weak muscle group predisposes the sacroiliac joints to injury from an anterior rotation of the innominates, even through minor trauma. This may occur when leaning forward if the innominate bones lack support and rotate downward anteriorly and up ward posteriorly around an acetabular axis immediately prior to the trunk moving forward, or, when lifting if the trunk extends on the anteriorly rotated innominate bones. Anterior rotation dysfunction may also occur during coughing or straining if the increased antra-abdominal pressure spreads the innominate bones and anteriorly rotates them on the sacrum.

As the posterior interosseous ligaments and iliolumbar ligaments are pre-stressed with the superincumbent weight in the trunk forward position, there is a continuing tendency for the distal aspect of the sacrum to swing posteriorly on the transverse axis of the sacroiliac joint until it reaches its limit of motion. However, when the innominate bones begin to rotate downward anteriorly and upward posteriorly they move on an acetabular axis and approximate the insertions of the sacrotuberous and sacrospinous ligaments and decrease self-bracing. The resultant decrease in friction allows the innominate bone(s) to rotate cephalad and laterally on the wider S-3 segment of the dorsal horn of the sacral surface of the sacroiliac joint and anteriorly, downward and laterally on the wider S-1 segment of the ventral horn of the sacral surface of the sacroiliac joint with fixation probably occurring near or at the S-3 segment (Fig. 8).

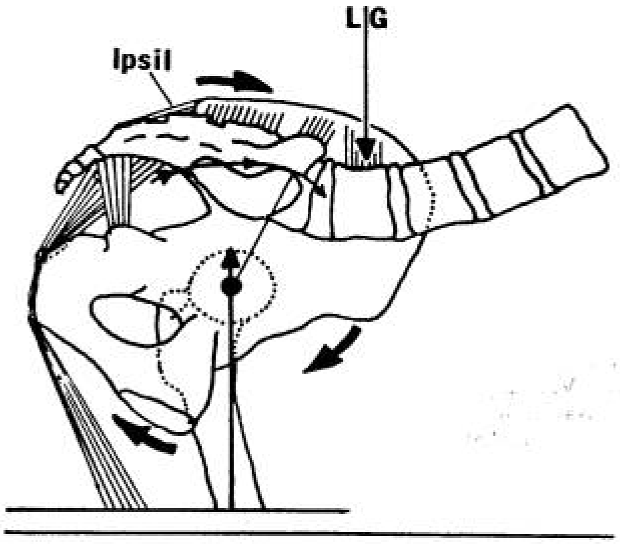

Fig. 8. Lack of anterior pelvic support allows the innominates to rotate anteriorly on an acetabular axis loosening the sacrotuberous and sacrospinous ligaments and decreasing self-bracing and friction. The innominate(s) shears cephalad and laterally on the sacrum at the posterior inferior iliac spine and downward anteriorly at the S-1 Segment. The rapid release of balanced force in this comples may cause a sudden stress on the paravertebral extensors, the hamstrings, piriformis and other related structures. The superficial long posterior sacroiliac ligaments (Ipsil) are particularly vulnerable.

The posterior cephalic shearing of the innominate bones could stretch or tear the joint capsule of the S-3 segment of the dorsal horn at the posterior inferior' iliac spine, deep to the conjoint origin of the gluteus maximus muscle. If extensive, the fibers of the gluteus maximus may be separated on a line from the conjoint origin to the greater trochanter with a concurrent release of bradykinins and prostaglandins resulting in pain and local edema. I have found that point tenderness is common at the posterior inferior iliac spine, but not obvious as it is frequently obscured by local edema, which must be removed with deep massage prior to being able to identify it with palpation.

A measurable movement of the posterior superior iliac spines occurs cephalad and laterally on the sacrum [8] stretching the superficial long posterior sacroiliac ligaments [9] and causing pain along the lateral border of the sacrum. As these ligaments function to limit motion of the innominate bones cephalad and laterally on the sacrum, any laxity or tearing of them may result in some instability of the joints.

As the posterior crests of the ilia rotate anteriorly the tension on the iliolumbar ligaments may be decreased, decreasing lumbosacral stability, further increasing the anterior inclination of the sacral plateau and resulting in increased shear forces on the discs, increased stress on a spondylolisthesis, or causing an unstable lumbosacral segment. Damping of local oscillation or vibration could be impaired thus allowing vibrational tissue creep to increase instability and shear. As the innominate bone(s) moves anteriorly, down ward and laterally on the S-I segment of the ventral horn, the joint space is opened centrally, the relatively thin anterior joint capsule is stretched and may be ruptured, and the fibers of the iliacus muscle may be separated at its conjoint origin with the sacrum. Synovial fluid may leak from the joint and irritate the lumbosacral plexus and other sensitive structures in this area.

With anterior innominate rotation, the posterior il- Sac spines rise relative to the acetabular axis as do the sacroiliac joints, causing the lilac crest to appear higher when standing or the legs to appear longer when supine. Various apparent alterations in leg length may occur(s) as well as an anterior and lateral inclination of the sacral plateau, which may result in a lateral inclination of the spine, a lumbar scoliosis, a 'wind- swept' back, an increase in shear forces on the lower discs, and changes in normal gait.

Caudally, as the ischial tuberosities approximate the coccyx, decreasing tension on the sacrotuberous ligaments, tension is also probably decreased in the muscles of the pelvic diaphragm. This may decrease sphincter control. Ligaments, muscles and fascia al lowed to remain in a shortened position may undergo functional shortening that could preclude restoration of the normal function of the lumbosacroiliac complex.

Pain may be referred into the groin and testicles and cause a pseudo-epididymitis. Pain and some displacement may occur at the pubic symphysis [10]. The patient may have an associated tendonitis in the tendon of the biceps femoris, posterior to the ischial tuberosity, and the ligaments of the head of the fibula may be strained from abnormal biceps femoris stress. This stress may continue distally and cause pain in the peroneus longus. Pain in the abdomen at Baer's sacroiliac point is not uncommon and may be misdiagnosed as appendicitis or ovarian pain.

### Treatment by Restoration of Self-Bracing

It is my observation that a simple shifting of the innominate bone(s) on the sacrum away from a position of self-bracing can adversely affect a wide variety of tissue and structure and give the impression of a multifactorial etiology or mimic disc disease. Some researchers it [11, 12] have developed very sophisticated methods to identify a wide variety of dysfunctions of the sacroiliac joints, but I have found that no matter what the apparent type of sacroiliac joint dysfunction seems to be present, essentially all (except perhaps those caused by major trauma) can be corrected simply by gently mobilizing the innominate bones down ward posteriorly and upward anteriorly on the sacrum to restore the joint to a position of self-bracing. This restores normal tension on the sacrotuberous and sacrospinous ligaments, and in the muscles of the pelvic diaphragm while relieving tension on the long and short posterior sacroiliac ligaments and on the anterior joint capsule. The posterior superior iliac spines will move caudad and medially on the sacrum and the legs will appear to become shorter when observing the relative leg length at the malleoli before and after mobilization, it does not matter much if the leg on the more painful side is longer or shorter than the other or if both legs appear to be of equal length, they will al ways appear to become shorter when self-bracing is properly restored [5].

I have found a very simple, but extremely effective active exercise that will relieve pain and restore self-bracing in over 90% of all cases of low back pain (Fig. 9).

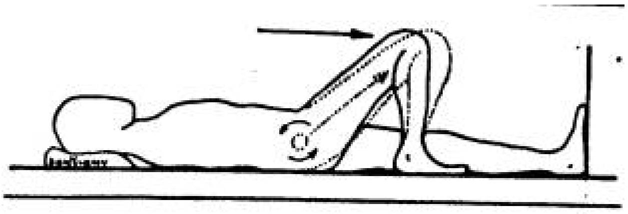

Fig. 9. Active extension of the hip so as to project the knee distally and ROCK the pelvis posteriorly is effective in restoring self-bracing. Alternate this exercise with each leg several times and repeat as necessary throughout the day.

With the patient supine and one hip and knee is flexed so the heel is as close as comfortably possible to the hip, then actively extend the hip, projecting the knee distally. This tilts the pelvis cephalad anteriorly and puts a little traction on the innominate bone and pulling it caudad posteriorly. Hold this position four or five seconds and then relax and repeat with the same leg three times. Now repeat this exercise with the other leg three times. Alternate this exercise with each leg at least three times. The joints are so strong and tight that they must be rather shuffled into position little by little with alternating pressures.

The onset or recurrence of dysfunction is effectively prevented by maintaining effective support of the anterior pelvis with an active contraction of the abdominal musculature, especially when leaning forward. If the joint(s) is unstable, a trochanteric bell or lumbosacral support worn low over the pelvis will limit movement of the innominate bones and help to maintain self-bracing, however the belt should be applied when the patient is supine and after self-bracing is restored.

Proliferant injections into the superficial long posterior sacroiliac ligament may be helpful in stabilizing the pathologically unstable joint. If bony fusion of the joint is considered, it should probably be done with the joint in the self-bracing position.

## Conclusions

The lumbosacroiliac complex appears to function as a self-compensating force couple that generates a variable, force-dependent transverse axis, usually through the posterior aspect of the sacroiliac joint. Self-bracing is a necessary function of the sacroiliac joint contributing to the force couple and explains why a limited range of motion for the joint is necessary for normal function. The high friction, that occurs with self-bracing probably allows greater ligamentous tension for the storage and release of energy and prevents disruption of the joints. In the absence of adequate anterior pelvic support in the trunk forward position, anterior rotation dysfunction of the innominates on the sacrum may be a protective shear relief mechanism. Without the pain caused by the protective shear relief, or if the sacroiliac joint were immobile, a sudden anterior rotation of the innominates around the acetabula could result in an over-contraction of the paravertebral extensors and rapid and acute extension of the lumbar spine, sharply narrowing the intervertebral foramina .

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