# Malalignment Syndrome in Runners 

Wolf Schamberger, MD, FRCPC, Dip Sports Med, Dip Electrodiagnosis*

## KEYWORDS

- Pelvic malalignment • Malalignment syndrome • Back • Groin and limb pain
- Asymmetrical forces - Problems in runners - Manual therapy


## KEY POINTS

- Understanding malalignment is essential for those caring for runners; approximately $80 \%$ have pelvic malalignment, which can mimic, hide, overlap with, trigger or aggravate other medical conditions.
- Malalignment syndrome includes the biomechanical changes, abnormal stresses, and resulting signs/symptoms seen with an upslip and rotational malalignment.
- A standard back examination can be misleading because it fails to assess alignment and does not look at the sites typically affected by pelvic malalignment.
- Malalignment can be corrected by following a supervised course of treatment that combines realignment, core strengthening, reestablishing movement patterns, and the timely use of appropriate complementary techniques.
- Treatment includes instruction in self-assessment and self-treatment to allow the runner to achieve and maintain realignment on a day-to-day basis and increase the chances of a full recovery and achieving his or her full potential.


## INTRODUCTION

Running is an asymmetric sport in that it requires bearing weight alternately on the right and left lower extremities and absorbing the resulting unilateral forces as best as possible as these are transmitted upward through the knee, hip, pelvis, and lumbosacral region to the spine. ${ }^{1}$ Malalignment refers to a minimal displacement from the normal alignment of any of the bones that are part of this kinetic chain and that results in abnormal biomechanical stresses that can compromise the ability to deal with these forces. This discussion focuses on the 3 most common presentations of pelvic

[^0]malalignment. The term 'malalignment syndrome' refers to the biomechanical changes, signs and symptoms consistently seen in association with 2 of these presentations. Recognition of malalignment and the resulting detrimental effects should be part of the routine examination carried out by those caring for runners to avoid misdiagnosis, mistreatment, delayed recovery, and possibly failure of the runner to realize his or her full potential.

## THE PELVIC RING: NORMAL AND ABNORMAL MOBILITY AND FUNCTION

The sacroiliac ( SI ) joint is an intricate joint that depends on its configuration and its supporting ligaments (Figs. 1 and 2), individual muscles (Fig. 3), and a system of inner and outer core muscles and myofascial slings to:

1. Allow for the smooth transfer of weight upward or downward through the lumbo-pelvic-hip complex ${ }^{2}$ (Fig. 4);
2. Help ensure stability of the joint when this is functionally required; for example, on the weight-bearing side during walking and running ${ }^{3-7}$; and
3. Permit a minimal ( $2-4 \mathrm{~mm}$ at most) of SI joint motion: rotation around all 3 axes and movement (translation) along the corresponding planes (Fig. 5). ${ }^{8-10}$

This motion is essential for mobility and helps to absorb stress and store energy while decreasing the energy cost of running. During the gait cycle, for example, there is rotation of the pelvis as a whole, of the sacrum around one of the diagonal axes (Fig. 6), and of each innominate relative to the sacrum ${ }^{5,9}$ :
a. In the coronal (or frontal) plane: upward on the weight-bearing side (see Fig. 4B);
b. In the sagittal plane: rotation forward (or anterior) during stance-phase, backward (or posterior) on swing-through (see Fig. 6); and
c. In the horizontal (or transverse) plane: outward (or outflaring) during stance phase, inward (or inflaring) with swing-through (Fig. 7).

Excessive rotation of an innominate relative to the sacrum around any of the 3 main axes can result in the innominate on one or both sides literally getting "stuck" in the direction of 1 or more of these 3 planes (see Fig. 5). Susceptibility to this occurring is attributable in part to the intricate configuration of the Sl joint (Fig. 8):

1. It is L-shaped, with the 2 main arms of the sacral articular surface being oriented along different planes;
2. The upper and lower sacral surfaces are intimately molded to those on the innominate by way of:
a. The concavity of 1 surface being matched by a corresponding convexity of the opposing surface ${ }^{11,12}$;
b. The gradual development of a crescent-shaped ridge running the length of the iliac surface, with a matching depression on the sacral side ${ }^{13-15}$; and
c. Anterior widening of the sacrum, which restricts movement between the innominates by causing wedging in an anterior-to-posterior direction.

These features enhance the stability of the joint, especially on weight bearing, and also allow for some movement of 2 to 4 mm between the joint surfaces. Abnormal loading conditions that exceed this normal displacement in any direction can cause the adjoining SI joint surfaces to end up in an aberrant position so that the surfaces no longer match and stay compressed in some areas, separated in others, affecting normal movement (see Fig. 7iii; Figs. 9 and 10). ${ }^{16}$ If the surfaces do become fixed


Fig. 1. Pelvic girdle: articulations and ligaments. (A) Anterior view. (B) Superior view (note the anterior widening of the sacrum).


Fig. 2. (A) Posterior pelvic ligaments and muscles that act on the sacroiliac joint. (B) Gluteus maximus.
or locked in an abnormal position, major consequences include dysfunction of SI joint mobility, a disturbance of the lumbo-pelvic-hip complex and its ability to transfer weight and absorb shock, persistent malalignment of the pelvic ring and an alteration of gait. ${ }^{17-19}$ Such a shift can be caused by:

1. Minimal excessive movement in 1 direction; for example, an awkward lift, especially with addition of a torqueing component by reaching up/downward or sideways;
2. Trauma to the pelvis itself or transmitted upward through an extremity; for example, in a motor vehicle accident or by falling onto 1 buttock (Fig. 11); landing hard on a straight leg, as on jumping while running cross-country, or simply missing a step (Fig. 12); and
3. Increased tension or spasm in muscles that attach to the pelvic ring or laxity in those needed to stabilize the joints (see Figs. 3 and 39).

However, in the majority of those presenting with malalignment, there is no obvious cause. One of the theories seeking to explain this phenomenon suggests that the malalignment is the outcome of a persistent asymmetry of muscle tension throughout the body caused by asymmetrical signals being generated at the segmental level (spinal cord), brain stem or cortex. ${ }^{20-24}$
A description of the 3 most common presentations of pelvic malalignment follows, after an outline of some basic tests that are helpful in making the diagnosis.

## ASSESSING PELVIC MALALIGNMENT

The diagnosis can usually be made by:

1. Looking for the characteristic asymmetry of major landmarks specific to each of these presentations by comparing the position of one thumb to that on the other side, to detect any:


Fig. 3. Stabilization of the sacroiliac joint (SIJ) by wedging of the anteriorly widening sacrum. (A) Piriformis pulling the sacrum backward against the innominate. (B) Iliacus pulling the innominate forward against the sacrum. (C) Anterior innominate rotation through the action of iliacus, rectus femoris, tensor fascia lata (TFL). (D) Wedging effect: superior view of joints. ITB, iliotibial band.
a. Relative upward or downward displacement (Fig. 13):
i. Compare the thumbs placed against the iliac crest, inferior aspect of the anterior superior iliac spine (ASIS), superior rim of the pubic bones and inferior aspect of the posterior superior iliac spine (PSIS).


Fig. 4. Weight transfer forces through the lumbo-pelvic-hip complex from above and below. (A) In standing and sitting (pelvis in alignment, leg length equal). (B) On right 1-leg stance. (C) Changes in loads and forces imparted to the sacroiliac joint with a left frontal plane asymmetry. The right joint is more vertical, creating greater shear. (From Schamberger W. The malalignment syndrome: Diagnosing and treating a common cause of acute and chronic pelvic, limb and back pain. Edinburgh (UK): Churchill Livingstone; 2013. Adapted from Porterfield JA, DeRosa C. Conditions of weight bearing: asymmetrical overload syndrome (AOS). In: Vleeming A, Mooney V, Stoeckart R, editors. Movement, stability and lumbopelvic pain. Integration of research and therapy. 2nd edition. Edinburgh (United Kingdom): Churchill Livingstone; 2007. p 394; with permission.)


Fig. 5. Axes and planes around which sacroiliac joint movement occurs.


Fig. 6. Movement of the pelvic ring with normal gait. (A) Contrary rotation of the innominates relative to the sacrum: right anterior, left posterior. (B) Sacral torsion around the right oblique axis associated with the rotation of the innominates.
b. Displacement from midline (Fig. 14):
i. Compare the thumbs placed against the medial aspect of the ASIS or PSIS.
2. Doing the sitting-lying test as follows:
a. Start with the runner lying supine on a firm surface and then assist him or her to come up into a sitting position to minimize any use of trunk or abdominal muscles in order to decrease the chance of veering off to 1 side in the process. A runner can carry out this step alone with a belt to pull up on, using the muscles in both arms.
b. With him or her in sitting up, place a thumb lightly against the inferior aspect of the medial malleolus on each side, pointing the tip downward, so that the distal phalanx ends up positioned vertically to allow for a more accurate side-to-side comparison.
c. Check to see if the thumbs are level with each other or if one is displaced upward relative to the other, as if the leg were shorter on that side (Fig. 15).
d. While maintaining the placement of the thumbs, have the runner lie down and observe if, on doing so:
i. The thumbs (ie, legs) move up together, or
ii. There is a relative shift in their position, one thumb moving upward and the other downward; if that is, the case, the reverse would be evident on having him or her sit up again (Fig. 16).

Repeat the test once or twice to confirm your observations.

## PRESENTATIONS WITH THE PELVIS ALIGNED

About $10 \%$ to $15 \%$ of the population present with the pelvis in alignment and no history of having had any adjustments (eg, manipulation, mobilization) carried out any time in the past. ${ }^{25-27}$ Findings with 2 common variants relating to leg length are as follows.


Fig. 7. Inflare and outflare of the innominates in the horizontal plane. During normal gait cycle (right stance, left swing-through phase), the right outflares, the left inflares: (i) anterior, (ii) posterior, and (iii) superior views. ASIS, anterior superior iliac spine; PSIS, posterior superior iliac spine.

## Pelvis Aligned, Legs Length Equal

All the pelvic landmarks are level with their counterpart on the left in standing, sitting, and lying. The right and left ASIS and PSIS are equidistant from the midline (see Fig. 14Aii, Bii). The malleoli lie at the same level and move together, downward on sitting up and upward on lying down.

## Pelvis Aligned, Right Anatomic (True) Leg Length Difference Present

Compared with the left side, the right iliac crest and all other right pelvic landmarks are higher in standing but are level and equidistant from midline when sitting and lying (Fig. 17). The right malleolus will appear to be displaced downward relative to the left one by the same amount in both sitting and lying (reflective of the true leg length difference) and the legs move together on changing from one position to the other.


Fig. 8. Posterior aspect of the sacrum and coccyx and configuration of the adult sacroiliac (SI) joint. (A) Anteroposterior view: bony landmarks. (B) Angulated inset showing orientation of the 2 main arms of the sacral articular surface along different planes relative to the sacral axis, which creates a propellerlike shape. (C) Lateral view: L-shape of the SI joint ( H , horizontal arm; V, vertical arm). (Adapted from Vleeming A, Mooney V, Stoeckart R, editors. Movement, stability and lumbopelvic pain. Integration of research and therapy. 2nd edition. Edinburgh (United Kingdom): Churchill Livingstone; 2007; with permission.)


Fig. 9. Posterior rotation (right) and anterior rotation (left) demonstrating joint closure at the (level of) S1 (right) and S3 (left) to create an oblique axis. A functional destabilization occurs at S1 (left) and S3 (right), allowing the joint to move on that oblique axis. (From DonTigny RI. Pelvic dynamics and the S 3 subluxation of the sacroiliac joint. Havre (MT): CD-ROM from DonTigny; 2004; with permission).


Fig. 10. Radiograph: standing anteroposterior view of pelvis in person with equal leg length and right anterior, left posterior rotational malalignment. Note the (1) femoral heads are level but the pelvic crests are oblique; (2) approximately 3 mm downward displacement of right superior pubic ramus relative to the left at symphysis pubis (white arrow); (3) apparent asymmetry of the (a) sacroiliac joint surfaces; for example, increased opening of the left lower joint compared with the right (see Fig. 9); (b) spacing between hip joint surfaces; and (c) size of lesser trochanter (LT; more of left visible - black arrow): with contrary rotation of the femurs (right external, left internal), the left LT rotates into view and seems to be larger; the right is partially hidden by overlapping with the femur.

## COMMON PRESENTATIONS OF PELVIC MALALIGNMENT

As indicated, in $80 \%$ to $90 \%$ of the general population the pelvis is not in alignment. ${ }^{25-27}$ Although there are several ways that the pelvic ring can go out of alignment, this discussion focuses on the 3 most common presentations that:

1. Can occur in isolation or in combination with 1 or both of the others; and
2. Altogether make up more than $90 \%$ of the $80 \%$ to $90 \%$ noted to have pelvic malalignment.

The remaining 5\% to 10\% present with other ways that the innominates and sacrum can go out of alignment, either symmetrically or asymmetrically; except for sacral torsion and a downslip of an innominate, they will not be discussed further. The 3 most common presentations, and their prevalence, are as follows:

1. Outflare and inflare: noted in $40 \%$ to $50 \%$;
2. Rotational malalignment: noted in $80 \%$ to $85 \%$; and
3. An upslip: noted in 20\%.

## OUTFLARE AND INFLARE <br> Examination Findings

1. Flaring of 1 or both innominates is the second most frequently seen of the 3 most common presentations of pelvic malalignment, noted in $40 \%$ to $50 \%$ altogether. ${ }^{27}$
2. The right or left innominate becomes fixed in excessive outward or inward rotation in the horizontal plane. The contralateral innominate, although it may be found to lie


Fig. 11. Common mechanisms of pelvic injury. (A) In a motor vehicle accident: the force impacting on the acetabulum at an angle below the inferior transvers axis (ITA) results in anterior rotation of the innominate. ( $B$ ) In a fall: forcing the leg upward or landing on the ischial tuberosity can stretch/disrupt the ligaments between the sacrum and ilium.
in its normal position, is usually fixed flared in the opposite direction, as if to compensate. With a right outflare and left inflare:
a. The right ASIS will have moved away from the midline of the abdomen, the left toward it (see Fig. 14Ai). Findings are the reverse for the PSIS: the left toward, the right away from midline, demarcated by the gluteal cleft and spinous processes (see Fig. 14Bi).
b. The left ASIS ends up moved forward with the inflare, the right backward with the outflare (see Fig. 7iii). As a result, the left one seems to be:
i. Protruded forward in standing and sitting compared with the right and
ii. Displaced upward (ie, higher) and the right downward (ie, IOwer) when observed with the runner lying supine (Fig. 18).
c. Barring a coexisting true leg length difference, the landmarks are level in the frontal plane in all positions and leg length is equal in sitting and lying.
d. Radiographs show the changes in the landmarks observed (Fig. 19).


Fig. 12. Missing a step and landing with increased force on 1 extremity can cause malalignment of the pelvis. The force created can result in displacement of the innominate relative to the sacrum. At the time of impact, if the leg is positioned (A) vertically, this can result in upward displacement (a so-called upslip) or ( $B$ ) at a hip-flexion angle, this can result in an anterior rotation of the innominate.

Diagnosis and Corrective Procedures: Right Outflare, Left Inflare
When a right outflare, left inflare is present, on lying supine:

1. The right ASIS is IOwer and displaced $\underline{O}$ utward, away from midline.

Remember the mnemonic of the $\mathbf{4} \underline{\text { Os }}$

THE LOW SIDE IS THE 'Ó' OR 'OUUTFLARE' SIDE. CORRECTION IS ACHIEVED BY RESISTING OUTWARD MOVEMENT OF THE KNEE.

The treatment method referred to here is a form of manual therapy, known as the muscle energy technique (MET). ${ }^{18,28-30}$ It gets the runner to harness the energy in muscles that are positioned in a way that enables them to effect the specific change. In this


Fig. 13. Rotational malalignment: right anterior, left posterior innominate rotation. (A) Asymmetry of anterior superior iliac spine (ASIS; right down, left up). (B) Asymmetry of posterior superior iliac spine (PSIS) and iliac crest (right up, left down); obvious downward displacement of shoulder and brassiere on left secondary to compensatory scoliosis. (C) Right superior pubic ramus displaced downward relative to the left. (D) Shift of the right pelvic landmarks relative to their left counterparts: right iliac crest, PSIS, and ischial tuberosity moved upward; right ASIS, anterior inferior iliac spine (AIIS), and pubic ramus moved downward.
case, resisting abduction and external rotation of the femur by blocking outward movement of the partially flexed right knee (Fig. 20) reverses the origin and insertion of the right piriformis and gluteus maximus (see Figs. 2 and 3). These muscles can act on the innominate (which is still free to move) to rotate it forward in the horizontal plane until it again comes to lie in its normal position relative to the sacrum. The repeated contraction-relaxation of these muscles also can decrease tone and increase muscle relaxation and lengthening that, together, make it easier for the bones to slot back into their proper place.

## 2. The left ASIS is higher and displaced inward, toward the midline.

Remember the mnemonic of the 4 Is:

THE HIGG SIDE IS THE '! ${ }^{\prime}$ OR 'IINFLARE' SIDE. CORRECTION IS ACHIEVED BY RESISTING INWARD MOVEMENT OF THE KNEE.

Blocking adduction of the left leg reverses the origin and insertion of the left gracilis and adductor longus (Fig. 21; see Fig. 55). The force generated is now directed to their


Fig. 14. (A) With an abnormal presentation - relative to midline, thumbs placed against inside of the anterior superior iliac spine (ASIS) show: (i) initial asymmetry, with right outflare (thumb away from midline), and left inflare (closer to midline); (ii) symmetry after correction (equidistant from midline). (B) Relative to midline (buttock crease, spinous processes), thumbs against inner aspect of PSIS show: (i) initial asymmetry with right outflare (thumb closer to midline), left inflare (thumb away from midline); (ii) symmetry after correction.
attachment onto the left pubic tubercle and is capable of rotating the innominate outward, back into alignment (Fig. 22).

## Clinical Correlation for Runners

1. An outflare strains the anterior SI joint ligaments/capsule and compresses the posterior joint margins; an inflare has the opposite effect (see Figs. 1, 2, 7iii, and 19B). There may be discomfort from the structures put under stress.
2. With a right inflare, left outflare, the left acetabulum faces progressively more posterolaterally as that innominate rotates outward (see Fig. 19A). The left superior rim comes to lie more directly anterior to the femoral head with the outward rotation of that innominate, sometimes to the point that the femoral head actually impinges against the rim as the hip joint is increasingly flexed going through swing phase. Compared with the ease with which the right leg moves through this phase:
a. The runner may literally sense the block to this motion occurring on the left side and there may be discomfort or pain with impingement of the acetabular rim, felt in the left groin and/or hip region. ${ }^{31}$
b. Left swing-through is limited. To compensate, he or she can:
i. Bring the acetabulum facing further forward by actively increasing the extent that the pelvic ring as a whole rotates clockwise during left swing phase, partly effected by increasing active clockwise rotation of the trunk and


Fig. 15. Sitting part of the sitting-lying test. (A) Long sitting. (B) The left leg seems to be longer than the right.


Fig. 16. Lying part of the sitting-lying test in same subject as in Fig. 14. (A) Supine lying. (B) There has been a shift in leg length: the right has lengthened relative to the left leg (findings are the reverse of those noted in Fig. 14B).
changing the movement pattern of the arms, in an attempt to match right stride length; and
ii. Cut back the degree of right swing-through to match that on the left and, instead, increase stride frequency to maintain the same speed.

Either compensation method leads to unwanted changes in the gait pattern that can prove costly in terms of decreased efficiency and increased energy demands.

## ROTATIONAL MALALIGNMENT

Examination Findings
Innominate rotation is the most frequently seen of the 3 common presentations of pelvic malalignment, noted in $80 \%$ to $85 \%$ altogether. ${ }^{26,27}$ An innominate can become fixed relative to the sacroiliac joint, in a position of excessive rotation in the sagittal plane, either forward (anterior) or backward (posterior). Usually, but not necessarily, the contralateral innominate is fixed in rotation in the opposite direction. Some $80 \%$ to $85 \%$ thus affected have a right anterior, left posterior and $15 \%$ to $20 \%$ a left anterior, right posterior rotation. ${ }^{26,27}$ The SI joint may be locked on one side so that on the kinetic rotational (Gillet) test the innominate and adjoining sacrum on the locked side move as 1 unit, upward on progressive hip flexion, downward on hip extension, which is opposite to what happens normally (Fig. 23).


Fig. 17. Pelvic obliquity with the belt and iliac crest angled up on the right side; compensatory scoliosis and downward displacement of left shoulder and arm; head remains centered and level. Findings could be in keeping with true leg length discrepancy (right leg long), upslip or rotational malalignment.


Fig. 18. Right outflare, left inflare. $(A, B) A$ spirit level resting on top of the right and left anterior superior iliac spine (ASIS) shows elevation of the left side. (B) Feet (clamps) attached to the level rest on the ASIS; they help to raise the bubble into view (eg, for someone who is obese, pregnant). (C) ASIS now level, bubble in center, after correction of the outflare/inflare (same subject as in $A$ ).


Fig. 19. Radiographic changes seen with a left outflare, right inflare. (A) Anteroposterior projection of pelvis and hip joints. The femoral heads remain at the same level as the left acetabulum moves outward and the right inward in the horizontal plane. Innominate width seems to be increased on the left and decreased on the right. The anterior superior iliac spine looks to be increased in overall size and broader on the outflare (left) side and smaller and narrower on the inflare (right) side. The left femoral neck lies further away from and the right one closer to the ipsilateral inferior pubic ramus. The left lesser trochanter (LT) seems to be smaller as a result of overlapping occurring with passive external rotation of the femur; on the right it seems to be larger, having been brought into view with internal rotation of that femur (see also Fig. 10). (B) Diagrammatic conceptualization of the AP beam projection onto the pelvis when aligned and with a left outflare, right inflare present; superoinferior view.

## Diagnosing Rotational Malalignment

With a right anterior, left posterior rotation (see Fig. 13; Fig. 24):

1. All the anterior and posterior landmarks are displaced asymmetrically on both side-to-side and front-to-back comparison. For example:
a. The right ASIS ends up lower compared with the ipsilateral PSIS and the left ASIS; and


Fig. 20. Using muscle energy technique (MET) to correct a right outflare: resist active right thigh abduction and external rotation; that is, block outward movement of flexed right knee. (A) One-person, sitting (or lying) approach. (B) A 2-person approach is easy to carry out with subject lying supine, ipsilateral hip and knee flexed and foot resting on bed.


Fig. 21. Neurovascular structures at risk of compromise within the femoral triangle by any increase in tension, particularly in iliacus, psoas and pectineus. (Note: adductor longus origin from pubic tubercle [see Fig. 22], also lateral femoral cutaneous nerve traversing the canal). (From Schamberger W. The malalignment syndrome: Diagnosing and treating a common cause of acute and chronic pelvic, limb and back pain. Edinburgh (UK): Churchill Livingstone; 2013. Adapted from Anderson JE. Grant's atlas of anatomy, 7th edition. Baltimore: Williams and Wilkins, 1980.)
b. The right pubic ramus is displaced downward and rotated forward in the sagittal plane; the left undergoes displacement in the opposite directions.
2. There is a pelvic obliquity, with the right iliac crest and ischial tuberosity ending up higher relative to left side (see Figs. 13 and 17).


Fig. 22. To correct a left inflare, resist active left thigh adduction and internal rotation; that is, block inward movement of flexed knee. (A) One-person lying (or sitting) approach. (B) Two-person approach (note: arrow on left inner thigh denotes direction of adductor longus pull on right pubic tubercle attachment to rotate innominate outward).


Fig. 23. Abnormal right kinetic rotational (Gillet) test, with right sacroiliac joint locked. (A) On initial right hip flexion to horizontal: right thumb (which marks the location of right posterior superior iliac spine [PSIS]) fails to drop down relative to the left one (marking the sacral base). (B) On increasing right hip flexion: the right thumb (PSIS) actually moves upward. The sacrum and PSIS are moving together as 1 locked unit, counterclockwise in the frontal plane.


Fig. 24. Typical pelvic distortion associated with rotational malalignment: right anterior, left posterior rotation, as shown. Pubic bones are rotated and displaced relative to each other at the symphysis; sacrum in torsion around the left oblique axis. Pelvic obliquity (shown inclined to right) and compensatory scoliosis (thoracic segment convex to right, lumbar convex to left, with L1-4 rotated into the convexity).


Fig. 25. Sitting-lying test: rotational malalignment presentation. All 3 subjects have right anterior, left posterior innominate rotation, with relative lengthening of the right leg compared with the left on moving from long sitting to supine lying. (A) The right leg is shorter sitting, longer lying; this is the most common pattern. (B) The right leg is shorter sitting but less so in lying. (C) The right leg is longer sitting and even more so in lying.
3. There is an apparent leg length difference noted in the sitting-lying test. Which leg seems to be longer or shorter is of little importance. What matters is that there is a shift in leg length on this test, with the right malleolus moving upward in sitting up and downward on lying down relative to the left (see Figs. 15 and 16; Fig. 25). This shift is characteristic of a right anterior, left posterior rotation; it would be in the opposite direction with a left anterior, right posterior rotation.
4. Remember the mnemonic of the $\mathbf{5} \underline{L}$ s to help determine the side of an anterior rotation:
$\underline{L} E G \underline{L} E N G T H E N S \underline{L} Y I N G, \underline{L} A N D M A R K S$ LOWER.

In the case of a right anterior, left posterior rotation, the right anterior landmarks end up lower relative to those on the left and the right leg lengthens on lying down.
5. Radiographs show the changes in the landmarks observed (Fig. 26).

## Corrective Procedures for Rotational Malalignment

There are a number of different manual therapy techniques that can be used to correct a rotational malalignment. However, MET, leverage, or a combination of the 2 techniques can be useful in that they may allow the runner to correct a recurrence between visits to the therapist or even when on the track or out on the road (Figs. 27-34 and 37). In the case of a:

1. Right anterior rotation:
a. Blocking movement of the right thigh away from the trunk (ie, right hip extension) activates right gluteus maximus (Figs. 30 and 31). Reversal of its origin and


Fig. 26. Radiographic changes with malalignment: the effect on sacroiliac and facet joint orientation to the anteroposterior beam. The L1-L4 vertebral rotation into the left convexity (ie, counterclockwise) opens up the left midlumbar facet joints and accentuates the closing/ compression of the right facet joints that results with the simultaneous left rotation and right side-flexion of the vertebrae. The right sacroiliac joint seems to be open along its full length, whereas only the midsection of the left one is visible as a result of overlapping and reorientation of the joint surfaces relative to the beam and to the right side (see also Figs. 10 and 19). L5 is sacralized on the left.
insertion allows it to rotate the right innominate in a posterior direction, by way of its attachments to the posterosuperior aspect of the ilium (see Fig. 2B).
b. Passively moving the right femur into increasing flexion to the point where the femoral head impinges against the anterior rim of the acetabulum creates leverage and simultaneously tightens some posterior structures, including the sacrotuberous ligament. The combined effect is a posterior rotational force on the right innominate (see Fig. 27A).
2. Left posterior rotation:
a. Blocking movement the left thigh toward the trunk (ie, left hip flexion) activates left iliacus (Figs. 32 and 33) and rectus femoris (see Fig. 28B); the latter also responds to blocking extension of the flexed knee (see Fig. 28A; Fig. 34). The muscles then exert an anterior rotational force by way of their attachments to the anterosuperior part of the ilium and to the pubic bone, respectively (see Fig. 3).
b. Passively extending the femur to the point where the femoral head impinges on the posterior acetabular rim turns the femur into a lever capable of creating an anterior rotational force on the left innominate (see Fig. 27B).


Fig. 27. Using a leverage effect to correct rotational malalignment. (A) Passive hip flexion to counteract a right anterior rotation: (i) 1-person and (ii) 2-person techniques. (B) Passive hip extension to counteract a left posterior rotation: (i) 1-person and (ii) 2-person techniques.

## Clinical Correlation for Runners

1. Runners should be discouraged from routinely doing excessive unilateral stretches of iliopsoas, rectus femoris, gluteal muscles, and hamstrings, especially when the pelvis is free to move, as in standing (Fig. 35). For example, a right iliopsoas/quadriceps stretch tightens up right iliacus and rectus femoris; the femur may also end up far enough in extension to exert a leverage effect (see Fig. 35A). This maneuver is capable of:
a. Forcing the right innominate to go out of alignment so it ends up fixed in an anterior rotated position; and
b. Undoing any realignment that has been achieved, because it can literally force the innominate back out of alignment again.
2. To decrease this risk, stretches are best carried out simultaneously on both sides, preferably with the pelvis stabilized; for example, bilateral hamstring stretch: sitting on the floor, legs out in front; quadriceps, iliopsoas and pectineus: leaning the pelvis and trunk backward while kneeling (Fig. 36).
3. However, unilateral leverage maneuvers can actually be used effectively by the runner on the side of a known rotation. For example, a right anterior rotation may respond to placing the right foot on a chair and gradually leaning forward with the trunk, arms dangling downward (Fig. 37). The same may be accomplished by having the right foot up on a ledge and leaning forward (see Fig. 35B). The progressive increase in passive hip flexion turns the femur into a lever capable of correcting the rotation.


Fig. 28. One-person muscle energy technique to correct a left posterior rotation by activating rectus femoris with the left knee $(A)$ in flexion, $(B)$ in extension. (C) Rectus femoris action in standing.
4. Unilateral stretches of a specific muscle may be indicated following realignment for:
a. Muscles that have undergone contracture while in a shortened state during the time that malalignment was present; and
b. Ones that fail to relax completely, show increased tone, or are actually in spasm.

## UPSLIP

## Examination Findings

Of the 3 most common presentations of pelvic malalignment, an upslip is the least frequently seen, appearing in isolation in $10 \%$ and in combination with a flare, rotational malalignment, or both in another $10 \% .^{26,27}$ The innominate on 1 side ends up displaced straight upward relative to the adjacent sacrum and becomes fixed in that position. Again, although often no cause may be evident, some obvious ones include:

1. Having the force of an impact transmitted straight upward, either through:
a. One extremity: for example, missing a step (see Fig. 12A); landing hard on 1 leg when jumping or running downhill with the knee in extension (Fig. 38) or
b. The innominate itself; for example, falling directly onto an ischial tuberosity (see Fig. 11B).


Fig. 29. Leverage effect of the femur on the innominate, by impingement against the acetabular rim (see also Fig. 27). Correction of (A) an anterior rotation; (B) a posterior rotation.
2. An upward traction force being applied to the innominate; for example, with a chronic increase in tension or spasm in quadratus lumborum, psoas major/minor (Fig. 39).

As a result, on the side of the upslip one finds:

1. The anterior and posterior pelvic landmarks are all displaced upward relative to those of the opposite innominate and to the sacrum.


Block to right hip extension = reversal of origin and insertion
Fig. 30. One-person muscle energy technique to correct an anterior rotation: using the gluteus maximus to create a posterior rotational force on the innominate.


Fig. 31. Two-person muscle energy technique using the gluteus maximus to correct a right anterior rotation.
2. The ipsilateral leg is moved upward passively with the innominate, creating an apparent leg length difference. Relative to the opposite leg, it seems shortened to the same extent in both sitting and lying and the malleolus moves downward and upward, respectively, together with that on the other side (Fig. 40).
3. A pelvic obliquity is evident in standing, sitting, and lying.

## Corrective Procedures for an Upslip

With the runner lying supine, applying gentle, repetitive traction to the leg on the upslip side usually suffices, often simply by helping to relax tense muscles around the hip/ pelvic girdle that are holding the innominate in the upslip position (see Fig. 39; Fig. 41). If that fails to achieve correction, manipulation using a quick downward pull on the leg once or twice may prove successful. The runner can be instructed in self-correction (see Fig. 41B):

1. Starting by simply letting that leg hang down while standing on a step or stool, and


Block to left hip flexion = anterior rotational force
Fig. 32. One-person muscle energy technique using iliacus to correct a left posterior rotation.


Fig. 33. Two-person muscle energy technique using iliacus to correct a left posterior rotation.
2. Progressively increasing either the time it is suspended or the amount of a weight attached, usually 20 to 30 minutes using 2.5 to 4.5 kg proves effective.

## Clinical Correlation for Runners

1. The apparent leg length difference, pelvic obliquity, and compensatory scoliosis combined result in unwanted stress points, change in style, and compensatory measures; for example, leaning into the weight-bearing low side to help clear the long leg for swing-through and adjustments for side-to-side differences in stride length. ${ }^{3,32}$


Fig. 34. Two-person muscle energy technique using the rectus femoris to correct a left posterior rotation. Having the runner's ankle/distal part of the lower leg propped up under the armpit (or lying on top of the shoulder; not shown) allows the assistant to use his body weight to advantage to generate the counterforce needed to block knee extension.


Fig. 35. (A) Popular unilateral quadriceps stretch that can cause or aggravate a preexisting right anterior rotation, by way of (1) rectus femoris pulling on its innominate origin and/or (2) the femur coming to act as a lever with increasing hip extension. (B) Unilateral hamstrings stretch (eg, straight leg propped up on a chair or table) can have a similar deleterious effect by causing/aggravating a posterior rotation. However, this same maneuver may be able to correct a preexisting right anterior rotation (see also Fig. 37).
2. Dysfunction of the SI joint on the side of the upslip increasing stress on the other parts of the lumbo-pelvic-hip complex bilaterally.
3. A coexisting rotational malalignment can hide an upslip; hence, it is important to recheck alignment after correction of the rotation.
4. A caution: keep the rare downslip in mind.

When dealing with a supposed upslip that fails to respond to treatment, including repeated downward traction, consider the possibility that the runner has actually sustained a downslip of the contralateral innominate. For example, a traction force on one


Fig. 36. Simultaneous, symmetric stretch of bilateral quadriceps, iliopsoas, and pectineus (see Figs. 3B, C and 19) carried out by subject kneeling and gently leaning backward.


Fig. 37. A right anterior rotation may be corrected by resting the right foot on a raised surface and simply letting the trunk hang down in forward flexion as far as is comfortable. With increasing right hip flexion, the femur can eventually exert a leverage effect, with posterior rotation of the innominate (see also Fig. 35B). Bouncing or straining while reaching down must be avoided because it can precipitate or aggravate pain and muscle spasm.
of the lower extremities that is strong enough to pull the innominate into a downslip position can occur when the runner:

1. Has to pull upward on a straight leg, often unexpectedly and in midstride, to extract a foot that got stuck in deep mud;
2. Is thrown forward, off the bike, during the cycling part of a biathlon or triathlon while 1 foot is still caught up in the stirrup.

## THE MALALIGNMENT SYNDROME

Both rotational malalignment and an upslip result in typical biomechanical changes, symptoms and signs that together constitute the malalignment syndrome. ${ }^{26,27} \mathrm{~A}$ discussion of the characteristic findings associated with this well-defined clinical entity and the implications for runners follows.

## Pelvic Ring Distortion

Displacement of the pelvic ring results in abnormal stresses on all of the joints of the lumbo-pelvic-hip complex, particularly on the adjoining surfaces of the joints and their capsule and supportive ligaments. The distortion also causes:

1. Disturbance of the normal transfer of weight through this complex (see Fig. 4) ${ }^{3,4,8}$;


Fig. 38. Right upslip caused by a unilateral upward force on the femur transmitted through the hip joint to the innominate. ASIS, anterior superior iliac spine; PSIS, posterior superior iliac spine.
2. Irritation of neural receptors lying within any of the structures put under stress, which can result in localized and/or referred pain and paresthesias (see Case History: Runner A, below);
3. Accelerated degeneration of any sites in the lower extremities, pelvis and spine put under increased stress as a result; in particular, the discs and facet joints in the lower lumbosacral region (see Figs. 10 and 26; Figs. 42 and 43) ${ }^{12,33}$; and
4. Pelvic obliquity and an apparent leg length difference.

## Clinical correlation for runners

Runners, who alternately bear all weight on one extremity, are likely to develop compensatory mechanisms that can affect their running biomechanics and efficiency. In an attempt to cope with any pain and/or the altered biomechanics of weight transfer, they may:

1. Actively change their pattern of weight bearing; for example:
a. Landing more on the mid foot or forefoot to shift impact away from a painful heel area;


Fig. 39. Muscles capable of generating forces (arrows) that can result in an upslip.
b. Tending to pronation and increasing dorsiflexion to improve shock absorption at the now more flexible foot/ankle level and decrease the forces transmitted upward; and
c. Offload the painful site by shortening the stance phase on this side and/ or shifting the center of gravity away, by leaning into the opposite direction.
2. Lean toward the side of an unstable SI joint, to approximate the surfaces and thereby increase stability (see Fig. 4C; Fig. 44).

## Compensatory Curves of the Spine

The pelvic obliquity results in a compensatory scoliosis-curves in the frontal planeto ensure the head ends up in midline as best as possible, with the eyes and ears level, to minimize any disturbance of visual function and the labyrinthine balancing mechanisms.

## Clinical correlation for runners

Superimposing these compensatory lateral curves on an existing lumbar lordosis and thoracic kyphosis creates additional stresses on the spine (Fig. 45).

1. It can cause back pain; in particular, at the:
a. Lumbosacral junction, where L5 interlinks with the sacrum. The lumbar convexity is formed by rotation of L1 to L4 inclusive into the convexity (see Fig. 24). Any


Fig. 40. Sitting-lying test: right sacroiliac joint upslip. The legs move together and the right leg remains short to the same extent in sitting and lying. The right anterior and posterior pelvic landmarks are all displaced upward relative to the sacrum and left innominate. ASIS, anterior superior iliac spine.
further rotation of $L 4$ relative to $L 5$ puts an additional torsional stress on the L4-5 disc, results in facet joint compression on 1 side and distraction on the other, and may actually cause unwanted rotation of L5 relative to the sacrum and secondarily of the sacrum itself (Fig. 46).
b. Thoracolumbar junction, with transition of a lumbar lordosis to thoracic kyphosis, superimposed reversal of the compensatory curves and contrary rotation of T12 and L1, all increasing stress on the discs and facet joints in the mid back region.
c. The cervicothoracic point of reversal, often manifest as muscle tightening and/or actual pain at the base of the neck and in the shoulder/scapular regions.
2. It can aggravate any existing discomfort or actually trigger onset of back pain in a runner who already has:
a. Some degree of idiopathic scoliosis (see: "Implications for the treating physician");
b. A coexisting rotational displacement of 1 or more vertebrae (see Fig. 46); and


Fig. 41. Correction of a right upslip. (A) Two-person technique. (B) One-person: using the weight of the leg (with or without extra weight attached) to exert a downward traction force on the innominate and releasing tension in muscles that may be perpetuating the upslip (see Fig. 39).
c. A site where movement of the spine itself and between the spine and pelvis is already compromised; for example, vertebral fusion, unilateral sacralization, or lumbarization (see Fig. 26).

## Asymmetrical Weight Bearing and Pattern of Shoe Wear

In all of those presenting with an upslip and more than $90 \%$ of those with rotational malalignment:

1. Weight-bearing shifts to the left on both sides and


Fig. 42. Effect of a malalignment-related shift toward right pronation, left supination on the knee. (A) Right side: the tendency toward pronation and knee valgus angulation increases the Q -angle and the pressure on the lateral compartment; excessive pronation can result in a forceful upward movement of the fibula and a jamming of the proximal tibiofibular joint (similar to what can occur with an ankle eversion sprain). ( $B$ ) Left side: the tendency toward supination and knee varus angulation decreases the Q -angle and increases pressure on the medial compartment.
2. There is some rotation of the lower extremities and feet, outward from midline on the right side and toward it on the left (Fig. 47B). ${ }^{26,27}$

When not bearing weight, the right foot rests in increased varus angulation compared with the left (Fig. 48B). As a result:

1. Right heel impact is more posterolateral compared with the left, which augments forcing the right foot into valgus/pronation.
2. The right foot may quite obviously pronate whereas the left may pronate less, stay in neutral or actually supinate on weight bearing (Figs. 49 and 50). Although there are variations of this pattern, these all reflect a shift toward the left; for example, both feet may pronate but the right more so than the left, or both supinate but the left more so than the right.
3. The same trend is consistently reflected in the wear pattern of the shoes (Fig. 51): a. The right heel cup collapses inward, the left stays in neutral or leans outward (see Fig. 51A); again, any variations are consistent with this pattern (Fig. 52; see also Fig. 78A).


Fig. 43. Osteoarthritic changes in the knee as a result of long-term pressure redistribution similar to what can occur with a malalignment-related shift in weight bearing: accentuated wear of right lateral and left medial joint compartments (see Figs. 49 and 50).
b. Asymmetrical wear of the soles, especially noticeable in the forefoot region and the heel (Fig. 53).
c. Compaction of the midsole and often a shift of the upper: medially on the side tending to pronation (see Fig. 51B) and laterally on the supinating side (see Fig. 78A).

In some 5\% to $10 \%$, the shift is in the opposite direction: the right leg rotating inward, the left outward and the right foot tending to supination, the left to pronation (see Fig. 47A; Fig. 54). This pattern seems to be linked to anyone presenting with a left anterior, right posterior rotation and simultaneous locking of the left SI joint (or left anterior and locked, for short). ${ }^{26,27}$

## Clinical correlation for runners

1. The increased tendency to right pronation and left supination puts contrasting stresses on specific muscles, nerves, ligaments, and joint structures from the foot upward to the hip girdle region (see Fig. 42; Figs. 55-57). Pronation stresses particularly soft tissue structures on the medial aspect of the foot and leg; supination stresses structures on the lateral aspect. Any of these can become symptomatic; typical complications are summarized here (see "Implications for the treating physician" for further discussion).
2. With increasing right pronation, the right knee progressively leans inward, tending to genu valgum with opening of the medial, compression of the lateral compartment. With left supination, the shift at the knee is toward neutral alignment or frank genu varum with opening of the lateral, compression of the medial compartment.


Fig. 44. Compensated right Trendelenburg gait. Impaired transfer of weight through an unstable right sacroiliac joint can occur with ligament laxity, decreased muscular support, or degenerative loss of joint surface. It may be reduced or prevented by having the pelvis abduct and shift to the right to increase compression and minimize vertical shear stresses through that joint (see Fig. 4C).

These changes put increased stress on structures such as the right medial collateral ligament and patellofemoral compartment/patellar tendon, the left lateral collateral ligament and iliotibial (IT) band insertion, respectively. The persistent or repetitive strain can cause these structures to become tender or outright painful (eg, right patellofemoral compartment syndrome; left IT band friction syndrome). These stresses are increased by activities like running on a slope declined to the left (Fig. 58B). A shift in joint loading is suspected of being able to accelerate joint degeneration; in the case of the knee, of the right lateral and left medial compartment (see Fig. 43). ${ }^{12,33}$
3. The combination of right pronation and outward rotation of the leg makes it more likely for the runner to just touch or actually hit the right heel against the left ankle or inner calf. With the inwardly rotated left side, there is an increased risk of losing balance or tripping by catching the left big toe on the right heel or ankle region.



Fig. 47. Two variants of the shift in weight bearing seen with rotational malalignment. (Ai, ii) With the rare left anterior rotation and sacroiliac joint locking: left foot turns outward from midline and pronates, the right inward and supinates. (Aii) Also shows the obvious narrowing of the left Achilles tendon as it is subjected to increased tension with pronation on this side. (B) With one of the more common presentations: the right foot typically turns outward and pronates, the left inward and supinates.

## Asymmetrical Muscle Tone

Paired muscles show tone to be increase, or "facilitated," on 1 side and decreased, or "inhibited," on the other side. The changes in tone seem to be mediated by the autonomic nervous system secondary to a mechanism, segmental or cortical, that affects the muscle spindle setting and results in either facilitation or inhibition of the resting tone. ${ }^{20,26,27,34-37}$ The pattern of muscles affected by the pelvic malalignment is:

1. Asymmetrical: some are automatically tensed up on the right, others on the left side, whereas their partner on the opposite side seems to be relaxed; for example,


Fig. 48. Angulation of the feet at rest (same subject, sitting). (A) In alignment: symmetric varus angulation of the sole of the feet. ( $B$ ) With an upslip and rotational malalignment: right varus angulation is increased (here to $35^{\circ}$ compared with $22^{\circ}$ on the left).
left quadratus lumborum, iliopsoas, hip abductors/tensor fascia lata (TFL), triceps surae; right piriformis, biceps femoris (Figs. 59 and 60); and
2. Consistent, regardless of what type of an upslip (right or left) or rotational malalignment (right or left anteroposterior) is present.

Malalignment can also cause a chronic increase in tone, and eventual tenderness, in muscles and myofascial slings as a result of:

1. Increasing the distance between muscle origin and insertion, typically affecting:
a. The paravertebral muscles on the convex (ie, longer) side of a curve in the spine;
b. The left hip abductors and peroneus longus with the tendency to left supination; right hip adductors and tibialis anterior/posterior with right pronation (see Fig. 55); and


Fig. 49. (A) Toe-walking can bring out the asymmetry of weight bearing seen with an upslip and rotational malalignment: inward whip and collapse of the heel (calcaneal eversion) on the pronating right side, outward whip and calcaneal inversion on the supinating left side. (B) A similar pattern, accentuated by walking on high heels: right pronates, with heel shifting inward (partly off the medial edge); the left supinates, with heel shifting slightly over the lateral edge. Note: increased tension (narrowing) of Achilles tendon on right pronating side in both subjects.


Fig. 50. Foot contact surface. (A) On an orthotic versus (B) barefoot on sand. (C) Barefoot weight-bearing pattern seen from below a glass surface, reflecting the typical malalignment-related shift in weight bearing: medially on the pronating right, noticeably increased foot surface contact in the midfoot region; laterally on the supinating left, decreasing contact especially along the inner longitudinal arch region.
c. The hamstrings on the side of an anterior rotation; rectus femoris and iliopsoas on the side of a posterior rotation (Fig. 61).
2. The muscle being constantly in some degree of contraction in an attempt to splint a painful area, stabilize a joint, or combination of these; typical involved are:
a. The paravertebral muscles lying alongside the thoracolumbar junction, with the contrary rotation of T12 and L1 at the site of curve reversal causing


Fig. 51. Reflection of the shift in weight bearing with malalignment (see Case History: Runner $A$ ). (A) With the more common patterns of rotational malalignment and an upslip: the tendency to right pronation, left supination, leads to heel cup collapse toward the left. ( $B$ ) Medial view of the same running shoes showing compression of the inside of the right heel/ sole (on left in photo) compared with the left shoe (on right in photo).


Fig. 52. The pattern of heel cup collapse in someone who pronates bilaterally still reflects the typical shift in weight bearing with malalignment: right leans in much more than the left, leading to desperation measures using duct tape to reinforce the right heel cup medially.
additional biomechanical stresses on the adjacent discs and facet joints (see Fig. 45).
b. The key muscles that act on an SI joint: piriformis, gluteus maximus and iliopsoas (see Figs. 2, 3 and 39), especially if the joint has become:
i. Unstable as a result of ligament laxity and/or actual joint degeneration, or


Fig. 53. Typical asymmetrical wear pattern of the soles seen with malalignment. Right ( $R$ ) side: increased wear posterolaterally in the heel (reflecting the increased varus angulation of the right foot at impact; see Fig. 48) and medially in the forefoot (reflecting the tendency to pronation). Left ( $L$ ) side: wear in the heel affects a wider area, located more posteriorly and medially (reflecting the comparatively decreased varus angulation at impact) and more laterally in the forefoot (reflecting the tendency to supination).


Fig. 54. Pattern of heel cup collapse typically seen with left anterior and locked rotational malalignment, reflecting the tendency to left pronation, right supination.
ii. Painful from irritation of joint surfaces, supporting capsule and/or ligaments.
c. The myofascial slings ${ }^{6,15,17,29,32,38-40}$; for example, those that help to stabilize the pelvis and spine:
i. The anterior oblique support systems, formed in part by the anterior abdominal fascia connected to the external/internal obliques and rectus abdominis; and


Fig. 55. Structures put under stress by the malalignment-related shift in weight-bearing, tending to right pronation and left supination. ITB, iliotibial band; LCL, lateral collateral ligament; MCL, medial collateral ligament.


Fig. 56. Peripheral nerves in the left leg affected by a shift in weight bearing. (A) Nerves affected by pronation forces. (B) Nerves affected by supination forces. (Schamberger 1987).


Fig. 57. Callus formation reflective of shift in weight bearing. (A) Subject $A$ is in alignment, feet pronate to equal extent: symmetric callus bilaterally under the second and third metatarsal (MT) heads reflects shift caused by relatively short first (Morton's) toe and collapse of the anterior transverse arch. (B) Subject B (out of alignment): asymmetrical callus formation reflects malalignment-related shift in weight bearing, $(B i)$ more medially on the pronating right side, under the second MT head (indicated by single arrow) and (Bii) more laterally on the supinating left side, under the fourth and fifth MT heads (indicated by the two arrows).


Fig. 58. The effect of slope on the malalignment-related shift toward right pronation, left supination. (A) Usual shift, with both feet leaning into left side, noted when on level ground. This tendency $(B)$ is accentuated on a grade sloping down to the left and (C) decreased on a grade sloping up to the left.


Fig. 59. Typical sites of increased muscle tension (and often tenderness) seen with pelvic malalignment and also minimal rotation of a vertebra (here shown at the interscapular level). If a muscle involved shows increased tone bilaterally, the one indicated here is usually the one affected more severely. TFL/ITB, tensor fascia lata/iliotibial band.


Fig. 60. Ober's test for limitation of hip adduction. (A) In a person with an upslip or rotational malalignment: $(\mathrm{Ai})$ the right adducts to touch the plinth, (Aii) left adduction is limited, and (Aiii) the facilitated left tensor fascia lata/iliotibial band complex proves consistently tense (and usually tender along part or all of its length). (B) After realignment: left adduction now equals that on the right.
ii. The posterior oblique system, formed in part by latissimus dorsi on 1 one side connected by the thoracolumbar fascia to gluteus maximus on the opposite side.

## Clinical correlation for runners

Chronic contraction of a muscle can eventually result in:

1. Tension myalgia, as well as development of trigger points within the muscle;
2. Irritation and inflammation at the myotendinous and fibro-osseous junctions; and
3. Inhibition or alteration of movement patterns that involve the tender muscle or the myofascial sling that it is part of; and


Fig. 61. Changes in tension resulting with the shift of a muscle origin toward or away from the insertion with an innominate anterior rotation: tension increased in biceps femoris, decreased in iliacus, rectus femoris and tensor fascia lata/iliotibial band (ITB) complex. The reverse changes occur with a posterior rotation.
4. Referral from the myotome itself and/or a trigger point to a distant site(s).

## Asymmetry of Muscle Strength and Bulk

Muscle strength is affected in a typical asymmetrical pattern that is more readily apparent in the lower extremities. Compared with their partner on the opposite side, a functional weakness ranging from $3+$ to $4+/ 5$ is consistently seen:

1. In the right: ankle invertors (tibialis anterior/posterior); hip flexors (iliopsoas, quadriceps) and extensors (primarily gluteus maximus); hip adductors; extensor hallucis longus.
2. In the left: ankle evertors (peroneus longus/brevis); hip abductors (gluteus medius/ minimus; TFL); hip external/internal rotators; hamstrings.
This asymmetrical pattern of weakness is consistently seen with either a right or left upslip and all the variations on rotational malalignment except for the left anterior, right anterior and left SI joint locked one, in which the findings are reversed.

Some of the muscles typically found to be weak on 1 side (eg, right quadriceps) may actually seem to be full strength $(5 / 5)$ on manual testing. This finding is likely to be more a reflection of the inherent strength of these muscles which the examiner just cannot overcome. In the case of the quadriceps, side-to-side differences may be detectable only on dynamometer studies, ${ }^{26,27,34,41}$ which have also shown that:

1. Both the power and endurance of the quadriceps can be reduced in the presence of malalignment and both can increase immediately following realignment; and
2. The increase in strength after manipulation may be greater for an eccentric than a concentric quadriceps contraction; the latter will frequently not improve at all.

The asymmetrical pattern of weakness cannot be ascribed to laterality; for example, handed/footedness, eye dominance or preferential hearing lateralization. ${ }^{26,27}$ Explanations proposed include:

1. Impaired proprioceptive or kinesthetic awareness ${ }^{36}$;
2. Dysfunction at the level of the spine, brain stem, or cortex ${ }^{35}$;
3. Impaired cerebrospinal fluid circulation (as manifest by the ability to achieve realignment using the craniosacral release technique) ${ }^{20}$; and
4. Lateralization of motor dominance to the left (70\%) or right (15\%).

As the malalignment persists, there can be evidence of a change in muscle bulk on side-to-side comparison (Figs. 62 and 63). The difference may reflect:

1. Reorientation of muscle fibers relative to the midline, placing some muscles in a position of advantage so that they end up increasing in size because of increased efficiency and/or demand; in contrast, their partner on the opposite side may now work at a disadvantage and ends up losing bulk;
2. Wasting as a result of a change in style of walking or running, in an attempt to:
a. Accommodate the biomechanical changes that have occurred;
b. Off-load a painful structure; for example, joint, tendon, or other soft tissue; or
c. Minimize the use of a muscle that has become painful, leading to disuse wasting.


Fig. 62. Quadriceps asymmetry in a person with malalignment (right anterior, left posterior innominate rotation): wasting of right and hypertrophy of left vastus medialis (VM).


Fig. 63. Quadriceps bulk of the person in Fig. 62, delineated with a laser scanner. (A) Asymmetry of vastus medialis (VM) noted with the malalignment: right wasted, left hypertrophied. (B) Almost symmetric VM bulk within 4 months of maintaining alignment and return to regular activities (ie, no selective muscle strengthening). (From Schamberger W. The malalignment syndrome: Diagnosing and treating a common cause of acute and chronic pelvic, limb and back pain. Edinburgh (UK): Churchill Livingstone; 2013.)
c. A muscle contracting inappropriately; for example, out of sequence with other muscles in an 'inner' or 'outer' sling or failing to respond at all on attempted volitional contraction. ${ }^{37,42}$

## Clinical correlation for runners

1. The runner may sense that 1 leg (typically the right) is weaker or somewhat unstable on weight bearing compared with the other one (see: 'Impaired balance and recovery') and may experience one leg fatiguing more readily or feeling sore as from overuse (see Case History: Runner A and B).
2. The runner participating in biathlons or triathlons, the leg on 1 side may:
a. Feel weak on the bike in terms of the amount of power it can generate and a tendency to fatigue more easily; and
b. Seem to move differently compared with the other side, with movement not being as spontaneous (or even awkward) on the weak side (Fig. 64).

Some authors have attributed these problems to a malalignment-related leg length difference, with one study showing up to a $5 \%$ decrease in power generated and a loss of pedal stroke efficiency on the short leg side. ${ }^{24}$
3. Realignment results in immediate return of full strength in most lower extremity muscles. The left hip abductors may show only partial improvement initially, but usually recovers full strength within days or 2 to 3 weeks at the most once alignment is being maintained for longer periods of time.
4. Muscle bulk usually recovers spontaneously within 2 to 3 months, but may be assisted by doing selective strengthening.

## Asymmetrical Ligament Tension

The biomechanical changes that occur with these 2 presentations can affect ligaments secondarily by placing them:


Fig. 64. Relationship of the knees to the midline (crossbar) in a cyclist with an upslip or rotational malalignment and the typical rotation of the legs (right outward, left inward; see Figs. 42, 47B, 55). (A) On pushing down on the pedal, the right knee moves toward midline, combining hip/knee extension, foot pronation, and a tendency to genu valgum. (B) On coming up, the right knee moves away from midline, with external rotation of the leg as the knee flexes. In contrast, the left knee maintains a relatively neutral position, traveling primarily in the sagittal plane throughout both phases.

1. Under increased tension; examples include: (Figs. 65 and 66); examples include:
a. The medial collateral ligament of the knee on the side of excessive pronation and secondary shift toward genu valgum; the lateral collateral ligament on the neutral or supinating side, with shift toward genu varum (see Figs. 55 and 56);
b. Posterior and interosseous SI joint ligaments (Figs. 1A and 2A), also the sacrotuberous and sacrospinous, on the side of a posterior rotation (see Figs. 65A and 66B);
c. Long dorsal sacroiliac ligament with an upslip or anterior rotation (see Fig. 65B); and
d. The medial ankle ligaments and flexor retinaculum on the pronating side, lateral ligaments on the supinating side (Figs. 55, 56 and 79).
2. In a slackened position:

Tension would be decreased in the counterparts of the ligaments mentioned in point \#1, above; for example, the sacrotuberous, sacrospinous with an anterior rotation, the long dorsal sacroiliac ligament with a posterior rotation.

## Clinical correlation for runners

1. Ligaments put under tension:
a. These gradually lengthen, decreasing their ability to support a joint. On realignment, laxity of these ligaments predisposes to recurrence of the malalignment, until they finally regain their normal length.
b. The pain-transmitting $C$ nerve fibers within ligaments can neither stretch as quickly nor as much as the elastic components, making them vulnerable to irritation, inflammation, and even disruption. They can become a source of localized and/or referred pain and paresthesias, long before elongation of the elastic components has reached its limit (see Case History: Runner A). ${ }^{43-45}$


Fig. 65. Ligaments put under tension by the movement of an innominate or the sacrum relative to each other. (A) Posterior rotation or a downslip: sacrotuberous, sacrospinous, also interosseous ligaments (not shown; see Fig. 1B). (B) Anterior rotation or an upslip: long dorsal sacroiliac ligament. PSIS, posterior superior iliac spine.


Fig. 66. Sacrospinous ligament origins and insertions on an anteroposterior view of pelvis. (A) The distance between the right origin and insertion (light dots) is equal to that on the left (black dots). (B) With rotational malalignment (right anterior, left posterior): the origin and insertion are brought closer together on the right and separated on the left.
2. Ligaments put in a slackened position:
a. These gradually undergo shortening, or contracture, and may limit joint range of motion.
b. They can be one cause of post-realignment pain (see "Implications for the treating physician").

## Asymmetrical Lower Extremity Range of Motion

Side-by-side comparison shows asymmetry of the range of motion attainable in any joint from the neck down to the great toes (Figs. 67-71). Differences of $10^{\circ}$ to $15^{\circ}$ are not uncommon. However, adding up the total range available in a particular line of movement (eg, hip flexion and extension) on 1 side equals that available on the opposite side. Barring any abnormalities of the joints (eg, degeneration, inflammatory conditions, contracture), realignment results in immediate return of equal bilateral ranges of motion. Frequently, the total range available in a particular direction actually comes to exceed that noted before correction by $5^{\circ}$ to $15^{\circ}$, as key muscles relax and allow other joints to regain their normal range of motion (see Figs. 67B and 68C).

## Clinical correlation for runners

1. Changes in pelvic and lower extremity ranges of motion can affect the gait cycle by causing side-to-side differences of the swing-through and stance phase. ${ }^{32,38}$ Any compensatory measures are likely to alter style, decrease efficiency and increase energy costs.
2. The malalignment results in changes that, in combination, will make it harder for the runner to bring the straight leg upward on 1 side. For example, in the runner with a right anterior rotation, this movement can be limited in part by:
a. Physical obstruction from the downward displacement of the right anterior acetabular rim with anterior rotation (see Fig. 67Ai);
b. The increased tone noted particularly in right gluteus maximus, biceps femoris and piriformis, in part owing to facilitation (see Fig. 59) and the further separation of their origin and insertion that occurs with this movement (see Fig. 61); and
c. Other factors, such as contracture of soft tissues that have been put into a relaxed or shortened state (e.g. right sacrotuberous and sacrospinous ligaments relaxed with right anterior rotation) (Figs. 65B and 66B, respectively), may also come into play.


Fig. 67. Effect of alignment on passive hip flexion and extension, tested with knees in flexion. (A) With rotational malalignment (right anterior, left posterior): (Ai) limitation of right hip flexion ( $105^{\circ}$ ) compared with the left ( $115^{\circ}$ ); (Aii) limitation of left hip extension $\left(10^{\circ}\right)$ compared with (Aiii) that on the right of $25^{\circ}$. (B) In alignment: hip flexion is now equal and actually increased to $130^{\circ}$, with extension equal at $25^{\circ}$.
3. Limitations would affect particularly a sprinter, who usually depends on greater stride length, and a hurdler or steeplechaser, who has to clear a barrier; all require more of the available range of motion of certain joints than a middle or distance runner. Some runners may be able to adapt their style to take advantage of these asymmetries of available ranges. For example, the fact that 1 hurdler preferentially approaches a jump with the right leg leading may reflect an increase in right hip flexion and left internal rotation (relative to their counterparts) that makes it easier to carry out the jump this way. However, it puts that same hurdler at a disadvantage


Fig. 68. Trunk rotation in sitting. ( $A, B$ ) Malalignment of the pelvis is present. ( $A$ ) Right rotation to $45^{\circ}$. (B) Left rotation limited to $35^{\circ}$. (C) On realignment, left came to equal right rotation, with improvement to $55^{\circ}$ now evident bilaterally.
and increased risk of injury if for some reason he or she is thrown off stride (eg, clipping a hurdle; an awkward landing and recovery) and has to take the next jump with the left leg leading and the right one trailing. He or she is then forced into and may even exceed the relative limitation of left hip flexion and right internal rotation, with the attendant risk of injury (Fig. 69).

Limitations of particular concern include:

1. Left pelvic and often also trunk rotation in the horizontal plane; that is, counterclockwise (see Fig. 68B; Fig. 70). The runner can try to compensate for the effect on stride length by:
a. Actively increasing left trunk rotation in an attempt to bring the pelvis further back on the left and lengthen stance phase on that side;


Fig. 69. Internal rotation of the hip. (A) In alignment: symmetric ( $40^{\circ}$ bilaterally). (B) With malalignment present: right decreased, left increased ( $30^{\circ}$ vs $50^{\circ}$, respectively). In both situations, total equals $80^{\circ}$.
b. Voluntarily decrease left swing-through to match the limitation on the right side; or
c. A combination of increased trunk rotation and reduction in swing-through.
2. Hip extension or flexion (see Fig. 67)
a. Any limitation of these could decrease the ability of the leg to go through full swing-through or stance phase, respectively. In an attempt to achieve equal


Fig. 70. Asymmetry of pelvic rotation around the vertical axis in the horizontal plane typically seen with rotational malalignment. (A) Active clockwise rotation to $40^{\circ}$. (B). Active counterclockwise rotation limited to $30^{\circ}$. Note the decreased facial, shoulder girdle, and chest profile compared with that seen in (A).


Fig. 71. Effect of an upslip and the more common patterns of rotational malalignment on ankle range of motion assessment, with relative increase of active and passive (A) right dorsiflexion and ( $B$ ) left plantarflexion.
stride length, the runner can actively increase ankle plantarflexion on swingthrough, go into a supination pattern of weight bearing earlier in stance phase, and/or land more on the forefoot to increase the length of the respective extremity.
3. Limitation of left ankle dorsiflexion, right plantarflexion (Fig. 71):
a. Right dorsiflexion is increased, contributing to the tendency to pronation and risk of developing plantar fasciitis and Achilles tendonitis on this side (see Figs. 47B, 49A, B, and 79, also "Implications for the treating physician"). ${ }^{46}$
b. Left plantar flexion is increased, augmenting the tendency to supination. Together, these make for a more rigid foot, poor at shock absorption, increasing:
i. The stress on proximal joints, muscles and soft tissue structures as more of the impact is now transmitted upward; and
ii. The risk of sustaining an ankle strain or stress fracture on this side.

## Apparent or Functional Leg Length Difference

The most common finding is that the right iliac crest ends up higher than that on the left when standing (see Figs. 13C, D and 17). The pelvic obliquity persists in sitting, unlike someone with an anatomic long leg whose pelvis would now be level; however, a concomitant underlying anatomic leg length difference could not be ruled out at this point. Most likely, the right side will continue to be higher, although a reversal (with the left side now higher) may become evident on sitting. That a pelvic obliquity is present in both standing and sitting merely suggests that pelvic malalignment is likely present but knowing this, or which iliac crest is higher, is not necessarily helpful in determining the side of an anterior rotation or an upslip. Also, leg length per se can be affected by other factors, including contracture and asymmetry of tension in the muscles and ligaments of the pelvic girdle and hip region.

## Clinical correlation for runners

1. Confirmation of the apparent leg length difference and the type of malalignment present depends on looking at the runner in several positions (standing, sitting and lying), checking for leg length changes on the sitting-lying test and assessment of pelvic landmarks.
2. Differences in leg length of as much as 2 to 4 cm :
a. Can be attributable entirely to the presence of rotational malalignment, an upslip, or a combination of these; and
b. May reverse completely on changing from long sitting to supine lying.
3. Whereas $80 \%$ to $85 \%$ of the adult population present with pelvic malalignment, only $6 \%$ to $12 \%$ of them actually have an anatomic leg length difference of 5 mm or more. ${ }^{26,27,47}$ Some runners may benefit from a heel lift once in alignment to avoid stresses attributable to the leg length difference and secondary changes (eg, pelvic obliquity, compensatory scoliosis).

## Impaired Balance and Recovery

A problem with balance and recovery is most noticeable on kinetic testing, particularly single leg stance (see Fig. 23). For example, the runner may have no problem supporting weight on the left leg alone, whereas carrying out the maneuver on the right side is at best achieved with increased concentration on the effort or may result in an obvious swaying of the pelvis and/or trunk to maintain balance. At worst, the runner is unable to carry out the maneuver at all. ${ }^{37,48}$ An obvious side-to-side difference may also become evident on toe walking and hopping on 1 foot (see Fig. 49).

The imbalance is likely a reflection of a combination of factors, including:

1. The asymmetry of weight bearing, with relative instability noted on the side of pronation where:
a. The foot and ankle are unlocked and more mobile (Fig. 72A); and


Fig. 72. Mobility of the foot and ankle related to the axes of the transverse tarsal joint. (A) When the calcaneus is in eversion (eg, pronation), the conjoint axis between the talonavicular and calcaneocuboid joints are parallel to one another so that increased motion occurs in the transverse tarsal joint. (B) When the calcaneus is in inversion (eg, supination) the axes are no longer parallel and there is decreased motion and increased stability of the transverse tarsal joint. (From Mann R. Biomechanics of running. In: Mack RP, editor. American Academy of Orthopedic Surgeons: symposium on the foot and leg in running sports. St Louis (MO): CV Mosby; 1982. p. 1-29.)
b. The Q-angle increases and the knee ends up no longer positioned directly over the foot (see Figs. 42A, and 55).
2. The asymmetry of muscle strength and tension.
3. Asymmetry of proprioceptive input from the pelvis, lower extremity joints and soft tissues, including the soles of the feet (see Fig. 50).

## Clinical correlation for runners

The runner can experience a sensation of a knee or hip giving way unexpectedly, sometimes preceded by a sharp pain, yet examination may fail to show any joint instability or tenderness. One explanation proposes that subconscious or conscious pain originates from soft tissues or nerves that:

1. Are already in trouble because of the malalignment; and
2. Lie either in the vicinity of a joint or can refer pain to this joint or to a distant site; for example, the T12/L1 lateral cutaneous branch referring to the lateral hip region (Fig. 83A3, B3); the hip joint ligaments referring to the lateral knee joint area (see Fig. 1A; Fig. 73).
The pain can cause a reflex relaxation of muscles that support the joint and result in it giving way. For example:
3. Relaxation of the quadriceps can make the knee buckle, an impulse that temporarily shuts down piriformis and gluteus maximus can have a similar effect on the hip joint, allowing it to collapse into flexion. Both mechanisms could cause the runner to stumble or fall.
4. Episodic giving way of one leg has also been ascribed to sudden failure of one or more of the key muscles that ensure stability of the SI joint, resulting in the so-called slipping clutch phenomenon. The sensation of something giving way in the hip girdle region is more likely to occur on initial weight bearing when standing up and also on entering the stance phase while walking or running. ${ }^{49}$
5. Recurrent ankle sprains are often attributed to having a chronic unstable ankle with lengthening of ligaments resulting from cumulative sprains. However, in those who are out of alignment, no lengthening or obvious instability or even tenderness may be evident on examination. The shift toward right pronation and left supination, as well as the relative weakness of right ankle invertors and left evertors, predispose to a right eversion, left inversion sprain. However, some runners have obvious difficulty when trying to move the foot and ankle in a specific direction on command (eg, the right down/up and in to test invertors, the left down and out for evertors); this difficulty can usually be overcome simply by providing tactile, verbal, and/or visual feedback. The fact that, in the absence of obvious ligament laxity, this apparent deficit can sometimes resolve with realignment suggests that the runner may be experience a feeling of instability, a problem of insecure foot placement and a tendency to recurrent ankle sprains which is attributable to one or more of the following factors:
a. The functional weakness, possibly a delay or actual failure to initiate a contraction (also referred to as a pseudoparesis ${ }^{37,48}$ ) of right ankle invertors or left evertors;
b. Some instability of the joint secondary to the malalignment; for example, of the right transverse tarsal joint, with the increase in dorsiflexion/tendency to pronation (see Fig. 72); and
c. Temporary ligament (and possibly joint) deafferentation, with impaired proprioception and kinesthetic awareness, a conjecture supported by research on


Fig. 73. Referred pain patterns from the iliofemoral and pubofemoral ligaments of the hip joint noted with hip joint instability. H, location of the hip joint; HF, referral from the femoral attachments; HP, referral from the pelvic attachments. (Adapted from Hackett GS. Ligament and tendon relaxation (skeletal disability) treated by prolotherapy (fibro-osseous proliferation). 3rd edition. Charles C. Thomas, Springfield, IL 1958.)
subjects who recently sustained a sprain or who had chronic unstable ankles but no evidence of ligament laxity. ${ }^{50,51}$

## Case Histories

The following case histories illustrate some of the phenomena seen as a result of the biomechanical and other changes that are part of the malalignment syndrome.

## Runner A: referred pain phenomenon presenting as heel pain

A 2:20 marathon runner first became aware of right heel pain after a 12-mile run along winding trails. There were no obvious problems during the run, no twisting or undue jarring. The pain became persistent, varied in intensity, and could be felt consistently on weight bearing but sometimes also when just resting. Pain at heel strike led to a change in gait, favoring the right side, eventually resulting in obvious wasting of the right buttock and lower extremity muscles. After a run of

10 miles or longer, the right leg muscles would ache in a way his muscles used to feel in both legs on completion of a marathon in the past. He had never had any back pain. Radiographs, a computed tomography scan, and a bone scan of the foot and ankle were all normal and there was never any localizable tenderness or pain elicited on the standard back examination and on stressing the soft tissue structures and joints of the pelvic girdle and right lower extremity. The pain failed to respond to:

1. Analgesics and courses of various antiinflammatory medications;
2. The use of a right heel lift for a supposed shorter right leg;
3. Provision of orthotics with bilateral 4 mm medial posting of forefoot and hindfoot to counter the problem of overpronation presumed to be present on both sides; and
4. Standard physiotherapy treatments, acupuncture and, once, an injection of xylocaine into all the soft tissues around the right calcaneus.

Seven years after onset of the pain, an osteopath rightly attributed the pain to the pelvis being out of alignment. The pain disappeared immediately on realignment using the MET; it returned with any recurrence of the malalignment during the initial treatment period, but stopped altogether once he started maintaining alignment for longer periods of time. After correction, leg length was equal and he was noted to supinate slightly to equal extent bilaterally (Fig. 74), in contrast with the obvious pronation noted on the right side before realignment (see Fig. 51A). Right muscle bulk recovered to equal that on the left just with an increase in his walking and running and without him having done any selective strengthening (see Figs. 62 and 63 ). However, his training and racing were affected from the onset of the heel pain so that he never again managed to run close to the times he had posted previously.

## Analysis of case history of runner A

1. This runner's heel pain was erroneously attributed to a number of problems, leading to inappropriate treatment measures that could easily have resulted in further harm. The shift in weight bearing was missed because of failure to examine the wear of his


Fig. 74. This runner had a pattern of right foot pronation, left supination evident when malalignment was present (see Figs. 47B and 51). On realignment, the true weight-bearing pattern became evident: bilateral, symmetric supination, with both heel cups now leaning out $5^{\circ}$ (see Case History: Runner A; also Runner B, see Fig. 78B).
shoes and assess the gait pattern under stress; for example, toe walking and hopping. In reality, excessive pronation was occurring only on the right side (see Fig. 51A). Provision of orthotics posted medially on both sides merely reinforced the malalignment-related biomechanical forces on the left side that were already causing the left foot to supinate (see Fig. 55; Fig. 75). It also failed to counter the right pronation, because this was in part owing to outward rotation of the lower extremity/foot and increased ankle dorsiflexion possible on this side (see Fig. 47B and 71). The diagnosis of supposed leg length difference had been based on examination of leg length in only 1 position: supine lying.
2. The heel pain resulted from irritation of S1 root fibers supplying the sacrospinous and sacrotuberous ligaments, because these were subjected to increased stress by the malalignment (Figs. 76 and 77). On the basis of referral, the brain had mistakenly attributed them to originating from the calcaneal bone and possibly the skin overlying the heel, which are part of the S1 sclerotome and dermatome, respectively.
3. The combination of failure to come up with the correct diagnosis and the ensuing pursuit of misguided treatment measures over the 7-year period effectively ended his running career at the national and international level.

## Runner B: biomechanical stresses on the left tensor fascia lata/iliotibial band complex

A 26-year-old long distance runner was seen within days of having failed in his third attempt at finishing a marathon. On each occasion, he had become aware of increasing pain over the lateral aspect of the left hip and upper thigh from around the 15 -mile mark and had to withdraw from the race within the next 5 miles because the pain became unbearable. The pain would settle quickly with rest, allowing him to return to training within days. The 2 previous episodes had been attributed to a left


Fig. 75. A person with right anterior, left posterior innominate rotation. (A) Tendency to right pronation, left supination. ( $B$ ) The effect of providing bilateral orthotics with a medial raise (posting): a decrease of right pronation, worsening of left supination.


Fig. 76. Nerve root versus referred pattern of dysesthesias. (A) S1 radiculopathy pattern. (B) Referred pattern from lower posterior sacroiliac (SIJ-D), sacrotuberous (ST), and sacrospinous (SS) ligaments associated with sacroiliac joint instability. (Adapted from Hackett GS. Ligament and tendon relaxation (skeletal disability) treated by prolotherapy (fibro-osseous proliferation). 3rd ed. Charles C. Thomas, Springfield, IL 1958).
trochanteric bursitis, despite the fact that injections of local anesthetic and cortisone into and around the bursa shortly after each of these attempts had failed to bring even temporary relief.
The examination after the third attempt showed the following:

1. There was no edema or increased warmth noted in the tissues overlying the left greater trochanter.
2. The left TFL/IT band complex (see Figs. 55 and 60Aiii) was:
a. Tender from origin to insertion and
b. Tight to the point of snapping across the greater trochanter (GT) on passive hip extension/flexion.
3. Muscles in the lower extremities showed asymmetrical weakness; specifically, strength in left hip abductors was $4 / 5$ compared with full ( $5 / 5$ ) in the right ones.


Fig. 77. Referral patterns from the posterior sacroiliac ligaments. From the superior segments: Relaxation (laxity) of the lumbosacral (LS) and upper portion of the sacroiliac articulations ( A and B ) occur together so frequently that their referred pain area from the iliolumbar ligament and $A B$ are combined in one dermatome. From the inferior segments (C and D): Relaxation occurs together so frequently that their referred pain areas from D and sacrospinous and sacrotuberous (SS-ST) are combined in one dermatome. SN, sciatic nerve. (Adapted from Hackett GS. Ligament and tendon relaxation (skeletal disability) treated by prolotherapy (fibro-osseous proliferation). 3rd ed. Charles C. Thomas, Springfield, IL 1958.)
4. Left hip adduction was restricted compared with the right side (see Fig. 60Aii).
5. Rotational malalignment (right anterior, left posterior) had resulted in a shift of weight bearing: the right foot rolled inward, the left outward, a pattern that was confirmed by the collapse of the heel cups of his runners to the left (see Fig. 78A).

After realignment:

1. The left TFL/IT band complex showed no tenderness and tone now equaled that on the right, allowing the left to adduct to the same extent as the right one (see Fig. 60B).
2. Left hip abductor strength normalized at $5 / 5$, on par with that on the right side.


Fig. 78. Case history: runner B's training shoes. (A) A pair used for 6 months before correction of the malalignment. Note the heel cup collapse (inward on the right, outward on the left) and increased left lateral heel wear and compression with supination. (B) A pair (identical make to those in $A$ ) used for 6 months while maintaining alignment; the heel wear is even and heel cups symmetric, positioned in neutral (vertical).
3. The shift in weight bearing was no longer evident; both feet were in a neutral position at heel strike and then rolled into a few degrees of supination.
4. He went on to complete his first marathon 6 months later without experiencing any pain in the left hip region. An examination after the race showed no tenderness over the TFL/IT band. After 6 months wear, the heel cups of his new running shoes had maintained a vertical position bilaterally, in keeping with his true weight-bearing pattern: neutral to slight supination (see Fig. 78B).

## Analysis of case history of runner B

1. On initial examination after his third attempt, there were no findings in keeping with a bursitis. The rapidity of his recovery with rest would also argue against that diagnosis, as did his favorable response to realignment.
2. The malalignment had resulted in the increase in tension in the left TFL/IT band complex, in keeping with the changes noted with a malalignment syndrome:
a. An automatic increase in tone (facilitation) in the left TFL compared with the right (see Figs. 59 and 60Aii); and
b. Increased tension on the left complex with the shift in weight bearing, increasing supination of the left foot and secondary tendency to left genu varum (see Fig. 55).
3. Asymmetry of strength, with relative weakness of left TFL and hip abductors, resulting in earlier fatiguing of these muscles with prolonged exertion.
4. The resulting pain would have caused a further, reactive tensing of these muscles.

## SORTING OUT COMBINATIONS OF THE 3 COMMON PRESENTATIONS

As indicated, the 3 common presentations can occur in isolation or with 2 or all 3 together at any time. Supposing that a runner who, in fact, has equal leg length, presented with a 'right anterior, left posterior rotational malalignment' combined with a 'right outflare/left inflare' and also a right 'upslip':

1. On initial examination there would be:
a. Pelvic obliquity noted in all positions of examination.
b. In keeping with the right anterior rotation: asymmetry of all pelvic landmarks on side-to-side and front-to-back comparison (see Fig. 13) and a lengthening of the right leg, shortening of the left, when lying down on the sitting-lying test (see Figs. 16 and 25).
c. In keeping with the flare noted: the right ASIS further out from midline (see Fig. 14Ai) and lower than the left one when observed with the runner lying supine (see Fig. 18A, B).
2. The outflare/inflare is corrected successfully by blocking attempted movement of the knees (outward on the low right, inward on the high left side; see Figs. 20 and 22). The right and left $\overline{A S I S}$ and $\overline{\text { PSSIS }}$ will now be equidistant from midline and level with each other (see Fig. 14Aii, Bii and 18C).
3. In $90 \%$, correction of an outflare/inflare simultaneously corrects a coexisting rotational malalignment. If that has not happened, there would be persistence of the asymmetry of the landmarks, the apparent leg length difference and the relative lengthening of the right leg that was noted on the initial sitting-lying test on lying down (see Figs. 16 and 25).
4. Correction of the rotational malalignment using MET—blocking right hip extension, left hip flexion (see Figs. 28-34)-uncovers the underlying right upslip with persistence of the pelvic obliquity, upward displacement of all the right landmarks, and a relative shortening of the right leg but both legs now moving together on the sittinglying test (see Fig. 40). Successful correction by using repeated gentle traction on the right leg (see Fig. 41) will result in a level pelvis and symmetric landmarks, including matching malleoli that move together.

## IMPLICATIONS FOR THE TREATING PHYSICIAN

The signs and symptoms seen in association with pelvic malalignment and the malalignment syndrome may cause confusion that can result in misdiagnosis, inappropriate and possibly harmful investigation and treatment and failure to provide the treatment indicated. Recognition of malalignment is of significance because it can aggravate, mimic, overlap with or precipitate another medical disorder. The following discussion describes problems typically seen in runners presenting with an upslip or rotational malalignment and associated malalignment syndrome. Given the tendency to right pronation, left supination, a number of the abnormal forces are accentuated by running on a road sloping down to the left; that is, against the traffic in North America (see Fig. 58).

## Aggravation or Precipitation of Another Medical Disorder

In the runner with an upslip or rotational malalignment, these disorders primarily involve the neuromusculoskeletal system and problems are in large part the result of the associated shift in weight bearing, instability of the pelvic ring, and asymmetric muscle strength and tension. Typical examples include the following.

## Back pain arising from conditions of the pelvis or spine

The runner may have a known condition of the spine, such as a bulging or protruding disc, facet joint degeneration, spondylolisthesis, progressive idiopathic scoliosis, and yet remain asymptomatic. ${ }^{52,53}$ Superimposing the stresses attributable to malalignment, with pelvic obliquity and compensatory curves, can tip the balance and cause these conditions to become symptomatic. Superimposing these stresses on a normal pelvis and spine can also result in back pain eventually. ${ }^{39,54-57}$ For example, the rotation of the L1-L4 vertebrae into a compensatory right lumbar convexity closes the left and opens the right facet joints (see Fig. 26; see also Fig. 46). Either facet joint can
eventually become symptomatic; for example, with irritation of the approximated surfaces and/or nerve fibers lying in the vicinity of the joint or within ligaments/capsules that end up elongating on being put under increased tension with any separation of the surfaces. Simply realigning the pelvis to remove these additional stresses may resolve the discomfort.

## Hip and knee joint osteoarthritis

Pelvic malalignment that results in a functional leg length difference and asymmetric weight-bearing changes the loading pattern on the hip and knee joint surfaces. Leg length difference, whether anatomic or functional, has been implicated in the acceleration of hip and knee osteoarthritis. Degeneration and pain are more likely to involve the hip joint on the long leg side and the knee on the short leg side. ${ }^{33}$ With the malalignment, the problem is compounded by 1 lower extremity turning outward, the other inward (see Figs. 42 and 47), also by the tendency toward genu valgum on 1 side and genu varum on the other (see Figs. 42, 55 and 56).

## Iliotibial band friction syndrome

As part of the TFL/IT band complex, the left IT band in particular is at risk of becoming irritated and inflamed, sometimes coupled with an underlying bursitis, where:

1. The TFL/IT band runs across the greater trochanter, and
2. The lateral IT band crosses the lateral femoral condyle.

The problem is more likely to occur on the left side and there may be snapping over either prominence, with tension increased in the complex on this side as a result of:

1. Facilitation of the left TFL (see Figs. 59 and 60Aii); and
2. Separation of its origin and insertion with the tendency to supination/secondary genu varum, also with a left innominate posterior rotation (see Figs. 55 and 61).

## Patellofemoral compartment syndrome

The malalignment can trigger or aggravate a patellofemoral syndrome, more likely to affect the right patella and its lateral facet owing to a combination of factors:

1. Lateral displacement of the patella with:
a. The increase in the Q-angle, as the right foot pronates and the knee tends toward genu valgum (see Figs. 42 and 55).
2. Outward rotation of the right femur (see Fig. 42A).
3. Functional weakness, reorientation, and early fatiguing of the right quadriceps affecting especially vastus medialis (see Figs. 62 and 63).

## Plantar fasciitis and achilles tendonitis

These issues are more likely to occur on the side that pronates, given the increased tension in both structures caused by the foot rolling inward (see Figs. 47Aii and 49; Fig. 79) as a result of:

1. A separation of the origin and insertion:
a. Of the fascia, as the longitudinal and transverse arches of the foot progressively collapse through the initial part of stance phase (see Fig. 79B) or
b. Of triceps surae as the calcaneus everts (see Figs. 47Aii and 49).
2. Earlier activation of the windlass mechanism on progressing through foot-flat and in anticipation of push-off from the forefoot (see Figs. 49 and 79). ${ }^{46}$
3. The increased dorsiflexion possible on that side (see Fig. 71).


Fig. 79. Structures put under tension by pronation. (A) The medial terminal branches of the superficial and the distal part of the deep peroneal nerve. (B) On the medial side of the ankle: posterior tibial and medial calcaneal nerve; plantar nerves (in particular, the medial one); plantar fascia, flexor retinaculum and Achilles tendon. ADM, abductor digiti minimi; AHL, abductor hallucis longus. (Schamberger 1987).

## Stress fracture

The runner is at increased risk of suffering a stress fracture of the tibia/fibula (presenting as shin splints) and lateral metatarsals on the left side, on account of:

1. Decreased ability to absorb shock at the foot/ankle level in stance phase, with:
a. Increased plantarflexion range available (see Fig. 71) and tendency to supination; and
b. Left calcaneal inversion, limiting transverse tarsal joint motion (see Fig. 72B).
2. The lateral shift in weight bearing, onto the fourth and fifth metatarsal heads (see Fig. 57Bii).

## Compartment syndrome

Running can result in repetitive overloading and swelling of muscles within a specific compartment, exacerbated by running on a sloping road surface (see Figs. 55 and 58):

1. Right anterior or medial compartment: right pronation increasing traction forces on the functionally weak tibialis anterior and posterior, respectively, both working hard to control the tendency to pronation (see Figs. 55 and 56);
2. Right posterior compartment: right pronation and increased ankle dorsiflexion range augmenting traction forces on triceps surae ${ }^{46}$; and
3. Left lateral compartment syndrome, with left supination increasing traction forces on the functionally weak left peroneus longus/brevis, both working hard to control the tendency to supination (see Figs. 55 and 56).

## Tibial stress syndrome/shin splints

Shin splints may be medial, lateral or anterior. In addition to a possible stress fracture or compartment syndrome, differential diagnoses include:

1. Periostalgia:

Tenderness typically noted along the origin of the right tibialis posterior and left peroneus longus (subjected to pronation and supination forces, respectively).
2. Asymmetrical stresses caused by the malalignment.

The resulting shin splints are usually activity-related, with excessive traction on the periosteal origins, exacerbated by any functional weakness and ease of fatigability:
a. Given the tendency to increased right pronation and shift to medial bearing, more likely to occur on the right side (or right worse than left):
i. Medially: involving tibialis posterior;
ii. Anteriorly: involving tibialis anterior;
b. Laterally: typically involving left peroneus and brevis (see Figs. 55 and 56).
3. Referred pain triggered by the malalignment.

If trigger points, periostalgia, stress fracture, and compartment syndrome have been ruled out, the shin splints may be on the basis of referral, especially if:
a. They are not necessarily activity- related, vary in the shape or area involved depending on which structures are being irritated at any given time, and
b. The discomfort is not confined to the area supplied by a specific nerve and is relieved by realignment (see Case History: Runner A).

In that case, they may be felt:
a. Anteriorly: in the tibial sclerotome with irritation of the sciatic nerve (Fig. 80); or
b. Anterolaterally: from the upper parts of the posterior SI joint ligaments (see Fig. 77) or the ligaments of the hip joint (see Figs. 1A and 73).

## Metatarsalgia, hallux valgus, and medial bunion formation

The tendency to right pronation and medial weight-bearing increase pressure on the medial aspect of the first toe, predisposing to formation of a medial bunion, hallux valgus and, eventually, formation of a secondary Morton's toe (see Fig. 57A, Bi). The shift also increases weight bearing on the sesamoids and medial metatarsal heads, with callus formation (typically noted under the second and third). The runner is at increased risk of experiencing pain from overloading of the right sesamoids and medial metatarsals. Increased left supination predisposes to lateral metatarsalgia and callus formation (see Fig. 57Bii).

## Peripheral nerve involvement

1. Nerves affected by right medial shift and tendency to pronation:
a. Right saphenous and posterior tibial nerve (see Figs. 55 and 56A). Both are put under tension along their length and the saphenous also where it runs under the distal fibula. The posterior tibial is at risk of entrapment and compression within the posterior tarsal tunnel as the overlying flexor retinaculum is also subjected to these medial traction forces (see Fig. 79). ${ }^{58}$
b. Peroneal nerve: deep branch distal to ankle; medial terminals of superficial branch.
c. Left sural nerve (see Fig. 56A). Excessive ankle eversion with pronation approximates the distal fibula, talus, and calcaneus, narrowing the space available for the nerve as it traverses this area. ${ }^{58}$


Fig. 80. Pattern of sciatica caused by sciatic nerve (SN) irritation that can occur with sacroiliac joint instability from relaxation (laxity) of the posterior sacroiliac (A, B, C, D), sacrospinous (SS), and sacrotuberous (ST) ligaments. (Adapted from Hackett GS. Ligament and tendon relaxation (skeletal disability) treated by prolotherapy (fibro-osseous proliferation). 3rd ed. Charles C. Thomas, Springfield, IL 1958.)
2. Nerves affected by left lateral shift and tendency to supination:
a. Left distal plantar nerves (see Fig. 79B). These forces can activate a latent Morton's neuroma by narrowing the space between the third and fourth metatarsal heads, irritating the natural thickening formed here by the junction of a branch from the medial and lateral plantar nerves.
b. Left peroneal nerve (see Figs. 56B and 79A):
i. Proximally, where it winds around the fibula and lies between the 2 heads of peroneus longus, with any excessive traction on the nerve and muscle; or
ii. Distally, if a deviant superficial branch ends up winding around the distal fibula.
c. Posterior tibial nerve (see Figs. 56B and 79B). Excessive ankle inversion with supination can approximate the distal tibia, talus, and calcaneus to the point of irritating or even compressing this distal branch of the tibial nerve within the posterior tarsal tunnel. ${ }^{58}$
3. Meralgia paresthetica.

The lateral femoral cutaneous nerve, formed by contributions from L2 and L3, can be subjected to abnormal traction/compression forces caused by the malalignment as it runs between iliacus and psoas, under the inguinal ligament and to the lateral thigh (see Fig. 21; Fig. 81). Resulting pain and/or paresthesias in the anterolateral and posterolateral thigh region may overlap with symptoms referred to the lateral hip/thigh region (see Figs. 73 and 77) or arising from underlying structures; for example, the greater trochanter (see Fig. 2); TFL/IT band (see Figs. 55 and 59-61).

## Pelvic floor dysfunction, coccydynia, and sacroccoccygeal junction pain

The pelvic floor musculature is part of the "inner core" that, along with the "outer core" muscles, help to stabilize the pelvis and trunk in anticipation of carrying out activities such as walking, running or standing on one leg while maintaining balance (see Fig. 23). ${ }^{3,4,6}$ Pelvic floor dysfunction for whatever reason (eg, pressure on


Fig. 81. Course of the lateral femoral cutaneous nerve (LFCN), which supplies sensation to the skin of the anterolateral thigh region (see also Fig. 21). Irritation/injury can occur at a number of points. On the left side (shown), malalignment-related causes include (1) compression (a) with any excessive/persistent increase in tension in left psoas major and iliacus, as it runs between them, (b) with a left innominate inflare, as it runs under the inguinal ligament (c) at both sites with a left innominate anterior rotation; (2) lateral traction forces caused by (a) a left innominate outflare, (b) excessive left supination, affecting it at the anterior superior iliac spine (ASIS)-inguinal ligament junction and also at the distal point where it is still relatively fixed as it penetrates the subcutaneous layers to reach the skin.
these muscles from an abdominal mass, fibroid, cyst, visceral adhesions/scars) and/or associated sacrococcygeal joint dysfunction can be a cause of instability of the pelvic ring and recurrent malalignment (Fig. 82). ${ }^{40}$ Alternately, the pelvic floor dysfunction may be a complication of malalignment, triggered by changes such as chronic asymmetric tension in pelvic muscles and ligaments. Either way, the pelvic floor dysfunction may complicate the malalignment because it can be associated with coccydynia and visceral symptoms including dysmenorrhea, urinary frequency/urgency/nocturia, stress incontinence, dyspareunia, and vaginal wall pain. ${ }^{16,59-61}$

## Mimicking Another Medical Disorder

## Piriformis syndrome and sciatica

Piriformis syndrome, as originally described by Yeomans in 1928, implies:

1. Compromise of the sciatic nerve where it exits through the greater sciatic notch or subsequently, as it or its tibial and peroneal components pass below, through, or above piriformis on their way to the leg (see Fig. 2), with a sharp, lancinating or burning pain felt in the buttock and radiating below the knee, possibly also dermatomal numbness or paresthesias;
2. Positive straight leg raising and Lasegue's sign; and
3. Increased pain in the distribution of the sciatic nerve or its components on being stressed further by bending/lifting or passively increasing tension in piriformis; for example, passive flexion, abduction and internal rotation (the FAIR maneuver). ${ }^{62}$
A bona fide piriformis syndrome very likely exists. ${ }^{63-65}$ However, the 3 common presentations of pelvic malalignment can all affect piriformis (eg, increased tension with facilitation or reaction to a painful or unstable SI joint; chronic tension myalgia and trigger point formation) to the point of compromising the sciatic nerve or its branches and evoking symptoms and signs that may be similar to those noted

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Fig. 82. Effect of angulation of the coccyx on the inserting ligaments and pelvic floor muscles. (A) Normal angulation of $120^{\circ}$ relative to the sacrum, with a $30^{\circ}$ range of motion; there is normal pelvic floor tone. (B) Excessive extension angulation resulting in hypertonus of the pelvic floor. (C) Excessive flexion angulation resulting in hypotonus of the pelvic floor (eg, passively on sitting in a slouched position); however, this angulation may also result with a chronic increase in tension in pelvic floor muscles from whatever cause (eg, irritation by a fibroid, cyst, or other pelvic mass; malalignment of the pelvic ring).
with a "piriformis syndrome". However, pain/paresthesias in the buttock, possibly with radiation to the posterior thigh and calf, that tend to come and go and vary from day to day in intensity and location are often more a reflection of irritation of the SI joint ligaments, which are primarily supplied by S1/S2 (see Fig. 76), and the SI joint itself. These symptoms usually decrease or resolve completely with realignment. The 2 disorders can coexist and symptoms may overlap. A bona fide piriformis syndrome may become apparent on realignment, in which case specific treatments (eg, physiotherapy, medication, possibly injections, or even decompression) may be indicated to resolve the problem.

## Mid back pain and thoracolumbar syndrome

The thoracolumbar junction area is put under stress when malalignment results in pelvic obliquity and a compensatory curve that reverses in the thoracolumbar region (see Figs. 17, 24, 59 and 70B). These changes, superimposed on the reversal from a lumbar lordosis to thoracic kyphosis and reorientation of the facet joint surfaces between L1 and T11, are capable of triggering mid back pain from discs and facet joints (see Fig. 45). The combination can also precipitate a "thoracolumbar syndrome", with irritation of cutaneous perforating branches originating from the posterior roots of T11, T12 and L1. ${ }^{66}$ Although there may be tenderness elicited with pressure applied to the spine and adjacent muscles in the T11-L1 region, the runner will note pain and/ or paresthesias distal to the site of origin, that is, in the distribution of one or more of the 3 branches (Fig. 83):

1. Anterior: to the inner upper thigh, abdomen and groin (close to McBurney's point and capable of mimicking appendicitis and other problems of the appendix);
2. Lateral: over the lateral hip region (mimicking pain from the hip and trochanter); and
3. Posterior: over the buttocks area (simulating low back/SI joint pain).


Fig. 83. Problems relating to the T 12 and L 1 cutaneous branches. (A1, B1) Posterior branch, low back pain. $(A 2, B 2)$ anterior branch, pseudovisceral pain. ( $A 3, B 3$ ) lateral perforating branch, pseudohip pain. (From Schamberger W. The malalignment syndrome: Diagnosing and treating a common cause of acute and chronic pelvic, limb and back pain. Edinburgh (UK): Churchill Livingstone; 2013. Adapted from Maigne R. Thoracolumbar junction syndrome: a source of diagnostic error. J Orthoped Med 1995; 17: 84-9.)

Symptoms usually respond to manipulation/mobilization of the T11-L1 or to pelvic realignment when malalignment is responsible for the stress on the junction.

## Osteitis condensans ilii, sacroiliitis, spondyloarthropathy

Degeneration of the SI joint may become evident starting in the 30s or 40 s but most people show some mobility and space between the surfaces of the joint well into their 70 s and 80 s. ${ }^{67,68}$ The intricate configuration of the joint (see Fig. 8) combined with any osteoarthritic changes and the effects of joint malalignment-overlapping of joint edges, asymmetrical approximation and separation of surfaces (see Figs. 8-10, 19, and 26) - can easily lead to misinterpretation of findings on radiography, computed tomography scans, or MRI and the clinical examination. As a result, degeneration and inflammatory conditions of the joint are probably overdiagnosed. If there is any concern, a trial of realignment, appropriate laboratory tests, selective joint injection and bone scans are indicated. Malalignment causes asymmetrical stresses on the symphysis pubis (see "osteitis pubis"), facet and SI joints that can result in increased bone turn over. Any SI joint changes seen on a bone scan tend to be asymmetrical, often localized to a small area(s); comparatively higher tracer concentration on one side may result in an SIS ratio that is asymmetric but usually still within normal limits.

## Osteitis pubis

The runner presenting with pelvic malalignment may report pain from the central pubic or groin region which may arise locally or be on a referred basis (see Figs. 77 and 83A2, B2). The pubic bones are displaced relative to each other, stressing the symphysis pubis, which may be painful on direct palpation if not outright symptomatic (see Figs. 10, 13, 24 and 38). Pain on joint distraction would be in keeping with a ligamentous, capsular, or disc problem as these are stressed by the malalignment (see Figs. 1, 2 and 24), whereas pain caused by joint compression is more likely to indicate joint pathology. Degenerative changes on radiographs and a positive bone scan could be consistent with such pathology. However, findings suggestive of osteitis pubis can result with the increased stress on the pubic symphysis caused by malalignment and hip/SI joint dysfunction. ${ }^{69}$

## Post-realignment pain and paresthesias

In the first 2 to 4 weeks after the initial realignment, some runners may experience pain or paresthesias in places that were never a problem while malalignment was present. Typically these symptoms, which may be mistakenly thought to be an entirely new problem affecting some part of the neuromusculoskeletal system, can arise from ligaments, muscles, or joint capsules that have undergone shortening and are now suddenly subjected to tension on realignment. Symptoms, which may remain localized to the contracted structures or be referred to a distant site(s), usually abate spontaneously as normal length is gradually regained.

## Iliolumbar ligament pain

These ligaments, which originate from the transverse process of L4 and L5 and have both a "superficial" and a "deep" insertion onto the iliac crest, help maintain lumbosacral and SI joint stability (see Fig. 1A). ${ }^{70}$ They can be subjected to increased tension with pelvic or spine malalignment that causes, for example, separation of their origins and insertions. The ligaments need to be considered in the differential diagnosis of pain around the greater trochanter, lateral thigh and groin, on the basis of referral to their sclerotomal and dermatomal distributions (see Fig. 77).

## Overlap with Findings Attributable to a Coexisting Medical Disorder

The following case histories serve as typical examples that illustrate this point.

## Case history: runner C-central disc protrusion

A 45-year-old runner presented with back pain localized just below the thoracolumbar junction. Full neurologic assessment revealed only a questionable root stretch test and an asymmetric weakness in lower extremity muscles, the latter in keeping with the pattern typically associated with the rotational malalignment found on examination. Repeated attempts by a manual therapist and self-corrections he carried out between visits failed to achieve lasting alignment and had no effect on his back pain. Subsequent computed tomography scans showed an L3-L4 central disc protrusion that likely caused irritation of the dura and secondary changes (eg, asymmetrical muscle tension or spasm) capable of causing the malalignment. Surgical resection relieved his pain and postoperative attempts at realignment were eventually successful.

## Case history: runner D-radiculopathy

A runner complained of a feeling of weakness in the left lower leg and paresthesias felt intermittently over parts of the posterior thigh and calf, also a more consistent patch of numbness along the lateral aspect of the left foot. Findings were limited to a rotational malalignment, asymmetric weakness of bilateral lower extremity muscles, and decreased touch and pin prick appreciation over the sole of the left foot. Repeat left bowstring/straight leg raising root stretch tests elicited a somewhat variable report of left buttock/posterior thigh discomfort, but Maitland's slump test was negative and Lasegue's sign absent. Radiographs showed some degenerative changes in the lower lumbar levels.

Whenever treatment allowed him to maintain alignment for a few days in a row:

1. He reported having only the feeling of weakness and a numbness in the sole;
2. Clinical findings were limited to $4 / 5$ weakness of left peroneus longus, a decreased left ankle reflex, the questionable left stretch test and decreased sensation not just over the sole of the foot but also along the posterior calf region.
MRI showed a large L5-S1 posterolateral disc protrusion that impinged on the S1 root. Findings relating to the left S1 radiculopathy (confirmed on electrodiagnostic studies) were hidden intermittently by the overlapping with symptoms attributable to a recurrence of the malalignment, coupled with referral from the irritated sacrospinous and sacrotuberous ligaments (see Figs. 76 and 77).

## Comments on case histories C and D

1. When attempts at realignment fail repeatedly, ensure that an underlying problem that may be causing malalignment to recur has been ruled out. Typical causes to consider include disc protrusions, radiculopathies, and abdominal masses (eg, uterine fibroids, ovarian cysts, aneurysms).
2. A radiculopathy results in a relatively consistent pattern of pain, sensory changes, weakness, and reflex changes. In contrast, pelvic malalignment can cause pain and paresthesias that may be localized or referred, can vary in terms of when and where they are felt and also in intensity, and may mimic a root or nerve lesion; however, weakness is not myotomal, reflexes remain intact, and the root stretch test is negative.

## TREATMENT

Correction of the 3 most common presentations of pelvic malalignment can be achieved in most runners, even those of advanced age. ${ }^{26,27,67,68}$ However, the aim should be to get to the stage where alignment is being maintained most of the time and the runner can return to a normal lifestyle that hopefully includes being able to resume training. Although most will respond to appropriate treatment within 3 to 4 months, others may take up to 1 to 2 years for symptoms to resolve and for the body tissues and the mind to adjust fully to the new state of being in alignment. ${ }^{19,48}$ Hence, achieving this goal requires a commitment on the part of the runner and adherence to a treatment approach that includes not just realignment, but that also focuses on all the factors that can affect the long-term outcome of the therapy.

## A Comprehensive Treatment Program

A progressive treatment program that includes participation by the runner is most likely to achieve lasting realignment and resolution of symptoms. The program should have the following components.

1. Supervision by someone trained in manual therapy.

The therapist should be skilled in the use of manipulation, mobilization, MET, and other manual therapy techniques, as indicated by the presentation at hand. Complementary treatment measures, such as acupuncture or massage, may be indicated for decreasing persistent pain and relaxing tight tissues to help achieve and maintain alignment. However, although these modalities may sometimes achieve realignment by relaxing muscles and allowing pelvic bones to slot back into their normal position, manual therapy approaches remain the key to achieving long-term results.
2. Instruction of the runner, including the following.
a. How to carry out self-assessment and self-treatment.

Being able to do the sitting-lying test and assessment of pelvic landmarks allows the runner to detect any recurrences of malalignment on a day-to-day basis. He or she may be able to achieve correction using self-treatment techniques or opt to see the therapist before the next scheduled appointment. This approach increases the chances of maintaining alignment for increasing periods of time and getting symptoms to settle down more quickly.
b. What activities to avoid.

Sitting for longer periods of time (especially in a slouched position), lifting heavy weights, and running and carrying out maneuvers with a torsion component (eg, twisting the pelvis and trunk when reaching up/downward or to 1 side) all predispose to recurrence of malalignment especially during the initial stage.
c. The basics of a graduated exercise program.

Initial strengthening of the inner and outer core muscles is essential for regaining stability of the pelvis and spine; emphasis is also on ensuring that muscles are contracting in the first place and in proper sequence/coordination with other muscles in their own and other, interacting slings. ${ }^{42,71-74}$ Once alignment is starting to be maintained, and at the therapist's discretion, the runner may gradually get back to improving overall strength and cardiovascular fitness. Concentrating on a graduated walking program is indicated if attempts at running continue to cause recurrences of malalignment; running in a pool may be an option to consider at that stage.
3. Return to a normal lifestyle.

The final stage of treatment is aimed at regaining normal movement patterns, balance, and proprioception, to enable the runner to carry out activities of daily living and, hopefully, start back on a regular training program. Techniques aimed at achieving this stage may include yoga exercises, the use of biofeedback and enrollment in a structured program such as Rehabilitation Pilates. ${ }^{75,76}$

## Shoes

If daytime and training shoes show any of the typical changes caused by malalignment (see Figs. 51-54), the runner should be advised to:

1. Discontinue their use immediately and replace them with walking/running shoes that are relatively neutral; that is, not intended to counter pronation or supination.
2. Delay purchase of new shoes specific for a pronator or supinator until alignment is being maintained and the true weight-bearing pattern has been determined.

## Orthotics

The runner should be advised as follows:

1. He or she should discontinue use of any orthotics that were provided before the diagnosis of the pelvic malalignment. These were most likely made from a cast taken when the runner was out of alignment, in which case they may incorporate unwanted changes relating to any previous shift in weight bearing and asymmetries of joint ranges of motion. If that is the case, they pose a risk of perpetuating abnormal forces at the foot level that could predispose to recurrences of malalignment once correction has been achieved (see Fig. 75).
2. If orthotics are felt to be indicated (eg, to provide more cushioning and/or some support for the medial longitudinal arch), then off-the-shelf orthotics are an adequate interim measure because they will provide not only symmetric support but also more symmetric proprioceptive input from the sole that may increase the chance of maintaining realignment (see Fig. 50).
3. If orthotics are felt indicated once the runner is starting to maintain alignment and his or her true weight-bearing pattern has become evident, the new orthotics:
a. Should preferably be constructed using data obtained while:
i. The runner is known to be in alignment and
ii. Weight bearing; for example, walking across a computerized sensory pad.
b. May incorporate:
i. Posting to counter residual excessive pronation or supination, especially if there are ongoing problems caused by these forces; for example, a TFL/IT band complex that continues to be painful after realignment in someone who turns out to be a supinator;
ii. A heel lift to make up for a true leg length difference that has been revealed on realignment and could predispose to recurrence of the malalignment.

## Sacroiliac Belt and Compression Shorts

An SI belt, compression shorts, or a combination of these may help to decrease pain and maintain realignment; however, their use should be limited to the initial treatment period when recurrences are more likely to occur. In someone with ongoing instability of the pelvis for whatever reason, addition of figure-of-8 hip and thigh straps provide adjustable compressive forces. Belts may also be placed so as to apply pressure to a specific tender point or other areas in the pelvic region (eg, a
specific ligament or muscle) when simple manual pressure exerted on these sites is noted to decrease the runner's pain and/or reinforce contraction in some of the core muscles. ${ }^{40}$

## Injections

## Prolotherapy

Prolotherapy is indicated when failure to maintain alignment is attributable to laxity of a joint capsule and ligaments. ${ }^{43,77,78}$ Injection of an irritant, such as hyperosmolar glucose, causes inflammation and triggers a natural response leading to new collagen formation and eventual strengthening of these supportive structures. Growth factor, platelet-rich plasma, and a number of other derivatives have also proven useful for stimulating collagen formation. ${ }^{79}$ Prolotherapy may also prove helpful in decreasing pain from persistently tender tendon or ligament insertions following realignment, probably by strengthening the fibro-osseous junction and settling down any irritated or hypersensitive nerve fibers.

## Cortisone

The use of cortisone should be limited given the risk of infection, weakening, and even rupture of the connective tissue being injected. However, a restricted number of spaced injections of cortisone combined with a local anesthetic may prove helpful to settle down any residual inflammation and pain in ligaments and tendons that:

1. Is aggravating to the point of causing muscles to tense up, recurrences of malalignment and generally interfering with the runner's treatment and recovery; and
2. Persists even though the runner has been maintaining alignment; this tends to be a problem particularly involving the posterior SI joint and iliolumbar ligaments.

## Surgery

Surgery may play a role when:

1. The runner's recurrent malalignment can be attributed to:
a. Joint laxity resulting with joint degeneration and/or laxity/tearing of the supporting ligaments (see Fig. 11B);
b. Ongoing pain definitely arising from the structure considered for resection or fusion; for example, pain localized by selective blocks to an abnormal disc, facet or SI joint; or
c. Asymmetrical forces are acting on a joint; for example, the hingelike motion around the facet joint contralateral to a unilateral sacral lumbarization or L5 sacralization.
2. The runner has complied fully with all recommendations and the conservative approach has definitely failed.

For example, in the case of instability of one or both SI joints, this may be as a result of joint degeneration, laxity of the supporting ligaments, or a combination of these. If all treatment measures, including prolotherapy injections, have failed and progress is stalled because of the pain and an inability to achieve or maintain alignment, surgery may be indicated. ${ }^{80}$ The procedure of choice is:

1. A bilateral SI joint fusion with a bone plug and fixation with 2 screws on each side.
2. To have the procedure carried out with:
a. A manual therapist in attendance, to ensure the bones of the pelvic ring are in alignment throughout the procedure; and
b. Simultaneous electrodiagnostic monitoring (eg, ongoing side-to-side comparison of L5 and S1 sensory latency) to allow for quick detection of any compromise of the lumbosacral plexus or a root and appropriate modification of the surgical technique.

## When Malalignment Fails to Respond to a Course of Treatment

In the runner who may or may not derive temporary benefit with realignment but fails to maintain alignment, the following possibilities should be considered:

1. The treatment program:
a. Has failed to address some of the issues that can be responsible for recurrences; for example, wearing the wrong type of shoes, or orthotics cast while out of alignment); and
b. Has not considered the use of other techniques that may help to achieve lasting alignment; for example, acupuncture or dry-needling to resolve residual muscle spasm; a trial of other manual therapy techniques, such as craniosacral release ${ }^{20,81}$ or ones that concentrate on alignment at the occipitocervical junction ${ }^{22-24}$; these techniques are worth considering because they may prove successful when other approaches aimed mainly at the pelvis or lower spine have failed.
2. The malalignment may be a manifestation of an underlying medical problem that has so far escaped detection (see "Implications for the treating physicians").
3. The runner has actually not adhered fully to the treatment program. Athletes in general are more likely to abandon formal treatment at the first sign of any improvement and go back to their sport. Returning to running before having achieved adequate stability of the pelvis and spine only invites recurrence of a problem that is unlikely to resolve completely with just intermittent therapy.

## Summary

1. More than $80 \%$ of runners, like the general population, are likely to be out of alignment.
2. The standard back examination should include assessment of pelvic alignment to avoid misdiagnosis and inappropriate investigations and treatment.
3. An awareness of pelvic malalignment and the phenomenon of the malalignment syndrome is essential to allow one to provide proper care of a runner because:
a. The abnormal biomechanics and any associated discomfort result in compensatory measures that are usually less efficient in terms of biodynamics and energy requirements and can set back the runner's training.
b. Failure to achieve alignment may impair the runner's:
i. Recovery from specific problems that are the result of the malalignment; and
ii. Ability to advance and achieve his or her maximum performance.
4. The 3 most common presentations usually respond to a supervised, progressive treatment program that includes a teaching component, including instruction in self-assessment and self-treatment techniques that the runner can use effectively on a day-to-day basis to maintain alignment and improve his or her chances of recovery.
5. The validity of any research into the biomechanics of running (eg, assessing the effect of various types of orthotics) should be questioned if the study has failed to look at whether pelvic malalignment was present and whether the altered,

## asymmetrical biomechanical changes attributable to the malalignment itself could have affected the results of the study.

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    Division of Physical Medicine and Rehabilitation, Faculty of Medicine, University of BC, Vancouver, Canada

    * 73-101 Parkside Drive, Port Moody, British Columbia, Canada, V3H 4W6.

    E-mail address: wschamberger@shaw.ca
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