

Predictability of sacral base levelness based on iliac crest measurements

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A level sacral base plane is necessary to allow normalization of complex lumbosacral mechanics. Palpatory examinations are often used to evaluate for leg length discrepancy and pelvic obliquity despite improved accuracy and consistency of radiographic techniques. Treatment based on palpatory examinations suppose a direct and consistent relationship between the pelvic bones (innominates) and the sacral base. To evaluate the relationship between iliac crest levelness and sacral base levelness, a radiographic postural survey in the upright, weight-bearing position was performed on 358 men and women thought to have pelvic obliquity. Of these subjects, 293 demonstrated unlevel iliac crest heights or sacral base $\geq 3/16$ inch (4.76 mm), with iliac crest heights accurately predicting sacral base position 62% of the time. At $\geq 3/8$ inch (9.53 mm), 68% of the cases were accurately predicted. When the criterion for unlevelness was increased to $\geq 1/2$ inch (12.70 mm), the predictive accuracy improved to 83%. Radiographic findings in this study demonstrate a significant difference between iliac crest heights and sacral base position. In cases of mild to moderate short leg syndromes, the iliac crest height is an unreliable predictor of the direction or degree of sacral base levelness.

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Low-back pain will affect 80% of the population at some time during their lives enough to restrict activities for a short time.^{1,2} In all US workers younger than 45 years, low-back pain is the leading cause of lost productivity and lost work time. Of all musculoskeletal ailments, it is the most expensive to the American healthcare system. Low-back pain accounts for up to \$50 billion annually in lost productivity, lost work time, diagnosis, treatment, litigation, and disability.¹

Many clinicians theorize that leg length discrepancy is a factor in low-back pain.³ Signs and symptoms of leg length discrepancy, in addition to low-back pain, may include flank pain, lower extremity pain, headache, knee arthropathy, increase in muscle activity, fatigue, right arm pain, and thoracic distress.⁴

Leg length discrepancy defined

Leg length discrepancy is categorized as "true" or "functional." True leg length discrepancy is a structural asymmetry. It can consist of bony anomalies such as sacralization of the fifth lumbar vertebra or spina bifida.⁵ An unequal growth of a long bone epiphysis due to trauma, infection, radiation, tumor, Perthes' disease, or fracture may also cause true leg length discrepancy.⁶ Taylor and Halliday⁷ cited "out of phase" growth as a factor. In this instance, one of the paired bones is more advanced in its maturity than its corresponding contralateral bone. These researchers also stated that asymmetric growth commonly occurred in the lower extremity. Addi-

tional factors in true leg length discrepancy could be a fallen arch, a low talus with a pronated foot, or a short first metatarsal with displaced sesamoid bones and weight redistribution.⁸

Functional leg length discrepancy is a physiologic response to altered mechanics suggesting the presence of a short leg in the absence of bony asymmetry.⁹ Thus, a functional leg length discrepancy is a distortion of balance, a joint compression or contracture, or soft tissue changes or all these factors that cause a compensatory scoliosis, pelvic tilt or obliquity, or sacral tilt.^{4,9-11} A reported 88% of persons with leg length discrepancies have a combination of structural and functional deformities.¹¹

Leg length discrepancy, for true or functional reasons, has an obvious physical effect on many patients. The discrepancy will cause pelvic obliquity due to the high femoral head's driving the pelvis up and back through acetabular contact. The pelvis will usually drop or tilt to the side of the shorter extremity so that the sacral base becomes unlevel and the lumbar spine buckles with convex curvature to the short side.¹²

Because of the association of leg length discrepancy and low-back pain, clinicians have been seeking a simple, cost-effective method of assessment. Historically, the anatomic landmarks helpful in evaluating leg length discrepancy have been the femoral heads, iliac crests, sacral base (SB), anterosuperior iliac spine, posterosuperior iliac spine, medial malleolus, and the lateral malleolus. To date, discussion continues on the accuracy and appropriateness of indirect external palpation, direct external landmark measurement, and radiographic evaluations.

Means of measuring leg length discrepancy

Various methods of palpation examination have been evaluated for reliability and accuracy of measurement by Woerman and Binder-Macleod.⁹ Of the five clinical palpation methods tested, the indirect method was most precise and accurate for assessing leg length discrepancy, but when compared with radiography, it tended to measure

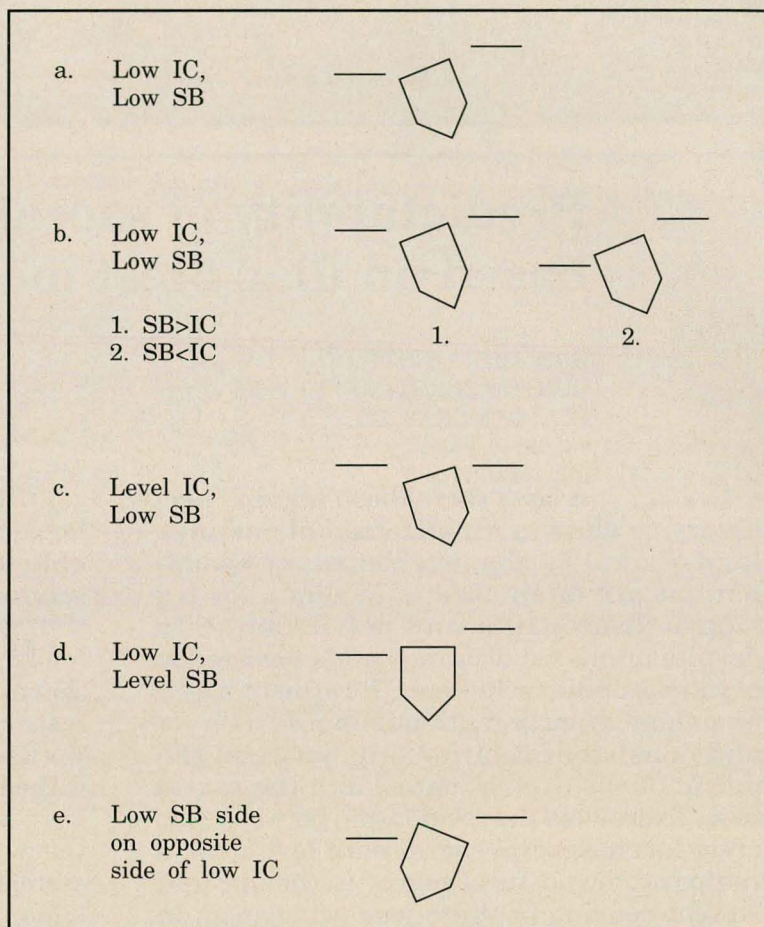


Figure 1. Possible iliac crest (IC) and sacral base (SB) relationships.

short of the actual length. The indirect techniques use evaluation of iliac crest (IC) height in a standing patient and the use of shims underneath the apparent short limb to produce a relatively symmetrical IC height. The height of the shims can then be added to represent the discrepancy in leg length.

Woerman and Binder-Macleod⁹ found that tape measurements taken from the anterosuperior iliac spine to the lateral malleolus was the most accurate direct method evaluated. However, one cannot discount the possibility of errors in tape measurements due to thigh asymmetry, pelvic rotation or torsion, sacroiliac joint asymmetry, obesity, or bony anomalies from previous injury or fracture.^{9,10,13} Radiography therefore is commonly accepted as being the most accurate (± 1.5 mm) means of diagnosing short leg syndrome or pelvic obliquity.¹⁴⁻¹⁸

The literature documents well the attempts at developing accurate and reliable methods of determining leg lengths.^{15,16,19,20} For more than 60 years, radiographic techniques have been used

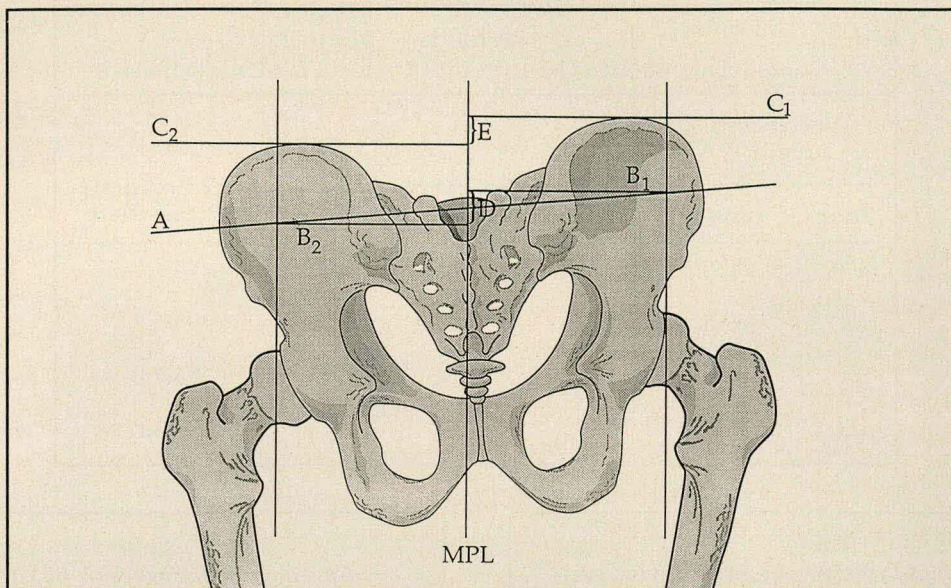


Figure 2. Evaluation of iliac crest (IC) and sacral base (SB) by means of weight-bearing radiography. MPL= midheel plumb line of eburation; D= difference in height between B_1 and B_2 ; E= difference in height between C_1 and C_2 .

in evaluating weight-bearing x-ray films of leg lengths, femoral head heights, IC heights, SB declination, and scoliotic curves.^{9,15,17,18}

The degree of correlation between radiographically identified ICs and SB had not previously been evaluated statistically. Without this correlation, the significance of palpatory landmarks (frequently the iliac spines or crests) as predictors of SB position and its relationship with lumbosacral mechanics cannot be calculated accurately. Clinical observations of patients diagnosed by palpatory examination and treated with orthotic lifting for "short leg syndrome" (leg length discrepancy) occasionally produced marked SB destabilization. The SB destabilization resulted in an exacerbation of the patient's symptoms. Therefore, identification of the SB position is very important when evaluating leg length discrepancy. The physician cannot simply assume that the SB mechanics are following the mechanics of the ilia. Because of the complex lumbosacral mechanics and axial spine stresses, a level SB must be obtained.¹⁶ A total treatment program consequently must include a plan for leveling the SB.

Figure 1 demonstrates the various possible abnormal relationships between the ICs and the SB. When lift treatment based solely on the presence or absence of IC levelness is instituted, the SB may not necessarily be leveled appropriately. Lift treatment based solely on IC evaluation potentially produces one of three scenarios:

- improvement in clinical complaints after cor-

rection of the degree of unlevelness;

- incomplete resolutions of associated complaints if lifting is inadequate or excessive at the SB; or
- destabilization and exacerbation of the patient's symptoms if the side of the "short leg" is opposite the low side of the SB. In our pilot study, 4 of 24 cases demonstrated this third scenario.

Some patients continue to be evaluated and treated solely on screening palpatory examinations of the IC height without regard to SB levelness. The purpose of this study is to evaluate statistically the relationship of IC levelness and SB levelness, both determined radiographically, and to discuss the potential hazards of treatment without a proper postural survey.

Methods

The subjects for this study were referred to the Radiology Department at the University of North Texas Health Science Center at Fort Worth/Texas College of Osteopathic Medicine by primary care physicians for radiographic evaluation of suspected pelvic obliquity. Such referrals were based on patients' symptoms, medical history, and results of physical examination and palpation of the iliac crests for levelness by the primary care physicians. Patients with current lifts or arch supports were eliminated from this study. Thus, of 452 patients referred, 358 remained as subjects, of whom 202 were women and 156 men. Their mean age was 39.4 years (± 15.6 years SD).

Each patient was evaluated with an anteroposterior radiographic postural survey that included the

Table 1 Comparison of Iliac Crest Height Criteria for Unelevelness			
Iliac crest height		No. correctly classified	% Correctly classified
Inch	mm		
3/16	(4.76)	221	61.7
1/4	(6.35)	236	65.9
3/8	(9.53)	242	67.6
1/2	(12.70)	298	83.2

Table 2 Frequency of Occurrence of Unelevelness— Iliac Crest Height/Sacral Base Position With Criterion of $\geq 3/16$ Inch (4.76 mm)			
	Low left sacral base (No.)	Level sacral base (No.)	Low right sacral base (No.)
Low left iliac crest (No.)	83	22	4
Level iliac crest (No.)	36	65	28
Low right iliac crest (No.)	5	42	73

Table 3 Frequency of Occurrence of Unelevelness— Iliac Crest Height/Sacral Base Position With Criterion of $\geq 1/4$ Inch (6.35 mm)			
	Low left sacral base (No.)	Level sacral base (No.)	Low right sacral base (No.)
Low left iliac crest (No.)	62	27	2
Level iliac crest (No.)	38	111	20
Low right iliac crest (No.)	3	32	63

lumbar spine and pelvis in the weight-bearing, upright position. The patients were positioned with their bare feet parallel and knees extended for proper anatomic alignment, with their buttocks resting against the film cassette to minimize pelvic obliquity that could cause distortion. The arms were folded across the chest out of the film's view. This standard technique allows for repeatable film conditions.^{17,18,21} A midheel plumb line of piano wire was used as a perpendicular reference to the earth.

The landmarks used were the ICs, femoral heads, SB, and lateral bend of the lumbar spine. For the sake of this study, the ICs and the SB will be the only landmark factors reported. Two radiologists evaluated the x-ray films for IC and SB levelness on the basis of the guidelines outlined herein.

As shown in *Figure 2*, a line (A) was drawn extending horizontally through the SB line of eburnation. The line of eburnation is a region of increased bone density reflecting a primary weight-bearing plane of the axial skeleton that is delineated on the radiograph.²¹

Perpendicular lines (B_1 and B_2) were drawn to the midheel plumb line (MPL) and extended laterally to intersect the line of eburnation at a point directly over the femoral head. The vertical distance (D) between B_1 and B_2 was recorded in inches to the nearest $1/16$ inch (1.59 mm) as the SB declination.

The IC height difference was measured similarly with perpendicular lines (C_1 and C_2) drawn medially from the most superior point of each IC to the MPL bilaterally. The vertical difference (E) between C_1 and C_2 was recorded to the nearest $1/16$ inch (1.59 mm) as the IC height unelevelness. The criterion for clinically significant difference in IC heights or in femoral head heights, or clinically significant SB declination, when evaluated by radiography, was $\geq 3/16$ inch (≥ 4.76 mm).^{9,12,16}

Data analysis included the Pearson Product Moment Correlation Coefficient of IC levelness versus SB levelness and paired t -test for the difference between the two landmarks. Cross-tabulation tables were used to determine the frequency of correct diagnoses of SB lev-

Table 4
Frequency of Occurrence of Unevelness—
Iliac Crest Height/Sacral Base Position
With Criterion of $\geq 3/16$ Inch (4.76 mm)

	Low left sacral base (No.)	Level sacral base (No.)	Low right sacral base (No.)
Low left iliac crest (No.)	24	28	1
Level iliac crest (No.)	42	187	20
Low right iliac crest (No.)	0	25	31

elness from IC levelness, and the frequency of false-positive and false-negative screening examination results. False-positive results are screening examinations that identify an abnormality when none exists. False-negative screening examination results are those that fail to identify an existing abnormality. For example, if the IC height is unlevel but the SB is level, then this is a false-positive result. Additionally, if the IC height is level but the SB is not, then this is an example of a false-negative result.

Results

The patients in this study demonstrated radiographic SB unevelness of approximately 1/3 inch (7.9 ± 7.7 mm), with the range of SB levelness being 0 to 2 inch (0 to 50.8 mm). Based on the criterion of $\geq 3/16$ inch (4.76 mm) difference in SB height, 129 (36%) of the patients were classified as having a level SB, and 229 (64%) as having an unlevel SB. Further evaluation found that 124 (35%) of all patients had a low left SB side, and 105 (29%) had a low right SB side.

The IC unevelness for these subjects was approximately 1/4 inch (7.1 ± 6.3 mm). The SB and IC heights were significantly correlated ($r = .74$; $P < .0001$), a result indicating that the two measures have a strong linear relationship. However, when IC and SB heights were compared using paired t -tests, the two variables were significantly different ($t = 3.82$; $P < .0002$). The mean difference between IC and SB unevelness was approximately 1/16 inch (1.59 ± 0.4 mm). Therefore, IC heights significantly underpredicted SB unevelness by approximately 1/16 inch (1.59 mm).

The accuracy of using IC height alone in pre-

dicting SB unevelness was evaluated further by use of cross-tabulations. With the use of approximately 3/16 inch (≥ 4.76 mm) difference as the criterion for unevelness, IC heights correctly predicted SB levelness in 221 patients (62%). Consequently, in 137 (38%) of the patients, IC heights incorrectly predicted SB levelness. Small increases in classification accuracy (66% to 68%) occurred when the unevelness criteria were raised to 1/4 inch (6.35 mm) and 3/8 inch (9.53 mm), respectively (Table 1). However, when the criterion was elevated to 1/2 inch (12.70 mm), IC heights correctly classified SB levelness in 83% of the patients.

Cross-tabulation frequencies for the $\geq 3/16$ inch (4.76 mm) unevelness criterion are presented in Table 2. Of the 124 patients with a low left SB, 83 (67%) had a correctly predicted low left IC, 36 (29%) were diagnosed with level IC, and 5 (4%) were diagnosed with low right IC. Meanwhile, of the 129 patients who exhibited a level SB, 65 (50%) had a correctly predicted level IC, 42 (33%) had a low right IC, and 22 (17%) had a low left IC. Of the remaining 105 patients with a low right SB, 73 (70%) were correctly predicted, 28 (27%) were correctly predicted with a level IC, and 4 (3%) with a low left IC. The accuracy of classification when the criterion for unevelness was raised to 1/4 inch (6.35 mm) and 3/8 inch (9.53 mm) is shown in Table 3 and Table 4, respectively.

The improved accuracy of classification observed when the criterion difference is increased to $\geq 1/2$ inch (12.70 mm) is presented in Table 5. Low left SB conditions were found in 44 patients, with 19 (43%) of these cases also having a low left IC. Of

Table 5
Frequency of Occurrence of Unevelness—
Iliac Crest Height/Sacral Base Position
With Criterion of $\geq 3/16$ Inch (4.76 mm)

	Low left sacral base (No.)	Level sacral base (No.)	Low right sacral base (No.)
Low left iliac crest (No.)	19	10	1
Level iliac crest (No.)	25	261	9
Low right iliac crest (No.)	0	15	18

the 286 patients who were now classified as having a level SB, 261 (91%) demonstrated agreement with a level IC, and of the remaining 28 patients with low right SB, 18 (64%) were correctly classified.

The frequency of false-positive results was 30% of all the positive results when the criterion for unlevelness was 3/16 inch (4.76 mm) (Figure 3), and the relative frequency increased to 49% with 3/8 inch (9.53 mm) as the criterion. The frequency of false-negative results was 50% of all negative results with 3/16 inch (4.76 mm) as the criterion and decreased to 12% with 1/2 inch (12.70 mm) as the criterion (Figure 4).

In some patients who had unlevel ICs as well as unlevel SBs, the unlevelness was to the opposite side. The incidence was 5% when the unlevelness criterion was 3/16 inch (4.76 mm), decreasing to 3% with 1/2 inch (12.70 mm) as the criterion.

Discussion

The major finding of this study was the unsatisfactory radiographic predictability of SB levelness from IC heights in mild to moderate short leg conditions, 3/16 inch (4.76 mm) to 3/8 inch (9.53 mm). The frequency of false-positive diagnoses increases from 30% at 3/16 inch (4.76 mm) to 49% at 3/8 inch (9.53 mm) and 40% at 1/2 inch (12.70 mm). Additionally, the relatively high false-negative finding of 50% at 3/16 inch (4.76 mm) decreases to 12% by 1/2 inch (12.70 mm). Finally, the incidence of unlevel IC and SB occurring in the same subject whose respective unlevel-

ness is to the opposite side, decreases from approximately 6% at 3/16 inch (4.76 mm) to 3% at 1/2 inch (12.70 mm). Even though 3% appears to be only marginally significant, with the criterion set at $\geq 1/2$ inch (12.70 mm), the patient who is incorrectly lifted would end up with an unlevel SB $\geq 1/2$ inch (12.70 mm) plus the amount lifted on the opposite side.

Previous investigations have not evaluated the relationship between IC and SB positions with both determined radiographically. Instead, researchers have used various direct and indirect methods that compared palpatory findings at pelvic landmarks with radiographic findings.^{9,10,14} Our investigation found agreement between IC height and SB levelness 62% of the time. We documented this agreement radiographically with 3/16 inch (4.76 mm) as the criterion for unlevelness. Clarke¹⁰ found only a 32% accuracy between the indirect method (palpation of the IC with the patient standing) and radiographic evaluation of IC height while using a similar criterion. Aspegren and coworkers¹⁴ also observed a similar trend, namely, a 37% agreement between IC height and SB levelness when using Cailliet's visual techniques¹³ and radiographs of femoral head heights. (Femoral head position may or may not provide an accurate assessment of SB levelness.)

Woerman and Binder-Macleod⁹ determined that IC palpation was the most accurate nonradiographic clinical technique for measuring leg length discrepancy. Observing a 40% predictive

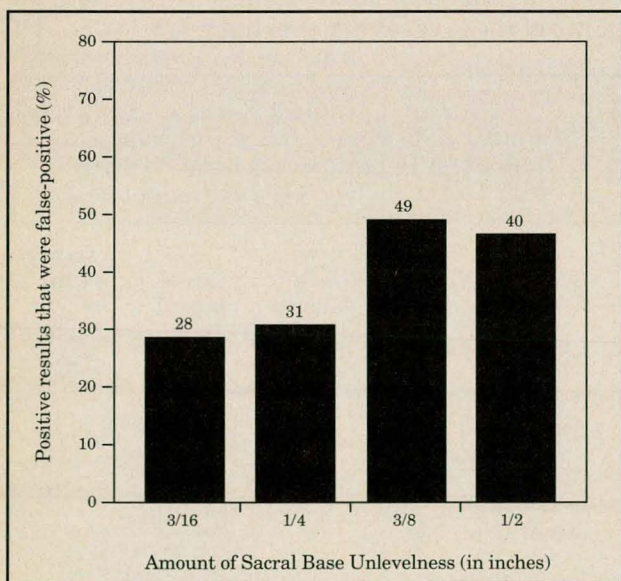


Figure 3. Percentage of positive screening results that were false-positive.

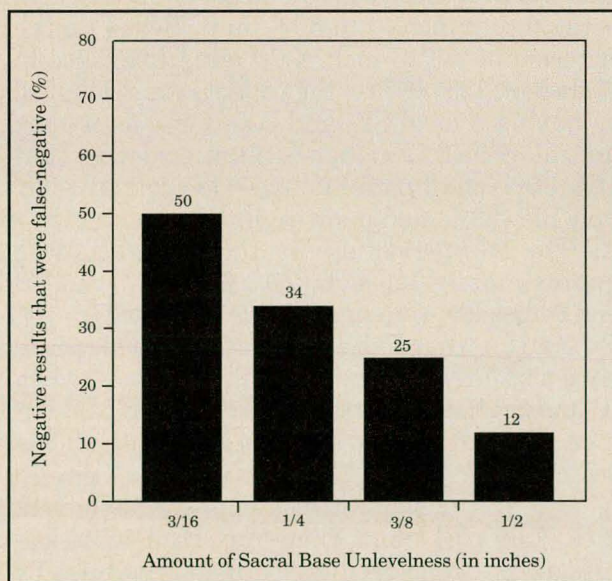


Figure 4. Percentage of negative screening results that were false-negative.

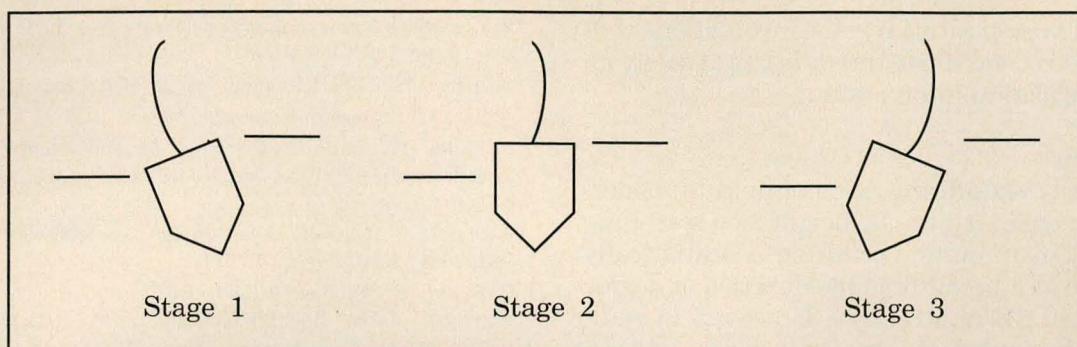


Figure 5. Beilke's³ stages of accommodation to lumbosacral and pelvic mechanics.

accuracy, they noted that IC palpation tended to underpredict the leg length discrepancy. Clarke's¹⁰ accuracy increased to 43% when comparing palpation with radiographic measurements of the ICs at 10 mm (approximately 3/8 inch). In our study using radiographically obtained IC heights, 83% of the patients had a correctly predicted SB position when the criterion for unlevelness was raised to 1/2 inch (12.70 mm).

The radiographic findings of this study demonstrated a significant difference between IC heights and SB position. Because the sacrum is totally suspended between the ilia by ligaments, the sacrum's movement is influenced not only by the ilia, but also by the tension of the surrounding musculature and by gravity.²² The ilia, however, are relatively restricted by the pubic symphysis and the entire axial spine. Thus, while pelvic obliquity, muscle tension, and other factors involved in leg length discrepancy influence both areas, the sacrum and the ilia may act independently of each in their accommodation processes. Furthermore, structural adaptations have no consistent or predictable pattern. The ilia and the sacrum are relatively independent of each other in their movement, although they are influenced by the same factors and tend to accommodate similarly to lumbosacral and pelvic mechanics. The sacrum, being suspended by ligaments between the ilia, may tend to have more variation in its position when accommodating pelvic obliquity.

Understanding of the mechanics in sacral base destabilization is aided by classifications of the lumbosacral and pelvic mechanics in the process of accommodation to leg length discrepancy²³ (Figure 5).

Stage 1: The SB is tilted to the side of the low IC or femoral head, with the lumbar vertebrae convex to the low/short side.

Stage 2: Transitional. The SB is level or tilt-

ed to the side of the low IC or femoral head, with the lumbar vertebrae convex to the high/long side.

Stage 3: The sacrum is tilted to the side of the high IC or femoral head, with the lumbar vertebrae convex to the high/long side.

Heilig²⁴ adds another classification, although not necessarily a fourth "stage," in which the IC or femoral head heights are level, but the SB is unlevel. Each patient, therefore, must be assessed and treated individually.

The predictability of SB levelness from IC heights observed in our study has many implications relative to clinical examinations and treatment of pelvic obliquity and leg length discrepancy. In mild to moderate short leg conditions, predictive accuracy of SB level from IC height was 62% radiographically, while IC palpation findings in the literature were 32% to 40% correct.^{9,10,14} Based on these observations, a clinically significant number (38%) of patients will have incomplete results or possible sacral base destabilization (or both) if they are treated based on their radiographic IC heights alone.

Predictive accuracy improved to 83% when the criterion for SB unlevelness was raised to $\geq 1/2$ inch (12.70 mm). It is suggested that if treatment with heel lift is used in this group with the emphasis on merely reducing the degree of imbalance, then a clinical trial may be warranted.

When considering the need for instituting lift therapy for symptoms related to pelvic obliquity secondary to an unlevel sacral base of 3/16 inch (4.76 mm), the data in Table 2 should be considered. Patients with unlevel ICs demonstrated a level SB 28% of the time. Patients with level ICs demonstrated an unlevel SB 50% of the time, and 5% of the patients had an unlevel SB to the opposite side of an unlevel IC. This represents an unacceptable number of false-neg-

ative and false-positive results or conditions that may be worsened if treatment is based solely on palpatory examination results.

Comment

In clinically significant cases of mild to moderate pelvic obliquity, the IC height as a screening palpatory examination criterion is statistically unreliable as a predictor of the direction or degree (or both) of SB unlevelness. However, in radiographically determined cases of IC height unlevelness $\geq 1/2$ inch (12.70 mm), statistical reliability of the predictability regarding the SB increases to 83%. Although the screening palpatory examination may still provide much information, the reliability of the information must be questioned in cases of mild to moderate pelvic obliquity, particularly if the patient's condition deteriorates during treatment. The patient's deterioration would underline the need to test the accuracy of screening examination results by performing a confirmatory radiographic postural survey. In general, as IC heights increase their degree of unlevelness from the horizon in the coronal plane, an increasing correlation can be found between the IC and the SB.

In mild to moderate cases of pelvic obliquity, treatment based solely on IC measurements would incorrectly treat 38% of patients and cause SB destabilization. Such destabilization would be expected to exacerbate symptoms and predispose patients to additional somatic and possible visceral dysfunction.

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