Effect of simulating leg length inequality on pelvic torsion and trunk mobility

Rebecca S. Young a, Paul D. Andrew b,*, Gordon S. Cummings c

a Carolinas Hospital System Home Health Therapy Services, 947 South Irby Street, Florence, SC 29501, USA
b Division of Physical Therapy, Institute of Health Sciences, Faculty of Medicine, Hiroshima University, Kasumi 1-2-3, Minami-ku, Hiroshima 734-8551, Japan
c Department of Physical Therapy, College of Health Sciences, Georgia State University, University Plaza, Atlanta, GA 30303-3083, USA

Accepted 21 January 2000

Abstract

Although techniques such as roentgenograms and magnetic resonance imaging can provide definitive information about leg length inequality, they are not easily implemented for screening purposes. Using relative heights of palpated iliac crests as criteria for determining degree of lateral pelvic tilt, we examined the immediate effect of simulating leg length inequality on pelvic torsion and trunk flexion. In seven healthy men and 22 healthy women, 18–28 years of age, a lift of at least 15 mm was placed under either foot to laterally tilt the pelvis 1.2° or more. In eight subjects with pre-existing lateral pelvic tilts of 1.8° or more, a lift was also used to eliminate the tilt. We examined how this tilting affected torsion between the innominate and mobility of the trunk. The innominate contralateral to the lift became more anteriorly rotated than the ipsilateral innominate and lateral flexion of the trunk increased toward the side of the lift. Both of these effects can be associated with clinical leg length inequality, so a lateral pelvic tilt on the order of 1.2°, if encountered in the clinic, should signal the suitability of more extensive examination for possible lower limb asymmetry. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Iliac crest heights; Leg length inequality; Pelvic torsion; Trunk mobility

1. Introduction

Many researchers have noted postural changes in individuals with leg length inequality. Some of these changes include lateral tilting of the pelvis in the frontal plane, pelvic torsion in the sagittal plane, and lumbar scoliosis [1–4]. A higher incidence of low back pain has been found in individuals with leg length inequality than in the general population [5,6], attributed by some to postural imbalance associated with the inequality [7,8]. Several studies have shown improvement in mobility [9], posture [10], and reduction of pain [11] when a unilateral heel or full sole lift was used to correct this imbalance.

Since many adults experience some degree of leg length inequality [1,4], the effect of this postural asymmetry on such function as trunk mobility is a question of interest. A further issue is how great a difference between leg lengths constitutes a functionally tangible ‘inequality’. Although some [12,13] have argued forcefully that any difference less than 20 mm should be regarded as clinically unimportant, Friberg [1] found that leg length inequality of 5–9 mm was much more frequent in patients with low back pain than in subjects with no pain.

Leg length inequality during standing can be measured accurately and precisely by a method involving roentgenograms [1], but this method is limited in clinical application due to expense and radiation. Computerized tomography [14] and magnetic resonance imaging are not currently designed to measure people in the functionally important position of upright standing. Ultrasound, adaptable to the standing subject [15], is less hazardous but not as accurate as roentgenogra-
phy, so its use for measuring leg length inequality might be further encouraged.

Woerman and Binder-Macleod [16] compared several inexpensive and readily implemented methods to estimate leg length inequality and advocated using the heights of iliac crests with the subject standing as a relatively precise method. Subsequent investigations have confirmed that difference between iliac crest heights cannot match the roentgenographic method in precision and accuracy [17,18]. This is not surprising, given that the innominates can rotate slightly at the sacroiliac joints. The question may thus arise whether examining relative height of the iliac crests is meaningful at all in relation to symmetry between the lower limbs.

For the present study, we were interested in using iliac crest heights as a criterion for artificially adjusting leg length inequality and measuring the immediate effect of such adjustment on pelvic torsion and trunk motion. Previous studies showed that putting a lift under one foot generally induced anterior rotation of the contralateral innominate [19–21]. A clinical study on trunk motion of persons with leg length inequality revealed that lateral flexion to the side of the longer leg was markedly greater than toward the shorter leg [9]. We wanted to find out if altering relative iliac crest height by inserting a lift under one foot would immediately affect trunk motion. We also considered it important to confirm whether pelvic torsion would be induced as in previous studies.

The purpose of this study was to ascertain whether artificially modifying leg length, using relative iliac crest height as a criterion, would be associated with alterations in pelvic torsion or trunk mobility. More specifically, in this study we examined whether, in young healthy adults with no known problems in the lumbosacral region, placing a lift under either foot of at least 15 mm and sufficient to produce at least a 1.2° lateral tilt of the pelvis (so that the iliac crest was higher on the side of the lift) was likely to change (1) pelvic torsion in the sagittal plane, (2) amount of forward flexion of the trunk, or (3) amount of lateral flexion of the trunk toward either side. We also wanted to know whether, if we had any subjects who already had lateral tilt of the pelvis exceeding 1.8°, use of a lift under one foot to make the pelvis level (to within 0.5° in the frontal plane) was likely to (1) decrease the magnitude of sagittal pelvic torsion, (2) change the amount of forward flexion of the trunk, or (3) change the amount of lateral flexion of the trunk toward either side.

2. Methods

A total of seven men and 22 women, 18–28 years of age, who fulfilled the following criteria volunteered to participate in the study. None of these 29 subjects had pain in the thoracolumbar or sacral region during the previous year lasting longer than 2 days or such that prescription medication or bed rest was required more than once every 2 months. No subject was pregnant or had any serious medical condition. We examined the subjects to confirm the absence of scoliosis, sacroiliac joint dysfunction, and asymmetry in the ankles and feet. Sacroiliac joint dysfunction was judged to be present if three of the following four tests were positive: standing flexion test (posterior superior iliac spines move asymmetrically), prone knee flexion test (relative positions of heels change between knees extended and knees flexed), supine long sitting test (relative positions of medial malleoli change between supine and long sitting), and Piedallu’s sign (relative heights of posterior iliac superior spines change between upright sitting and sitting with trunk flexed forward).

The subjects were informed about the study both orally and in writing and were given the option to quit participation at any time. The protocol for this study was approved by the Human Subjects Committee at Georgia State University.

2.1. Lateral pelvic tilt, innominate inclination, and pelvic torsion

For purposes of the present paper, certain terms regarding configuration of the pelvis need to be defined. Lateral pelvic tilt is an angle in the frontal plane between a line connecting the right and left iliac crests and a horizontal line. A positive value of the angle indicates that the left iliac crest is higher than the right, and a negative value that the right iliac crest is higher than the left (Fig. 1, left). Innominate inclination is an angle in the sagittal plane between a horizontal line and a line passing through both the anterior superior iliac spine and the posterior superior iliac spine. Innominate inclination assumes a positive value when the anterior superior iliac spine is lower than the posterior superior...

Fig. 1. Illustrations of pelvic angles defined in this study. (Left) Pelvic lateral tilt is the angle by which a line connecting the left and right iliac crests deviates from horizontal. The angle is positive if the left iliac crest is higher than the right. (Right) Innominate inclination is the angle by which a line connecting the anterior superior iliac spine and the posterior superior iliac spine deviates from horizontal. The angle is positive if the posterior superior iliac spine is higher than the anterior superior iliac spine.
iliac spine (Fig. 1, right). Pelvic torsion, defined here as right innominate inclination minus left innominate inclination, is rotational asymmetry of the two halves of the pelvis as viewed in the sagittal plane. When pelvic torsion is positive, the right innominate is said to be more anteriorly inclined than the left, and vice versa. Note that pelvic torsion, as used in this paper, denotes the angular orientation of one innominate relative to the other, but does not indicate whether one innominate or the other is anteriorly or posteriorly rotated with respect to the rest of the body.

Of the 29 subjects, eight had, coming into this study, lateral pelvic tilts with magnitudes of \(1.8^\circ\) or more, six with the right iliac crest higher and two with the left iliac crest higher. In these eight subjects, the effect of reducing the pre-existing lateral pelvic tilt was additionally studied.

Observations were made with the subject standing on a platform with the pelvis lightly abutting a bar in front, feet 150 mm apart, under the following four conditions: (1) placing under the entire right foot a lift with a height of at least 15 mm and sufficient to produce at least a \(-1.2^\circ\) lateral pelvic tilt; (2) placing under the entire left foot a lift with a height of at least 15 mm and sufficient to produce at least a \(+1.2^\circ\) lateral pelvic tilt; (3) in eight cases placing under one foot a lift with a height just great enough to reduce lateral pelvic tilt to less than \(\pm 0.5^\circ\); and (4) without a lift at all. The order of these conditions during measurement was determined randomly. The heights of the lifts ranged from 15 to 24 mm.

The subject was instructed to stand erect but relaxed, to bear weight solidly on both feet, and to maintain very light contact of the pelvis with the bar in front. A custom made inclinometer with a digital display was used to measure both lateral pelvic tilt and innominate inclination (Fig. 2). A detailed description of this inclinometer, as well as its reliability and validity for innominate inclination, have been reported elsewhere [22]. All intraclass correlations exceeded 0.90. Jonson and Gross [23] examined use of a grossly similar device to measure lateral pelvic tilt and obtained an intraexaminer intraclass correlation coefficient (ICC[2,1]) [24] of 0.87 and an interexaminer intraclass correlation coefficient (ICC[2,1]) [24] of 0.70. In the present study, the principal investigator performed the measurements in such a way that she could not see the digital display. An assistant recorded the measurements and the investigator was given the results only after the testing. Each measurement was performed three times and the mean value was used as the datum for the main analysis.

2.2. Forward and lateral trunk flexion

Each subject stood on a level floor with each foot placed under the ipsilateral hip joint on a paper tracing of the subject’s feet made during the pelvic measurements. A skin marker was used to mark points overlying the lumbar spine and lateral trunk according to the method of Moll and Wright [25] and as modified by Merritt et al. [26] for lateral flexion. The point over the first sacral spinous process was marked (at the level of the posterior superior iliac spines), as were points 100 mm directly above and 50 mm below the sacral mark. On the lateral aspect of the trunk, one mark was made at the level of the iliac crest and another mark 200 mm directly superior to the first mark while the subject maintained his or her hands behind the head. These marks were made on both right and left sides of the trunk.

The order for measuring forward flexion, lateral flexion to the left, and lateral flexion to the right was determined randomly. For forward flexion, the subject was asked to bend forward as far as comfortable keeping heels on the floor and without bending the knees. The amount of movement was determined by measuring the distance between the uppermost and lowermost skin marks over the lumbar spine and sacrum. This distance minus 150 mm was the index of forward trunk flexion. For lateral trunk flexion, determined with the subject’s hands behind the head, the subject was asked to bend to one side as far as comfortable keeping the heels on the floor and without allowing the trunk to rotate or knees to bend. This index of movement was determined by measuring the distance between the two marks on the contralateral aspect of the trunk and subtracting 200 mm from this distance.
2.3. Data analysis

To assess the effect of laterally tilting the pelvis, analyses of variance with repeated measures were used for pelvic torsion, forward flexion, and lateral flexion of the trunk. The conditions of right and left lateral tilts of the pelvis were compared with the even condition, which was the condition in which the tilt was reduced to less than $\pm 0.5^\circ$. In eight subjects who had natural tilts of at least $1.8^\circ$, and in the remaining subjects was the natural tilt itself. When an analysis indicated that a difference existed among even, right tilted, and left tilted conditions, we used Tukey’s test for honestly significant differences to determine which situation of lateral tilt was significantly different from the others.

For the eight subjects who had at least $1.8^\circ$ of lateral pelvic tilt with no lift under either foot, paired $t$-tests were performed to investigate whether pelvic torsion, forward flexion, or lateral flexion of the trunk differed between the naturally tilted condition and the even condition of less than $\pm 0.5^\circ$ of lateral pelvic tilt. In looking at the extent to which reducing lateral inclination led to reduced pelvic torsion, the absolute value of torsion for the even condition was subtracted from the absolute value of torsion for the natural condition.

To assess reliability of the measurements performed in this study, intraclass correlation coefficients (ICC[3,1]) [24] and standard errors of measurement were calculated for three repetitions of every measurement across subjects. Error variance for these calculations was defined as the sum of variances attributable to repetition of measurement, interaction between subjects and repetitions, and residual variance.

3. Results

Inserting a lift under one foot to elevate one iliac crest higher than the other significantly increased pelvic torsion, the disparity in rotation between the two innominates viewed in the sagittal plane, compared to the amount of pelvic torsion seen when the iliac crests were at similar heights ($P < 0.001$). The innominate contralateral to the side of the elevation tended to be more anteriorly inclined than the ipsilateral innominate (Fig. 3). Compared to the pelvic torsion seen when the iliac crests were at similar heights ($0.58 \pm 0.42^\circ$, mean $\pm$ S.E.M.), the right innominate became anteriorly tilted relative to the left innominate by $2.55 \pm 0.58^\circ$ when the left leg was elevated, and the left innominate became anteriorly tilted relative to the right innominate by $3.48 \pm 0.52^\circ$ when the right leg was elevated.

When a lift was placed under one foot to elevate the ipsilateral iliac crest, lateral flexion became greater to the side of the elevation ($P < 0.01$), but decrease
in lateral flexion away from the side of the lift was not significant (Fig. 4). No significant change in amount of trunk forward flexion was found as a result of elevating either iliac crest (Fig. 4).

In the eight subjects with pre-existing lateral pelvic tilts of 1.8° or greater, when a lift was used under the foot on the side of the lower iliac crest to reduce lateral pelvic tilt to less than ±0.5°, the subject exhibited more lateral flexion toward the side of the originally lower iliac crest than in the natural condition ($P < 0.05$, Fig. 5). For these subjects, however, no difference was seen between the natural and even conditions either for lateral flexion toward the side of the originally higher iliac crest or for forward flexion. Making the heights of the two iliac crests even did not significantly reduce pelvic torsion, either.

Intraclass correlation coefficients and standard errors of measurement are shown in Table 1. All of these numbers indicate that the measurements were well within statistical control and thus reliable.

### 4. Discussion

#### 4.1. Pelvic torsion

Imposing an artificial leg length difference by introducing a lift under one foot tended to make the contralateral innominate more anteriorly rotated than the innominate on the side of the lift (Fig. 3). This finding agrees with the results of other studies [19–21]. Pitkin and Pheasant [19] used a large lift (38 mm) and thereby induced relative anterior rotation of the innominate on the side opposite the lift as well as other effects on the pelvis and lumbar spine that they observed to be similar to a typical functional scoliosis. Cummings et al. [20] examined the effects of lifts ranging in height from 6 to 22 mm in subjects with leg length inequalities less than 4 mm and found relative anterior rotation of the contralateral innominate, to a degree proportional to the height of the lift. Beaudoin et al. [21] used a 15-mm lift and likewise found relative anterior rotation of the contralateral innominate. The lifts in the present study ranged in height from 15 to 24 mm.

#### 4.2. Trunk flexion

Introducing a lift under one foot did not appreciably alter the extent of either forward trunk flexion or flexion of the trunk toward the opposite side. Flexion of the trunk toward the side of the lift, however, increased as a result of inserting the lift. These results suggest that the functional scoliosis induced by the lift might constrain lateral flexion of the spine in an asymmetrical manner.

Ascertaining precisely why lateral flexion increased toward the side of the lift is difficult. One consideration might be the tendency for the lumbar vertebrae to undergo conjoint rotation during lateral flexion so that the vertebral bodies rotate slightly toward the side of flexion [19,27], which would also be the side of the concavity of an accompanying functional scoliotic curve. This may put the facet joints on the concave side in a slightly more advantageous position to permit sagittal sliding and thus lateral rotation. Apparently the corresponding effect on the facet joints of the convex side of the curve is less dramatic, so lateral rotation becomes freer toward the side of the lift but is less affected in the direction away from the lift.

The eight subjects in the present study who happened to have 1.8° or more of lateral pelvic tilt prior to the study exhibited greater lateral flexion toward the side of the originally lower iliac crest after a lift was introduced.

### Table 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>Intraclass correlation coefficient (ICC[3,1]) [24]</th>
<th>Standard error of measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelvic lateral tilt</td>
<td>0.81</td>
<td>0.41°</td>
</tr>
<tr>
<td>Pelvic sagittal tilt</td>
<td>0.99</td>
<td>0.52°</td>
</tr>
<tr>
<td>Trunk forward flexion</td>
<td>0.99</td>
<td>1.29 mm</td>
</tr>
<tr>
<td>Trunk lateral flexion</td>
<td>0.98</td>
<td>2.32 mm</td>
</tr>
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to equalize the heights of the two iliac crests. Neither lateral flexion toward the side of the originally higher iliac crest nor forward flexion was altered by introducing the lift. These results are qualitatively identical to those in which a lift was used to artificially produce lateral pelvic tilt in all of our subjects.

These findings on the eight subjects also agree with the results of a study by Gibson et al. [9], in which 15 subjects who had suffered femoral fractures after achieving skeletal maturity had leg length discrepancies of 15–55 mm. Roentgenographic examination of lateral flexion of the spine between the highest thoracic vertebra on the roentgenogram (usually about the 11th) and the first sacral vertebra revealed that use of a corrective lift restored motion that had been limited toward the side of the shorter leg and also restrained lateral flexion toward the side of the longer leg to the extent that the two motions became roughly symmetrical. As in our study, increase in motion toward the side of the lifted was greater than the contralateral decrease of lateral flexion.

5. Conclusion

We artificially increased leg length on one side in 29 healthy young adults to alter relative height of the two iliac crests, producing a lateral pelvic tilt. This tended to cause the innominate contralateral to the side of the inserted lift to be more anteriorly rotated in the sagittal plane than the ipsilateral innominate. In addition, lateral flexion of the trunk toward the side of the lift increased. These findings indicate that an artificially induced sudden leg length inequality on the order of 15–24 mm can tangibly alter body movement.

Because our results on lateral flexion, taken from subjects with relatively subtle leg length inequalities, are similar to previously published radiographic measurements in subjects with obvious leg length inequalities, we conclude that relative heights of iliac crests can provide clinically useful evidence for suspecting leg length inequality.

4.3. Iliac crest height versus leg length inequality

Measuring leg length inequality in a way that is both definitively accurate and functionally meaningful requires the use of pelvic imaging in a standing subject [1]. The findings in the present study are of interest in that the method used herein has previously been put forward as a ‘clinically’ useful approach for assessing functional leg length inequality [16]. Lateral pelvic tilt, determined from the heights of the iliac crests (Fig. 1), does not necessarily reflect lateral sacral tilt [17], in part because of accompanying pelvic torsion (Fig. 3) [19–21]. A clinician would thus be naïve to believe that a given difference in height between the iliac crests directly reflects a leg length inequality of the same magnitude. Pelvic torsion nevertheless appears to result from the asymmetrical situation of unequal leg lengths, so presence of a lateral pelvic tilt should still serve as an alarm to search further for signs of bilateral asymmetry from the pelvis itself down to the feet.

We made leg lengths unequal to the extent of 15–24 mm, producing at least a 1.2° lateral pelvic tilt and found that the immediate mechanical effects included pelvic torsion and increased lateral trunk flexion toward the side of the elongated leg. Since these effects are also associated with clinical leg length inequality, our results suggest that 15–24 mm is not necessarily a ‘clinically negligible’ difference.

We thus advocate interpreting a lateral pelvic tilt of 1 or 2° as signaling the need for further examination of possible leg length inequality. A definitive examination [1] is both expensive and radiologically invasive, so examining the heights of iliac crests still has its place in clinical practice as a vehicle to tentative diagnosis.

References


