



ELSEVIER

## Literature reviews

# The relationship between pelvic torsion and anatomical leg length inequality: a review of the literature<sup>☆</sup>

Robert Cooperstein MA, DC<sup>a,\*</sup>, Makani Lew DC<sup>b</sup>

<sup>a</sup>Professor, Director of Technique, Director of Research, Palmer Center for Chiropractic Research, Palmer Chiropractic College, San Jose, CA 95134

<sup>b</sup>Instructor, Palmer Center for Chiropractic Research, San Jose, CA

Received 8 April 2009; received in revised form 10 June 2009; accepted 11 June 2009

### Key indexing terms:

Leg length inequality;  
Sacroiliac joint;  
Torsion, Mechanical;  
Posture;  
Ilium

### Abstract

**Objective:** Although it is common to find assertions relating functional leg length inequality (LLI) to pelvic torsion and other states of subluxation, comments and/or data concerning anatomical LLI in this same context are uncommon. This review of the literature synthesizes the evidence on pelvic torsion in relation to anatomical LLI.

**Methods:** The literature was searched using the PubMed; Manual, Alternative, and Natural Therapy Index System; Allied and Complementary Medicine Database; Cumulative Index to Nursing and Allied Health Literature; and Index to Chiropractic Literature databases for primary studies that related LLI, either artificially created or naturally occurring, to pelvic torsion. Extracted data included natural vs artificial LLI, method of creating or detecting LLI, subject selection, methodology for measuring pelvic torsion, and results.

**Results:** Nine English-language studies were retrieved published 1936-2004. Seven determined the impact of artificial, transient LLI on pelvic torsion, whereas 2 studied the effect of naturally occurring LLI.

**Conclusion:** Across varying methodologies for measuring LLI and pelvic torsion, a consistent, dose-related pattern was identified in which the innominate rotates anteriorly on the side of a shorter leg and posteriorly on the side of the longer leg. This finding was contrary to the common assertion that the ilium rotates posteriorly on the side of a short leg and vice versa. Practitioners of manual medicine who derive vectors for intervention based on leg checking procedures should consider the possibility that the direction of pelvic torsion may be variable depending on whether the LLI is of anatomical or functional origin.

© 2009 National University of Health Sciences.

<sup>☆</sup> Funding sources and conflicts of interest: The funding for this study is courtesy of the Palmer Center for Chiropractic Research. Neither author is involved in any conflict of interest related to participation in this project.

\* Corresponding author. Tel.: +1 408 944 6009; fax: +1 408 944 6118.

E-mail address: cooperstein\_r@palmer.edu (R. Cooperstein).

## Introduction

Practitioners of manual medicine typically evaluate the pelvic girdle in cases of low back pain, with or without associated lower extremity complaints. Sacroiliac pain and dysfunction can be difficult to distinguish from those of other spinal structures, including lumbar disks, nerve roots, and facet joints. The associated pain is generally experienced on one side of the low back or buttocks, and can radiate down the leg to varying degrees and sometimes to the ankle or foot.

The physical examination of the pelvic girdle and lumbar spine involves a variety of orthopedic, neurologic, pain provocative, functional, and postural assessment procedures. Many of these tests are intended to identify the side and location of probable joint dysfunction. Some, such as provocative blocking<sup>1,2</sup> and the McKenzie directional preference examination,<sup>3</sup> are intended to identify mechanical vectors likely to help the patient and others less likely to do so. Finally, the postural assessment addresses whether abnormal sagittal plane lumbopelvic angles, frontal plane pelvic obliquity, or pelvic torsion may be related to the patient's complaints.

Practitioners of manual medicine often check the legs of low back pain patients for evidence of inequality.<sup>4</sup> The literature clearly demonstrates that an anatomical short leg is a risk factor for low back pain and furthermore is very common.<sup>5</sup> Friberg<sup>5</sup> found that about 50% of an asymptomatic population had uneven anatomical leg lengths and about 75% of low back pain patients had leg length inequality (LLI) of 5 mm or more. At the same time, heel lifts have been shown to have some therapeutic value<sup>6-10</sup> when used to offset the many postural consequences of LLI, including spinal curvature, pelvic obliquity, and abnormal sagittal plane pelvic tilting.

Chiropractic practitioners as well as other manual therapists suggest an intimate and important relationship of LLI to pelvic torsion. Their general belief is that pelvic torsion causes functional LLI, such that the legs merely appear unequal in length despite being anatomically of the same length.<sup>11-13</sup> Practitioners have not adequately considered the possibility of a reversed cause and effect, whereby anatomical LLI can cause pelvic torsion<sup>12-14</sup> and in a different direction. This possible confounding of cause and effect may lead to inappropriate diagnoses and therapeutic courses of action.<sup>13,15</sup> In addition to questions of diagnostic acumen, we must also take into account that the evidence relating back and leg pain to pelvic torsion is rather equivocal.<sup>16</sup>

Pelvic torsion is present when the left and right innominate bones are rotated in opposed directions around a horizontal axis running through the symphysis

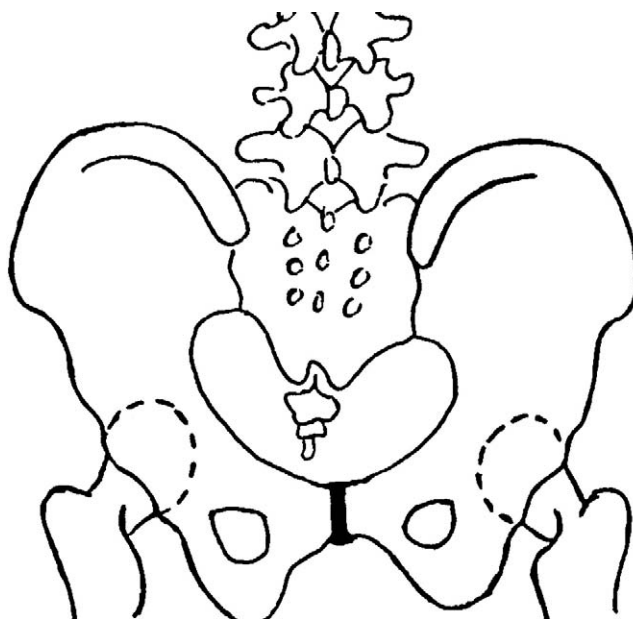


Fig 1. Pelvic torsion.

pubis. It was first characterized as such by Pitkin and Pheasant<sup>17</sup> in their seminal article in 1936. Hildebrandt,<sup>18</sup> apparently unaware of this original research, attaches his own name to this through-the-symphysis concept of pelvic torsion in his effort to bring it to the attention of the chiropractic profession. Fig 1, adapted from one of his drawings, portrays pelvic torsion.

Despite the demonstration of a clinically important association between anatomical LLI and low back and mechanical pelvic pain, the pathoanatomical mechanisms are not entirely clear. The purpose of this review of the literature is to gather the evidence on one such mechanism: the production of pelvic torsion.

## Methods

The literature was searched using the PubMed; Manual, Alternative, and Natural Therapy Index System; Allied and Complementary Medicine Database; Cumulative Index to Nursing and Allied Health Literature; and Index to Chiropractic Literature databases for studies that related LLI, either artificially created or naturally occurring, to pelvic torsion. The search strategy included using various combinations of terms related to LLI (eg, *leg length inequality*, *leg length discrepancy*, *anisomelia*), pelvic torsion (eg, *ilium anteversion and ilium retroversion*, *iliac crest heights*, *pelvic tilt and obliquity*, *pelvic kinematics*), and heel lifts. As qualifying articles were obtained, a secondary search was performed using their references. The only inclusion criterion was that the article had to be a primary study of

**Table 1** The STARLITE mnemonic for search strategy used

S: sampling strategy	Purposive: samples 5 databases commonly used in the manual therapy professions
T: type of study	Primary studies collecting data on anatomical LLI as it relates to pelvic torsion
A: approaches	Database searches, citation searching, contact with experts
R: range of years (start date, end date)	No limitations imposed
L: limits	Human studies, any language (only English studies were found)
I: inclusion and exclusions	Only primary studies included. Commentaries excluded.
T: terms used	<i>Leg length inequality, leg length discrepancy, anisomelia, pelvic torsion, ilium anteversion/retroversion, iliac crest heights, pelvic tilt, pelvic obliquity, pelvic kinematics</i>
E: electronic sources	PubMed, MANTIS, AMED, CINAHL, and ICL databases

*MANTIS*; Manual, Alternative, and Natural Therapy Index System; *AMED*, Allied and Complementary Medicine Database; *CINAHL*, Cumulative Index to Nursing and Allied Health Literature; *ICL*, Index to Chiropractic Literature.

the relationship of anatomical LLI to pelvic torsion. Articles that themselves merely commented on such a relationship, but did not report original research, were excluded. Several of the studies, in addition to reporting on the relationship between LLI and pelvic torsion, also described the impact on other biomechanical properties, including joint ranges of motion and other postural parameters. This review does not, for the most part, discuss these other associated findings and rather parsimoniously sticks to the question at hand: anatomical LLI and pelvic torsion. For a variety of technical reasons, a narrative rather than systematic review was performed, as explained in the “Discussion” section. Table 1 uses the STARLITE mnemonic<sup>19</sup> to summarize the search strategy used in this study.

## Results

A total of 9 primary studies were retrieved consistent with the inclusion criteria. The most salient character-

istics and findings of these 9 qualifying articles are summarized in Table 2. The first 7 listed, in chronological order, investigated the impact of artificially created LLI on pelvic torsion, whereas the last 2 articles were concerned with the impact of naturally occurring LLI. The 9 studies included, despite their flaws, all found the same relationship between LLI and pelvic torsion; and those studies with appropriate methodology for determining a dose relationship indeed found one to be present. From a data analysis point of view, this is a very robust finding, not likely to be due to chance alone. Let us suppose, for example, that methodological weaknesses resulted in pelvic torsion or LLI measurements that were, in essence, random. If indeed that had been the case, we would have expected on average that half the studies would find a given direction of relationship between LLI and torsion, and the other half an opposite direction. The likelihood that all 9 studies would show *the same direction*, under these assumptions, would be only  $1/2^9$ , which calculates out to  $1/512$  or 0.02%.

### Artificial, temporarily induced LLI

In 1936, Pitkin and Pheasant<sup>17</sup> took pelvic inclinometer measurements on 144 healthy subjects. Each subject’s *angle of inclination*—the angle formed between the plane of the floor and a line passing through the posterior superior iliac spine and anterior superior iliac spine—was measured using calipers fitted with a plumb line and a protractor scale. Measurements were taken in 3 positions: neutral stance, stance with the right foot elevated 1.5 in by standing on a block of wood, and stance with the left foot elevated in the same manner. On the side of the “lengthened” leg, the pelvis rotated posteriorly, whereas on the contralateral side, the pelvis rotated anteriorly. The average total antagonistic iliac mobility was  $11^\circ$  (range,  $3^\circ$ - $19^\circ$ ). This very large number is discussed below. The amount of induced pelvic torsion was dose related, meaning the greater the amount of the lift, the more torsion that resulted. The data are reported using descriptive statistics only, but that was typical of the time for this pioneering 1930s study. Pitkin and Pheasant<sup>17</sup> may have been the first investigators to develop a pelvic inclinometer. As such, neither the reliability nor the validity if this tool was measured, as was to be expected given the limited motion-detecting technology of the time compared with more modern times.

In 1987, Drerup and Hierholzer<sup>20</sup> examined 20 mild to medium idiopathic scoliosis patients (age and sex unknown) who were presenting for anteroposterior full-

Table 2 Summary of findings

Study	Type of Subjects	Methodology	Results	Comments
1. Pitkin and Pheasant <sup>17</sup>	Artificial LLI 144 Female college students	Pelvic inclinometer using plumb line/ 1.5 in (38.1 mm) wood block to create LLI	Posterior innominate rotation on side of lifted leg and anterior rotation on nonlifted side; range, 3-19°; mean, 11°. Baseline: right PI 1.3°. Pelvic torsion did not entirely correct induced pelvic tilt.	Pioneering study. Descriptive statistics only. Only 1 lift size used, preventing determination of dose relationship. Very large (1.5 in) LLI created, beyond expected clinical amounts that might occur. No left vs right outcomes reported. Induced torsional spread inconsistent with anatomical studies for joint ROM. No information on reliability and validity of inclinometer used.
2. Drerup B, Hierholzer <sup>20</sup>	Artificial LLI 20 Scoliosis patients (sex not provided)	Rasterstereographic measurement of dimples of Venus/up to 30 mm of block inserted (applied in 5-mm increments) to create LLI	A 20% "dimple lag" on lifted side suggested posterior innominate rotation on lifted side, anterior rotation on nonlifted side. Calculated up to 6.4° of torsional spread compared with baseline. Dose relationship reported; very linear.	Not known if scoliosis patients in study exhibited typical responses. Data not reported with side specificity (ie, only relative innominate rotations are calculated.
3. Cummings et al <sup>21</sup>	Artificial LLI 10 Female college students; 19-23 y old. Relatively equal leg lengths (scanogram radiograph to rule out LLI >4 mm) and well-functioning SI joints.	"Pelvometer": handheld calipers with digital readout. Waterloo Spatial Motion and Recording Technique used to measure pelvic positional changes/2/8-7/8 in (6.35-22.23 mm) Plexiglass plates to create LLI	Left lift caused posterior rotation of left innominate and anterior rotation of right innominate; dose related. Right lift caused posterior rotation of right innominate and anterior rotation of left innominate; dose related. Range: 1.62-5.73° of torsional spread from 6.35-22.23 mm of lift. Dose relationship reported, quite linear.	Measurement tool tested vs radiograph showed validity of .97 ICC, <sup>3</sup> intertester reliability of .95 ICC. <sup>3</sup> Absolute values provided for left/right innominate rotation changes compared with baseline.
4. Beaudoin et al <sup>22</sup>	Artificial LLI 20 Women, 19-24 y old, <5° scoliometer reading	3D motion analysis with reflective anatomical markers and 8 video cameras/15-mm shoe lift to create LLI	Lifting right foot results in right posterior innominate rotation 1° ± 1.5° and 2° ± 1.4° anterior rotation on nonlifted side. Lifting left foot results in left posterior innominate rotation 1° ± 1.3°, and 2° ± 1.4° right anterior rotation.	Changes with artificial LLI noted to be statistically significant. Only 1 lift size used; therefore, no dose effect reported.

5. Young et al <sup>2,3</sup>	Artificial	29 Healthy 18-to 28-y-old subjects (7 men). There were 21 without LLI, and 8 with preexisting > 1.8° lateral pelvic tilt	Pelvic inclinometer with bubble/15-to 24-mm lift to create ≥ 1.2° lateral pelvic tilt. In 8 subjects with preexisting pelvic tilt, lift used to level pelvis.	Lifting right leg results in 2.55° 0.58 mm relatively increased anterior rotation right ilium; lifting right leg results in 3.48° 0.52 mm relatively increased anterior rotation left ilium. Lifts did not reduce torsion in subjects with preexisting pelvic tilt.	Pelvic sagittal tilt measurement reliability = 0.99 ICC <sup>3,4</sup> with 0.52 standard error of measurement. Data are provided for pre- and posttorsional spread, not for absolute changes in either anterior or posterior innominate rotation. Regression analysis not performed, although a provided scatter plot confirms a dose response.
6. Zabeck et al <sup>2,4</sup>	Artificial	46 (Average age, 12 y) old scoliosis patients, 37 female; 14 evaluated radiologically	Stereo videography of reflectors on anatomical landmarks/5-, 10-, or 15-mm lifts under left foot	Innominate rotations observed with left lift: 11% bilateral posterior rotation; 20% bilateral anterior rotation; 68% with pattern of right anterior and left posterior innominate rotation. For bilateral movements, the deltas, if any, were not reported. Lifts did seem to reduce torsion in subjects with preexisting pelvic tilt.	Statistically significant changes are stated to be dose related, although data not reported by size of lift. Changes with lift reported as absolute values only, rendering interpretation difficult.
7. Hanada et al <sup>41</sup>	Artificial	14 Subjects (5 men), ≥ 19 y old, with <10 mm LLI for reliability study; 30 subjects for iliac crest comparison	Open book placed under leg, page number noted that levels iliac crests. Termed <i>ICPBC</i> method.	Book method understated known induced mean LLI by 3.8 ± 10.3 mm. Underestimated radiologically determined mean LLI by 5.1 ± 8.6 mm. Scatter plots provided for correlation of crest leveling and radiology with induced LLI.	Summary data reported as mean values only. ICCs calculated. Investigators did not attempt to measure torsion, but results suggest torsion occurred (analogous to “dimple lag” of Drerup et al. <sup>20</sup> )
8. Giles <sup>2,5</sup>	Natural	Convenience sample of 100 radiographs, subjects 19-77 y old. 50 radiographs with >9 mm LLI, 50 radiographs with 0-3 mm LLI. Subjects with facet tropism disqualified.	Radiograph measurement of left vs right lumbosacral facet angle using anteroposterior and oblique lumbopelvic films. LLI estimated from radiograph femoral head heights. No artificial LLI created.	50 Patients with a mean of 13.9 mm LLI “always” showed a smaller lumbosacral facet angle of the short leg side mean 64.7° vs 70.3° on long leg side, suggesting anterior rotation of ilium and sacrum on the side of the shorter leg. No artificial LLI created.	Mann-Whitney test comparing the difference between the left and right measurements in both groups was highly significant, z value of 7.293 Note: Data do not distinguish whether there was an effect on 1 or both innominate bones.
9. Krawiec et al <sup>2,6</sup>	Natural	44 Male college athletes	Pelvic inclinometer (PALM, aka <i>Palpation Meter</i> )/tape measure/TMMs used to measure LLI. No artificial	ICC calculated for LLI and torsion measurements (ICC = .99). 42 subjects (95%) had pelvic torsion; 73% were	TMM for LLI may not be very accurate. No threshold for identifying LLI provided.

(continued on next page)

Table 2 (continued)

Study	Type of Subjects	Methodology	Results	Comments
	LLI	LLI created.	relatively right anterior (mean $1.9 \pm 0.2.6^\circ$ ); 27% left anterior (mean not provided); 95% had LLI; 68% short right; mean $2.2 \pm 7.3$ mm using medial malleolus TMM and mean $1.4 \pm 6.2$ mm using lateral malleolus TMM/no artificial LLI created. Relating pelvic torsion to LLI: $r = 0.33$ , $P = .026$ (med mall method); $r = -0.44$ , $P = .003$ (lat mall method)	Correlations not very strong. Patient population not heterogeneous. Some other studies have shown baseline right posterior innominate rotation. Supine vs standing assessment of LLI noted as interpretive dilemma.

ROM, Range of motion; SI, sacroiliac joint; ICC, intraclass correlation coefficient.

spine radiograph. They used standing rasterographic surface curvature analysis to measure movements of the dimples of Venus (soft-tissue depressions located just superior and lateral to the posterior superior iliac spines) when  $\pm 10^\circ$  of pelvic obliquity was introduced by having the subjects stand with 1 foot on an elevated block, in increments of 5 mm up to 30 mm. As expected, the dimple rose on the elevated leg side; but there was a systematic lag in dimple movement, about 20% as compared with the amount predicted from trigonometric calculations based on the known amount of lift applied. Data are not provided for absolute dimple movements, but rather for changes in the relative tilting of a line connecting the dimples. The amount of so-called dimple lag was as much as 1.5 mm per dimple, moving in opposite directions parallel to the y-axis, using a 30-mm heel lift. The authors theorized that dimple lag resulted from pelvic torsion. This millimetric measurement corresponds to a torsional spread of about  $6.4^\circ$  between the innominate bones, in turn suggesting a  $3.2^\circ$  range of motion for each sacroiliac joint from extreme anterior to posterior rotation. The amount of torsion was found to be "dose related." Consistent with Pitkin and Pheasant,<sup>17</sup> the innominate on the raised leg side was thought to have rotated posteriorly; and the contralateral side, anteriorly. It is interesting to note that innominate response to induced LLI was the same in this sample of scoliosis patients as in the original nonscoliotic group. The investigators in this study did not actually measure absolute rotations of the innominate bones relative to baseline, but rather their relative change. The study inference that anterior rotation occurred on the one side and posterior on the other is consistent with the data, but is not proven by it.

In 1993, Cummings et al<sup>21</sup> measured pelvic position and motion with the Waterloo Spatial Motion and Recording Technique, whereby infrared LEDs attached to landmarks were monitored by 2 cameras. Ten healthy female volunteers were examined in neutral stance, with incrementally increasing lifts placed under each foot. Lifts ranging from 2/8 to 7/8 in (6.3-22.2 mm) were deployed. They found that a lengthened leg resulted in ipsilateral posterior innominate tilt and contralateral anterior innominate rotation. Total antagonistic iliac mobility ranged from  $2^\circ$  to  $6^\circ$  and was dose related.

In 1999, Beaudoin et al<sup>22</sup> used video cameras and reflective markings to determine various postural responses to the placement of a 15-mm heel lift, under each leg sequentially, in 20 asymptomatic females, scoliotics excluded. In this carefully executed study, there was a very tight correlation between leg elevation and innominate rotation. Elevating either the right or the

left leg produced an average of  $3^\circ$  of posterior rotation of the raised pelvis side compared with the other side ( $P < .05$ ). It is interesting to note that there was an average of  $1^\circ$  of anterior innominate rotation in the control (unlifted condition), consistent with the findings of Krawiec et al<sup>26</sup> in naturally occurring LLI, but opposite in direction from what was found by Pitkin and Pheasant,<sup>17</sup> who found a baseline posterior rotation of the right innominate. The authors point out that pelvic torsional responses to heel lifts complicate the procedure of using lifts to correct scoliosis because the overall impact on the pelvis is made variable by the torsion effect. Because only one lift size was used, the study design did not allow calculation of a dose response.

In 2000, Young et al,<sup>23</sup> interested in both exploring the effect of artificial LLI on trunk motion and confirming the results of other studies, placed various amounts of lift (ranging from 15-34 mm) under either the left or right foot of 29 mostly female subjects, so as to either level or unlevel the pelvis, as the case may be. The iliac crests were measured with an inclinometer using bubble technology. On average, raising the right leg produced relative ipsilateral posterior innominate rotation of  $2.55 \pm 0.58^\circ$ , whereas raising the left leg produced ipsilateral relative posterior innominate rotation of  $3.48 \pm 0.52^\circ$ . Data are provided for pre- and post-torsional spread, but not for absolute changes in either anterior or posterior innominate rotation. The data were not analyzed using regression, but a provided scatter plot confirms that a dose relationship was indeed present. Lifts did not reduce torsion in subjects with appreciable preexisting pelvic tilt, unlike the positive outcome in Zabjek et al.<sup>24</sup>

In 2001, Zabjek et al<sup>24</sup> studied the impact of 5-, 10-, or 15-mm heel lifts in a population of 46 young scoliotic females, mean age of 12 years, all with left convex lumbar or lumbopelvic curvature of the spine. The lift was always inserted under the left foot. Innominate rotations were detected using stereo videography of 56 reflectors placed on anatomical landmarks. The effects of the heel lift were not reported stratified by lift size, so no dose relationship could be inferred. Lifting the left foot resulted 11% of the time in bilateral posterior innominate rotation compared with baseline measurements; 20% of the time in bilateral anterior innominate rotation; and 68% of the time in right anterior, left posterior innominate rotation. In the case of bilateral innominate rotations, possible left-right differences in the degree of innominate rotation were not reported, thus precluding determination of possible changes in the induced pelvic torsion. Moreover, lift-related changes in innominate rotation were

reported as absolute values only, rendering interpretation challenging. Statistically significant changes were stated to be dose related, although supporting data were not provided. Lifts did seem to reduce torsion in subjects with preexisting pelvic tilt, unlike what was reported in the study of Young et al<sup>23</sup> in nonscoliotics, where lifts did not reduce the amount of pelvic torsion.

In 2001, Hanada et al<sup>41</sup> determined the reliability and validity of measuring LLI using the “iliac crest and book correction” method. There were 14 subjects (5 men), 19 years or older, with less than 10 mm of LLI as determined by an initial screen using the “iliac crest palpation and book correction” (ICPBC) method. This method involved noting the page number required to level the iliac crests when a subject places one foot on an open book. In one phase of the study, to establish content validity, the investigators induced artificial LLI by elevating the subject’s legs between 7 and 53 mm, randomizing the side and magnitude of elevation. Afterward, a second examiner, blinded as to the magnitude and side of the artificial LLI, used a second book to level the iliac crests. The investigators noted that the book correction method underestimated the elevation of the leg by 3.8 mm; in their adjunct study, radiographs underestimated the elevation by 5.1 mm. Although the investigators do not attempt to explain these findings, they are consistent with all the other studies herein discussed: there was almost certainly a probable posterior rotation of the innominate on the raised leg side, thus lowering the iliac crest. The results were very consistent with the “dimple lag” effect noted by Drerup and Hierholzer.<sup>20</sup> Data are provided for the pre- and post-pelvic torsion angles, but not for absolute changes in either anterior or posterior innominate rotation related to lift implementation. Thus, no regression analysis was performed; and no dose response was reported. Clarifying the investigators’ terminology, what they described as resulting “anterior pelvic rotation” is not actually an absolute innominate or whole pelvis rotation, but rather a change in the amount of innominate rotation around a transverse (ie, horizontal) axis, that is, pelvic torsion. Lifts did not reduce torsion in subjects with appreciable preexisting pelvic tilt, consistent with the finding of Young et al<sup>23</sup> in another population of nonscoliotic patients.

### Naturally occurring LLI

In 1981, Giles<sup>25</sup> used a convenience sample of 100 radiographs of adults 19 to 77 years old to determine the right and left lumbosacral facet joint angles in nonacute low back pain patients. The sample was

divided into a group of 50 subjects with mean anatomical LLI of 13.9 mm and another group of 50 with LLI of 3 mm. Giles found that there was always anterior rotation of the innominate bone on the side of a the short leg. Although Giles himself does not make the following point, Cummings et al<sup>21</sup> interpret these findings to mean that there must have been anterior rotation of the ilium and sacrum on the side of the shorter leg. This study, therefore, qualifies as a natural experiment in which the impact of naturally occurring anatomical LLI on pelvic torsion may be inferred.

In 2004, Krawiec et al<sup>26</sup> also performed a natural experiment, investigating the relationship of pelvic torsion and LLI in 44 healthy male athletes. Sagittal plane innominate positions were measured in the standing position using the Palpation Meter,<sup>27</sup> a type of pelvic inclinometer. Leg lengths were determined in the supine position using a tape measure, from the anterior superior iliac spine to both the lateral and medial malleoli. Forty-two of the 44 subjects had innominate asymmetry, with the right innominate rotated anteriorly in 73% of cases, an average of  $1.9 \pm 2.6^\circ$ . Thirty of the 42 subjects with LLI exhibited a short right leg:  $0.22 \pm 0.73$  cm using the medial malleolus tape measure method (TMM) and  $0.14 \pm 0.62$  cm using the lateral malleolus TMM. A short leg was associated with anterior innominate rotation ( $r = 0.33$  using the medial malleolus TMM;  $r = 0.44$  using the lateral TMM). It was noted that the amount of torsion was related to the amount of LLI and that there was an obvious dose response. Although it is difficult to draw firm conclusions from the study because the data are not entirely or clearly presented, nor are levels of statistical significance provided, its findings are consistent with those of the other investigators who created artificial LLI and detected the same posterior rotation on the lengthened side. This study, therefore, qualifies as a natural experiment in which the impact of naturally occurring anatomical LLI on pelvic torsion may be inferred. The baseline tendency of right anterior innominate rotation is opposite in direction from what was found in yet another population of young gymnasts by Barakatt et al<sup>28</sup>; Krawiec hypothesizes that this other investigators' sample of young athletes may have been unusually flexible, thus accounting for the difference.

### Representative examples of relevant nonincluded articles

During the course of the literature search, we retrieved some articles that amounted to nonquantita-

tive observations on the relationship of anatomical LLI and pelvic torsion, both in the osteopathic and physical therapy literature. For example, Grieve<sup>29</sup> writes, "When there is shortening of 2 inches or more, there is a natural tendency for the pelvis to take up a torsional position which most nearly 'rights' the upper sacral surface." Such studies are not eligible for inclusion in this literature, but it is interesting to note that "on-the-shop-floor" clinicians have made frequent note of our central point in their writings.

In 2007, Sabharwal et al<sup>30</sup> performed a study comparing the reliability of scanograms and full-spine radiographs for measuring LLI. Although their intent did not include assessing for torsion, their article includes a full-spine radiograph taken with a subject standing on a 4.5-cm lift to level the pelvis. It can clearly be seen in the radiograph that the pelvis has rotated posteriorly on the lifted side, in addition to the valgus angle of the knee having increased. The investigators do not seem to realize that these induced pelvic torsional and lower extremity changes have altered their assessment of LLI. We decided not to include this study, even though an included illustration was consistent with the findings of the included articles, because no quantitative analysis had been performed relevant to our literature review.

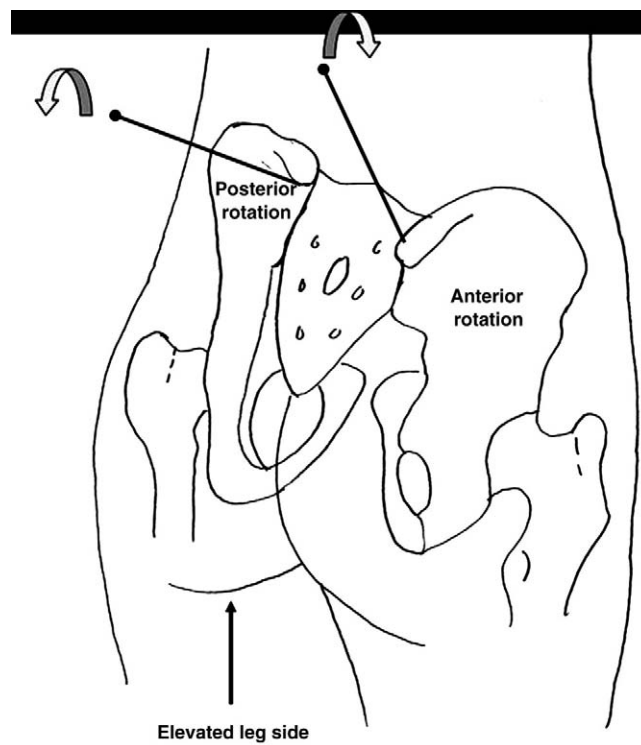


Fig 2. Anatomic LLI and pelvic torsion.



## Discussion

Although systematic reviews are generally considered preferable to narrative reviews,<sup>31</sup> several factors argued against (if not precluded) rating the retrieved studies for methodological quality and for erecting more rigorous inclusion criteria. Only 9 articles of any quality were retrieved. In these studies, the investigators used very different subject populations depending on their study-specific goals; and it was not obvious that any one choice had been superior to another. They used a variety of means to measure pelvic torsion, with arguably different amounts of largely unstudied accuracy; created artificial LLI or detected natural LLI in a variety of ways, the relative merits of which were not entirely clear; and reported induced innominate rotations in either relative or absolute terms, obfuscating study comparisons. Most precedents for systematic reviews address therapeutic interventions, and some address the reliability of diagnostic procedures; but fewer address observational studies and controlled experiments such as were retrieved in this literature review. The highly variable circumstances in which such investigational studies were conceived rendered systematic reviewing difficult.

The included studies measured pelvic torsion in a variety of ways, ranging from low-tech methods such as pelvic inclinometers to high-tech systems using reflective anatomical markers and even the use of surrogate measures such as dimple observation. We could not herein undertake to discuss the relative merits of all such methods, an undertaking that would be worthy of yet another paper unto itself. The primary studies each had to deal with issues of reproducibility and accuracy in rationalizing their methodology. For example, Drerup and Hierholzer<sup>20</sup> used displacement of the dimples of Venus as an outcome measure, a surrogate measure for ilium rotations. In justifying this methodology, the investigators cited a previous article in which they established dimple visualization as reliable.

In each of the included studies, there was a strong tendency for posterior innominate rotation to occur on the side of an anatomically longer leg and anterior innominate rotation to occur on the side of an anatomically shorter leg. This is portrayed in Fig 2. This did not depend on whether the anatomical leg was artificially induced (ie, during a laboratory experiment) or whether it was naturally occurring. One may have supposed that “in real life,” when a person has congenital LLI, the opportunity to adapt to and compensate for LLI over many years would have resulted in outcomes different from what happens in a

laboratory setting when temporary LLI is induced; but this was not the case.

## Study observations

The ancestral study by Pitkin and Pheasant<sup>17</sup> found by far the largest induced pelvic torsion, a mean of 11° and a range of 3° to 19°. These are very large numbers relative to some very conservative contemporary estimates of sacroiliac mobility, such as those of Sturesson et al<sup>31-33</sup> and those appearing in a review article by Goode et al.<sup>34</sup> However, the 1.5 in of artificial LLI created by Pitkin and Pheasant is also very large compared with the amount of LLI produced or found in other studies herein reviewed, some of which showed a linear, monotonic dose response of pelvic torsion to induced LLI. Moreover, the mean amount of torsion reported by them is within shouting distance of other modern investigators who have reported far more torsion to occur, such as a clinical study by Cibulka et al,<sup>35</sup> a cadaveric study using advanced imaging by Smidt et al,<sup>36</sup> another clinical study by Smidt et al,<sup>37</sup> and the Drerup and Hierholzer<sup>20</sup> study included in this review. That stated, the average torsion reported by Pitkin and Pheasant<sup>17</sup> does seem very large and out of the question in comparison with more contemporary studies of motion available to the sacroiliac joint. One of the authors wrote an article discussing the limitations of the very conservative studies of Sturesson et al as they relate to the step (aka *Gillet*) test.<sup>38</sup>

The study of Krawiec et al<sup>26</sup> is especially significant in that it confirms that the effect on pelvic torsion is irrespective of whether the LLI is natural or artificial, and thus chronic or purely transient. Although these investigators deemed the association weak because of relatively low figures for the Pearson correlation coefficient, their judgment may have been somewhat harsh. Tape measure methods for measuring LLI have been found to be of equivocal accuracy and may be less accurate than a radiological criterion standard method for assessing anatomical LLI<sup>39</sup>; this might explain the relatively low observed correlations between LLI and pelvic torsion. In any case, the percentage agreement between direction of short leg and associated anterior innominate rotation remains rather high at 73%. Given that decision making related to LLI often involves dichotomous choices (left vs right) rather than careful scrutiny of correlation, the magnitude of agreement may not be especially clinically relevant. A 73% accurate prediction rule for side specificity may be clinically useful, especially because the study methodology leads one to conclude that this understates the actual accuracy.

Young et al<sup>23</sup> point out that it would be “naive” to suppose that differences in iliac crest heights of a standing patient reflect LLI alone; pelvic torsional effects also impact upon crest heights and in fact may result in underestimating anatomical LLI. This might explain the poor agreement found by Rhodes et al<sup>40</sup> between visual methods of leg checking and upright radiographs. These investigators may have overstated their case that the standing radiograph should be considered the criterion standard compared with prone and supine visual leg checking procedures. The point of Young et al also explains the poor concurrent validity noted by Hanada et al,<sup>41</sup> who do not seem to realize that their results, far from undermining the clinical value of their ICPBC method, are actually consistent with it being sensitive enough to detect torsional changes with artificial LLI.

### Technique implications

Knowing that anatomical LLI tends to result in pelvic torsion is of some clinical interest, in that it may explain some of the pathoanatomical consequences of LLI, including pain syndromes and osteoarthritic changes related to asymmetric joint breakdown.<sup>25</sup>

Chiropractic leg checking involves determining the relative “length of the legs” or, more precisely, determining the relative position of the distal legs in either a supine or prone patient, by careful observation of the location of the feet. Asymmetry in distal foot positions, commonly known as *leg length inequality* or *LLI*, may be the result of an actual discrepancy in the length of the lower extremities (structural LLI) or may result from a postural imbalance.<sup>11,12</sup> It is commonly stated that there is a posterior-inferior innominate subluxation on the side of the short leg.<sup>13,42</sup> (chap 4, pp 23-30) Major technique systems, such as Activator Methods,<sup>43</sup> Thompson,<sup>44</sup> Pierce-Stillwagon,<sup>45</sup> and Sacro-Occipital Technique,<sup>46</sup> treat patients in accordance with this dictum. As may be seen in these representative examples, the technique situation in osteopathy<sup>47</sup> and physical therapy<sup>48</sup> is largely the same, these professions generally sharing the chiropractic view that a short leg reflects ipsilateral posterior innominate rotation.

An evident consequence of this review is that everything depends on whether perceived LLI is purely functional or rather anatomical in nature. Although it is beyond the scope of this review to comment on whether a functional short leg predicts ipsilateral posterior innominate rotation, let us for the purpose of discussion assume that it does. Detecting a short leg on physical examination by means of a typical visual inspection

procedure, a clinician would be hard pressed to know a priori whether there is functional or anatomical LLI present, or even a combination of the two. If it is functional LLI, posterior innominate rotation may (based on our assumption) be inferred; but if it is anatomical LLI, then anterior rotation is more likely to be present (based on the findings of this review). So that we may judge how much the possibility of anatomical LLI confounds the usual assumption of posterior innominate rotation, Friberg<sup>5</sup> found that about 50% of an asymptomatic population had uneven anatomical leg lengths and about 75% of low back pain patients had LLI of 5 mm. In short, if the relationship of LLI and pelvic torsion were other than is commonly thought, then the possibility exists that inappropriate adjustive procedures and outcome measures are being applied. We intend to develop this theme in another paper.

### Limitations of the study

Each of the articles included in this review featured a significant design flaw, incompletely reported the data, or failed to accomplish rigorous statistical analysis. On the other hand, their findings are so mutually consistent that the evidence is persuasive that the effect of both artificial and natural LLI is established. The evidence on the amount and direction of sacroiliac motions in a variety of test positions is largely contradictory.

### Conclusions

This review of the literature demonstrates that there tends to be, although certainly not invariably, posterior innominate rotation on the side of an anatomical long leg. This is true whether that long leg is created artificially and transiently in the laboratory setting or rather occurs naturally. Given that many clinicians and technique systems believe that posterior innominate rotation occurs on the short leg side, the possibility exists that sacroiliac adjusting procedures may be using inappropriate vectors with a negative impact on patient outcomes.

The tendency is for high-tech measurement methods to show less movement and for lower-tech measurement methods to show more movement. One is reminded of the fact that, according to folklore, it is commonly stated that the laws of aerodynamics “prove” that the bumblebee should be incapable of flight, although every such flight properly throws doubt on the methods and conclusion of flight engineers. Time will tell whether high-tech demonstrations of sacroiliac immobility will meet up with a similar fate.

Future studies might address the clinical relevance of the LLIs and pelvic torsion angles typically found or produced in these studies, as well as address the question as to whether a clinician taking advantage of the information is likely to achieve improved patient outcomes.

## References

- Cooperstein R. Sacro-occipital technique use of padded wedges for diagnosis and treatment. In: Chaitow L, editor. *Positional release*. 3 ed. New York: Churchill-Livingstone; 2008. p. 179-98.
- Cooperstein R. Padded wedges for lumbopelvic mechanical analysis. *J Am Chiropr Assoc* 2000;37(10):24-6.
- Long A, Donelson R, Fung T. Does it matter which exercise? A randomized control trial of exercise for low back pain. *Spine* 2004;29(23):2593-602.
- Mannello DM. Leg length inequality. *J Manipulative Physiol Ther* 1992;15(9):576-90.
- Friberg O. Leg length inequality and low back pain. *Clin Biomech* 1987;2:211-9.
- Baylis WJ, Rzonca EC. Functional and structural limb length discrepancies: evaluation and treatment. *Clin Podiatr Med Surg* 1988;5(3):509-20.
- Danbert RJ. Clinical assessment and treatment of leg length inequalities. *J Manipulative Physiol Ther* 1988;11(4):290-5.
- Irvin RE. The origin and relief of common pain. *J Back Musculoskeletal Rehabil* 1998;11(2):89-130.
- Triano JJ. Objective electromyographic evidence for use and effects of lift therapy. *J Manipulative Physiol Ther* 1983;6(1):13-6.
- Irvin RE. Reduction of lumbar scoliosis by use of a heel lift to level the sacral base. *J Am Osteopath Assoc* 1991;91(1):34, 37-44.
- Knutson GA. Anatomic and functional leg-length inequality: a review and recommendation for clinical decision-making. Part I, anatomic leg-length inequality: prevalence, magnitude, effects and clinical significance. *Chiropr Osteopat* 2005;13(1):11.
- Knutson GA. Anatomic and functional leg-length inequality: a review and recommendation for clinical decision-making. Part II, the functional or unloaded leg-length asymmetry. *Chiropr Osteopat* 2005;13(1):12.
- Cooperstein R, Lisi A. Pelvic torsion: anatomical considerations, construct validity, and chiropractic examination procedures. *Top Clin Chiropr* 2000;7(3):38-49.
- Knutson GA. The functional "short leg"; physiological mechanisms and clinical manifestations. *J Vertebral Subluxation Res* 2000;4(1):22-5.
- Cooperstein R. Relationship of pelvic torsion and anatomical leg length inequality. *J Chiropr Educ* 2008;22(1):53.
- Levangie PK. The association between static pelvic asymmetry and low back pain. *Spine* 1999;24(12):1234-42.
- Pitkin H, Pheasant H. Sacroarthrogenetic telalgia. II A study of sacral mobility. *J Bone Jt Surg* 1936;18(2):365-75.
- Hildebrandt RW. *Chiropractic spinography*. 2nd ed. Baltimore: Williams & Wilkins; 1985.
- Booth A. "brimful of STARLITE": toward standards for reporting literature searches. *J Med Libr Assoc* 2006;94(4):421-9, e205.
- Drerup B, Hierholzer E. Movement of the human pelvis and displacement of related anatomical landmarks on the body surface. *J Biomech* 1987;20(10):971-7.
- Cummings G, Scholz JP, Barnes K. The effect of imposed leg length difference on pelvic bone symmetry. *Spine* 1993;18(3):368-73.
- Beaudoin L, Zabjek KF, Leroux MA, Coillard C, Rivard CH. Acute systematic and variable postural adaptations induced by an orthopaedic shoe lift in control subjects. *Eur Spine J* 1999;8(1):40-5.
- Young RS, Andrew PD, Cummings GS. Effect of simulating leg length inequality on pelvic torsion and trunk mobility. *Gait Posture* 2000;11(3):217-23.
- Zabjek KF, Leroux MA, Coillard C, Martinez X, Griffet J, Simard G, et al. Acute postural adaptations induced by a shoe lift in idiopathic scoliosis patients. *Eur Spine J* 2001;10(2):107-13.
- Giles LG. Lumbosacral facetal "joint angles" associated with leg length inequality. *Rheumatol Rehabil* 1981;20(4):233-8.
- Krawiec CJ, Denegar CR, Hertel J, Salvaterra GF, Buckley WE. Static innominate asymmetry and leg length discrepancy in asymptomatic collegiate athletes. *Man Ther* 2003;8(4):207-13.
- Petrone MR, Guinn J, Reddin A, Sutlive TG, Flynn TW, Garber MP. The accuracy of the Palpation Meter (PALM) for measuring pelvic crest height difference and leg length discrepancy. *J Orthop Sports Phys Ther* 2003;33(6):319-25.
- Barakatt E, Smidt GL, Dawson JD, Wei SH, Heiss DG. Interinnominate motion and symmetry: comparison between gymnasts and nongymnasts. *J Orthop Sports Phys Ther* 1996;23(5):309-19.
- Grieve GP. The sacro-iliac joint. *Physiotherapy* 1976;62(12):384-400.
- Sabharwal S, Zhao C, McKeon J, Melaghari T, Blacksin M, Wenker C. Reliability analysis for radiographic measurement of limb length discrepancy: full-length standing anteroposterior radiograph versus scanogram. *J Pediatr Orthop* 2007;27(1):46-50.
- Sturesson B, Selvik G, Uden A. Movements of the sacroiliac joints. A roentgen stereophotogrammetric analysis. *Spine* 1989;14(2):162-5.
- Sturesson B, Uden A, Vleeming A. A radiostereometric analysis of movements of the sacroiliac joints during the standing hip flexion test. *Spine* 2000;25(3):364-8.
- Sturesson B, Uden A, Vleeming A. A radiostereometric analysis of the movements of the sacroiliac joints in the reciprocal straddle position. *Spine* 2000;25(2):214-7.
- Goode A, Hegedus EJ, Sizer P, Brismee JM, Linberg A, Cook CE. Three-dimensional movements of the sacroiliac joint: a systematic review of the literature and assessment of clinical utility. *J Man Manipulative Ther* 2008;16(1):25-38.
- Cibulka MT, Delitto A, Koldehoff RM. Changes in innominate tilt after manipulation of the sacroiliac joint in patients with low back pain. An experimental study. *Phys Ther* 1988;68(9):1359-63.
- Smidt GL, Wei SH, McQuade K, Barakatt E, Sun T, Stanford W. Sacroiliac motion for extreme hip positions. A fresh cadaver study. *Spine* 1997;22(18):2073-82.
- Smidt GL, McQuade K, Wei SH, Barakatt E. Sacroiliac kinematics for reciprocal straddle positions. *Spine* 1995;20(9):1047-54.

38. Cooperstein R. A tale of two papers: the demise of the Gillet test may be greatly exaggerated. *J Am Chiropr Assoc Online* 2009;47.
39. Sabharwal S, Kumar A. Methods for assessing leg length discrepancy. *Clin Orthop Relat Res* 2008;466(12):2910-22.
40. Rhodes DW, Mansfield ER, Bishop PA, Smith JF. The validity of the prone leg check as an estimate of standing leg length inequality measured by x-ray. *J Manipulative Physiol Ther* 1995;18(6):343-6.
41. Hanada E, Kirby RL, Mitchell M, Swuste JM. Measuring leg-length discrepancy by the "iliac crest palpation and book correction" method: reliability and validity. *Arch Phys Med Rehabil* 2001;82(7):938-42.
42. Cooperstein R, Gleberzon B. *Technique systems in chiropractic*. Churchill Livingstone: Edinburgh; 2004.
43. Fuhr AW, Green JR, Colloca CJ, Keller TS, editors. *Activator methods chiropractic technique*. St. Louis: Mosby; 1997.
44. Thompson C. *Thompson technique reference manual*. Elgin, Illinois: Thompson Educational Workshops, Williams Manufacturing; 1984.
45. Pierce WV, Stillwagon G. *Pierce-Stillwagon seminar manual*. Pennsylvania: Monongahela; 1976.
46. DeJarnette MB. *Sacro occipital technic: 1983; 1983*. Nebraska City, Nebraska: self-published.
47. Dott GA, Hart CL, McKay C. Predictability of sacral base levelness based on iliac crest measurements. *J Am Osteopath Assoc* 1994;94(5):383-90.
48. Manheimer J, Lampe G. *Clinical transcutaneous electrical nerve stimulation*. Philadelphia: F. A. Davis Company; 1984.