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Does the Gillet test assess sacroiliac motion or asymmetric one-legged stance strategies?

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Objective: *The purpose of this study was to quantify the extent to which apparent movements of the posterior superior iliac spine and sacral base areas Gillet sacroiliac motion testing were related to (a) degree of hip flexion and (b) the examiner's palpatory pressure.*

Methods: *A preliminary exploratory study quantified relative PSIS/S2 displacements in 10 sacroiliac joints among 5 asymptomatic subjects at 10° increments of hip flexion from 0-90°. A comprehensive follow-up asymptomatic study quantified PSIS/S2 displacements at 0° vs. 30° vs. 90° hip flexion, and for light vs. firm pressure at 30° hip flexion. Displacements measured in pixels on digital photographs were transformed to mm. Mean differences for the various test conditions*

Objectif : *Cette étude visait à déterminer dans quelle mesure les déplacements de l'épine iliaque postéro-supérieure (EIPS) par rapport à la base sacrée durant le test de la mobilité sacro-iliaque de Gillet étaient reliés a) au degré de flexion de hanche et b) à la pression palpatoire exercée par l'examinateur.*

Méthodologie : *Une étude exploratoire préliminaire avait consisté à mesurer les déplacements relatifs de l'EIPS par rapport à S2 dans 10 articulations sacro-iliaques chez 5 sujets asymptomatiques, en augmentant progressivement par palier de 10 degrés la flexion de hanche, à partir de 0° jusqu'à 90°. Une étude de suivi chez des patients asymptomatiques a consisté à mesurer les déplacements de l'EIPS par rapport à S2 lorsque la flexion de hanche était de 0°, de 30° et de 90°, quand l'examinateur exerçait une pression légère et une pression forte et que la flexion de hanche était de 30°. Les déplacements exprimés en pixels sur des photographies numériques ont été convertis en millimètres. Les différences moyennes entre les diverses conditions du test ont été évaluées par tests t pour*

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were evaluated for statistical significance using paired t-testing and Wilcoxon signed rank test.

Results: *With light pressure, the left PSIS moved caudal for hip flexion ≤30° during right-legged stance, whereas the right PSIS moved cephalad relative to the sacral base. For hip flexion =90°, both PSISs moved cephalad. The use of firm palpatory pressure abolished the initial caudal movement of the left PSIS, as well as differences in the amount of cephalad PSIS movement at 30° vs. 90° hip flexion.*

Conclusions: *The results are consistent with there being left-right differences in gluteus medius and biceps femoris activation among asymptomatic individuals that result in different balancing strategies during one-legged stance. This may create the appearance of relative PSIS/SB displacement, even though the results of Gillet testing can be wholly or partially explained by pelvic obliquity owing to muscle function asymmetry. This study questions the validity of the upright Gillet test for sacroiliac motion.*

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KEY WORDS: chiropractic, palpation, ilium, anatomic landmarks, motion palpation, physical examination, sacroiliac joint

échantillons appariés et par test des rangs signés de Wilcoxon.

Résultats : *Quand l'examinateur exerçait une pression légère, l'EIPS gauche se déplaçait en direction caudale lorsque le patient se tenait sur la jambe droite et que la flexion de hanche était de ≤ 30°, alors que l'EIPS droite se déplaçait en direction céphalique par rapport à la base sacrée. Lorsque la flexion de hanche* était *de 90°, les deux EIPS se déplaçaient en direction céphalique. En exerçant une forte pression palpatoire, l'examinateur abolissait le déplacement initial en direction caudale de l'EIPS gauche de m*ême que les *différences de déplacement des EIPS en direction céphalique observées entre une flexion de hanche de 30° et une flexion de hanche de 90°.*

Conclusions : *Les résultats sont compatibles avec les différences d'activation du muscle moyen fessier et du biceps fémoral gauche et droit observées chez des patients asymptomatiques et qui expliquent les différentes stratégies d'adaptation pour le maintien de l'équilibre en position debout sur une jambe. Il pourrait en résulter un semblant de déplacement relatif de l'EIPS par rapport à S2, même si les résultats du test de Gillet pourraient s'expliquer en tout ou en partie par l'inclinaison du bassin causée par l'asymétrie musculaire. La présente étude remet en question la validité du test de Gillet en position debout pour évaluer la mobilité sacro-iliaque.*

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MOTS CLÉS : chiropratique, palpation, ilion, repères anatomiques, palpation en mouvement, examen physique, articulation sacro-iliaque

Introduction

The Gillet test[1-3] and variants of it are used by manual therapists to assess motion at the sacroiliac joint. It is also known as the step test[4, p. 64], one-legged stance test[2], and stork test[5, 6]. There is another orthopedic test involving one-legged stance and hyperextension that is also called the stork test, and is said to identify spondylolysis.[7, 8] Among the numerous variants of the Gillet test, the most common one is conducted by the examiner placing one thumb on the posterior superior iliac spine (PSIS) area and the other thumb on the sacral base (SB) at the approximate location of the second sacral tubercle. The patient flexes the hip on the tested side. The usual interpretation of the test is that if the SI joint is movable, the ilium rotates posteriorly and inferiorly during hip flexion, as evidenced by the examiner's PSIS thumb moving caudally in relation to the sacral thumb.[9]

The results of interexaminer reliability studies on the

Gillet test have been quite variable, ranging from poor to good.[6, 9-21] To explain this variability and put in question the validity of the test, Sturesson *et al*.[22-24] conducted a series of basic science studies that suggested SI joint motion was so small that examiners performing the step test would not be able to detect motion; not even among subjects with SI joint dysfunction syndrome, who were expected to exhibit joint hypermobility. A review article on three-dimensional SI movement measurements came to a similar conclusion.[25] In a study concerning the impact of palpator experience on the interexaminer reliability of SI motion assessment[17], the investigators included, unbeknownst to the palpators, two cases of ankylosing spondylitis. The fact that neither palpator found either of the SI joints fixed in these subjects also put in question the validity of the Gillet test. In the light of these studies, some manual therapists have suggested abandoning it as a test of SI excursion.[3] They suggest retooling the test as a qualitative indicator of SI stability, as evidenced by the subject's ability to maintain effective balance in one-legged stance.[6, 12]

In a prior exploratory study[26], the first author determined that a relatively small amount of hip flexion was often but not always associated with caudal movement of the PSIS; but for larger amounts of hip flexion, the subject would lean toward the support leg side, whereupon the PSIS would reverse direction and move cephalad. Arab[14] had also noticed this reversal of PSIS direction of movement as the hip increased its angle of flexion, calling it "paradoxical" PSIS motion; but this latter author did not attempt to explain this curious observation. We determined in the exploratory study, which plotted movement of the PSIS as a function of hip flexion in 10° increments, that the maximum caudal movement of the PSIS (if any occurred) was at close to 30° of hip flexion, beyond which the PSIS usually reversed direction and moved cephalad. The first author hypothesized[26] that interaction between the Gillet and Trendelenburg tests could explain these observations, not only confounding standardizing the method of executing the test but also confounding interpreting its findings. Despite the traditional practice of interpreting relative displacement of the PSIS and SB as evidence of SI movement, it seemed that the *appearance* of displacement could be explained by the induction of pelvic obliquity (lateral pelvic tilt) during one-legged stance. One would expect this pelvic obliquity as the contralateral gluteus medius contracts to maintain balance. Indeed, gross failure of this mechanism constitutes the Trendelenburg sign[27 p.491], in which sagging on the flexed hip side provides evidence of a weak gluteus medius on the support leg side.

More recently, the first author observed that in clinical settings the amount of PSIS movement during the Gillet test seemed to not only depend on the amount of hip flexion, but also on the degree of palpatory pressure upon the pelvic landmarks. More pressure seemed to diminish the amount of observed relative displacement of the PSIS and SB. The primary purpose of the current study was to quantify the amount of apparent relative movement of the PSIS in relation to the SB at 30° compared to 90° of hip flexion, using a larger sample size than was used in the earlier exploratory study. The secondary objective was to quantify the degree to which lighter vs. firmer palpatory pressure on the pelvic landmarks impacted the amount of apparent PSIS movement relative to the SB.

Methods

Experimental procedure

This study was approved by the college's Institutional Review Board. All subjects were required to provide written informed consent prior to participation. Figure 1 is a

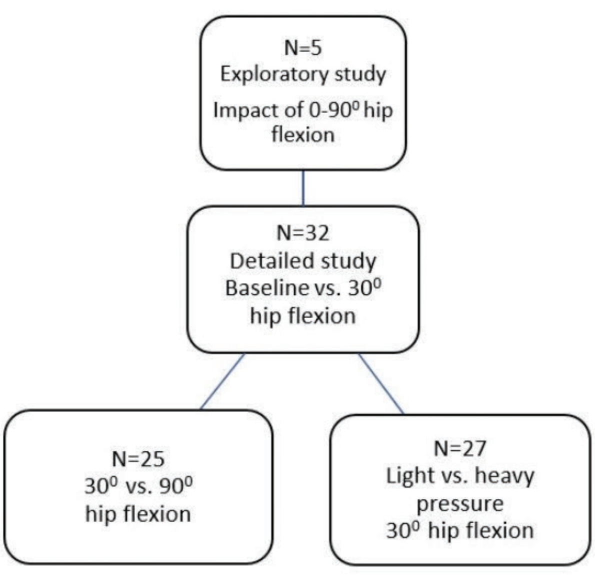


Figure 1.
Flow chart for the study.

flowchart depicting the process of data acquisition in this study.

In performing the most common version of the Gillet test, the examiner places one thumb on the PSIS and the other thumb on the SB approximately at the second sacral tubercle. Since this is an excursion test[28], it does not matter where the thumbs are exactly positioned, but it easier to determine what happens if the thumbs are pointed directly at each other and lie on a horizontal line [9, 29] (throughout this article, comments to the effect that a thumb was applied to the "PSIS" or "sacral tubercle" should be interpreted liberally, as signifying the PSIS or sacral tubercle "area."). The subject stabilizes his or her stance by facing and standing about a foot from a wall, touching the wall with the fingertips of each hand; the feet are situated directly under the hips so that the subject is neither leaning forward nor back. The subject then flexes the hip ipsilateral to the contacted PSIS and SB. Most authorities describe lifting the knee (i.e., flexing the hip) to approximately 90°, while others describe lifting the knee "as high as he can"[3,4]; one qualitative study has the subject flex the hip to only 60° [5]. This is repeated on the other side of the body.

In a small exploratory study using a convenience sample of asymptomatic young students[26], the first author used a photographic method to measure movements of the PSIS in relation to the SB as a function of hip flexion at 10° increments. The results of this small study, which suggested that movements of the PSIS relative to the SB depended on the angle of hip flexion, suggested a larger study would not only be more convincing, but be able to test various explanatory hypotheses.

The present follow-up study recruited another convenience sample of asymptomatic subjects, the inclusion criterion for which was being able to flex their hips without pain or fear of falling. Subjects stood at an arms' length from a wall in front of them and balanced themselves by contacting the wall with both hands. A digital camera was mounted on a tripod placed directly behind and above the kneeling examiner, with the lens focused on the subject's PSIS and sacral base. An experienced clinician (32 years of practice) kneeled behind each subject to perform Gillet's test. The examiner's thumbnails were marked with a line drawn in the middle of the nail and parallel to the length of the finger. The marked thumbs were then placed on the SB (near S2) and PSIS, using modest palpatory pressure. The thumbs were parallel to the floor, pointed at each other, and visibly judged to lie on a horizontal line (Figure 2). A research assistant used a universal goniometer to determine the degrees of hip flexion for each of the tested positions.

In Group A, a subset of the subjects, an initial baseline photograph was taken at 0° hip flexion. The subject was then asked to slowly flex the hip on the tested side to 30°. The examiner looked downward, to avoid visualizing the amount or direction of thumb movement. A second photograph was taken, after which the subject was instructed to return the flexed hip leg to the floor.

In Group B, another subset of the subjects, after photographic assessment at 30° the subject was instructed to return their leg to the floor, then flex the hip to 90°, whereupon another photograph was taken. The leg was then returned to the floor.

In group C, yet another subset of the subjects, after photographic assessment at 30° of hip flexion using modest pressure on the PSIS and SB, the examiner applied a soft tissue algometer to the PSIS and increased the pressure until the subject stated it had approximated the force previously applied by the examiner's thumb on the PSIS. The assessment was then repeated at 30° but with firmer pressure applied by each of the examiner's thumbs. The subject was then instructed to return the leg to the floor. The examiner applied a soft tissue algometer to the PSIS and increased the pressure until the subject stated it had approximated the force applied by the examiner's thumb on the PSIS at this heavier pressure level.

Analysis of photographs

Digital photographs were analyzed using a graphics program (GIMP, Gnome.org) that permitted identification of the x-y coordinates of the thumb positions at the PSIS and SB areas. The y-axis coordinates for each were identified and recorded for each photograph. Pixel distances on the screen were transformed into millimetric equivalent distances by using a conversion factor based on the width of the examiner's thumbnail as measured in both pixels and millimeters. Since the data were gathered in four different sessions in which the distance of the camera to the subjects and the settings of the lens were somewhat different, the conversion factors deployed were unique for each session.

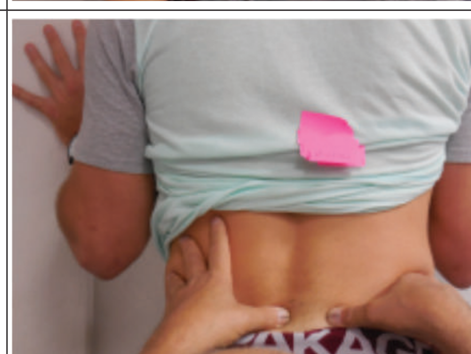
	Left		Right	
30° hip flexion		PSIS and sacral base thumbs even at 30° hip flexion.		PSIS thumb accidentally lower at 30° hip flexion.
30° hip flexion		PSIS thumb drops compared to 30° hip flexion. Body slight shift right.		Slight rise of PSIS thumb compared to 30° hip flexion, no body shift.
90° hip flexion		PSIS thumb rises compared to 30° hip flexion. Major body shift right.		Major rise of PSIS thumb compared to 30° hip flexion, no body shift.
30° hip flexion, heavy pressure		Heavy pressure abolishes both PSIS thumb dropping and body shifting.		Heavy pressure abolishes PSIS thumb drop, no body shift.

Figure 2.
Representative example of effect of variable hip flexion and thumb pressure.

Statistical analysis

To assess intra-examiner reliability in the photometric analysis, the first author repeated his assessment of the PSIS and sacral base thumb positions in 10 randomly chosen photographs one week later, thus generating 20 test-retest measurements (10 subjects, 2 SI joints per subject), to test for intraexaminer reliability. To assess inter-examiner reliability both authors analyzed another randomly chosen subset of 10 photographs, thus generating another 20 test-retest measurements to assess interexaminer reliability in the photo assessment. Intraclass correlations (ICC) were calculated using SPSS, v.19, published by IBM. Intraclass correlation coefficient (ICC) is a widely used reliability index in test-retest, interexamainer, and interexaminer analyses for continuous data.[30]

For eight comparisons drawn under a variety of test conditions, a paired sample t-test was conducted (SPSS, v.19, IBM) to determine whether the mean difference between two pairs of observations was different from zero. These eight comparisons were:

- PSIS/SB difference at 0° vs. 30° hip flexion, left
- PSIS/SB difference at 0° vs. 30° hip flexion, right
- PSIS/SB difference at 30° vs. 90° hip flexion, left
- PSIS/SB difference at 30° vs. 90° hip flexion, right
- PSIS/SB difference at 0° vs. 90° hip flexion, left
- PSIS/SB difference at 0° vs. 90° hip flexion, right
- PSIS/SB difference at 30°, light vs. heavy pressure, left
- PSIS/SB difference at 30°, light vs. heavy pressure, right

For each comparison, the Shapiro-Wilk statistic (http://sdittami.altervista.org/shapirotest/ShapiroTest.html) was used to assess the normality of the paired differences. The Wilcoxon signed-rank test (http://vassarstats.net/wilcoxon.html), the nonparametric equivalent of the paired samples t-test, was used to supplement the analysis for sample data that were not normally distributed.

Results

Exploratory study, N=5 (10 SI joints)

A convenience sample of five young asymptomatic subjects was recruited, 60% male. All screened potential subjects satisfied the inclusion criteria.

Among these five subjects there was an initial caudal movement of the PSIS relative to the SB in eight of 10 joints, creating the appearance of posterior ilium rotation and thus SI motion. However, in each case after this initial caudal movement there was a reversal of direction as the hip flexed to 90°, whereupon the PSIS rose. On average, the reversal of direction occurred at 24.5°, which for convenience may be rounded off to 30°. In the two SI joints in which there was no initial PSIS drop with hip flexion, PSIS elevation accelerated after approximately 60°. With increasing hip flexion the subject's torso invariably tilted away from the side of hip flexion, with associated cephalad movement of the innominate bone (i.e., "hip-hiking") on the flexed hip side. Stated otherwise, the subject manifested increasing iliac crest height on the flexed hip side as hip flexion increased from 30° to 90°.

Comprehensive study, N=32 (64 SI joints)

In the present comprehensive study, the subjects were a convenience sample of 32 asymptomatic students, 47.6% males, 52.4% females. All screened subjects satisfied the inclusion criteria. Their mean age was 25.1 (s=2.7) years, weight 71.4 (s=13.0) kg, height 171.8 (s=7.6) cm, and BMI 24.1(s=3.59) kg/m^2.

We first determined the inter- and intraexaminer reliability of measuring distances on the digital photographs. The intraexaminer reliability in a convenience sample of 20 measurements was as follows: intraclass correlation (2,1)=0.99 (95% CI=0.97, 0.99). The intraexaminer reliability in another convenience sample of 20 measurements was as follows: intraclass correlation (2,1)=0.99 (95% CI=0.98,1.00).

Table 1 summarizes the results of a series of paired t-tests conducted on the measurements taken from the digital photographs in subject Groups A, B, and C. These t-tests addressed whether the mean change in PSIS/SB displacement was statistically different under a variety of Gillet test conditions. Data are reported for 0° vs 30° vs. 90° of hip flexion, as well as for light vs. heavy pressure on the pelvic landmarks at 30° of hip flexion. When the measurement for PSIS/SB displacement was negative, the PSIS moved caudal in relation to the SB between test conditions; when the measurement was positive, the PSIS moved cephalad between test conditions

Group A: 0° vs. 30° hip flexion, N=32

There was an apparent statistically significant *caudal* movement of the left PSIS relative to the SB at 30° of hip

Table 1.
Paired Samples t-test.

Subject group	Condition	Mean diff, mm	SD diff	SE of mean	t	p	Lower 95% CI	Upper 95% CI
A N=32	0° vs. 30°, left	–2.69	3.58	0.64	–4.18	0.00	–4.00	–1.38
	0° vs. 30°, right*	1.32	3.94	0.71	1.87	0.07	–0.12	2.76
B N=25	30° vs. 90°, left*	7.14	3.69	0.75	9.49	0.00	5.59	8.70
	30° vs. 90°, right	6.94	3.10	0.63	10.98	0.00	5.64	8.25
	0° vs. 90°, left	4.38	5.22	1.07	4.11	0.00	2.18	6.58
	0° vs. 90°, right	8.02	4.93	1.01	7.96	0.00	5.94	10.10
C N=27	Light vs. firm pressure, 30°, left	3.55	3.62	0.71	5.00	0.00	2.09	5.01
	Light vs. firm pressure, 30°, right*	–0.10	4.33	0.85	–0.11	0.91	–1.84	1.65

Negative values signify caudal movement of PSIS relative to SB between test conditions. Abbreviations: PSIS=posterior superior iliac spine, SB=sacral base, diff=difference in mm, SE=standard error SD=standard deviation, CI=confidence interval, 2-tailed. * signifies the paired differences data are not normally distributed.

flexion compared to 0°: M=-2.69mm, SD=43.58, p=0.00. There was an apparent *cephalad* movement of the PSIS on the right, that did not quite reach statistical significance: M=1.32, SD=3.94, p=0.07. Since the distribution was non-normal, the Wilcoxon signed-rank test was used to determine the probability that the difference was due to chance: p(2-tail)=0.03, confirming a significant difference.

Group B: 0° vs. 30° vs. 90° hip flexion, N=25

There was a statistically significant apparent *cephalad* movement of the left PSIS relative to the SB at 90° of hip flexion compared to 30°: M=7.14mm, SD=3.69, p=0.00. Since the distribution was non-normal, the Wilcoxon signed-rank test was used to determine the probability that the difference was due to chance: p(2-tail): p=0.00, confirming the difference was significant. There was a statistically significant apparent movement of the PSIS on the right at 90° compared to 30°: M=6.94mm, SD=3.10, p=0.00.

There was a statistically significant apparent *cephalad* movement of the left PSIS relative to the SB at 90° of hip flexion compared to 0°: M=4.38mm, SD=5.22, p=0.00. There was a statistically significant and *greater cephalad* apparent movement of the PSIS on the right at 90° compared to 0°: M=8.02mm, SD=4.93, p=0.00.

Group C: Light vs. firm pressure, 30° hip flexion, N=27

The results of using a soft-tissue algometer to heuristically calibrate the mean pressure applied to the PSIS were as follows: "light" pressure was perceived equivalent to 2.1kg, whereas "heavy" pressure was perceived equivalent to 3.4kg. Since kilograms can be converted to Newtons by multiplying by 9.807, these measurements were equal to 20.6 and 33.3 Newtons, respectively.

The tendency of the left PSIS to apparently move *caudally* on left hip flexion to 30° was abolished by the application of firm pressure to the PSIS and SB. With firm pressure, the left PSIS moved *cephalad*: 3.55mm, SD=3.62, p=0.00. The previously-described tendency of the right PSIS to apparently move cephalad on hip flexion was unaffected by the application of firm pressure: M=-0.10mm, SD=4.33, p=0.91. Since the distribution on the right was non-normal, the Wilcoxon signed-rank test was used to determine the probability that the difference was due to chance: p(2-tail): p=0.98, confirming there was no difference.

Discussion

The Shapiro-Wilk test is commonly regarded to be the best choice for testing the normality of data.[31] The paired t–test is used when there are multiple pairs of observations, testing whether the mean difference in the pairs is different from zero.[32] The Wilcoxon signed-rank test may be used as an alternative to the paired t-test when the differences are severely non-normally distributed.[33] Although paired t-testing assumes that the means of the different samples are normally distributed, only 20 to 30 subjects are needed for the sample means to approximate normality.[33, 34] Therefore, although the non-normal distributions of three of these comparisons did not preclude paired t-testing, it seemed prudent to add confidence to the findings by performing supplemental Wilcoxon testing for these three comparisons.

Since the Wilcoxon p value was <0.05 for 0° vs. 30° hip flexion on the right, and for 30° vs. 90° of hip flexion on the left, the null hypothesis that the difference was due to chance was rejected in both, supporting the t-test finding that the differences were statistically significant. In the case of light vs. firm pressure, at 30° hip flexion on the right, the Wilcoxon p value was >0.05, supporting the t-test conclusion that there was no difference.

Exploratory (n=5) study

Our initial n=5 exploratory study found the Gillet test most sensitive for detecting this caudal movement of the PSIS at approximately 30°. By comparison, Hungerford found maximum posterior rotation of the innominate occurring at approximately 70° of hip flexion.[3] In her study, skin-mounted 15mm balls and a six-camera system and software package were used to record and analyze motion.[3] Despite the relatively high-tech methodology, Hungerford cautioned that there may have been movement of the skin markers in relation to bony landmarks. She concluded that the main emphasis in her study was on *patterns* of bone motion, rather than range of motion. In the present study, the pressure of the examiner's thumbs on the pelvic landmarks presumably "clamped" the skin to the underlying bone to some extent, to minimize movement of the thumbs independently of the overlying skin.

Comprehensive (n=32) study

It the n=32 comprehensive study, for hip flexion ≤30°, one-legged stance on the right resulted in an apparent caudal movement of the left PSIS compared with the SB, whereas one-legged stance on the left resulted in a relative apparent cephalad movement of the right PSIS. If the traditional understanding of the Gillet test as a form of SI motion palpation were correct, our findings were tantamount to finding that most left SI joints are movable, and most right SI joints hypomobile. The investigators, thinking this interpretation of the study findings implausible, formulated alternative explanations for the study's findings: first, there appear to be opposite strategies for left and right one-legged stance, at least for hip flexion ≤30°; and second, asymmetry in left/right hamstring muscle tone results in relatively more movement of the left PSIS relative to the skin during Gillet testing. Hypotheses 1-4 below provide a detailed account of these explanations.

In the n=25 module of the study the apparent initial caudal movement of the left PSIS at hip flexion ≤30° was abolished as the hip flexed higher. Apparent cephalad movement of the PSIS was directly proportional to hip flexion for hip flexion > 30°. Hypotheses 1 and 2 address these findings.

Hypothesis 1: Asymmetric balancing strategies in left and right one-legged stance

With modest flexion of the left hip to approximately 30°, the pelvis tends to sag slightly on the left, resulting in apparent caudal movement of the PSIS relative to the SB. Rather than reflecting left SI joint movement, the apparent displacement of the PSIS and SB may be fully or partially accounted for by pelvic obliquity, inferior to the left. When flexing the right hip to approximately 30°, subjects tend to lean toward the left, hiking the right hip such that the PSIS appears to move cephalad in relation to the SB. Rather than reflecting hypomobility of the SI joint, this effect can be fully or partially accounted for by pelvic obliquity.

This asymmetry in left vs right balancing strategies in one-legged stance may reflect left/right differences in muscle function, probably related to handedness. One-legged stance involves several supporting muscles, including the hip extensors and abductors, primarily gluteus maximus and medius.[35] The left hip extensors tend to be stronger than those on the right[36], and the left gluteus medius muscle tends to be stronger than the right gluteus medius[37, p.76]. According to Kendall *et al.*, the gluteus medius tends to be weaker on the side of handedness, usually the right [37, p.76]. The iliac crest tends to be elevated on this same side, gluteus medius being in a state of stretch-weakness which is the result of being elongated (however slightly) for prolonged periods of time. The asymmetry of gluteus medius strength is especially pronounced in a symptomatic population, with right-sided weakness occurring 71% of the time in males and 90% of the time in females; by comparison, the left gluteus medius is weak only 15% of the time in males, and 6% in female.[37, p.8] The delayed activation or lesser strength of the right gluteus medius for modest amounts of left hip flexion would therefore explain the sagging on the left and hip-hiking on the right during Gillet testing; and thus the appearance but not necessarily the actuality of SI movement.

Hypothesis 2. Asymmetric hamstring tone
Yet another typical muscle function asymmetry may play a part in the opposite apparent movements of the left/right PSISs during hip flexion ≤30°. The long head of the biceps femoris, one of the hamstring muscles, attaches to the sacrotuberous ligament, a part of which (the long dorsal SI ligament) attaches to the caudal aspect of the PSIS. As the hamstring tightens during hip flexion, the sacrotuberous and long dorsal ligaments transmit a caudal tug on the PSIS. Since the left hamstrings tend to be tighter and less flexible than the right hamstrings[38], this tug on the PSIS during hip flexion would be more pronounced on the left, resulting in pelvic obliquity, inferior to the left. This would provide the appearance of relative PSIS/SB displacement, without there necessarily having been very much, if any SI movement. As the hip flexes to 90°, this small pelvic drop would be overwhelmed by hip hiking, as part of the balancing strategy. The less contracted state of the right hamstring would not produce an equivalent caudal tug on the right PSIS during one-legged stance on the left. The right biceps femoris would simply elongate, accommodating right-sided hip hiking.

In the n=27 light vs. firm pressure module of the study, conducted at 30° hip flexion, PSIS movements were pressure-sensitive on the left but not on the right. Hypotheses 3 and 4 address these findings.

Hypothesis 3. The pelvic compression effect
The one-legged stance balancing mechanism may be more efficient with greater palpatory pressure due to pelvic compression, which presumably leads to enhanced activation of the left/right gluteus medius muscles. According to this hypothesis, firmer pressure would negate the inherent relative weakness or delayed activation of the right gluteus medius, the premise of Hypothesis 1. In support of Hypothesis 3, we may invoke the findings of the active straight leg raise test (ASLR), which assesses pain provocation and the ability to load the pelvis through the lower extremity. In the ASLR, the supine patient is instructed to lift the tested leg 20 cm off the table.[39] It has been demonstrated that compression of the pelvic girdle with a trochanteric belt can increase the ease of supine leg raising among patients with pregnancy-related pelvic pain.[40] Manual pelvic compression has been shown to have a similar effect in pelvic pain patients.[41] Although the subjects in our student were asymptomatic, we may hypothesize that SI compression produced by increased palpatory pressure on the PSIS and SB enhanced activation of the right gluteus medius, abolishing the initial caudal movement of the left PSIS, although not impacting the movement of the right PSIS.

Hypothesis 4. The clamping effect
The examiner's thumb, which is said to "contact the subject's PSIS", is in fact placed upon soft tissue and not directly on the bone. Therefore, its position could be affected by soft tissue movement in relation to the underlying osseous structure. As described above, hip flexion produces increased tension in the biceps femoris, which in turn tightens up the sacrotuberous ligament and eventually tugs at the long dorsal ligament, which attaches to the inferior aspect of the PSIS. With typical modest palpatory pressure, the soft tissue overlying the PSIS would presumably be carried caudally by this tension, creating the appearance of SI motion. Since the left hamstrings have been found to be tighter and less flexible than the right hamstrings[38], this movement of the overlying skin relative to the PSIS would be greater on the left than on the right.

> With heavier palpatory pressure, the soft tissue would be more "clamped "to the underlying bone. In effect, this would abolish the apparent caudal movement of the left PSIS presumed in Hypothesis 2 to result from greater hamstring tone on the left.

The traditional expected normal finding in performing the Gillet test is generally understood to be posterior rotation of the innominate bone, with caudal movement of the PSIS on the flexed hip side relative to the SB.[2] Kapandji explains: hip flexion results in hamstring tension, thus drawing the innominate bone posteriorward.[42, p. 70] Manual therapists would add, given the oblique plane of the SI joint, that this posterior rotation is coupled with medial movement as well. Absent or diminished motion is considered abnormal and rationalizes a manipulative or other manual therapy procedure to restore motion.

Our study, on the other hand, suggests pelvic obliquity during one-legged stance can create the appearance of SI movement, especially on the left. Another line of research has questioned the utility of the Gillet test based on the demonstration that sacroiliac movement is so slight even in stressed positions of the joint, that an examiner would be unlikely to perceive movement in Gillet testing positions. Sturreson *et al*.[23, 24, 43] inserted tantalum balls into the ilium and SB, then used radiology to investigate the movements that occurred during Gillet testing in a variety of test positions. Not only did they find very little movement, but that both ilia moved as a unit in relation to the sacrum during the performance of the test; only very small movements (<1°) were produced. Hence, the investigators concluded that the Gillet test "cannot be recommended as a diagnostic tool for evaluating joint motion in the SIJs." Goode *et al*.[25] reviewed studies similar to those of Sturesson *et al*., and came to similar conclusions. It remains to be seen how the results of these high-tech studies showing relatively slight SI movements can be reconciled with the results of lower tech studies that detect greater movements.[44]

Our study suggested that in asymptomatic individuals there is efficient activation of the left gluteus muscle during ipsilateral one-legged stance for modest amounts of hip flexion, ≤30°. The underlying explanation may be that most people are right-handed, which correlates with preferring to use the right leg during motor activities.[45] Athletes usually use their right foot to kick during various sporting activities that involve kicking, while using their left leg for support.[45] One would expect the subjects in this study, most of whom were young, active students and right-handed, to manifest among these tendencies.

Although our study did not exclude the possibility that the Gillet test can detect movement, it did suggest that detection of such movements may be confounded by the subject's balancing strategy during one-legged stance, as well as by differences among examiners in the amount of pressure they apply to the pelvic structures. Indeed, the failure to control for the degree of hip flexion and/or the amount of examiner pressure used may account for the mostly poor interexaminer reliability that has been reported for the Gillet test.[46]

Pelvic obliquity during one-legged stance is typical, as the contralateral gluteus medius contracts to maintain balance. Indeed, failure of this mechanism marks the well-known Trendelenburg sign.[22, p.491] In a normal test finding, the body shifts weight toward the stance leg, positioning the center of gravity above the support leg to balance body weight. Our data suggest, given the observed asymmetry in one-legged balance strategies among asymptomatic subjects for hip flexion ≤30°, that the hip flexion or leg lifting during Trendelenburg testing should be >30° to reduce the risk of false positive test results. That stated, the magnitude of the caudal movements of the PSIS seen in our study, limited to just a few mm, are unlikely to be confused with a *bona fide* positive Trendelenburg sign.

Limitations

Since this study was not intended to address the reliability of the Gillet test, all observations were performed by one examiner; other examiners may have achieved different results. Although we believe using direct manual palpatory methods of detecting SI motion avoids the primary problem of slippage when using skin markers, we cannot rule out some deviation of the palpated landmarks from the bony landmarks, especially approaching 90° of hip flexion. Our study did not measure movements on the stance side during the Gillet test, as did Hungerford.[6] Since there was only one left-handed individual in the study, no inferences could be drawn based on handedness. No effort was made in this study to directly determine hamstring tightness or gluteus medius activation, granted that the hypotheses advanced depended on their activation efficiency. Although we suspect the caudal movement of the PSIS on the left relative to the sacral base reflects pelvic tilt more than SI movement, no effort was made to measure pelvic tilt other that these apparent PSIS/SB displacements on the Y axis. Apart from the gender mix, which was known, the other demographic data from the original N=5 exploratory study were not available. The asymptomatic subjects in our study were not representative of patients who generally undergo Gillet testing; it is possible that using symptomatic subjects would have resulted in different findings. Some studies have reported asymmetric gluteus medius activation in injured subjects.[36, 47] Although we believe our data are most consistent with asymmetric one-legged stance strategies, two other hypotheses could be considered: although the Gillet test may be valid for assessing sacroiliac motion (a) the palpator in this study may have exhibited systematic bias, finding the great majority of right sacroiliac joints hypomobile compared with left joints; or (b) the great majority of right sacroiliac joints are actually hypomobile compared with left joints.

Conclusions

This study found that using relatively light palpatory pressure, with hip flexion ≤30°, the left PSIS appeared to move caudal and the right PSIS cephalad to the sacral base. For hip flexion =90°, both PSISs appeared to move cephalad to the sacral base. Firm palpatory pressure mostly abolished these apparent PSIS movements relative to the sacral base. The data suggest slight pelvic tilting, the result of asymmetric muscle activation patterns and tone, may account for all or part of the appearance of sacroiliac movement during Gillet testing.

Future studies on this topic should include additional subjects, some with and some without symptoms, so that a better representation of SI motion during the Gillet test can be ascertained. Since the present study as well as other basic science studies showing very little SI movement diminish our confidence in the traditional interpretation of the Gillet test, clinicians and investigators might put more emphasis on other SI motion palpation procedures, including but not limited to the sitting flexion test.[21, 48] The authors suggest that the limitations of our study ought to mitigate against any tendency to immediately and completely reject the Gillet test; just as it was not appropriate to immediately accept its validity.

There may be ways to mitigate the impact of asymmetric one-legged stance strategies by performing a Gillet-like motion palpation test in a non-weightbearing position. In principle, this would allow discrimination of SI movement from pelvic obliquity as a determinant of relative PSIS and SB positions.

Conflicting commercial interests

Neither of the authors has any commercial interest in the outcome of this study.

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