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Altered Motor Control Strategies in Subjects With Sacroiliac Joint Pain During the Active Straight-Leg-Raise Test

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Study Design. An experimental study of respiratory function and kinematics of the diaphragm and pelvic floor in subjects with a clinical diagnosis of sacroiliac joint pain and in a comparable pain-free subject group was conducted.

Objective. To gain insight into the motor control strategies of subjects with sacroiliac joint pain and the resultant effect on breathing pattern.

Summary of Background Data. The active straight-leg-raise test has been proposed as a clinical test for the assessment of load transfer through the pelvis. Clinical observations show that patients with sacroiliac joint pain have suboptimal motor control strategies and alterations in respiratory function when performing low-load tasks such as an active straight leg raise.

Methods. In this study, 13 participants with a clinical diagnosis of sacroiliac joint pain and 13 matched control subjects in the supine resting position were tested with the active straight leg raise and the active straight leg raise with manual compression through the ilia. Respiratory patterns were recorded using spirometry, and minute ventilation was calculated. Diaphragmatic excursion and pelvic floor descent were measured using ultrasonography.

Results. The participants with sacroiliac joint pain exhibited increased minute ventilation, decreased diaphragmatic excursion, and increased pelvic floor descent, as compared with pain-free subjects. Considerable variation was observed in respiratory patterns. Enhancement of pelvis stability *via* manual compression through the ilia reversed these differences.

Conclusions. The study findings formally identified altered motor control strategies and alterations of respiratory function in subjects with sacroiliac joint pain. The changes observed appear to represent a compensatory strategy of the neuromuscular system to enhance force closure of the pelvis where stability has been compromised by injury. [Key words: diaphragm, low back pain, pelvic floor, respiration, sacroiliac joint, spirometry, ultrasonography] **Spine 2002;27:E1–E8**

The estimated prevalence of sacroiliac joint pain (SIJP) is approximately 13% to 30% in patients with a classification of nonspecific chronic low back pain.[24] This is a significant group worthy of investigation. The sacroiliac joint (SIJ) is designed for stability rather than mobility. This facilitates safe load transfer through the pelvis. It has been proposed that the stability of the pelvis depends on form and force closure.[21] *Form closure* results primarily from the bony structure of the sacrum and the joint surfaces that allow the SIJ to be resistant to shear forces.[25,26,29,30] *Force closure* refers to the additional compressive force necessary for maintaining stability of the pelvis.[25,26] Force closure is primarily a dynamic process performed by the muscular system that depends on the integrity of ligamentous and fascial structures in the region of the SIJ. Impairment of form or force closure mechanisms may be associated with pain disorders of the lumbopelvic region.[16,25,28]

It has been proposed that the functional integrity of the form and force closure mechanisms can be examined clinically by use of the active straight-leg-raise (ASLR) test.[16,18] This maneuver has been advocated as a reliable test for the quality of load transfer through the lumbopelvic region.[18] During this test, subjects are instructed to assume a relaxed supine position, and then to lift one leg 5 cm from the couch. It has been documented that this is accompanied by profound heaviness of the leg in subjects with postpartum SIJ instability.[16,18] The test then is repeated while a manual compressive force is applied through the ilia, or with a belt tightened around the pelvis. A positive test is denoted by improved ability to raise the leg.[16,18] The proposed mechanism for this improvement is the augmentation of force closure.[16,25] Recent research has shown a strong correlation between impairment of ASLR and a unilateral increase in pelvic mobility at the symphysis pubis visualized radiographically.[16] These findings support the use of ASLR as a measure of impaired load transfer through the lumbopelvic region in subjects with pelvic pain disorders.[16]

The transversus abdominis, internal oblique, diaphragm, and pelvic floor form part of the abdominal cavity's muscular boundaries. These muscles work together in a coordinated pattern to produce and control intraabdominal pressure (IAP).[11,12] These same muscles are thought to have a role in maintaining pelvic stability *via* force closure[21,25,26] and a role in respiration.[23] Alterations in motor control that involve this musculature have been reported in subjects with lumbar segmental instability, resulting in disruption to respiration.[20] Similar alterations also have been observed clinically in sub-

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Table 1. Inclusion and Exclusion Criteria for All Subjects*

Inclusion criteria for the SIJP group

- The subject has a clinical presentation suggestive of SIJP longer than 3 months, that shows no sign of abating.
- The subject reports pain over the SIJ, with no proximal referral.[7,9,10,15,24]
- The outcome of ASLR test is positive.[16]
- At least four of five SIJ provocation tests are positive:[13,14]
  1. distraction and compression test
  2. posterior shear test (thigh-thrust test)
  3. pelvic torsion (right and left posterior rotation)
  4. sacral thrust test
  5. palpation of long dorsal sacroiliac ligament

General Exclusion Criteria for Both Groups	Specific Exclusion Criteria for the Comparison Group
Any neurologic dysfunction	Medical history that might lead to an inability to perform an ASLR.
Facial pain that could lead to an inability to use the mask	History of low back, pelvis, hip, knee, or ankle disorder in the past 6 months.
History of significant respiratory disorder	Surgery to the lumbar spine, pelvis, chest or abdomen in the past 12 months.
Pregnancy less than 6 months postpartum.	Any inflammatory disorders.
Body mass index less than 31 kg/m.	

* The inclusion criteria for the SIJP group shown in the first part of the table were all negative or absent in the comparison group. The exclusion criteria are shown in the second part of the table.
SIJ = sacroiliac joint; SIJP = sacroiliac joint pain; ASLR = active straight leg raise.

Table 2. Demographic Data of Subjects

	SIJP Group	Comparison Group
Age (years)	32.3 ± 11.2	31.4 ± 11.4
Duration of symptoms (months)	40.8 ± 35.7	–
Weight (kg)	64.4 ± 9.3	64.7 ± 14.4
Height (cm)	165.3 ± 8.5	169.5 ± 7.9
BMI (kg/m)	23.8 ± 4.2	22.6 ± 3.5
Subjects postpartum (n)	5	2
Subjects posttrauma (n)	13	0
Subjects with bladder dysfunction (n)	13	0

Mean ± SD.
SIJP = sacroiliac joint pain; BMI = body mass index.

jects with SIJP during ASLR. This appears to result from the attempt of the neuromuscular systems to compensate for inadequacies in the force closure mechanism. At this writing, these strategies have not been investigated in subjects with SIJP.

The purpose of this experimental study was to gain an insight into the motor control strategies adopted by subjects with a clinical diagnosis of SIJP during ASLR and, because the diaphragm is involved, the resultant effect of these strategies on respiratory patterns. It was hypothesized that respiratory function and kinematics of the diaphragm and pelvic floor in a group of subjects with a clinical diagnosis of SIJP would differ from that of a comparison group with no pain during ASLR, and that augmentation of force closure *via* the addition of pelvic compression during ASLR would homogenize the two groups. It was expected that this would provide further validation of the ASLR test and identify compensatory motor control strategies in subjects with this diagnosis.

■ Methods

For this study, 13 participants (11 women and 2 men) with a clinical diagnosis of SIJP were recruited. An equal number of symptom-free subjects matched for gender, age, and body mass index volunteered for the study. Statistical analysis of the two groups showed no significant differences in age, gender, or anthropometric measurements. Subjects were included or excluded according to the strict criteria shown in Table 1. Demographic data for both groups are displayed in Table 2. The study was approved by the Human Research Ethics Committee of Curtin University of Technology, and written informed consent was obtained from all the participants before testing.

Spirometry and ultrasonography were performed separately with the participant the supine lying position during the following test conditions: at rest, while performing an ASLR, and while performing an ASLR with manual pelvic compression through the ilia. Respiratory rate and tidal volume were recorded using a Stead-Wells water-sealed spirometer (60 Hz, serial number 3657, Warren E. Collins, Inc., Braintree, MA). Subsequently, minute ventilation was calculated.

Movement of the diaphragm and pelvic floor was recorded with a Toshiba Sonolayer SSA 250A real-time ultrasound unit (3.75-MHz probe, serial number 32926, Toshiba, Corp., Tochigi, Japan) in movement mode. For diaphragmatic motion, the probe was positioned in the midclavicular line below the right costal margin.[5] In-built electronic calipers were used to measure displacement of the diaphragm's leading edge over three breaths, and the mean of the three breaths was recorded in millimeters.[3]

Sonography of the pelvic floor was performed transabdominally with the sound head angled inferiorly and posteriorly to the symphysis pubis.[32] Anatomically, the bladder, urethra, and vesical neck are seen as part of the pelvic floor.[6] Given this relation, motion of the inferior bladder was interpreted as motion of the pelvic floor. A resting position of the inferior bladder was recorded as zero using in-built electronic callipers, and movement from this position was recorded in millimeter.

A test–retest repeatability study for all measures was performed on five of the participants from the comparison group to establish the reliability of the measures. Repeat measures of all variables were recorded in each of the three test conditions.

Visual analysis of spirometry data was performed, followed by statistical analysis of both sonography and spirometry data using a two-group (SIJP group and comparison group) for three-condition (resting supine position, ASLR, and ASLR with compression) analysis of variance (ANOVA). Simple contrasts were performed between all possible pairs of the three conditions. A critical alpha value of 0.05 was used to determine statistical significance. Repeatability data were analyzed using a two-way mixed intraclass correlation coefficient for single measures. The data management software package used was SPSS version 10.0 for Windows.

■ Results

Respiratory Function

Minute ventilation was significantly different between the SIJP and pain-free groups ($F[1,24] = 5.49$; $P = 0.028$) and the three testing conditions ($F[1.28,30.63] =$

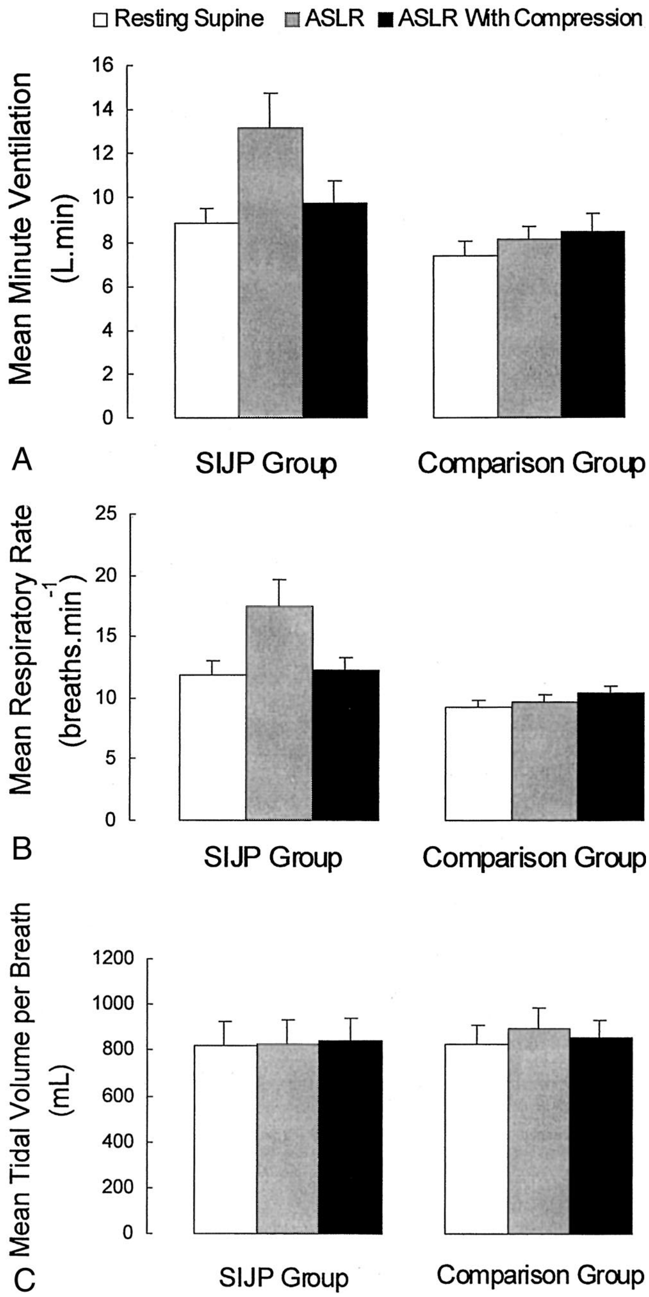

Figure 1. Means (standard error) for minute ventilation (**A**), respiratory rate (**B**), and tidal volume per breath (**C**) during the three test conditions for the sacroiliac joint pain group and the pain-free comparison group.

6.43; P = 0.011). An interaction was evident between the resting supine and ASLR conditions ($F[1,24] = 5.17$; P = 0.032). The key feature of this interaction was an increase in minute ventilation in the group with SIJP during ASLR (Figure 1A). An interaction between ASLR and ASLR with compression also was identified ($F[1.24] = 4.42$; P = 0.046). In the participants with SIJP, it was observed that minute ventilation decreased to a level similar to that in the comparison group (Figure 1A). There was no interaction between the resting supine condition and ASLR with compression ($F[1,24] = 0.07$, P = 0.800), indicating that minute ventilation during compression was the same as that during the resting supine condition. The repeatability intraclass correlation coefficient values were 0.91 for the resting supine condition, 0.92 for ASLR, and 0.74 for ASLR with compression.

A subanalysis of minute ventilation was performed to investigate the components of this measure. The respiratory rate was different between the two groups ($F[1,24] = 10.42$; P = 0.004) and between the three testing conditions ($F[1.25,29.95] = 5.85$; P = 0.016). The difference noted was a respiratory rate increase in the participants with SIJP during ASLR (Figure 1B). No difference in tidal volume was observed between groups ($F[1,24] = 0.055$; P = 0.816) or conditions ($F[1.74,41.85] = 0.48$; P = 0.599) (Figure 1C).

Respiration Patterns

In the comparison group, the spirometry tracings were observed to be similar across the three test conditions. In contrast, high variability of respiratory pattern was observed in participants with SIJP when performing ASLR. Whereas the overall trend for this group was increased respiratory rate during ASLR (Figures 2A and 2B), two participants demonstrated a decreased respiratory rate. Five participants exhibited transient breath holds during ASLR while displaying an increase in respiratory rate (Figures 2A and 2B). This was observed during either the middle or end phase of inspiration. A large variability in tidal volume was observed in the participants with SIJP. This variability occurred not only between the participants, but within the same participant on a breath-to-breath basis (Figure 2C). With the addition of compression, respiratory rate and tidal volume were normalized and breath holds were eliminated (Figures 2A–C).

Diaphragmatic Excursion

The magnitude of diaphragmatic excursion across all conditions was not significantly different between the two groups ($F[1,24] = 0.97$; P = 0.335), whereas a significant difference did exist between the three conditions ($F[2,48] = 22.25$; $P < 0.001$). An interaction was distinguished between the resting supine condition and ASLR ($F[1,24] = 60.93$; $P < 0.001$). The main feature of this interaction was decreased diaphragmatic excursion during ASLR in the participants with SIJP (Figure 3). In seven participants, diaphragmatic motion actually was zero. Again, with the addition of compression, diaphragmatic excursion increased, returning to a level comparable with that of the comparison group (Figure 3). This interaction also was significant ($F[1,24] = 34.85$; $P <$ 0.001). An interaction also was found between the resting supine condition and ASLR with compression ($F[1,24] = 9.62$; P = 0.005), demonstrating that it did not return to the resting level. This resulted from an initial difference between the two groups during the resting supine condition (Figure 3). The repeatability intra-

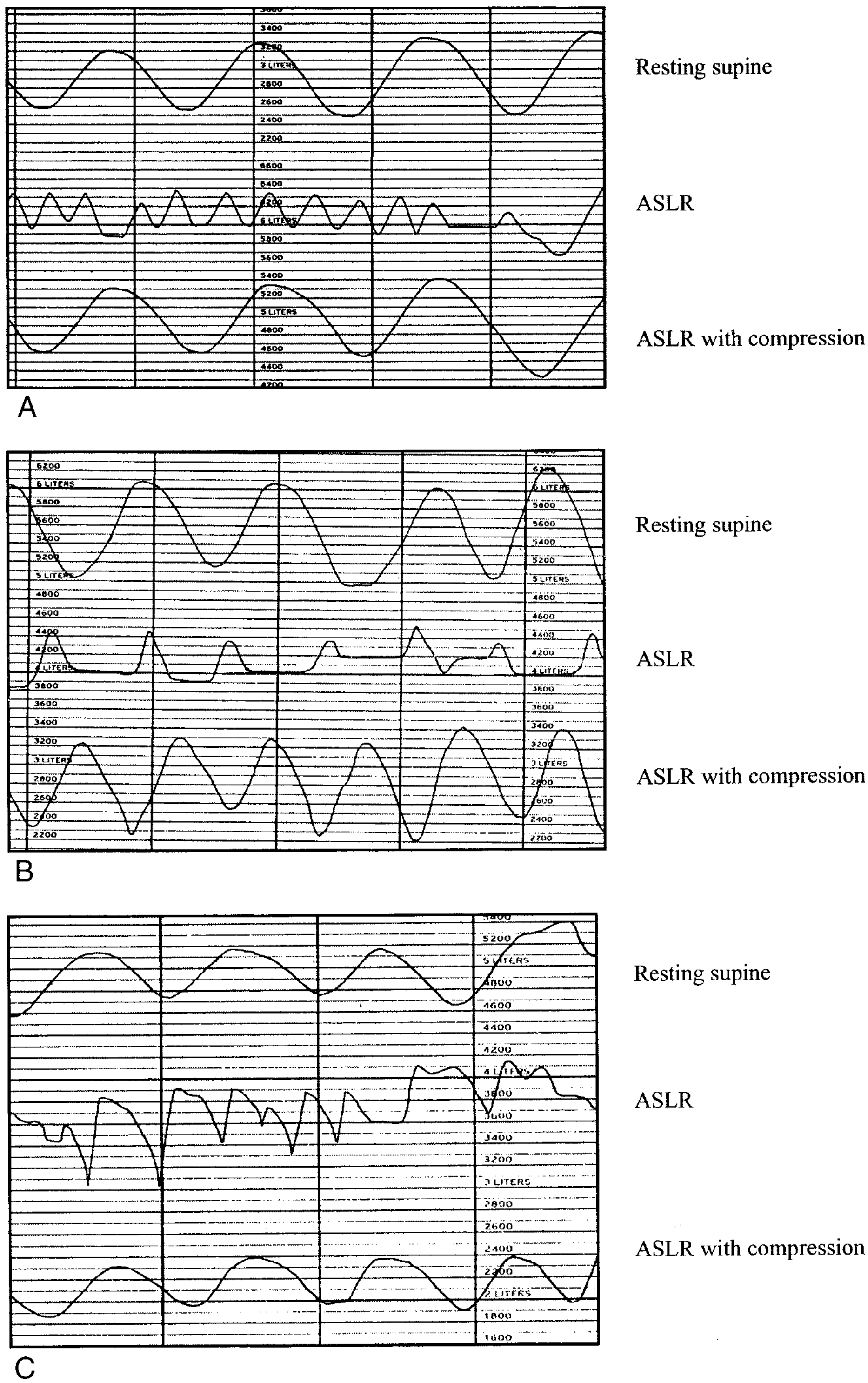

Figure 2. Spirometry traces for three subjects with sacroiliac joint pain. **A**, Increased respiratory rate, decreased tidal volume, and two transient breath holds during the active straight-leg-raise (ASLR) test. **B**, Multiple transient breath holds with increased respiratory rate and decreased tidal volume during the ASLR test. **C**, Erratic tidal volume and increased respiratory rate during the ASLR test.

class correlation coefficient values were 0.94 for the resting supine condition, 0.71 for ASLR, and 0.89 for ASLR with compression.

Pelvic Floor Descent

A significant difference was observed between the two groups ($F[1,24] = 22.95$; $P < 0.001$) and between the two conditions ($F[1,24] = 27.75$; $P < 0.001$) for pelvic floor descent. An interaction between the resting supine condition and ASLR could not be tested because there was no pelvic floor motion in the resting supine condition. However, an interaction did exist between ASLR and ASLR with compression ($F[1,24] = 26.82$; $P < 0.001$). The distinguishing feature of this interaction was

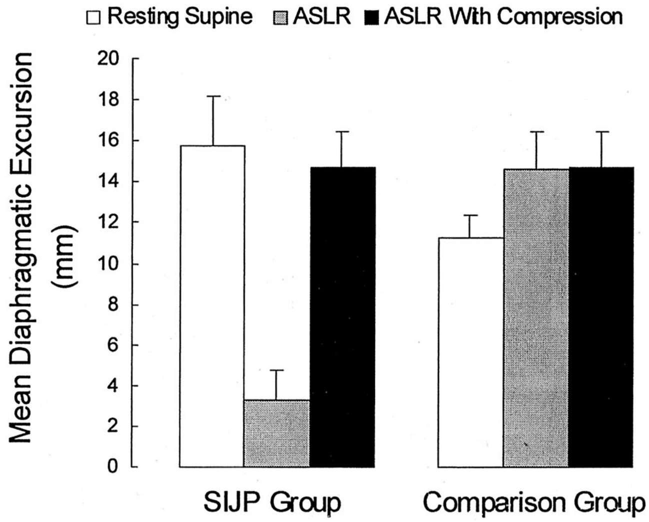

Figure 3. Means for diaphragmatic excursion during the three test conditions for the sacroiliac joint pain group and the pain-free comparison group.

the magnitude of pelvic floor descent during ASLR in the SIJP group (Figure 4). Repeatability intraclass correlation coefficient values for pelvic floor descent were 0.95 for ASLR and 0.85 for ASLR with compression.

■ Discussion

The results of this study document altered breathing patterns and kinematics of the diaphragm and pelvic floor during the ASLR test in subjects with SIJP, as compared with a pain-free comparison group. The addition of pelvic compression during ASLR homogenized the two groups.

Respiratory Responses

This study used real-time ultrasound to measure diaphragmatic motion. The small values measured during tidal breathing of the subject at rest and the absence of a fixed anatomic reference point from which to measure diaphragmatic motion have been suggested as limitations of this method.[4,5] To minimize potential error in measuring diaphragm excursion, the apex of the diaphragm where the largest excursion takes place was measured. The repeatability data for diaphragm excursion were good, implying that low variability was introduced in the measurement approach. In the current study, the measures of diaphragmatic excursion observed with the participant in the supine lying position were comparable with those of other studies using both fluoroscopy[31] and ultrasonography,[2,4] supporting the validity of the instrument and the methods used.

It was observed that the participants with SIJP displayed greater diaphragm excursion at rest than the control group, although no significant difference in minute ventilation, respiratory rate, or tidal volume was observed between the groups. A possible reason for the observed increase in diaphragm motion may have been a lower level of abdominal muscle resting tone in the SIJP participants, resulting in reduced resistance to diaphragm excursion. On the other hand, this increase may reflect an altered resting respiratory pattern in subjects with lumbopelvic pain. Electromyographic studies are required for further investigation of these findings.

During ASLR, the SIJP participants displayed a decrease in diaphragmatic motion, with a complete loss of diaphragmatic motion in seven subjects. This finding represents the presence of a bracing or splinting action of the diaphragm in conjunction with what appears to be increased production of IAP. It is interesting to note that despite the overall decrease in diaphragmatic motion, respiratory function itself actually was enhanced, as indicated by increased minute ventilation. The increase in respiratory rate accounts for the increased minute ventilation. Presumably this was achieved *via* the recruitment of other respiratory muscles, implying a change in respiratory motor control mediated by a neuromuscular mechanism involving musculature not investigated in this study.

The altered diaphragmatic function during ASLR observed in the participants with SIJP may represent the attempt of neuromuscular systems to control load transfer through the lumbopelvic region during limb loading. In this case, it appears that the respiratory function of the diaphragm was disrupted as it was recruited to generate and control IAP. In contrast, subjects in the comparison group had no observed alteration of the diaphragm or respiratory function during ASLR. This indicates that in these participants the neuromuscular system was able to coordinate the respiratory role of the diaphragm with its role as a producer and controller of IAP during physical loading. This view is consistent with the increased levels of IAP generation found in subjects with low back pain during low-level spine loading tasks in weightbearing.[8] Further research is required to investigate the action of the diaphragm and its relation to IAP generation under

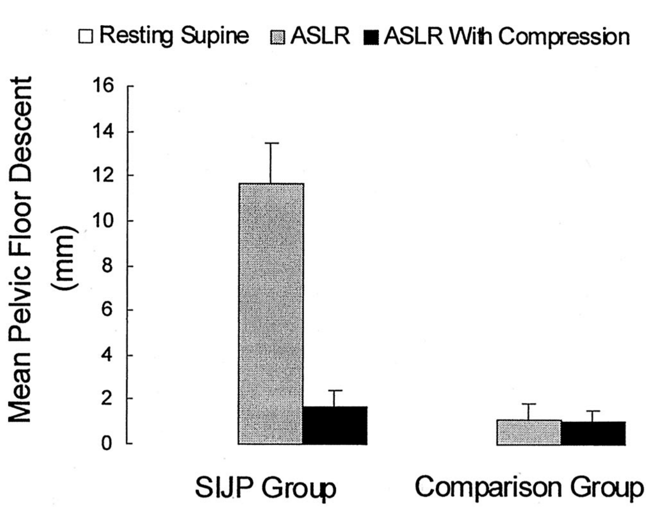

Figure 4. Means for pelvic floor descent during the three test conditions for the sacroiliac joint pain group and the pain-free comparison group. Note that there is no bar for the supine resting condition because the value is zero for both groups.

different respiratory and physical loading demands and in different pain populations, and to clarify its dual function as a respiratory- and trunk-stabilizing muscle.

Pelvic Floor Response

It has been suggested that the pelvic floor plays a role in the control of IAP.[11] It may contribute also to pelvic stability by enhancing force closure.[25,26] In the current study, all the participants with SIJP demonstrated a significant drop of the pelvic floor during ASLR, as compared with little movement in the comparison group. Aberrant movement of the pelvic floor also was reported in another group of subjects with SIJP.[1] One explanation for these findings is that the pelvic floor depression is a response to what appears to be the generation of increased IAP from diaphragmatic splinting during ASLR. Alternatively, pelvic floor descent may reflect a primary motor dysfunction of the pelvic floor muscles. The possibility of pelvic floor musculature dysfunction is supported in this study by the report of impaired bladder control (stress incontinence and urinary frequency) in all the SIJP participants. Currently, further investigation is underway to clarify the nature of these relations.

Sacroiliac Joint Pain

It is accepted that the SIJ can be a source of pain.[7,9,10,15,24] Other authors have defined an association between pelvic pain disorders and pregnancy,[17,19] with Mens et al[18] suggesting that pain may arise from impaired load transference through the pelvic girdle. This impairment can be assessed clinically using the ASLR test.[16] Positive results from the ASLR test alone may not be diagnostic for involvement of the SIJ and its supporting ligaments because other structures such as the symphysis pubis and lumbosacral spine also are stressed during the test. However, all the symptomatic participants in this study reported pain directly over the SIJ without proximal referral,[7,9,10,15,24] had positive SIJ pain provocation test results,[13,14] and positive results on the ASLR test.[16] These findings support the hypothesis that the SIJ, the supporting ligamentous structures, or both were a source of the participants' symptoms. Interestingly, the participants reported that the onset of their symptoms related to a traumatic incident occurred at a time other than the peripartum period. The nature of the trauma involved sudden high load shear forces through the pelvis such as a fall on one buttock. This mechanism is consistent with potential injury to the ligaments of the pelvis, suggesting that trauma may be another etiologic factor in the development of a clinical presentation similar to that observed in peripartum subjects.

Implications

The findings from this study raise a number of questions regarding the ASLR test. These questions relate to the specificity of the test, the implications of the reported sensation of heaviness of the leg, the findings of altered motor and respiratory patterns, and the normalization of motor control patterns after compression of the pelvis.

It could be argued that the motor and respiratory responses observed during ASLR are associated with the adoption of splinting strategies as a reaction to pain,[8] fear of loading painful structures, or both.[27] However, the primary reported problem of subjects during the ASLR test was not that of pain, but of "heaviness" and an inability to lift the leg. This tends to negate the explanation that these findings are simply a motor response to a painful stimulus. Furthermore, the addition of pelvic compression over painful tissue likely would provoke pain and therefore magnify the motor response. In fact, the opposite was the case with the normalization of motor and respiratory patterns observed and the decreased heaviness of the leg reported. The other possibility is that pelvic compression causes increased stiffness in the pelvic joints, which unloads sensitized ligamentous structures, allowing normalized motor responses during ASLR.

The authors propose that the altered motor responses observed during ASLR in subjects with SIJP is an attempt by the neuromuscular system to compensate for a lack of ability to load transfer through the lumbopelvic region resulting from an impairment of form and/or force closure in the pelvis. This proposal is supported by the finding that these observed responses are normalized with application of pelvic compression.

A loss of form closure could arise potentially from an underlying lesion in the ligamentous system of the pelvis after a traumatic injury. In this scenario, the neuromuscular system attempts to compensate for a deficit in the form closure mechanism during ASLR by recruiting the diaphragm to generate IAP, with resultant disruption of respiration. With the application of external pelvic compression, this deficit is compensated for allowing normalization of diaphragmatic and respiratory patterns.

Another possibility is that the participants in this study had underlying dysfunction of the muscles that control force closure of the pelvis, such as the deep abdominal wall and pelvic floor muscles. In this scenario, inability of the neuromuscular system to create adequate force closure of the lumbopelvic region during ASLR may result in substitution strategies such as splinting of the diaphragm and respiratory disruption. In this case, the application of manual pelvic compression compensates for the deficit in the force closure mechanism, normalizing the motor responses. This underlying muscle dysfunction could occur in response to a pain disorder, or it could reflect some underlying motor control deficit in these participants.

A final possibility is that compromise to both the form and force closure mechanisms could coexist in subjects with SIJP. To test these hypotheses, further studies are required to assess the specificity of the ASLR test for different lumbopelvic pain disorders, and to determine whether these motor patterns are associated with other functional movement tasks demanding load transfer through the lumbopelvic region.

Enhancement of pelvic stability *via* compression has been demonstrated theoretically,[25,26,28] and in subjects with peripartum pain syndrome.[16] The action of the deep abdominal muscles to enhance stiffness in the SIJ also has been demonstrated.[22] This suggests that an intervention program focused on integrating control of the deep abdominal muscles with normal pelvic floor and diaphragm function may be effective in managing subjects with SIJP, as defined in this study. Outcome studies are required to test this premise, and to determine whether the altered motor control strategies observed in this study can be normalized with a resultant resolution of symptoms and disability.

In conclusion, this study documents changes in the kinematics of diaphragm and pelvic floor muscles, with consequential alteration of respiratory function during the ASLR test in subjects with SIJP. It is hypothesized that these alterations in motor control result from an ineffective attempt by the neuromuscular system to maintain lumbopelvic stability during ASLR. The reversal of these alterations with the addition of pelvic compression supports and validates the use of this test procedure to assess load transfer in subjects with apparent impairments of lumbopelvic stability.

■ Key Points

- Altered motor control patterns have been reported in subjects with a clinical diagnosis of sacroiliac joint pain, but have not been formally investigated previously.
- Altered kinematics of the diaphragm and pelvic floor were observed in subjects with sacroiliac joint pain during the active straight-leg-raise test.
- Resultant disruption in respiratory patterns is associated with the altered kinematics of the diaphragm and pelvic floor during the active straight-leg-raise test.
- The augmentation of force closure *via* manual compression through the ilia normalizes these altered motor control strategies.

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