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Movement of the sacroiliac joint during the Active Straight Leg Raise test in patients with long-lasting severe sacroiliac joint pain

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ABSTRACT

Background: The Active Straight Leg Raise is a functional test used in the assessment of pelvic girdle pain, and has shown to have good validity, reliability and responsiveness. The Active Straight Leg Raise is considered to examine the patients' ability to transfer load through the pelvis. It has been hypothesized that patients with pelvic girdle pain lack the ability to stabilize the pelvic girdle, probably due to instability or increased movement of the sacroiliac joint. This study examines the movement of the sacroiliac joints during the Active Straight Leg Raise in patients with pelvic girdle pain.
Methods: Tantalum markers were inserted in the dorsal sacrum and ilium of 12 patients with long-lasting pelvic girdle pain scheduled for sacroiliac joint fusion surgery. Two to three weeks later movement of the sacroiliac joints during the Active Straight Leg Raise was measured with radiostereometric analysis.
Findings: Small movements were detected. There was larger movement of the sacroiliac joint of the rested leg's sacroiliac joint compared to the lifted leg's side. A mean backward rotation of 0.8° and inward tilt of 0.3° were seen in the rested leg's sacroiliac joint.
Interpretation: The movements of the sacroiliac joints during the Active Straight Leg Raise are small. There was a small backward rotation of the innominate bone relative to sacrum on the rested leg's side. Our findings contradict an earlier understanding that a forward rotation of the lifted leg's innominate occur while performing the Active Straight Leg Raise.

1. Introduction

According to the European guidelines for low back pain, pelvic girdle pain (PGP) is a subgroup of low back pain and is defined as pain experienced between the posterior iliac crest and the gluteal fold, particularly in the vicinity of the sacroiliac joint (SIJ) (Vleeming et al., 2008). Hence, the SIJ is of interest in understanding PGP. Patients suffering from PGP commonly have functional impairments and the Active Straight Leg Raise (ASLR) test is commonly used to assess patients with PGP. The ASLR test is a functional test compared to provocation tests (Laslett et al., 2006; Vleeming et al., 2008). Whereas the provocation tests are designed to provoke and trigger pain in the SIJ and surrounding structures, the ASLR test is considered to assess the ability to transfer load from the spine to the legs through the pelvis (Mens et al., 1999). The ASLR test is found to be reliable, valid and responsive and can be used to evaluate the severity of PGP (Kwong et al., 2013; Mens et al., 1999; Mens et al., 2001, 2002a; Mens et al., 2012). When performing the ASLR test the patients are lying supine and raise one leg 20 cm and consequently grade their difficulties to do so from 0 (no difficulties) to 5 (unable to do). When the scores from each leg are summarized the patient can score between 0 and 10 (Mens et al., 2002b).

It is still debated what the actual movements in the SIJs are. The opinions differ from movement that can be felt by an examiner (Hungerford et al., 2007) to almost no movement at all (Goode et al., 2008; Kibsgard et al., 2014; Sturesson et al., 1989; Sturesson et al., 2000a, 2000b). There is increasing evidence that the movements in the SIJs are small and it has been reported that in a loaded pelvis the rotational movements between the innominates and the sacrum are no more than 1–2° with almost no translation (Goode et al., 2008; Kibsgard et al., 2014; Sturesson et al., 1989; Sturesson et al., 2000a, 2000b). This limited movement has been explained by the concept of form and force closure, where a combination of pelvic anatomy, ligaments and muscular forces more or less locks the SIJs (Snijders et al., 1993; Vleeming

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et al., 2012). Because of the SIJ's anatomical position it is difficult to measure the actual movement. The radiostereometric analysis (RSA) has been used in several studies that measure SIJ movement (Kibsgard et al., 2014; Sturesson et al., 1989; Sturesson et al., 1999; Sturesson et al., 2000a, 2000b; Tullberg et al., 1998), and the method has high precision and accuracy (Kibsgard et al., 2012). All the studies that have used the RSA method have measured SIJ movement in a loaded pelvis. The degree of movement in an un-loaded situation is however not well studied.

It has been hypothesized that a lack of ability to stabilize the SIJs is one reason why patients have difficulties performing the ASLR test. A high ASLR score could theoretically represent hypermobility in the SIJ and/or an inability to stabilize the pelvic girdle, which could be expected to be found in patients with severe symptoms. This theory has been strengthened by studies showing that patients perform the ASLR test easier with a pelvic belt applied (Hu et al., 2010; Mens et al., 1999). Mens et al. (1999) reported a downward ipsilateral displacement in the pubic symphysis on X-ray during the ASLR test and concluded that this displacement was caused by a forward rotation of the ipsilateral innominate bone relative to sacrum. Since the hip flexors are the major muscles involved when the ASLR test is performed a forward rotation of the lifted leg's innominate could be expected (Hu et al., 2010; Hu et al., 2012). However, earlier RSA studies have shown that the innominate is in a forward rotation in supine position with straight legs and posterior rotation in standing position (Sturesson et al., 1989). If the innominate is in a maximal anterior rotation before the patients lift the leg during the ASLR, a further forward rotation might seem unlikely. As the actual movement of the SIJ during the ASLR has not been tested by precise RSA methods, the aim of the current study was to measure this movement during the ASLR test by using RSA, in patients with severe PGP.

2. Methods

We used RSA to measure the in-vivo movement of the SIJ during the ASLR test in patients with PGP. This study was conducted at two orthopaedic centres, Oslo University Hospital in Norway and Ängelholm Hospital in Sweden. The study was approved by the Regional Committee for Medical Research Ethics (Number: 1.2006.1574), and all patients signed an informed consent.

2.1. Patients

In the study period from 2007 to 2010 a total of 17 patients with PGP were assigned for SIJ fusion. Inclusion criteria were: long duration of pain localized to one or both SIJs, two out of five positive clinical tests (Posterior Pelvic Pain Provocation test, ASLR, Palpation of the long dorsal sacroiliac ligament, Modified Trendelenburg, Palpation of the symphysis) and high degree of pain and disability measured by visual analogue scale (VAS) and Oswestry Disability Index (Kibsgård et al., 2014). Similar criteria have previously been used when studying women with pelvic girdle pain (Stuge et al., 2004; Stuge et al., 2013) and are recommended by the European Guidelines (Vleeming et al., 2008). All patients had normal MRI of the spine. Pre-operatively these patients had 1 mm RSA tantalum markers implanted in the dorsal part of the sacrum and both ilia under general anesthesia, but after the evaluation of the RSA data only 12 patients, including 11 women and 1 man, had proper X-ray quality to be included in the analysis. The reasons for exclusion were misplaced markers (markers placed outside the bone) or that the markers were unable to be localized in the X-rays during the software analysis. Patients' characteristics are presented in Table 1.

Table 1
Descriptives of the patients.

	Mean	Range
Number of patients	12	
Age (years)	39	(29–47)
Body mass index	24	(19–30)
Female/male	11/1	
Duration of PGP (years)	8	(1.5–20)
Oswestry disability index	56	(26–76)
Evening VAS	75	(53–91)
ASLR score total (0 – 10)	5.8	(4–8)
ASLR score in the most painful joint (0–5)	3.6	(2–4)
ASLR score in the less painful joint (0–5)	2.2	(0–4)
Bilateral pain/unilateral pain	8/4	

2.2. RSA protocol

Through small skin incisions the 1 mm markers were inserted with a RSA marker gun under general anesthesia as earlier described in detail (Kibsgård et al., 2014). After 2–3 weeks, three pairs of RSA X-ray pictures were taken; one in supine position, two during the ASLR test right and left (Fig. 1). Each pair of radiographs was taken with two X-ray tubes. The specifications are reported in Table 2. The RSA software calculates the translation and rotations in an x, y, z coordinate system (Fig. 2) together with the true axis of rotation and translation (helical axis). The coordinate system is along the Cartesian axis when reporting RSA results which is defined by the calibration caged (Valstar et al., 2005). The movement is always described of one moving segment (ileum) compared to the fixed segment (sacrum). The position of the fixed segment, within this global coordinate system can be different between measurements, but the RSA computer program transforms the data in order to compare different X-ray uptakes.

This coordinate system differs from the coordinate system used in the guidelines from the International Society of Biomechanics in regard of origin and use of x, y, z as definitions for directions (Wu et al., 2002). The rotational angles were Euler angles that describe the movement as rotations about the fixed x-, y- and z axis. In the text we define a forward rotation of the innominate relative to sacrum as a positive rotation around the x-axis and a backward rotation as a negative rotation around the x-axis. In the test text the term inward tilt of the rested leg's innominate is used and this was defined as a positive rotation of the left innominate around the y-axis (Fig. 2). The accuracy of the SIJ RSA has in a previous study proven to be good without any systematic bias (Kibsgard et al., 2012). The precision of the SIJ RSA measurements, when only dorsal markers are used, are for rotations; $x = 0.5°$, $y = 0.4°$, $z = 0.1°$ and for the translation; $x = 0.1$ mm, $y = 0.2$ mm, $z = 0.5$ mm (Kibsgard et al., 2012). As for the quality of the measurements the limit for condition number (CN) was set to 150. A low CN represents a good scatter of markers in the segments and an upper limit of 150 is suggested to ensure a reliable marker distribution (Valstar et al., 2005). The mean error was set to 0.35 mm (maximum movement of a marker within the segment between two examinations).

2.3. Statistical analysis

The ASLR test was performed on both sides in each patient to compare the movement of the SIJ on the lifted leg with the movement of the SIJ of the rested leg. Since there are differences in interpretation of positive and negative movement between left and right side we converted the sign and the calculation were performed in a setting where the lifted leg was right side and the resting leg was left side. The mean of the two sides were used in the analysis. The movement of each direction was presented with mean, standard deviation and range. A one-sample *t*-test was used to calculate if the mean was different from zero. As the measurements were close to the precision of the method, the fraction of measurements that exceeded this threshold was presented together with the range. We used SPSS® Version 18 (SPSS Inc., Chicago, IL, USA) for statistical analysis.

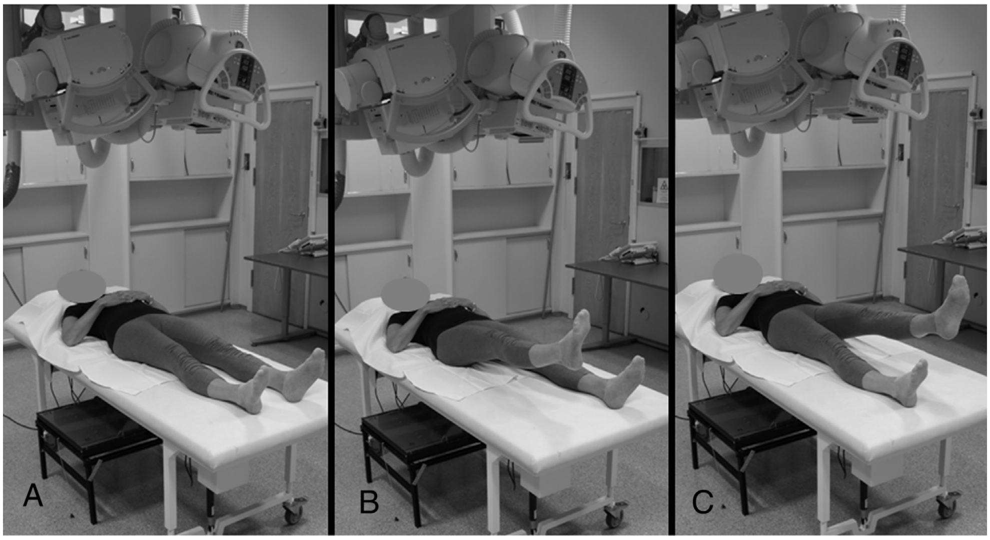

Fig. 1. RSA setup. A - Patient in supine position. B - Patient lifting the right leg. C - Patient lifting the left leg.

Table 2
Technical specifications of the two RSA labs.

	Norwegian lab	Swedish lab
Marker placement	4–9 dorsally placed markers in both ilia and sacrum	
Tantalum markers	1 mm	
Manufactures of X-ray tubes	GE system (GE Healthcare, Piscataway, NJ, USA) Philips OPTIMUS (Philips Healthcare, Best, The Netherlands)	GE system (GE Healthcare, Piscataway, NJ, USA)
RSA software	UmRSA version 6.0 software (UmRSA Biomedical)	
Approximate angle between tubes	40°	30°
Film-focus distance	155 cm	130 cm
Exposure	133 kV, 6.5–8 mAs	125 kV, 13 mAs
Calibration cage	43	41
Marker identification	User-assisted edge detection (UmRSA digital measure)	

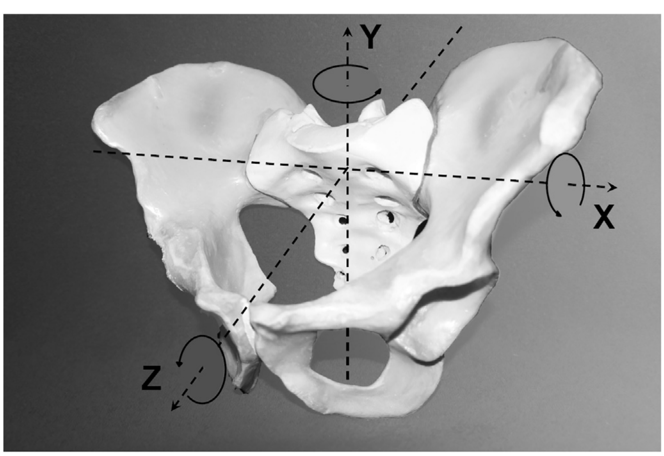

Fig. 2. The x, y, z coordinate system. The positions and orientation of the RSA calibrations cage defines the global coordinate system and in a supine position the coordinates are similar to this situation.

3. Results

Twelve patients (5 from Norway and 7 from Sweden) were analyzed (Table 1). Four patients had unilateral and 8 bilateral SIJ pain. Overall there were only small movements detected in the SIJ during the ALSR test, as only 31% of the measurements were above the precision of the method.

When the leg was lifted during the ASLR test there was a total of 0.7° (SD 0.4) rotation around the helical axis (true axis of rotation) in the lifted leg's SIJ and a total of 1.0° (SD 0.3) on the rested leg's side (diff: 0.3°, P-value = 0.001) (Table 3). No translations that were above the precision of the method were detected (Table 3). When the movements were divided into the x, y, z coordinates, the movements on the lifted leg's SIJ were small, close to zero with the majority of the measurements below the precision of the method (Table 3). On the rested leg's side a rotation was seen around the x-axis with a backward rotation of the innominate relative to sacrum of mean 0.8° (SD 0.3) and around the z-axis 0.3° (SD 0.2) (Fig. 3 and Table 3). In these directions the movements were larger on the rested leg's side than the lifted leg's side with a difference along the x-axis of 0.8° ($P < 0.001$) and along the y-axis of 0.3° ($P = 0.001$). Although these differences were seen, only 45–60% of the measures were above the precision of the method (Table 3). Translation along the y-axis showed a statistically significant directional movement, but these differences were close or under the precision of the method.

Four patients had unilateral pain and ASLR score of 0 on one side, and when the movements in these four pain free SIJs were compared with the other 20 SIJ with pain, there was a tendency of less rotation around the helical axis in the lifted leg's SIJ. There was a mean total rotation of 0.8° (SD 0.4) in the painful joints and 0.4° (SD 0.2) (diff: 0.4°, P-value = 0.034) in the pain free joints. Except from this difference we did not find any statistical significant differences and the patients had the same pattern of backward rotation of the innominate on the rested leg side.

Because the patients were observed in two different centres with different laboratory setups, the results from the two labs were compared. The patients had similar joint specific ASLR test score (0–5) at the two centres, mean 3.1 (SD 1.5) in Norway and mean 2.8 (SD 0.9) in Sweden, respectively (P-value = 0.5). When the RSA findings were compared between the two centres we found the same backward rotation of the rested leg's innominate of mean 0.7 (SD 0.3) and 0.9 (SD 0.3), respectively. All the measurements met the quality standards with the condition numbers with a mean in sacrum of 23 (range: 13–41) and in ilium of 68 (37–137). The error had a mean of 0.12 mm (0.03–0.2) in the sacrum and 0.11 mm (0.02–0.3) in the ilium and numbers of markers ranged from 4 to 9.

4. Discussion

In this study we used the precise RSA method to measure the in vivo movement of the SIJ during the ASLR test. The movements were small in both the lifted and the rested legs' SIJs. In the lifted leg's SIJ these

Table 3
Movement in the sacroiliac joint during the Active Straight Leg Raise (n = 12).

		Movement in the lifted leg's SIJ (right)				Movement in the rested leg's SIJ (left)			
		Mean (SD)	P-value	Range	% above precision	Mean (SD)	P-value	Range	% above precision
Rotation	X	0.0 (0.4)	0.688	(− 1.0,0.5)	30%	− 0.8 (0.3)	< 0.001	(− 1.3, − 0.3)	60%
	Y	-0.1 (0.3)	0.253	(− 0.8,0.5)	34%	− 0.2 (0.3)	0.078	(− 0.8, 0.5)	30%
	Z	0.0 (0.2)	0.962	(− 0.5, 0.5)	31%	0.3 (0.2)	0.001	(− 0.1, 0.7)	45%
Translation	X	0.0 (0.2)	0.314	(− 0.3, 0.4)	39%	− 0.1 (0.2)	0.221	(− 0.4, 0.2)	30%
	Y	0.2 (0.1)	0.001	(− 0.1, 0.5)	26%	0.1 (0.2)	0.042	(− 0.1, 0.3)	25%
	Z	0.0 (0.2)	0.695	(− 0.3, 0.2)	9%	− 0.2 (0.3)	0.075	(− 0.6, 0.5)	15%
Helical axis									
Rotation		0.7 (0.4)	< 0.001	(0.3, 1.4)		1.0 (0.3)	< 0.001	(0.5, 1.4)	
Translation		0.0 (0.1)	0.750	(− 0.3, 0.3)		0.0 (0.1)	0.712	(− 0.1, 0.1)	

Mean = mean movement in the sacroiliac joint; rotations in degrees and translations in mm; P-value = *t*-test whether the mean values were different from zero; % above precision = the fraction of the measurements that are above the RSA precision; helical axis = the true axis of rotation.

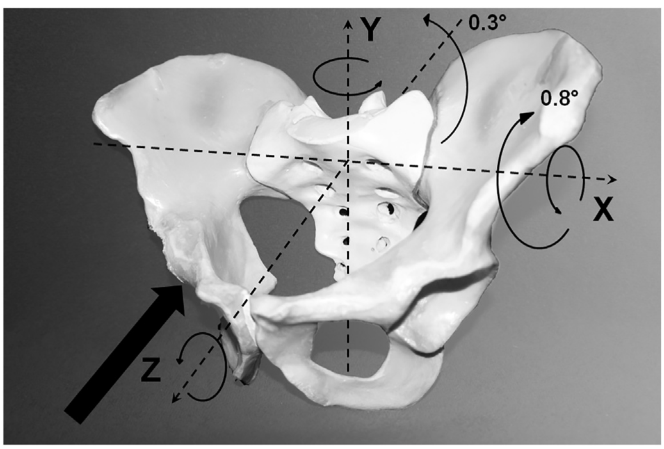

Fig. 3. The results of the RSA measurements. A mean 0.8° backward rotation and 0.3° inward rotation of the rested leg's innominate compared to sacrum were seen. Arrow = the lifted leg. Sacrum is the fixed segment.

small movements were variations close to zero, but in the rested leg's SIJ there was a mean 0.8° backward and 0.3° inward rotation of the innominate bone compared to sacrum.

A limitation to this study is that only 12 patients were examined. A large sample is hard to collect since the method is invasive and expensive. A strength, however, is that the RSA measure technique was applied. RSA is to our knowledge the most precise method for in vivo measurements in orthopaedic research (Valstar et al., 2005), and it has been shown that the RSA technique can be applied to the SIJ (Kibsgard et al., 2012). RSA markers were placed into the bone in both ilium and sacrum close to the joint line and the movement measured is likely to represent the SIJ movement in our participants. The findings between the two orthopaedic centers were comparable and this strengthens the validity of the findings. The patient population is however a weakness for the external validity as the patients was a selected group of patients with severe PGP. Hence our results may not apply to healthy volunteers and patients with mild symptoms and other types of pathologies. On the other hand, a strength is that the included patients probably are representative for women with long-lasting and severe PGP. They were diagnosed based on strict inclusion criteria which included clinical tests and all had a high degree of disability and pain.

Although an increasing number of studies report movement of the SIJ (Kibsgard et al., 2014; Sturesson et al., 1989; Sturesson et al., 1999; Sturesson et al., 2000a, 2000b) there are still controversies about the true range of motion in the SIJ (Goode et al., 2008; Vleeming et al., 2012). The RSA studies demonstrating small SIJ movements are all done in a standing position. According to the theory of form and force closure the movement of the SIJ should be limited in weight bearing position and hence small movement is expected in these studies (Snijders et al., 1993; Vleeming et al., 2012). During the ASLR test, where subjects lie supine, the gravity ceases and the form closure is minimized due to reduced compressive forces. This could theoretically be associated with larger mobility of the SIJ. In a previous study we used RSA to examine movements during the single-leg stance and there were only small variations close to zero (Kibsgard et al., 2014). In the present study the same patients showed a small rotational movement of the rested leg's SIJ, with a mean below 1°. The SIJ seems to have limited range of motion both in standing position and during the ASLR.

One study has previously assessed the movement of the SIJ during the ASLR test using pictures of the pubic symphysis and from these pictures concluded about the SIJ movement (Mens et al., 1999). Mens et al. (1999) reported a forward rotation of the lifted leg's innominate bone relative to the rested leg's innominate bone during the ASLR and assumed that this was caused by rotation at the lifted leg's SIJ. The SIJ movement was estimated to be large enough to cause a relatively large and visible step in the pubic symphysis. A visible step in the pubic symphysis is an uncertain indirect measure to examine the SIJ movement because it indirectly measures the absolute movement in the two SIJ and a possible deformation of the bone is ignored (Kibsgard et al., 2014; Pool-Goudzwaard et al., 2012). According to our findings a forward rotation of the lifted leg's innominate compared to the rested leg's innominate occurs, but the movements of the SIJ are predominantly a backward rotation on the rested leg's side. The opposite findings in these studies might be due to different methodology. Our measurements were based on direct examination of the SIJ with the precise RSA method, which gives a more reliable and valid result. In the study by Mens et al. (1999) they examined patients with unilateral SIJ pain, whereas in our study most patients had bilateral pain. The four asymptomatic joints in our study showed, however, similar patterns of movement as the symptomatic joints.

Our findings with backward rotation of the rested leg's innominate bone might be explained by the muscle activity described in other studies. Hip flexors are prime movers in the ASLR test and theoretically this might cause forward rotation of the innominate bone which is counteracted by activation of abdominal muscles and activity of contralateral hip extensors (Hu et al., 2012). There is moderate evidence that PGP is associated with dysfunction in the motor control system (Aldabe et al., 2012; Sjödahl et al., 2016), and it seems that subjects with PGP recruit more muscles to perform the ASLR test compared to healthy persons (Beales et al., 2009; Hu et al., 2012). Increased muscle activity of the biceps femoris on the contralateral side is reported (Hu et al., 2010) and rectus femoris on the lifted leg's side has larger activation compared to healthy controls (de Groot et al., 2008). Also increased activity in the abdominal muscles, erector spina and psoas major and increased intra-abdominal pressure have been reported to occur during the ASLR and can be a contribution to why only small movements were detected in our study (Beales et al., 2009, 2010; Hu et al., 2012). We might assume that dynamic stabilization occur on the lifted leg side and on the resting leg side the dynamic stabilization may be somewhat less which allows movement of the SIJ. During hip flexion tasks patients with PGP have shown to have increased activity of the contra lateral biceps femoris (Bussey and Milosavljevic, 2015; Hungerford et al., 2003). This increased in activity might be a symptom led strategy for bracing the pelvic girdle and can also explain the backward rotation of the innominate seen in our subjects, which might increase mechanical stress on the SIJ and aggravate pain. (Bussey and Milosavljevic, 2015; Hungerford et al., 2003).

We found a pattern of movement of the SIJ that predominantly were rotations. These small movements might stress the joint and surrounding ligaments enough to create pain. The SIJ ligaments function as passive stabilizers and it is speculated that the ligaments also might be involved in active neuromuscular feedback mechanisms as regulators of joint position (Sichting et al., 2013). It has been stated that the SIJ is more stable with the ilium in backward rotation (Mens et al., 1999; Vleeming et al., 2008) and forward rotation of the ilium stretches the ipsilateral long dorsal sacroiliac ligament (Vleeming et al., 1996). If the innominates are already in maximal anterior rotation in supine position (Sturesson et al., 1989), the muscular contractions that occur during the ASLR will further increase the stress on the SIJ ligaments. Even though SIJ motion and ligament strain might be altered to a minimal in an absolute term, the relative effect might be large (Sichting et al., 2013). In a study by Palsson et al. (2015) increased muscle activity were reported during the ASLR test in asymptomatic volunteers after injected hypertonic saline to create pain in the long dorsal ligament. It seems that pain in the SIJ or surrounding ligaments can cause alterations in motor control and influence on the ASLR test. Pelvic compression or a pelvic belt is found to reduce muscle activity and difficulty of performing the ASLR test (Beales et al., 2010; Hu et al., 2010; Stuge et al., 2013). This external force might provide force closure enough to alter SIJ motion to the effect that the most loaded ligaments are relieved (Sichting et al., 2013; Vleeming et al., 1992). A SIJ fusion with decrease in SIJ motion, might increase the form and force closure and hence reduce ligament strain and consequently reduce pain (Kibsgård et al., 2014; Polly et al., 2016).

5. Conclusion

In patients with severe and long-lasting PGP the movements in the SIJs during the ASLR test are limited to small rotations and almost no translations. Small movements were detected in the lifted leg's SIJ, but these were movements close to zero with the majority of the measurements below the precision of the method and without any clear pattern. There was, however, a pattern of backward rotation of the rested leg's innominate compared to sacrum of mean 0.8° together with a small 0.3° inward tilt. These findings contradict the earlier understanding that the movement of the SIJ during the ASLR test is a forward rotation of the innominate on the lifted legs SIJ.

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References

Aldabe, D., Milosavljevic, S., Bussey, M.D., 2012. Is pregnancy related pelvic girdle pain associated with altered kinematic, kinetic and motor control of the pelvis? A systematic review. Eur. Spine J. 21, 1777–1787.

Beales, D.J., O'Sullivan, P.B., Briffa, N.K., 2009. Motor control patterns during an active straight leg raise in pain-free subjects. Spine (Phila Pa 1976) 34, E1–E8.

Beales, D.J., O'Sullivan, P.B., Briffa, N.K., 2010. The effects of manual pelvic compression on trunk motor control during an active straight leg raise in chronic pelvic girdle pain subjects. Man. Ther. 15, 190–199.

Bussey, M.D., Milosavljevic, S., 2015. Asymmetric pelvic bracing and altered kinematics in patients with posterior pelvic pain who present with postural muscle delay. Clin. Biomech. 30, 71–77.

Goode, A., Hegedus, E.J., Sizer, P., Brismee, J.M., Linberg, A., Cook, C.E., 2008. Three-dimensional movements of the sacroiliac joint: a systematic review of the literature and assessment of clinical utility. J. Man. Manip. Ther. 16, 25–38.

de Groot, M., Pool-Goudzwaard, A.L., Spoor, C.W., Snijders, C.J., 2008. The active straight leg raising test (ASLR) in pregnant women: differences in muscle activity and force between patients and healthy subjects. Man. Ther. 13, 68–74.

Hu, H., Meijer, O.G., van Dieen, J.H., Hodges, P.W., Bruijn, S.M., Strijers, R.L., Nanayakkara, P.W., van Royen, B.J., Wu, W., Xia, C., 2010. Muscle activity during the active straight leg raise (ASLR), and the effects of a pelvic belt on the ASLR and on treadmill walking. J. Biomech. 43, 532–539.

Hu, H., Meijer, O.G., Hodges, P.W., Bruijn, S.M., Strijers, R.L., Nanayakkara, P.W., van Royen, B.J., Wu, W., Xia, C., van Dieen, J.H., 2012. Understanding the Active Straight Leg Raise (ASLR): an electromyographic study in healthy subjects. Man. Ther. 17, 531–537.

Hungerford, B., Gilleard, W., Hodges, P., 2003. Evidence of altered lumbopelvic muscle recruitment in the presence of sacroiliac joint pain. Spine 28, 1593–1600.

Hungerford, B.A., Gilleard, W., Moran, M., Emmerson, C., 2007. Evaluation of the ability of physical therapists to palpate intrapelvic motion with the Stork test on the support side. Phys. Ther. 87, 879–887.

Kibsgard, T.J., Roise, O., Stuge, B., Rohrl, S.M., 2012. Precision and accuracy measurement of radiostereometric analysis applied to movement of the sacroiliac joint. Clin. Orthop. Relat. Res. 470, 3187–3194.

Kibsgard, T.J., Roise, O., Sturesson, B., Rohrl, S.M., Stuge, B., 2014. Radiosteriometric analysis of movement in the sacroiliac joint during a single-leg stance in patients with long-lasting pelvic girdle pain. Clin. Biomech. 29, 406–411.

Kibsgård, T.J., Røise, O., Stuge, B., 2014. Pelvic joint fusion in patients with severe pelvic girdle pain–a prospective single-subject research design study. BMC Musculoskelet. Disord. 15, 85.

Kwong, E.H., Virani, N., Robert, M., Gerry, K., Harding, A., Rose, M.S., Dukelow, S.P., Barton, P.M., 2013. Inter-rater reliability of the active straight-leg raise and one-leg standing tests in non-pregnant women. J. Rehabil. Med. 45, 1058–1064.

Laslett, M., Aprill, C.N., McDonald, B., 2006. Provocation sacroiliac joint tests have validity in the diagnosis of sacroiliac joint pain. Arch. Phys. Med. Rehabil. 87, 874–875.

Mens, J.M., Vleeming, A., Snijders, C.J., Stam, H.J., Ginai, A.Z., 1999. The active straight leg raising test and mobility of the pelvic joints. Eur. Spine J. 8, 468–473.

Mens, J.M., Vleeming, A., Snijders, C.J., Koes, B.W., Stam, H.J., 2001. Reliability and validity of the active straight leg raise test in posterior pelvic pain since pregnancy. Spine 26, 1167–1171.

Mens, J.M., Vleeming, A., Snijders, C.J., Koes, B.W., Stam, H.J., 2002a. Validity of the active straight leg raise test for measuring disease severity in patients with posterior pelvic pain after pregnancy. Spine (Phila Pa 1976) 27, 196–200.

Mens, J.M.A., Vleeming, A., Snijders, C.J., Koes, B.W., Stam, H.J., 2002b. Validity of the active straight leg raise test for measuring disease severity in patients with posterior pelvic pain after pregnancy. Spine 27, 196–200.

Mens, J.M., H.I.t.V., Y.H., Pool-Goudzwaard, A., 2012. The Active Straight Leg Raise test in lumbopelvic pain during pregnancy. Man. Ther. 17, 364–368.

Palsson, T.S., Hirata, R.P., Graven-Nielsen, T., 2015. Experimental pelvic pain impairs the performance during the active straight leg raise test and causes excessive muscle stabilization. Clin. J. Pain 31, 642–651.

Polly, D.W., Cher, D., Wine, K., Whang, P., Frank, C., Lockstadt, H., Harvey, C., Sembrano, J., 2016. Randomized controlled trial of minimally invasive sacroiliac joint fusion using triangular titanium implants vs. nonsurgical management for sacroiliac joint dysfunction. Glob. Spine J. 6, GP113.

Pool-Goudzwaard, A., Gnat, R., Spoor, K., 2012. Deformation of the innominate bone and mobility of the pubic symphysis during asymmetric moment application to the pelvis. Man. Ther. 17, 66–70.

Sichting, F., Rossol, J., Soisson, O., Klima, S., Milani, T., Hammer, N., 2013. Pelvic belt effects on sacroiliac joint ligaments: a computational approach to understand therapeutic effects of pelvic belts. Pain Physician 17, 43–51.

Sjödahl, J., Gutke, A., Ghaffari, G., Strömberg, T., Öberg, B., 2016. Response of the muscles in the pelvic floor and the lower lateral abdominal wall during the Active Straight Leg Raise in women with and without pelvic girdle pain: an experimental study. Clin. Biomech. 35, 49–55.

Snijders, C.J., Vleeming, A., Stoeckart, R., 1993. Transfer of lumbosacral load to iliac bones and legs: part 1: Biomechanics of self-bracing of the sacroiliac joints and its significance for treatment and exercise. Clin. Biomech. 8, 285–294.

Stuge, B., Laerum, E., Kirkesola, G., Vollestad, N., 2004. The efficacy of a treatment program focusing on specific stabilizing exercises for pelvic girdle pain after

pregnancy: a randomized controlled trial. Spine (Phila Pa 1976) 29, 351–359.
Stuge, B., Saetre, K., Ingeborg, H.B., 2013. The automatic pelvic floor muscle response to the active straight leg raise in cases with pelvic girdle pain and matched controls. Man. Ther.
Sturesson, B., Selvik, G., Uden, A., 1989. Movements of the sacroiliac joints. A roentgen stereophotogrammetric analysis. Spine (Phila Pa 1976) 14, 162–165.
Sturesson, B., Uden, A., Onsten, I., 1999. Can an external frame fixation reduce the movements in the sacroiliac joint? A radiostereometric analysis of 10 patients. Acta Orthop. Scand. 70, 42–46.
Sturesson, B., Uden, A., Vleeming, A., 2000a. A radiostereometric analysis of movements of the sacroiliac joints during the standing hip flexion test. Spine 25, 364–368.
Sturesson, B., Uden, A., Vleeming, A., 2000b. A radiostereometric analysis of the movements of the sacroiliac joints in the reciprocal straddle position. Spine 25, 214–217.
Tullberg, T., Blomberg, S., Branth, B., Johnsson, R., 1998. Manipulation does not alter the position of the sacroiliac joint. A roentgen stereophotogrammetric analysis. Spine (Phila Pa 1976) 23, 1124–1128.
Valstar, E.R., Gill, R., Ryd, L., Flivik, G., Borlin, N., Karrholm, J., 2005. Guidelines for standardization of radiostereometry (RSA) of implants. Acta Orthop. 76, 563–572.
Vleeming, A., Buyruk, H.M., Stoeckart, R., Karamursel, S., Snijders, C.J., 1992. An integrated therapy for peripartum pelvic instability: a study of the biomechanical effects of pelvic belts. Am. J. Obstet. Gynecol. 166, 1243–1247.
Vleeming, A., Pool-Goudzwaard, A.L., Hammudoghlu, D., Stoeckart, R., Snijders, C.J., Mens, J.M., 1996. The function of the long dorsal sacroiliac ligament: its implication for understanding low back pain. Spine 21, 556–562.
Vleeming, A., Albert, H.B., Ostgaard, H.C., Sturesson, B., Stuge, B., 2008. European guidelines for the diagnosis and treatment of pelvic girdle pain. Eur. Spine J. 17, 794–819.
Vleeming, A., Schuenke, M.D., Masi, A.T., Carreiro, J.E., Danneels, L., Willard, F.H., 2012. The sacroiliac joint: an overview of its anatomy, function and potential clinical implications. J. Anat. 221, 537–567.
Wu, G., Siegler, S., Allard, P., Kirtley, C., Leardini, A., Rosenbaum, D., Whittle, M., D'Lima, D.D., Cristofolini, L., Witte, H., Schmid, O., Stokes, I., 2002. ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion–part I: ankle, hip, and spine. International Society of Biomechanics. J. Biomech. 35, 543–548.s.