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Three-Dimensional Movements of the Sacroiliac Joint: A Systematic Review of the Literature and Assessment of Clinical Utility

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Abstract: The high frequency of static and dynamic palpation methods used during evaluation of SIJ problems in clinical practice demands an understanding of the factual quantity of movement at the SIJ. The objective of this systematic literature review was to synthesize three-dimensional (3-D) motion of the sacroiliac joint (SIJ) during various functional static postures and movements and to determine the clinical utility of movement during examination. A computer-based search was performed by means of OVID, which included Medline (February 1966 to April 2007) and CINAHL (February 1982 to April 2007) using the key words *Pelvis*, *Kinematics*, *Imaging*, *Three-dimensional*, and *Stereophotogrammetric*. Articles included *in-vivo* or *in-vitro* studies that investigated human SIJs with 3-D analysis. Three-dimensional analyses conducted using mathematical modeling, computerized modeling, and/or skin markers were not included because of concerns of transferability and validity. Studies that failed to report standard error of measurement (SEM) or defined tabulated values for translations or rotations using the Cartesian coordinate system were not considered for this study. Studies included for review were analyzed by the SBC biomechanical checklist to measure the quality of procedural design. Seven manuscripts were eligible for inclusion in this study. Rotation ranged between –1.1 to 2.2 degrees along the X–axis, –0.8 to 4.0 degrees along the Y-axis, and –0.5 to 8.0 degrees along the Z-axis. Translation ranged between –0.3 to 8.0 millimeters (mm) along the X-axis, –0.2 to 7.0 mm along the Y-axis, –0.3 to 6.0 mm along the Z-axis. Motion of the SIJ is limited to minute amounts of rotation and of translation suggesting that clinical methods utilizing palpation for diagnosing SIJ pathology may have limited clinical utility.

Key Words: Sacroiliac Joint, Cartesian Coordinate System, Roentgen Stereophotogrammetric Analysis, Pelvic Kinematics, Systematic Review.

The sacroiliac joints (SIJ) are multi-planar, simultaneously rotating and translating along three axes of motion through an origin point that lies midway between the left and right posterior superior iliac spines (PSIS)[1]. The sacral X-axis (transverse axis) courses mediolateral through the left and right PSIS, with corresponding sacral rotation occurring in the sagittal plane. The sacral Y-axis (longitudinal axis), accounts for sacral rotation in the horizontal plane, whereas the Z-axis (sagittal axis), courses anterior-posterior midway between the anterior superior iliac spines (ASIS) and accounts for sacral rotation in the coronal plane[2]. The previously described motion about the X, Y, and Z axes constitutes a Cartesian coordinate system and is used by investigators to account for the 3-D sacral motion at the SIJs in reference to a fixed pelvis[2-8] with occasional alterations of the X and Z axes[1,9].

The 3-D Cartesian coordinate system relates joint motion over three orthogonal planes, intersecting at the point of origin for the joint[10]. The SIJ is considered to possess six degrees of freedom secondary to the three angular and three linear motions occurring at each joint. The three axes course

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along the three planes and are used as a reference for rotational and translational motions. Translational or linear motions are considered positive for movements that are produced anteriorly, superiorly, and to the right. Rotational motions or angular movements occur along the axes of rotation, with positive values indicating a counterclockwise movement around the respective axis[10].

The amount of translational and rotational motion reported during movement has varied between investigators, as have the methods used for determining the calculated values. Radiographs and inclinometers have both been used to describe 2-dimensional (2-D) sacroiliac motion[11-13], but have failed to capture 3-D linear movements such as translations. Conversely, the 3-D Cartesian coordinate system allows for a more complete joint movement profile.

To calculate 3-D Cartesian movements, investigators have utilized Roentgen Stereophotogrammetric Analysis (RSA)[4,6-8], direct 3-D digitizing with skin markers of the joints[1,5], or an *in-vitro* optical lever system[9]. Results comparing RSA with studies that utilize skin markers vary greatly as skin-marker studies often result in report of movements that are five times greater than RSA[8]. As such, RSA has been viewed as the "gold standard" in evaluating growth-related mobility, small movements in joints and tendons, and micromotion associated with arthropathies[14], and has been utilized in more than 200 original research articles[15]. An RSA procedure used in detection of SIJ motion is accomplished by percutaneously inserting tantalum balls into motion segments of the pelvis, followed by an RSA examination within two weeks after implementation. Direct 3-D digitizing allows the investigator to record the position of pelvic landmarks, as determined through palpation and the relative locations of these markers during movements.

A wealth of literature is dedicated to the examining of the diagnostic value associated with SIJ clinical tests and measures. Numerous theoretical signs of sacroiliac dysfunction are advocated by clinicians including regional abnormalities in length tension relationships, selected postures, leg length changes, static and dynamic changes in osseous landmarks, and asymmetrical movements of the pelvis[16]. Movement- or palpation-based assessments historically have demonstrated poor reliability and diagnostic value[17] but are still commonly used for the detection of potential sacroiliac pathology[18,19]. Despite the variety of suggested examination methods, few conclusive tests are universally accepted for their diagnostic value in isolating SIJ dysfunction. Selected authors have suggested that there is no evidence to support the use of mobility testing for dysfunction of the sacroiliac joints[20,21]. In a recent series of systematic literature reviews, Van der Wurff et al[20,21] determined that all nine of the tested movement or palpation/landmark identification tests that were examined lacked sufficient reliability (where max kappa (κ) scores ranged from 0.02 to 0.42) and denounced each test for insufficient validity (sensitivity and specificity ranged from 0.41–0.43 and 0.68–0.83, respectively).

Since clinical utilization of static and dynamic palpation methods for determining SIJ pathology continues to be frequent among practitioners, it is imperative to fully understand the nature and extent of movement at the SIJ by assessing the gold standard for determining this movement at the joint. Establishing the nature and extent of SIJ motion could assist clinicians in pathology detection by establishing the clinical utility of static and dynamic palpatory tests of the SIJ. The primary purpose of this paper is to establish the nature and extent of 3-D motions occurring at the SIJ during various static postures and functional movements. It is our goal to use this information to determine whether clinical motion assessment of the SIJ exhibits face validity and clinical utility.

Methods

Study design. The study was a systematic literature review with a corresponding assessment of design quality for each accepted manuscript.

Language. Studies written in English, French, and German languages were eligible.

Inclusion criteria. Articles included for review were limited to those that used a method of 3-D analysis of motion, such as RSA. Any 3-D analysis that was performed using mathematical modeling, computerized modeling, and/or skin markers was not included because of concerns of transferability and validity. Studies that utilized *in-vivo* (live subjects) or *in-vitro* (cadaver specimens) human SIJ 3-D experimental procedures were included. Movement measurements were considered if motions observed were greater than the standard error of measure (SEM) for the measurement method. Conversely, studies that failed to report SEM were not considered secondary to concerns of validity. In addition, studies without a defined tabulated value for translation or rotation using elements of the Cartesian coordinate system for each specimen or for a mean or median of all specimens were not included.

Search strategy for selection of studies. Study selection was initiated with the aide of the computer-based search engine OVID, which included Medline (February 1966 to April 2007) and CINAHL (February 1982 to April 2007). The search strategy is outlined in Table 1. Furthermore, a comprehensive hand search of all references from those studies collected in the computer-based search, as well as those studies that were known by the authors was performed. Abstracts were pulled for the studies identified through the online and manual search. For those studies that met the initial abstract screen, full-text articles were obtained and reviewed. These abstracts were reviewed by two investigators (AG) and (CC).

TABLE 1. Search template taken from search of OVID database

#	Search History Pubmed and CINHAL	Results
1	exp Sacroiliac joint/	2721
2	exp Pelvis/	13882
3	1 or 2	16509
4	exp Imaging, Three-Dimensional/	15738
5	stereophotogrammetric.mp.	374
6	pelvic kinematics.tw.	6
7	3 and (4 or 5 or 6)	105
8	limit 7 to humans	103

If the investigators disagreed on a particular abstract, then it was re-reviewed by a third investigator (EH), who served as the tie-breaker in the event of non-agreement in determining the abstract's applicability to the review.

Quality scoring. All studies included in the review were analyzed by the SBC biomechanical quality checklist. The checklist involves 16 items that measure quality of reporting for specimen, methods, analysis, and application of the biomechanical analysis; it was previously used to measure coupling of the thoracic spine[22]. Three of the 16 criteria from the checklist that were based on spinal or rib movements were deemed not applicable for assessment in this study and were not recorded. Two investigators (PS) and (JMB) independently utilized the SBC to evaluate each study previously accepted in the final analysis. A third investigator (CC) served as the tie-breaker in the event of non-agreement for each of the 13 item scores for each study.

Results

The online search strategy in PubMed and CINAHL produced 103 resulting citations, and a thorough hand search of multiple journals produced 15 additional citations. Of the 103 abstracts reviewed from PubMed and CINAHL, 98 were ineligible based on failure to meet inclusion criteria. After abstract review of the PubMed and CINAHL studies, 5 were eligible for full manuscript review and with 15 hand search citations found, 20 articles were eligible for full manuscript review.

After full manuscript review, 10 of the 20 studies were eliminated by both reviewers (AG and CC). The elimination of 6 of these studies was based on failure to meet inclusion criteria, for reporting the same data in a previous study, using skin markers, or for use of 2-D analysis. Three studies failed to provide measurements for all three planes of motion around the SIJ, and two were eliminated due to failure to report a defined tabulated value for rotation or translation. There was disagreement in the inclusion of one article by investigators (AG and CC), which was eliminated by majority vote (EH) secondary to inadequate reporting of data and use of a biomechanical SIJ model. Two German language articles were reviewed by a German-speaking assistant with the assistance of the lead author (AG). One of the two German articles used 2-D analysis of the SIJ and therefore did not meet the inclusion criteria for this review. After full manuscript reviews, 7 manuscripts were eligible for inclusion in this study. Figure 1 outlines the flow chart associated with inclusion/exclusion within this study.

Tables 2 and 3 outline the SIJ rotation about the three different axes of the Cartesian coordinate system based on positions or movements with selected leg positioning such as supine to standing, supine to sitting, standing to prone, and various hip positions. Rotation ranged between –1.1 and 2.2 degrees along the X–axis, –0.8 and 4.0 degrees along the Y-axis, and –0.5 and 8.0 degrees along the Z-axis. Higher values of rotation were associated with studies with higher SEM in experimental design. Similarly, Tables 4 and 5 outline the SIJ translational movements along the three axes based on positions or movements. Translation ranged between –0.3 and 8.0 millimeters (mm) along the X-axis, –0.2 and 7.0 mm along the Y-axis, –0.3 and 6.0 mm along the Z-axis.

Larger ranges of motion were reported to occur along each of the axes using RSA in unembalmed cadavers[23], and these measurements accounted for the entire range of motion moved through between extremes of each position. The SEM values were higher for the study by Smidt et al[23] but all calculated mean measures were considered for analysis because none were found to be greater than their respective SEM.

Quality of the reviewed studies varied from a score of 13 of 13[24] to 10 of 13[23]. The most frequent deficit identified was failure to report reliability measures (5 studies), data variance (3 studies), adequate set-up description (1 study), and failure to report study limitations (1 study). Table 6 presents the quality scores of the seven studies.

Discussion

The purpose of this systematic review was to investigate studies that measured 3-D movements of the SIJ using RSA studies that plotted movements along a Cartesian coordinate system. The findings of this study suggest that the rotational and translational movements available at the SIJ are minute. Interestingly, studies that demonstrated the highest levels of quality and that offered the lowest levels of error in measure also reported the lowest values available at the SIJ.

Unreliable or invalid methods used to obtain measurements for the SIJ result in research outcomes that may be inapplicable to clinical practice. Methods that do not account for the multi-dimensional motions occurring at the SIJ or that do not capture motion of the SIJ along with its adjacent joints may be impractical as their measurements may not be

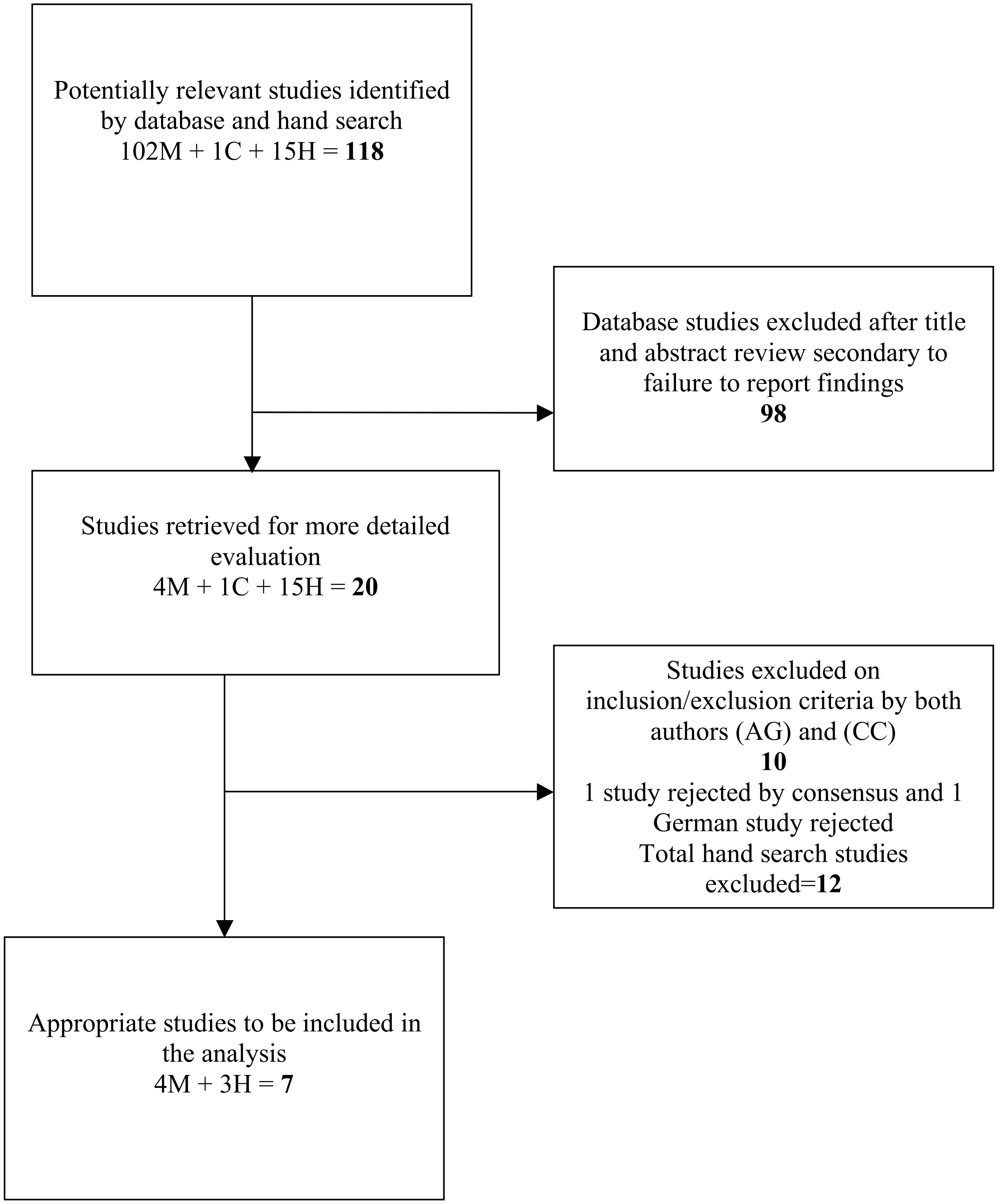

Fig. 1. Consort QUOROM Flow chart for inclusion criteria within the study. C = articles from Cinahl. M = articles from Medline. H = articles from the hand search

TABLE 2. Measures Associated with Report of Rotation about the SIJ during Trunk Initiated Movements

Author Year Ref	Number of SIJs	*In-vivo* or *In-vitro*	Amount of Movement and (Rang and/or Standard Deviation (SD)			Instrument (i.e., RSA)	Standard Error of Instrument Measure
			X axis (Range or SD)	Y axis (Range or SD)	Z axis (Range or SD)		
			Supine to Standing				
Sturesson et al, 2000[8]	6 Left	*In-vivo*	–1.1° (–2.2 to –0.5)	0.7° (0.1 to 1.6)	–0.3° (–1.0 to 0.2)	RSA	0.3° (X) 0.4° (Y) 0.1° (Z)
	6 Right		–1.1° (–2.5 to –0.2)	0.2° (0.0 to 0.5)	0.3° (0.0 to 0.7)		
Sturesson et al, 1989[2]	23 Left	*In-vivo*	–1.1° (–1.8 to 0.0)	0.1° (–1.0 to 1.2)	0.0 ° (–0.4 to 0.5)	RSA	0.1 to 0.2°
	24 Right		–1.2° (–2.0 to 0.5)	0.3° (–0.1 – 0.9)	0.1° (–0.4 to 0.2)		
Sturesson et al, 1999[6]	10 Left	*In-vivo*	Median –1.2° (–2.3 to –0.5)	N/T	N/T	RSA	0.3° (X)
	10 Right		Median –1.1° (–2.4 to –0.4)				
			Supine to Sitting Position with Straight Legs				
Sturesson et al, 1989[2]	11 Left	*In-vivo*	–1.4° (–2.2 to –0.4)	0.1° (0.6 to 1.1)	0.5° (0.2 to 0.8)	RSA	0.1 to 0.2°
	11 Right		–1.4° (–2.5 to –0.6)	0.4° (– 0.4 to – 1.1)	–0.3° (–0.7 to 0.0)		
			Standing to Prone with Left Leg Hyperextended				
Sturesson et al, 1989[2]	15 Left	*In-vivo*	2.2° (1.6 to 3.2)	0.0° (–1.1 to 2.4)	–0.1 (–0.6 to 0.8)	RSA	0.1 to 0.2°
	16 Right		1.8° (0.8 to 3.0)	0.0° (0.9 to 1.2)	0.0° (–0.5 to 0.5)		
Sturesson et al, 2000[8]	6 Left	*In-vivo*	1.7° (0.9 to 3.9)	–0.1° (–0.8 to 1.0)	–0.4° (–0.9 to 0.1)	RSA	0.3° (X) 0.4° (Y) 0.1° (Z)
	6 Right		1.5° (0.8 to 3.4)	–0.8° (–2.0 to –0.1)	–0.5° (–0.6 to –0.2)		
			Standing to Prone with Right Leg Hyperextended				
Sturesson et al, 1989[2]	15 Left	*In-vivo*	1.6° (0.6 to 2.9)	–0.5° (–1.8 to 0.0)	0.0° (–0.4 to 0.8)	RSA	0.1 to 0.2°
	17 Right		2.2° (1.2 to 3.6)	–0.4° (–1.1 to 1.2)	0.2° (–0.1to 0.8)		

TABLE 2. Measures Associated with Report of Rotation about the SIJ during Trunk Initiated Movements *(continued)*

Author Year Ref	Number of SIJs	*In-vivo* or *In-vitro*	Amount of Movement and (Rang and/or Standard Deviation (SD)			Instrument (i.e., RSA)	Standard Error of Instrument Measure
			X axis (Range or SD)	Y axis (Range or SD)	Z axis (Range or SD)		
Sturesson et al, 2000[8]	6 Left	*In-vivo*	1.8° (0.8 to 3.0)	–0.2° (–0.9 to 0.8)	0.1° (–0.1 to 0.6)	RSA	0.3° (X) 0.4° (Y) 0.1° (Z)
	6 Right		1.3° (0.2 to 2.8)	–0.7° (–1.2 to –0.1)	–0.4° (–0.8 to 0.2)		
			Standing Erect with Both Feet on the Floor and Maximum Anteflexion				
Jacob & Kissling, 1995[24]	21	*In- vitro*	1.11° SD (0.78)	0.83° SD (0.81)	0.59° SD (0.53)	Cam k-wires	0.34°
			Standing Erect on Both Feet with Maximum Retroflexion				
Jacob & Kissling, 1995[24]	21	*In-vivo*	0.91° SD (0.61)	0.73° SD (0.6)	0.44° SD (0.46)	Cam k-wires	0.34°

Cam = camera, X axis = transverse axis, Y axis = longitudinal axis, Z axis = sagital axis, ° = Degrees.

specific to the three planes of motion at the SIJ and may not represent the spectrum of movements that the joint actually exhibits. In our study, radiographic, inclinometer, and potentiometer studies were not considered accurate methods for determining motion secondary to their use of 2-D data collection methodology to describe a joint that exhibits 3-D movement. A study of interrater reliability on the use of handheld inclinometers for measuring static pelvic angle demonstrated a mean of 0.9 degrees with a SEM of 5.4 degrees[25]. This SEM value is significantly greater than the measured mean, indicating that the measured inclinometer value data will not allow for any conclusion to be drawn on the position of the ilium in the sagittal plane relative to the horizontal. Other investigators have used a potentiometer for similar measures, but this instrument was not able to accurately account for pelvic motion because it recorded 2-D motion and did not adequately control for motion at the low back and hip[12].

Three-dimensional motion analysis is possible without the use of palpation or skin markers. The RSA is a very accurate and well documented method of detecting small motions in joints[7]. Nonetheless, a careful evaluation of the design and motions measured for each study is merited. Although all studies included in this review used RSA, appreciable variability was present between findings in all three axes. These differences could be attributed to a number of different factors. Of the seven articles reviewed for this study, there was a wide range of positions and initiating movements used for determining SIJ motions. For example, Smidt et al[23] utilized the long levers of the cadavers' lower extremities to apply maximum stress to the SIJ and they reported larger values of motion (nearly 5 times higher) than studies performed by others. The use of cadavers and the procedural method of using long lever torque to incorporate movement could have eliminated the effects of active pelvic stabilities on the SIJ, thus potentially reducing the clinical applicability of the findings. Sturesson et al[8] demonstrated much smaller motions at the SIJ joint in their study with the purpose of evaluating the SIJ motions with RSA and comparing those to previous studies by Smidt et al[1,23].

There was consistency in the *in-vivo* study findings that met inclusion for this review. Sturesson et al[2,6-8] performed four of these studies utilizing RSA methods to record SIJ motion in various positions. Rotations occurring around the X- and Y-axes with standing hip flexion were less than their SEM, excluding these measures from our analysis. Rotation around the Y-axis during a straddle stance position was also excluded for being less than the SEM. This suggests that the measures and design used in the study accurately measured the finite movements at the SIJ.

From a clinical standpoint, the limited movements may not support a clinician's ability to palpate selected move-

TABLE 3. Measures Associated with Report of Rotation about the SIJ during Lower Extremity Initiated Movements

Author Year Ref	Number of SIJs	*In-vivo* or *In-vitro*	Amount of Movement and (Range and/or Standard Deviation (SD): X axis (Range or SD)	Y axis (Range or SD)	Z axis (Range or SD)	Instrument (i.e., RSA)	Standard Error of Instrument Measure
			Double Hip Flexion to Double Hip Extension Angular Motion				
Smidt et al, 1997[23]	5 Left	*In-vitro*	2.0° (1.0 to 4.0)	2.0° (1.0 to 4.0)	7.0° (4.0 to 11.0)	CT Scan	1.0°
	5 Right		1.0° (0.0 to 4.0)	2.0° (0.0 to 5.0)	8.0° (3.0 to 17.0)		
			Reciprocal Hip Flex/Extension				
Smidt et al, 1997[23]	5 Left	*In-vitro*	4.0° (–4 to +3)	4.0° (1 to 7)	5.0° (1 to 11)	CT Scan	1.0°
Sidelying	5 Right		4.0° (–3.0 to + 2.0)	1.0° (0.0 to 4.0)	8.0° (2.0 to 10.0)		
			Standing Erect on Both Feet to One-Legged Stance				
Jacob & Kissling, 1995[24]	21	*In-vivo*	0.97° SD (0.82)	0.77° SD (0.68)	0.5° SD (0.39)	Cam k-wires	0.34°
Sturesson et al, 2000[7]	21 Left	*In-vivo*	–0.2° 1.0 to 0.5° SD (0.4)	0.2° –0.7 to 0.8° SD (0.4)	0.2° –0.3to 0.9° SD (0.3)	RSA	0.3° (X) 0.4° (Y) 0.1° (Z)
	20 Right		–0.2° –1.4 to 0.2° SD (0.4)	–0.1° –0.8 to 0.5° SD (0.4)	0.1° –0.4 to 0.8° SD (0.3)		
			Right Hip Extension with Left Hip Flexion				
Wilke et al, 1997[30]	6 Left	*In-vivo*	–0.3° SD (0.2)	–0.1° SD (0.1)	0.0° SD (0.4)	Goni	0.1°
	6 Right		0.5° SD (0.5)	–0.1° SD (0.2)	–0.2° SD (0.1)		
			Right Hip Flexion with Left Hip Extension				
Wilke et al, 1997[30]	6 Left	*In-vivo*	0. 3° SD (0.2)	–0.1° SD (0.1)	0.0° SD (0.1)	Goni	0.1°
	5 Right		–0.3° SD (0.4)	0.1° SD (0.1)	–0.4° SD (0.5)		
			Ipsilateral Hip Extension				
Wilke et al, 1997[30]	4 Left	*In-vivo*	1.2° SD (0.6)	0.1° SD (0.2)	0.0° SD (0.5)	Goni	0.1°
	6 Right		0.8° SD (0.4)	–0.2° SD (0.3)	–0.1° SD (0.2)		

TABLE 3. Measures Associated with Report of Rotation about the SIJ during Lower Extremity Initiated Movements *(continued)*

Author Year Ref	Number of SIJs	*In-vivo* or *In-vitro*	Amount of Movement and (Range and/or Standard Deviation (SD)			Instrument (i.e., RSA)	Standard Error of Instrument Measure
			X axis (Range or SD)	Y axis (Range or SD)	Z axis (Range or SD)		
			Ipsilateral Hip Flexion				
Wilke et al, 1997[30]	6 Left	*In-vivo*	–0.4° SD (0.2)	–0.1° SD (0.1)	0.1° SD (0.2)	Goni	0.1°
	6 Right		–0.5° SD (0.4)	0.1° SD (0.1)	–0.1° SD (0.2)		
			Ipsilateral Hip Abduction				
Wilke et al, 1997[30]	6 Left	*In-vivo*	0.0° SD 0.2	–0.1° SD 0.1	–0.5° SD 0.2	Goni	0.1°
	6 Right		–0.1° SD 0.1	0.0° SD 0.1	–0.4° SD 0.2		
			Ipsilateral Hip Adduction				
Wilke et al, 1997[30]	6 Left	*In-vivo*	0.5° SD 0.3	0.1° SD 0.2	0.5° SD 0.3	Goni	0.1°
	6 Right		0.4° SD 0.3	–0.1° SD 0.2	0.3° SD 0.1		
			Ipsilateral Hip Internal Rotation				
Wilke et al, 1997[30]	6 Left	*In-vivo*	0.4° SD 0.3	–0.2° SD 0.2	–0.2° SD 0.1	Goni	0.1°
	5 Right		0.3°	0.3° SD 0.2	–0.2° SD 0.2	SD 0.1	
			Ipsilateral Hip External Rotation				
Wilke et al, 1997[30]	6 Left	*In-vivo*	0.2° SD 0.1	0.2° SD 0.1	–0.4° SD 0.2	Goni	0.1°
	6 Right		0.1° SD 0.1	–0.3° SD 0.2	0.2° SD 0.1		
			Ipsilateral Hip Extension with Internal Rotation				
Wilke et al, 1997[30]	5 Left	*In-vivo*	1.1° SD 0.7	0.0° SD 0.3	–0.1° SD 0.4	Goni	0.1°
	5 Right		1.1° SD 0.6	0.1° SD 0.3	–0.1° SD 0.4		

Goni = goniometer, X axis = transverse axis Y axis = longitudinal axis, Z axis = sagital axis, º = Degrees.

TABLE 4. Measures Associated with Report of Translation about the SIJ during Trunk Initiated Movements

Author Year Ref	Number of SIJs	*In-vivo* or *In-vitro*	Amount of Movement and (Range and/or Standard Deviation (SD)			Instrument (i.e., RSA)	Standard Error of Instrument Measure
			X axis (Range or SD)	Y axis (Range or SD)	Z axis (Range or SD)		
			Standing Erect with Both Feet on the Floor and Maximum Anteflexion				
Jacob & Kissling, 1995[24]	21	*In-vivo*	0.71 mm (0.75)	0.45 mm (0.51)	0.4 mm (0.45)	Cam k-wires	0.34 mm
			Standing Erect on Both Feet with Maximum Of Retroflexion				
Jacob & Kissling, 1995[24]	21	*In-vivo*	0.45 mm (0.39)	0.36 mm (0.29)	0.27 mm (0.31)	Cam k-wires	0.34 mm
			Supine to Standing Position				
Sturesson et al, 1989[2]	23 Left 24 Right	*In-vivo*	Total Translation 0.5 mm 0.2 to 1.0 0.4 mm 0.1 to 1.0			RSA	0.1 mm
			Supine to Sitting with Straight Legs				
Sturesson et al, 1989[2]	11 Left 11 Right	*In-vivo*	Total Translation 0.5 mm 0.1 to 1.2 0.5 mm 0.4 to 0.8			RSA	0.1 mm
			Standing to Prone with Left Leg Hyperextended				
Sturesson et al, 1989[2]	15 Left 16 Right	*In-vivo*	Total Translation 0.7 mm 0.3 to 1.6 0.5 mm 0.2 to 1.2			RSA	0.1 mm
			Standing to Prone with Right Leg Hyperextended				
Sturesson et al, 1989[2]	15 Left 12 Right	*In-vivo*	Total Translation 0.7 mm 0.3 to 1.6 0.7 mm 0.3 to 1.6			RSA	0.1 mm

X axis = transverse axis Y axis = longitudinal axis, Z axis = sagital axis, mm = millimeters.

TABLE 5. Measures Associated with Report of Translation about the SIJ during Lower Extremity Initiated Movements

Author Year Ref	Number of SIJs	*In-vivo* or *In-vitro*	Amount of Movement and (Range and/or Standard Deviation (SD)			Instrument (i.e., RSA)	Standard Error of Instrument Measure
			X axis (Range or SD)	Y axis (Range or SD)	Z axis (Range or SD)		
			Standing Erect on Both Feet to One-Legged Stance				
Jacob & Kissling, 1995[24]	21	*In-vivo*	0.62 mm (0.72)	0.45 mm (0.56)	0.34 mm (0.46)	Cam k-wires	0.34 mm
Sturesson et al, 2000[7] Helical Axis	21 Left 20 Right	*In-vivo*	0.3 mm 0.1 to 1.0 (0.2)	N/T	N/T	RSA	0.2 mm
			Bilateral Hip Flexion and Extension				
Smidt et al, 1997[23]	5 Left 5 Right	*In-vitro*	Vertical 4.0 mm 5.0 mm	Med /Lat 7.0 mm 5.0 mm	Ant/Post 4.0 mm 3.0 mm	CT scan	1.3 mm
			Reciprocal Hip Flexion and Extension				
Smidt et al, 1997[23]	5 Left 5 Right	*In-vitro*	Vertical 8.0 mm 7.0 mm	Med/Lat 6.0 mm 5.0 mm	Ant/Post 6.0 mm 5.0 mm	CT scan	1.3 mm
			Ipsilateral Hip Extension				
Wilke et al, 1997[30]	4 Left 6 Right	*In-vivo*	–0.3 mm SD (0.2) 0.1 mm SD (0.2)	0.3 mm SD (0.3) 0.0 mm SD (0.1)	0.5 mm SD (0.7) 0.3 mm SD (0.2)	Goni	0.1 mm
			Ipsilateral Hip Flexion				
Wilke et al, 1997[30]	6 Left 6 Right	*In-vivo*	–0.1 mm SD (0.2) 0.2 mm SD (0.2)	0.1 mm SD (0.2) 0.0 mm SD (0.2)	–0.2 mm SD (0.2) –0.2 mm SD (0.1)	Goni	0.1 mm
			Left Hip Flexion and Right Hip Extension				
Wilke et al, 1997[30]	6 Left 6 Right	*In-vivo*	0.0 mm SD (0.2) –0.2 mm SD (0.3)	0.4 mm SD (0.4) 0.0 mm SD (0.2)	–0.3 mm SD (0.2) 0.2 mm SD (0.2)	Goni	0.1 mm
			Left Hip Extension and Right Hip Flexion				
Wilke et at, 1997[30]	6 Left 5 Right	*In-vivo*	0.0 mm SD (0.1) 0.3 mm SD (0.5)	0.1 mm SD (0.4) –0.2 mm SD (0.3)	0.2 mm SD (0.2) –0.3 mm SD (0.4)	Goni	0.1 mm

TABLE 5. Measures Associated with Report of Translation about the SIJ during Lower Extremity Initiated Movements *(continued)*

Author Year Ref	Number of SIJs	*In-vivo* or *In-vitro*	Amount of Movement and (Range and/or Standard Deviation (SD)			Instrument (i.e., RSA)	Standard Error of Instrument Measure
			X axis (Range or SD)	Y axis (Range or SD)	Z axis (Range or SD)		
				Ipsilateral Hip Abduction			
Wilke et al, 1997[30]	6 Left	*In-vivo*	–0.1 mm SD (0.1)	–0.1 mm SD (0.3)	–0.1 mm SD (0.1)	Goni	0.1 mm
	6 Right		0.0 mm SD (0.2)	–0.1 mm SD (0.2)	–0.1 mm SD (0.1)		
				Ipsilateral Hip Adduction			
Wilke et al, 1997[30]	6 Left	*In-vivo*	0.1 mm SD (0.1)	0.2 mm SD (0.3)	0.2 mm SD (0.2)	Goni	0.1 mm
	6 Right		–0.3 mm SD (0.3)	0.1 mm SD (0.1)	0.2 mm SD (0.2)		
				Ipsilateral Hip Internal Rotation			
Wilke et al, 1997[30]	6 Left	*In-vivo*	0.1 mm SD (0.1)	0.1 mm SD (0.3)	0.0 mm SD (0.1)	Goni	0.1 mm
	5 Right		0.0 mm SD (0.2)	–0.1 mm SD (0.1)	–0.1 mm SD (0.1)		
				Ipsilateral Hip External Rotation			
Wilke et al, 1997[30]	6 Left	*In-vivo*	0.0 mm SD (0.2)	0.1 mm SD (0.2)	0.2 mm SD (0.2)	Goni	0.1 mm
	6 Right		0.1 mm SD (0.3)	0.0 mm SD (0.0)	0.0 mm SD (0.1)		
				Ipsilateral Hip Extension with Internal Rotation			
Wilke et al, 1997[30]	5 Left	*In-vivo*	–0.1 mm SD (0.2)	0.1 mm SD (0.4)	0.3 mm SD (0.4)	Goni	0.1 mm
	5 Right		0.0 mm SD (0.2)	0.2 mm SD (0.2)	0.3 mm SD (0.2)		

Goni = goniometer, X axis = transverse axis Y axis = longitudinal axis, Z axis = sagital axis, mm = millimeters.

TABLE 6. Composite Quality Scores Utilizing the SBC Checklist

Total # of studies complying with a standard

Y = Yes; N = No; NA = Not Applicable

Quality Standard	Jacob and Kessling[24]	Smidt et al.[23]	Wilke et al.[30]	Sturesson et al[6]	Sturesson et al.[8] STRADDLE	Sturesson et al.[7] HIP FLEXION	Sturesson et al.[2]	*Yes (Y) Totals*	*No (N) Totals*	*Not Applicable (NA) Totals*	*Percentage of Studys Complying with Standards*
Specimens											
1. Study specimens or subject pathology or status is adequately described.	Y	Y	Y	Y	Y	Y	Y	*7*	*0*	*0*	100%
2. Study specimen or subject preparation is adequately described.	Y	Y	Y	Y	Y	Y	Y	*7*	*0*	*0*	100%
3. Study performed with intact articular tissue (ligaments, capsule, cartilage, disc).	Y	Y	Y	Y	Y	Y	Y	*7*	*0*	*0*	100%
4. Study performed with intact adjacent soft tissue (muscle, tendon, fascia).	Y	Y	Y	Y	Y	Y	Y	*7*	*0*	*0*	100%
5. Study is performed without rib structures intact (rib, CVJ, CTJ).	NA	NA	NA	NA	NA	NA	NA	*0*	*0*	*11*	0%
Methods											
6. Set-up is adequately described and reproducible.	Y	Y	Y	Y	Y	Y	N	*6*	*1*	*0*	86%
7. Study identifies the use of 3-dimensional measures of assessment.	Y	Y	Y	Y	Y	Y	Y	*7*	*0*	*0*	100%
8. Study identifies single spinal level of assessment (not multiple levels).	NA	NA	NA	NA	NA	NA	NA	*0*	*0*	*11*	0%
9. Study outlines movement initiation for each measure.	Y	Y	Y	Y	Y	Y	Y	*7*	*0*	*0*	100%
10. Study defines a "directional coupling pattern" using the Cartesian system.	NA	NA	NA	NA	NA	NA	NA	*0*	*0*	*11*	0%
Analysis											
11. Data variance is reported (eg., SD or SEM).	Y	N	Y	N	N	Y	Y	*4*	*3*	*0*	57%
12. Reliability measures are reported when appropriate.	Y	N	N	Y	N	N	N	*2*	*5*	*0*	29%
13. Experimental error is reported.	Y	Y	Y	Y	Y	Y	Y	*7*	*0*	*0*	100%
14. Study reported instrumentation errors lower than the actual movement measured.	Y	Y	Y	Y	Y	Y	Y	*7*	*0*	*0*	100%
Application											
15. Reported movements are reproducible as clinically important values.	Y	Y	Y	Y	Y	Y	Y	*7*	*0*	*0*	100%
16. Study outlines limitations on experimental design.	Y	N	Y	Y	Y	Y	Y	*6*	*1*	*0*	86%
Yes' Grand Totals (out of a total of 16 standards)	*13*	*10*	*12*	*12*	*11*	*12*	*11*				
Composite Quality Score (% of total)	*100*	*76.9*	*92.3*	*92.3*	*84.6*	*92.3*	*84.6*				

ments. It has been suggested that the "movements in the SIJ . . . are so minute that external determination by manual methods is virtually impossible"[7]. Therefore, clinical evaluation may be limited in determining relative position and motion of the SIJ. Static and dynamic palpation has been repeatedly determined to be unreliable and invalid in the literature. Studies[11,13,20,21,26-28] examining SIJ clinical tests for palpation of motion and position report varying results, many finding a lack of reliability and validity. Selected mobility studies do not address agreement with respect to direction of motion, only agreement that motion is occurring[11,13,27,28], further undermining the use of clinical joint motion tests to evaluate the SIJ.

Sacroiliac joints with dysfunction were included in 4 of the 7 studies[2,6-8], further suggesting that even in the presence of clinically confirmed SIJ pathology, the motions of the SIJ are minute. The most common movements performed to establish SIJ mobility were supine to sitting and single leg stance with contralateral hip flexion, all of which are behaviors used to clinically assess and diagnose SIJ pathology. For example, Sturesson et al[7] performed an RSA study assessing a common clinical test thought to evaluate SIJ motion in a population of patients considered to have SIJ syndrome as confirmed through pain provocation and positive mobility test findings in the physical exam. The standing hip flexion test (SHFT), also referred to as the Gillet's test, is a frequently utilized test in clinical practice. The SHFT is performed in standing with palpation of the PSIS and S2 tubercle. Motion is assessed upon maximum unilateral flexion of the hip and knee on the testing side. A test is considered positive for hypomobility of the SIJ if the thumb of the clinician placed on the PSIS on the testing side moves cranially upon hip flexion[17]. Results of Sturesson et al[7] indicate a mean posterior rotation of the sacrum at 0.2 degrees posteriorly and a mean translation of 0.3 mm. In light of the very small motions exhibited during this test, investigators have reported a 47% intertester reliability for test execution and interpretation, indicative of poor reliability[7].

Overall, the quality of the reviewed studies varied from a score of 10 out of 13 to 13 out of 13 on a Composite Quality Score with 13 being the maximum score for highest quality[22]. The use of a specific checklist to determine study quality is a recent phenomenon, and the presently used scoring system might not have accurately identified the best study methodology and design to evaluate the SIJ motion. Nonetheless, this scoring system evaluated the quality of studies through examination of the sample methodology, design, and applicability of the study findings. This process allowed for comparisons among studies to determine which design adhered to the highest standards.

Limitations

The included studies provided qualitative and quantitative data in regard to physiological movements of the SIJ but failed to consistently measure similar movements across studies as well as to capture all movements that are clinically applicable. Although we identified no studies that met the criteria outside our language groups of French, German, and English, a hand search of additional languages might have identified articles that were appropriate for inclusion. In addition, our review included both *in-vitro* and *in-vivo* studies therefore assessing two different cohorts of patients.

Conclusion

Based on the current available literature, motion at the SIJ is limited to minute amounts of rotation and of translation that we feel may be sub-clinically detectable. Current clinical methods utilizing palpation for diagnosing SIJ pathology have been found to be unreliable and invalid in the literature and may have limited clinical utility. Continued research is needed to substantiate the current recorded motions for the SIJ, as well as to find less invasive methods of movement analysis. Additionally, follow-up studies should be performed to substantiate the findings of these previous studies. Continued efforts are also required to find a valid and reliable means of safely measuring the SIJ motion during pregnancy. This population is regularly affected by pain in the pelvic region, and while the literature documents changes in laxity and hormonal levels in peripheral joints[29], its effects on SIJ mobility have not been quantified. Further research including post-partum participants with and without pelvic pain for the evaluation of SIJ mobility would be valuable to correlate the mobility findings with the presence and absence of pelvic pain.

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REFERENCES

1. Smidt GL, McQuade K, Wei SH, Barakatt E. Sacroiliac kinematics for reciprocal straddle positions. *Spine* 1995;20:1047–1054.
2. Sturesson B, Selvik G, Udén A. Movements of the sacroiliac joints: A roentgen stereophotogrammetric analysis. *Spine* 1989;14:162–165.
3. Bussey MD, Yanai T, Milburn P. A non-invasive technique for assessing innominate bone motion. *Clin Biomech* 2004;19:85–90.
4. Egund N, Olsson TH, Schmid H, Selvik G. Movements in the sacroiliac joints demonstrated with roentgen stereophotogrammetry. *Acta Radiol Diag* 1978;19:833–846.
5. Hungerford B, Gilleard W, Lee D. Altered patterns of pelvic bone motion determined in subjects with posterior pelvic pain using skin markers. *Clin Biomech* 2004;19:456–464.
6. Sturesson B, Udén A, Onsten I. Can an external frame fixation reduce the movements in the sacroiliac joint? A radiostereometric analysis of 10 patients. *Acta Orthop Scand* 1999;70:42–46.
7. Sturesson B, Uden A, Vleeming A. A radiostereometric analysis of movements of the sacroiliac joints during the standing hip flexion test. *Spine* 2000;25:364–368.
8. Sturesson B, Uden A, Vleeming A. A radiostereometric analysis of the movements of the sacroiliac joints in the reciprocal straddle position. *Spine* 2000;25:214–217.
9. Miller JA, Schultz AB, Andersson GB. Load-displacement behavior of sacroiliac joints. *J Orthop Res* 1987;5:92–101.
10. Neumann DA. *Kinesiology of the Musculoskeletal System: Foundations for Physical Rehabilitation.* St. Louis, MO: Mosby, 2002.
11. Cibulka MMT, Koldehoff RR. Clinical usefulness of a cluster of sacroiliac joint tests in patients with and without low back pain. *J Orthop Sports Phys Ther* 1999;29:83–89; discussion 90.
12. Perret C, Poiraudeau S, Fermanian J, Revel M. Pelvic mobility when bending forward in standing position: Validity and reliability of 2 motion analysis devices. *Arch Phys Med Rehabil* 2001;82:221–226.
13. Riddle DL, Freburger JK. Evaluation of the presence of sacroiliac joint region dysfunction using a combination of tests: A multicenter intertester reliability study. *Phys Ther* 2002;82:772–781.
14. Sturesson B. Movement of the sacroiliac joint with special reference to the effect of load. In: Vleeming, A, ed. *Movement, Stability, and Lumbopelvic Pain: Integration of Research and Therapy*. Edinburgh, UK: Churchill Livingstone, 2007:343–352.
15. Cibulka MMT. Re: A radiostereometric analysis of the movements of the sacroiliac joints in the reciprocal straddle position. *Spine* 2001;26:1404–1405.
16. Dreyfuss P, Michaelsen M, Pauza K, McLarty J, Bogduk N. The value of medical history and physical examination in diagnosing sacroiliac joint pain. *Spine* 1996;21:2594–2602.
17. Cook C, Hegedus, E. *Orthopedic Physical Examination Tests: An Evidence-Based Approach*. Upper Saddle River, NJ: Prentice Hall, 2007.
18. Robinson HS, Brox JI, Robinson R, Bjelland E, Solem S, Telje T. The reliability of selected motion- and pain-provocation tests for the sacroiliac joint. *Man Ther* 2007;12:72–79.
19. Holmgren U, Waling K. Inter-examiner reliability of four static palpation tests used for assessing pelvic dysfunction. *Man Ther* 2007 (Jan 6 E-pub ahead of print).
20. van der Wurff P, Hagmeijer RH, Meyne W. Clinical tests of the sacroiliac joint: A systemic methodological review. Part 1: Reliability. *Man Ther* 2000;5:30–36.
21. van der Wurff P, Meyne W, Hagmeijer RH. Clinical tests of the sacroiliac joint. *Man Ther* 2000;5:89–96.
22. Sizer P, Brismee, JM, Cook, C. Coupling behavior of the thoracic spine: A systematic review of the literature. *J Manipulative Physiological Ther* 2007;30:390–399.
23. Smidt GL, Wei SH, McQuade K, Barakatt E, Sun T, Stanford W. Sacroiliac motion for extreme hip positions: A fresh cadaver study. *Spine* 1997;22:2073–2082.
24. Jacob HA, Kissling RO. The mobility of the sacroiliac joints in healthy volunteers between 20 and 50 years of age. *Clin Biomech* 1995;10:352–361.
25. Freburger JK, Riddle DL. Using published evidence to guide the examination of the sacroiliac joint region. *Phys Ther* 2001;81: 1135–1143.
26. Levangie PK. Four clinical tests of sacroiliac joint dysfunction: The association of test results with innominate torsion among patients with and without low back pain. *Phys Ther* 1999;79:1043–1057.
27. O'Haire C, Gibbons P. Inter-examiner and intra-examiner agreement for assessing sacroiliac anatomical landmarks using palpation and observation: Pilot study. *Man Ther* 2000;5:13–20.
28. Potter NA, Rothstein JM. Intertester reliability for selected clinical tests of the sacroiliac joint. *Phys Ther* 1985;65:1671–1675.
29. Cook C, Massa L, Harm-Ernandes I, et al. Interrater reliability and diagnostic accuracy of pelvic girdle pain classification. *J Manipulative Physiol Ther* 2007;30:252–258.
30. Wilke HJ, Fischer K, Jeanneret B, Claes L, Magerl F. [*In vivo* measurement of 3-dimensional movement of the iliosacral joint]. *Z Orthop Ihre Grenzgeb* 1997;135:550–556.