Pain Physician. 2006;9:61-68, ISSN 1533-3159

A Focused Review

The Sacroiliac Joint: Anatomy, Physiology and Clinical Significance

Stacy L. Forst, PA-C, Michael T. Wheeler, DO, Joseph D. Fortin, DO, and Joel A. Vilensky, PhD

The sacroiliac joint (SIJ) is a putative source of low back pain. The objective of this article is to provide clinicians with a concise review of SIJ structure and function, diagnostic indicators of SIJ-mediated pain, and therapeutic considerations.

The SIJ is a true diarthrodial joint with unique characteristics not typically found in other diarthrodial joints. The joint differs with others in that it has fibrocartilage in addition to hyaline cartilage, there is discontinuity of the posterior capsule, and articular surfaces have many ridges and depressions. The sacroiliac joint is well innervated. Histological analysis of the sacroiliac joint has verified the presence of nerve fibers within the joint capsule and adjoining ligaments. It has been variously described that the sacroiliac joint receives its innervation from the ventral rami of L4 and L5, the superior gluteal nerve, and the dorsal rami of L5, S1, and S2, or that it is almost exclusively derived from the sacral dorsal rami.

Even though the sacroiliac joint is a known putative source of low back and lower extremity pain, there are few findings that are pathognomonic of sacroiliac joint pain. The controlled diagnostic blocks utilizing the International Association for the Study of Pain (IASP) criteria demonstrated the prevalence of pain of sacroiliac joint origin in 19% to 30% of the patients suspected to have sacroiliac joint pain. Conservative management includes manual medicine techniques, pelvic stabilization exercises to allow dynamic postural control, and muscle balancing of the trunk and lower extremities. Interventional treatments include sacroiliac joint, intra-articular joint injections, radiofrequency neurotomy, prolotherapy, cryotherapy, and surgical treatment. The evidence for intra-articular injections and radiofrequency neurotomy has been shown to be limited in managing sacroiliac joint pain.

Key words: Sacroiliac joint, low back pain, rehabilitation, intra-articular injections, radiofrequency neurotomy

The sacroiliac joint (SIJ) was considered the primary source of low back pain in the early 20th century (1). It became overshadowed by the herniated nucleus pulposus after the hallmark 1934 article by Mixter and Barr (2). Mounting evidence on computed tomography (CT), magnetic resonance imaging (MRI), and scintography demonstrating destructive, inflammatory, and degenerative pathology (3-9) suggests that the joint should again be considered a potential source of low back pain. Provocative and palliative intra-articular injections have validated the SIJ as the pain generator in a subset of patients. Nevertheless, information pertaining to the SIJ is sparse within medical textbooks and courses. Therefore, this article serves to highlight the key elements of anatomy, biomechanics, kinetics, diagnosis, and treatment of SIJ-mediated pain.

From: Spine Technology and Rehabilitation & Indiana University School of Medicine Fort Wayne, Indiana
Address Correspondence:
Stacy L. Forst, PA-C
7230 Engle Road, Suite 210
Fort Wayne, IN 46804
E-mail: stacy.forst@verizon.net
Disclaimer: There was no external funding in the preparation of this manuscript
Conflict of Interest: None
Manuscript received on 11/14/05
Revision submitted on 12/23/05
Accepted for publication on 12/23/05

Structural Anatomy

The SIJ is a true diarthrodial joint: matching articular surfaces separated by a joint space containing synovial fluid and enveloped by a fibrous capsule (5-7,10-15). It does, however, have unique characteristics not typically found in other diarthrodial joints. The SIJ has fibrocartilage in addition to hyaline cartilage (16). There is discontinuity of the posterior capsule. Rather than being smooth, the articular surfaces have many ridges and depressions that minimize movement and enhance stability. Primary stability, however, is attributed to the many adjacent ligaments. There are several myofascial structures that influence movement and stability, the most notable of which are the latissimus dorsi via the thoracolumbar fascia, the gluteus maximus, and the piriformis (17,18).

Innervation

Historically, information on the innervation of the sacroiliac joint has been sparse and variable. There is no mention of it in *Gray's Anatomy* (19-21). Solonen (22) examined data from earlier studies (1857-1944) that collectively identify branches from the lumbosacral plexus, superior gluteal nerve, dorsal rami of S1 and S2, and obturator nerve. *Cunningham's Textbook of Anatomy* states, "The sacroiliac joint is supplied: (1) by twigs directly from the sacral plexus and the dorsal ramus of the first two sacral nerves; and (2) by branches from the superior gluteal and obturator nerves" (16,21).

Nagakawa (23) reported that nerve filaments to the joint are derived from the ventral rami of L4 and L5, the superior gluteal nerve, and the dorsal rami of L5, S1, and S2. Another study concluded that the superior ventral portion of the joint is innervated mainly by the ventral ramus of L5; the inferior ventral portions are mainly supplied by the ventral ramus of S2 or branches from the ventral rami of the sacral plexus; the superior dorsal portion is innervated mainly by the dorsal ramus of L5; and the inferior dorsal portion is supplied by a plexus derived from the dorsal rami of sacral nerves (21,24).

In contrast, Grob et al (25) found that the innervation of the sacroiliac joint is almost exclusively derived from the sacral dorsal rami. Dissections of fetal pelvises confirmed that innervation of the SIJ originates in the dorsal rami because neurofilaments were noted solely in the dorsal mesenchyme (21,25). Research generated by one author (JF) of this paper supports this observation: areas of hypoesthesia were found only in the distribution of the sacral dorsal rami after intra-articular anesthetic injection (21,26).

Histologic analysis of the sacroiliac joint has verified the presence of nerve fibers within the joint capsule and adjoining ligaments. Samples of capsular ligamentous tissue from the ventral aspect of the SIJ were obtained from macroscopically normal but chronically painful SI joints. The tissue was examined microscopically and revealed both nerve fascicles and individual axons (21,27). The nerve fascicle contained both myelinated and unmyelinated nerve fibers, two morphotypes of paciniform-encapsulated mechanoreceptors, and a single non-paciniform mechanoreceptor (21,27-30). This would strongly suggest that both pain and proprioception are transmitted from the SIJ (17,21,26,28-30).

Furthermore, communication exists between the SIJ and nearby neural structures (3). Patterns of extracapsular extravasation from the SIJ have been observed on post-arthrography CT (3). These include posterior extension into the dorsal sacral foramina, extravasation into the L5 epi radicular sheath via the superior recess, and ventral leakage into the lumbosacral plexus (3,27). It is plausible that in the setting of capsular disruption, inflammatory mediators could leak from the SIJ to the nearby neural structures. If so, SIJ pathology could explain radicular pain in certain patients (3,27).

Biomechanics

The sacrum is wedge-shaped in both rostrocaudal and ventrodorsal dimensions (5,31). This "keystone" configuration functions with the many sacral ligaments to prevent displacement (5,15,19,32,33). As previously mentioned, the many small ridges and depressions present on the articular surfaces also serve to optimize joint stability (5,10). They develop in response to stress and vary among individuals. SIJ differences exist between the sexes and are most predominant in the second and third decades of life (34). Male sacroiliac development is a functional adaptation to cope with major forces (34), and a thickening of ligaments results in decreased mobility. Hormonal influences in females increase pelvic ligamentous laxity (34), resulting in relatively hypermobile SIJs for the purpose of childbirth.

The SIJ is 20 times more vulnerable to axial compression failure and twice as susceptible to axial torsion overloading than are the lumbar motion segments (5,14,15,34,35). Imbalanced or unilateral loads may jeopardize the interlocking sacral mechanics by impeding balanced transiliac bony fixation and ligamentous tension across the "keystone" (5,32,33,35). Miller et al (15) discovered a threefold increase in sacral rotation with both ilia fixed versus a 2- to 8-fold increase in sacral rotation upon loading with one ilia fixed (5,36). Hence, athletes and workers participating in activities requiring repetitive, unidirectional pelvic shear and/or torsional forces (e.g., figure skaters) may have a higher propensity to develop sacroiliac joint dysfunction (5,37).

Kinematics

Conventional wisdom has held fast to the notion that the SIJ is immobile. However, studies have demonstrated a screw-axis motion of simultaneous sagittal plane rotation and translation (5,15,38-51). The term, nutation, denotes sacral base movement anteroinferior in relation to the ileum (5,52). During counter nutation, the sacral base moves posterosuperior (5,52) (Fig. 1). These motions occur with lumbosacral extension and flexion, respectively (5). However, there is gross incongruity among various reports pertaining to the position of the instantaneous axes of rotation, the extent of movement, and the existence of motion in other dimensional planes (5,38-40,43,46-47,50,51).

Clinical Considerations

Several mechanisms of injury may be linked to the development of SIJ pain, including a direct fall on the buttocks, a rear-end motor vehicle accident (with the ipsilateral foot on the brake at the moment of impact), a broadside-type motor vehicle accident (via a blow to the lateral aspect of the pelvic ring), and a step into an unexpected hole or from a miscalculated height (5,6,17). Additionally, the past medical history and review of systems should be noted for such conditions including polyarthritis, lumbar fusion surgery, and gravida/para. All patients with suspect presentations of SIJ pain should have the necessary laboratory and radiologic work-up for spondyloarthropathic, metabolic, or infectious etiologies.

Pain diagrams can be useful. The SIJ commonly refers pain in a rectangular pattern approximately 3 x 10 cm just inferior to the posterior superior iliac spine (27,53,54). This often predicts which patients will respond to provocative and palliative SIJ injections.

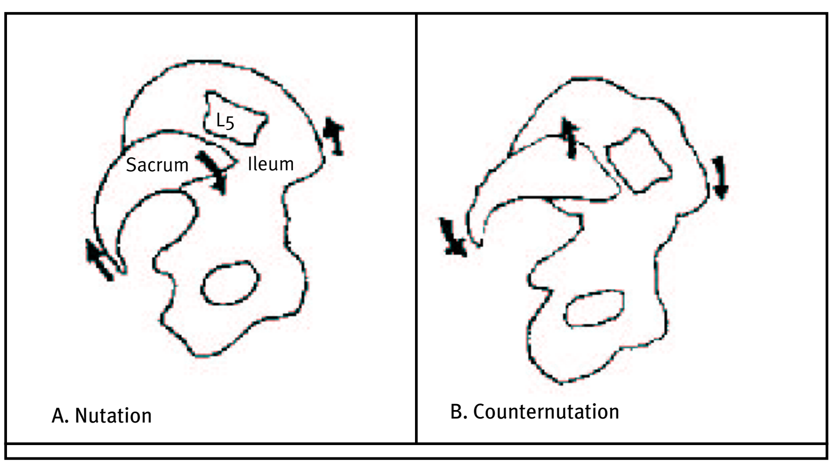

Fig. 1. *A. Nutation denotes sacral base movement anteroinferior in relation to the ileum.*
B. Counternutation represents sacral base movement posterosuperior in relation to the ileum.

Unfortunately, there are few findings that are pathognomonic for most causes of low back pain (20,31). Palpation, provocation/palliation maneuvers, and special tests have yielded rather low sensitivity and/or specificity for detecting a pathological SIJ (17,31). Physical findings that are suggestive include: positive Fortin Finger test (6,17,31,55) (Fig. 2); positive seated flexion-standing test, or Gillet's test for aberrant sacroiliac motion; pain provocation with Patrick's maneuver; positive Gaenslen's test; positive distraction and compression tests; and tenderness over the ipsilateral sacroiliac joint, sacrotuberous ligament, piriformis muscle, and pubic symphysis (5,17,31,55,56).

The diagnosis of sacroiliac joint pain may be made by controlled diagnostic blocks utilizing IASP criteria (57-62). The prevalence of sacroiliac joint pain has been demonstrated as 10% to 19% in patients with symptoms of suspected sacroiliac joint pain by a double block paradigm (57-62). The false-positive rate of single, uncontrolled, sacroiliac joint injections was reported as 20%. The evidence for validity of sacroiliac joint nerve blocks is limited (57,61). However, the medical history, physical examination, and radiographic evaluation have been shown to yield mixed results in the diagnosis of sacroiliac joint pain (4-9,64-67)

Fig. 2. *The Fortin finger test. A positive Fortin finger test is confirmed when a patient points to the area of pain just medial and inferior to the posterior superior iliac spine. Radiographically, this area lies directly over the sacroiliac joint.*

Treatment

Conservative treatment should include cold application, anti-inflammatory medication, and relative rest in the acute stages. Once pain has subsided, further efforts should be employed to restore normal mechanics, including: manual medicine techniques (52,68-71); pelvic stabilization exercises to allow dynamic postural control (37,72,73); and muscle balancing of the trunk and lower extremities (5,15,17,48,49).

Muscle balancing efforts should concentrate on the powerful two-joint muscles around the sacroiliac joint (e.g., gluteus maximus and biceps femoris) as they exert shear and torsion loads proportional to the strength of their contraction (5,14,15,49). Vleeming et al (48,49) have documented that muscles attached to the sacrotuberous ligament (i.e., gluteus maximus and, in some individuals, biceps femoris and piriformis) can significantly limit ventral rotation (i.e., nutation). The clinical relevance of Vleeming's work may be seen in a patient with a flexed sacrum (69) or ventral capsular tear (53), tight psoas muscles, and weak gluteus/hamstrings (5). This individual will require correction of the imbalance to impede aberrant sacroiliac motion and loading.

Impact loading exercises, such as plyometrics or the use of a Heiden board should be implemented in the final stages of the rehabilitation process (5,37,72,74). The patient must have demonstrated proper pelvic control during less demanding activities or exacerbation will likely result.

SIJ belts or pelvic stabilization orthoses will provide confidence and proprioceptive awareness for sacroiliac joint dysfunction sufferers. Properly positioning the belt directly superior to the greater trochanters can significantly limit sacroiliac motion and thereby decrease pain (5,75,76). Orthotic options range from the application of water-resistant tape, cinch-type belts, three-point pelvic stabilization orthoses with transiliac fixation, and sophisticated antigravity "leverage" devices which purportedly rotate the sacrum anteriorly and the ilium posteriorly (5,77). The particular type of orthosis should be chosen based on comfort, activity, and the severity of the patient's condition. The brace should be used as an adjunct to the rehabilitation process, enabling a progressive return to activity. Patients wearing SIJ orthoses may experience mild headache or interscapular pain as their axial skeletons seek a homeostasis with a new center of gravity (5). These symptoms should abate within the first 3 weeks of proper use and therapeutic exercise if other causes are eliminated.

Injections

If conservative treatment fails, SIJ intra-articular injections should be considered not only as a therapeutic intervention but also to confirm the diagnosis (5-7,17). Reproduction of symptoms upon distension of the joint capsule and/or mitigation of symptoms by analgesic block is the most reliable and reproducible means by which a pain-generator can be identified (5-7,53,54,57-63,78-81).

Selection should be reserved for those patients who have not responded to aggressive, conservative treatment or who have reached an unsatisfactory plateau (6,82). In these cases, SIJ injection may affirm the diagnosis, avoid unnecessary surgery, reduce pain, and facilitate rehabilitation (6,82).

In order to optimize diagnostic and therapeutic certainty fluoroscopy must be employed. "Blind" injections are unlikely to reach the joint space (6,7,82,83). A study involving "experienced" spinal interventionalists revealed that among those performing "SIJ injections" without fluoroscopic guidance only 12% were successful in cannulating the joint (84). Hansen (85) and Rosenberg et al (86) also showed successful placement of the needle in a low number of patients without fluoroscopy with extravasation. Under image guidance, a standard 22- or 25-gauge, 3.5-inch spinal needle is generally used (6,7,53). Skin and subcutaneous tissues are anesthetized with 1% lidocaine (6,7). Contrast medium is used for needle position verification, provocation, and arthrography (6,7). Nonionic contrast agents (e.g., iohexol and iopamidol) at concentrations of 240-300 mg per ml are preferred because they carry less potential for allergic reactions (6,7). The authors (JF and MW) prefer to use a 2:1 mixture of 0.75% bupivacaine and betamethasone for intra-articular analgesia.

The patient is prepped following sterile procedures and draped in the prone position. The spinal needle is directed toward the inferior aspect of the sacroiliac joint using a direct posterior approach (6,7,53). The usual portal of entry is the inferior one-third of the joint where a lucent space should allow the least resistance upon needle passage. There may be two or more "limbs" of the joint, because the joint is laterally divergent from its posterior to anterior borders and has interdigitations. In this instance, the medial or posterior division is the most amenable to cannulation. When the inferior aspect of the joint cannot be entered, the joint can be accessed through the deeper, more rostral aspect. Rotating the C-arm side to side in the axial plane (or rolling the patient obliquely 5-10° when using an overhead fluoroscopy unit) will permit a better three-dimensional perspective of the joint and enable selection of the "window" for optimal needle trajectory. Once the dorsal sacroiliac and interosseous ligaments are engaged, the needle often takes a characteristic bend because it conforms to the interdigitating contours of the diarthrodial joint. This phenomenon is often preceded by a subtle tactile sensation of "giving way" at the needle hub as the needle purchases and then penetrates the ligaments to enter the joint. If bony resistance is met and the needle is not yet within the joint margin, the needle should be withdrawn slightly without becoming disengaged. Subsequent needle advancement while simultaneously rotating it around its own longitudinal axis will allow it to deflect and conform to the joint margins .

Fig. 3. ***Ventral capsular and anterior sacroiliac ligamentous tear on an oblique sacroiliac joint arthrogram. The smooth line of contrast demarcating the anteroinferior capsule (closed arrows), is interrupted by a tear in the anterior capsule (open arrows), allowing extravasation of contrast medium.***
5 = L5 pedicle. 1 = S1 pedicle

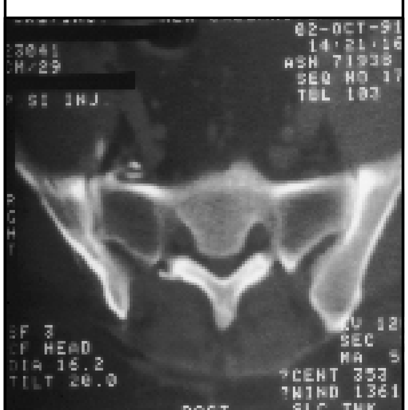

Fig. 4. ***Post sacroiliac joint arthrography/CT verifies a right ventral tear noted on plain film.***

Instillation of contrast medium should outline the coin-shaped inferior recess on anteroposterior (AP) projection and produce the unique auricular shape on the oblique view to confirm cannulation (6,7,83). If only provocation and arthrography are desired, further contrast is instilled to a volume commensurate with firm end-point resilience or extravasation. Provocation responses are then recorded. Transient, pressure-type buttock discomfort is a negative response in contrast to the intense buttock pain produced upon stimulating a symptomatic SIJ (6,53).

For analgesic injections, contrast volume should be just enough to confirm placement. The capacity of the SIJ is only 1.08 mL (standard deviation 0.29ml) (3,6,74). Thus, the practitioner must also allow room for the analgesic and corticosteroid.

SIJ arthrography may disclose abnormalities in capsular morphology that encompasses discrete attenuated areas, schisms, frank tears, and diverticula varying in size, shape, and number (6,7) (Fig. 3). Communication pathways between the SIJ and neural elements (described previously) may become evident, perhaps explaining radicular pain beyond the usual SIJ-referred region seen in a subset of patients (3). Both plain film and CT arthrography are helpful in evaluating normal and aberrant morphology. Plain films optimally display diverticula, whereas CT is superior in identifying anterior capsular tears, extravasation, and communication (4) (Fig. 4). Parenthetically, the presence of structural pathology does not absolutely ensure the presence of a physiological painful condition.

Under fluoroscopy, the AP view demonstrates the inferior recess of the joint, contrast within the joint margins, and any subligamentous or inferior recess extension (6,7). The oblique (en-face or auricular) view is essential in delineating contrast in relation to the joint borders (6,7). It will reveal diverticula and ventral capsular tears. The lateral view demonstrates posterior ligamentous extravasation, diverticula, and ventral tears (6,7). If bilateral arthrograms are obtained, an "offset" lateral (10°-20° from a true lateral projection) will allow a comparison of both capsular borders on one film (6,7). As the result of beam attenuation in the lateral projection, ventral tears and diverticula are not as sharply resolved as in the en-face view (6,7). At times, the opposite oblique view can add additional information including contrast within the superior joint space, superior recess extravasation, an outline of some diverticula, and confirmation of extravasation from the inferior recess or anteroinferior capsule (6,7).

Following SIJ arthrography, patients should be monitored following injection for at least 15-20 minutes while vital signs are obtained and fluids provided. If desired or indicated, post-arthrography CT should be performed within 1-2 hours of injection of the contrast medium (6). Post-procedure instructions include relative rest and application of ice to the affected area. Driving, manual labor, and sports activities are discouraged the day of the procedure. Most patients may resume their usual activities within 24 hours. An instruction sheet should be provided that gives emergency phone numbers and details the warning signs of infection. A majority of patients can be safely discharged 1-2 hours following the procedure. They should be instructed to complete a post procedure pain journal to be reviewed at their next follow-up appointment.

Systematic review of evidence for the effectiveness of intra-articular injections was shown to be limited (57). This study utilized the available studies published prior to 2004 (87-89).

Radiofrequency Neurotomy

Significant but temporary relief following intra-articular injections may warrant consideration of radiofrequency neurotomy. This is analogous to the interventional algorithm for treating facet syndrome (61). A few retrospective and prospective case studies have been performed, but no controlled studies have yet been attempted. Preliminary results suggest a modest success rate. Ferrante et al (90) reported 12 of 33 patients (36.4%) with at least 50% reduction in pain lasting at least 6 months following sacral lateral branch RF denervation. A study by Yin et al (91) reported 60% improvement or greater for more than 6 months. They targeted the lateral branches of the S1, S2, and S3 dorsal rami (91). Collectively, the reported complications were few and included transient dysesthesia and hypoesthesia over the buttocks (91).

The limited success rates have been attributed to course variability of the innervating lateral branches (80). Dispute also remains over the exact innervation of the SIJ. As a result, there is no validated method for denervating the SIJ.

Evidence synthesis by McKenzie-Brown et al (57) showed limited evidence for the effectiveness of radiofrequency neurotomy in controlling chronic sacroiliac joint pain.

Prolotherapy

Prolotherapy treatment is based on the traditional orthopedic principle of stabilizing weakened joints and ligaments (92). In cases where sacroiliac joint dysfunction has been diagnosed by intra-articular injection but fails to respond to physical therapy modes of stabilization, a trial of prolotherapy may be considered. Dorman and co-workers observed in vitro that injecting chemical irritants into ligamentous tissue incites collagen proliferation (93). Theoretically, scarring and tightening of the ligaments results in stabilization of the joint. In 1937 Earl Gedney (94) injected a hypermobile sacroiliac joint with sclerosing agents, resulting in satisfactory results (93). George Hackett (95) perfected this technique in 1958 by serially injecting saline and glucose solutions to the SIJ ligaments (93). Klein studied this phenomenon in 1989 and concluded that prolotherapy improves range of motion and reduces pain and disability (93).

Drawbacks to this method of treatment include multiple injections, potential for considerable post-injection pain, and general lack of research as to efficacy (96).

Cryotherapy

Cryotherapy is another potential treatment for sacroiliac joint dysfunction. The lateral branches of the sacroiliac joint are exposed to liquid or gas nitrogen, resulting in necrosis analogous to RF lesioning (97,98). It can also be used to cause an inflammatory response within the capsular ligaments as a means of prolotherapy (97).

No controlled studies have been performed as a treatment remedy for SIJ mediated pain. Limitations are similar to that of RF.

Surgical Treatment

Arthrodesis of the sacroiliac joint for chronic, non-traumatic, painful dysfunction is controversial but may be considered if all non-surgical treatments have failed (99,100). Moore found a 75% success rate for modified Smith-Pederson fusion involving atlanto-occipital screw fixation (99). Complications include infection, radicular irritation and pseudoarthrosis. Clinical judgment should be used if lumbar spine pathology coexists with sacroiliac joint dysfunction (99).

Conclusion

The SIJ is a potential pain generator that must be considered within the differential diagnosis of low back pain. Failure to recognize and treat SIJ-mediated pain will result in unsatisfactory outcomes in a subset of patients who suffer low back pain. Standard clinical evaluation techniques are often limited in producing concrete evidence of SIJ pain. Intra-articular injection provides the best means of obtaining diagnostic certainty when performed correctly. This requires fluoroscopic guidance and meticulous technique. The information generated from plain film and CT arthrography can provide valuable details of the anatomy as well. However, radiographic findings must be correlated with the provocation and/or analgesic response to be significant. Initial treatment should always encompass more conservative measures. SIJ analgesic injections may be indicated in patients who fail to respond satisfactorily. Finally, treatment of chronic SIJ pain by RF denervation, prolotherapy, and cryotherapy may hold promise for a more lasting effect, but further study is warranted.

Author Affiliation:

Stacy L. Forst, PA-C
Physician Assistant
Spine Technology and Rehabilitation, PC
Jefferson Center, 7230 Engle Road, Suite 210
Fort Wayne, IN 46804
E-mail: stacy.forst@verizon.net

Michael T. Wheeler, DO
Attending Physician
Spine Technology and Rehabilitation, PC
Jefferson Center, 7230 Engle Road, Suite 210
Fort Wayne, IN 46804
E-mail: wheele23@msu.edu

Joseph D. Fortin, DO
Medical Director
Spine Technology and Rehabilitation, PC
Clinical Professor
Indiana University School of Medicine
Jefferson Center, 7230 Engle Road, Suite 210
Fort Wayne, IN 46804
E-mail: fortin@pol.net

Joel A. Vilensky, PhD
Interim Center Director
Professor of Anatomy
Indiana University School of Medicine
2101 Coliseum Blvd. East
Fort Wayne, IN 45605
E-mail: vilensk@ipfw.edu

References

1. Smidt G, Wei S, Mc Quade K, Barakatt E, Sun T, Stanford W. Sacroiliac motion for extreme hip positions. *Spine* 1997; 22: 2073-2082.
2. Mixter WJ, Barr JS. Rupture of the intervertebral disc with involvement of the spinal canal. *N Engl J Med* 1934; 211:210-215.
3. Fortin JD, Falco F, Washington W. Three pathways between the sacroiliac joint and neural structures exist. *Am J Neuroradial* 1999; 20:1429-1434.
4. Fortin JD, Tolchin R. Sacroiliac arthrograms and post-arthrography/CT. *Arch Phys Med Rehab* 1993; 74:1259.
5. Fortin JD. The sacroiliac joint: A new perspective. *J Back Muskuloskel Rehabil* 1993; 3:31-43.
6. Fortin J, Sehgal N. Sacroiliac joint injection and arthrography with imaging correlation. In Lennard TA (ed.), P*ain Procedures*

in Clinical Practice. Hanley & Belfus, Philadelphia, 2000, pp 265-273.

7. Fortin JD, Pier J, Falco F. Sacroiliac joint injection: Pain referral mapping and arthrographic findings. In Vleeming A, Mooney V, Dorman T, Snijders C, Stoeckart R (eds.), *Movement, Stability, and Low Back Pain: The Essential Role of the Pelvis*. Churchill Livingstone, New York, 1997, pp 271-285.
8. Ebraheim NA, Mekhail AO, Wiley WF. Radiology of the sacroiliac joint. Spine 1997; 22:869-876.
9. Slipman CW, Sterenfeld EB, Chou LH. The value of radionuclide imaging in the diagnosis of sacroiliac joint syndrome. *Spine* 1996; 21:2251-2254.
10. Vleeming A, Stoeckart R Volkers ACW. Relation between form and function in the sacroiliac joint (I): The clinical anatomical aspects. (II): The biomechanical aspects. *Spine* 1990; 15:130-132.
11. Smidt GL, Wei S, McQuade K. Sacroiliac motion for extreme hip positions. *Spine* 1997; 22:2073-2082.
12. Bowen V, Cassidy JD. Macroscopic and microscopic anatomy of the sacroiliac joint from embryonic life until the eighth decade. *Spine* 1981; 6:620-628.
13. Brooke R. The sacroiliac joint. *J Anat* 1924; 58:299-305.
14. Gunterberg B, Romanus B, Stener B. Pelvic strength after major amputation of the sacrum: An experimental approach. *Acta Orthop Scand* 1976; 47:635-642.
15. Miller JAA, Schultz AM, Anderson GISJ. Loading displacement behaviors of sacroiliac joints. *J Orthop Res* 1987; 5:92-101.
16. Cunningham DJ. *Cunningham's Text-Book of Anatomy*. Oxford University Press, New York, 1931.
17. Slipman CW, Whyte WS, Chow DW. Sacroiliac joint syndrome. *Pain Physician* 2001; 4:143-152.
18. Vleeming A, Pool-Goudzwaard AL, Stoeckart E. The posterior layer of the thoracolumbar fascia. *Spine* 1995; 20:753-758.
19. Williams PL. *Gray's Anatomy*, 38th edition. Churchill Livingstone, New York, 1995.
20. Clemente DC. *Gray's Anatomy*, 30th edition. Lea and Febiger, Philadelphia, 1985.
21. Fortin JD, Kissling RO, O'Connor BL. Sacroiliac joint innervation and pain. *Am J Orthop* 1999; 12:687-690.
22. Solonen KA. The sacroiliac joint in the light of anatomical, roentgenological and clinical studies. *Acta Orthop Scand Suppl* 1957; 27:1-127.
23. Nakagawa T. A study on the distribution of nerve filaments of the iliosacral joint and its adjacent region in the Japanese. *J Jap Orthop Assoc* 1966; 40:419-430.
24. Ikeda R. Innervation of the sacroiliac joint. Macroscopical and histological studies. *J Nippon Med Sch* 1991; 58:587-596.
25. Grob KR, Neuhuber WL, Kissling Ro. Die Innervation des Sacroiliacalgelenkes beim Menschen. *Z Rheumatol* 1995; 54:117-122.
26. Fortin JD, Dwyer AP, West S. Sacroiliac joint: Pain referral maps upon applying a new injection/arthrography technique – Part I: Asymptomatic volunteers. *Spine* 1994; 19:1475-1482.
27. Fortin JD, Vilensky JA, Merkel GJ. Can the sacroiliac joint cause sciatica? *Pain Physician* 2003; 6:269-271.
28. Vilensky J. Innervation of the joint and its role in osteoarthritis. In Brandt K, Doherty M, Lohamander L (eds.), *Osteoarthritis*. Oxford University Press, Oxford, 1998, pp 176-188.
29. Vilensky JA, O'Connor BL, Fortin JD. Histologic analysis of neural elements in the human sacroiliac joint. *Spine* 2002; 27:1202-1207.
30. Sakamoto N, Yamashita T, Takebayashi T. An electrophysiologic study of mechanoreceptors in the sacroiliac joint and adjacent tissues. *Spine* 2001; 26:E468-E471.
31. Mooney V. Sacroiliac joint dysfunction. In Vleeming A, Mooney V, Dorman T, Snijders C, Stoeckart R (eds), *Movement, Stability, and Low Back Pain: The Essential Role of the Pelvis*. Churchill Livingstone, New York, 1997, pp 37-52.
32. Friedenberb ZB. Fractures of the pelvis. In Hepenstall RB (ed), *Fractures, Treatment and Healing*. WB Saunders Co., Philadelphia, 1980, pp 473-477.
33. White Ah, Panjabi MM. The basic kinematics of the human spine. A review of past and current knowledge. *Spine* 1978; 3:12-20.
34. Vleeming A, Stoeckart R, Snijders CJ. General introduction: Developmental biology of the sacroiliac joint. In Vleeming A, Mooney V, Snijders C, (eds), *Low Back Pain and Its Relation to the Sacroiliac Joint*. ECO, Rotterdam, 1992, pp 13-24.
35. Scholten PJM, Schultz AB, Lunchies CW, Ashton-Miller JA. Motions and loads within the human pelvis: A biomechanical model study. *J Othop Res* 1988; 6:840-850.
36. Sturesson B, Uden A, Vleeming A. A radiosterometric analysis of the movements of the sacroiliac joints in the reciprocal straddle position. *Spine* 2000; 25:214-217.
37. Fortin JD, Falco F. Enigmatic causes of spine pain in athletes. P*hys Med Rehabil State Art Rev* 1977; 11:445-464.
38. Colachis SC, Worden RE, Bechtol CO, Strohm BR. Movement of the sacroiliac joint in the adult male: A preliminary report. *Arch Phys Med Rehabil* 1985; 44: 490-498.
39. Egun N, Olsson TH, Schmid H, Selvic G. Movements in the sacroiliac joint demonstrated with roentgenstereophotogrammetry. *Acta Radiol Diagn* 1978; 19:833-846.
40. Frigerio NA, Stowe RR, Howe JW. Movement of the sacroiliac joint. *Clin Orthop* 1974; 100:370-377.
41. Grieve E. Mechanical dysfunction of the sacroiliac joint. *Int Rehabil Med* 1982; 5: 46-52.
42. Kapandji IA. *The Physiology of the Joints,* Volume 3. Churchill Livingston, New York, 1974, pp 54-71.
43. Lavignolle B, Vital JM, Senega J, Destandau J, Toson B, Bouyx P, Morlier P, Delorme G, Calabet A. An approach to the functional anatomy of the sacroiliac joints in vivo. *Anat Clin* 1983; 5:169-176.
44. Pitkin HC, Pheasant HC. Sacrarthrogenic telalgia I: A study of referred pain. *J Bone Joint Surg* 1936; 18:111-133.
45. Pitkin HC, Pheasant HC. Sacrarthrogenic telalgia II: A study of sacral mobility. *J Bone Joint Surg* 1936; 18:365-374.
46. Reynolds HM. Three dimensional kinematics in the pelvic girdle. *J Am Osteopath Assoc* 1980; 80:277-280.
47. Sturesson B, Selvik G, Uden A. Movements of the sacroiliac joints: a roentgenstereophotogrammetric analysis. *Spine* 1989; 14:162-165.
48. Vleeming A, Van Wingerden JP, Snijders CJ, Stoeckart R, Stijnen T. Load application to the sacrotuberous ligament. Influences on sacroiliac joint mechanics. *Clin Biomech* 1989; 4:204-209.
49. Vleeming A, Stoeckart TR, Snijders CJ. The sacrotuberous ligament: A conceptual approach to its dynamic role in stabilizing the sacroiliac joint. *Clin Biomech* 1989; 4: 201-203.
50. Weisl H. The movements of the sacroiliac joint. *Acta Anat* 1955; 23:80-90.
51. Wilder DG, Pope MH, Frymoyer JW. The functional topography of the sacroiliac joint. *Spine* 1980; 5:575-579.
52. Greenman PE. Clinical aspects of sacroiliac function in walking. *J Manual Med* 1990; 5: 125-129.
53. Fortin JD, Dwyer AP, West S. Sacroiliac joint: Pain referral maps upon applying a new injectin/arthrography technique – Part I: Asymptomatic volunteers. *Spine* 1994; 19:1475-1482.
54. Fortin JD, Aprill CN, Ponthieux B. Sacroiliac joint: Pain referral maps upon applying a new injection/arthrography technique – Part II: Clinical evaluation. *Spine* 1994; 19: 1483-1489.
55. Fortin JD, Falco FJE. The Fortin Finger test: An indicator of sacroiliac pain. *Am J Orthop* 1997; 26:477-480.
56. Bernard PN, Cassidy JD. Sacroiliac joint syndrome: Pathophysiology, diagnosis and management. In Frymoyer J (ed), T*he Adult Spine: Principles and Practice*. Raven Press, New York, 1991, pp 2107-2131.
57. McKenzie-Brown AM, Shah RV, Sehgal N, Everett CR. A systematic review of sacroiliac joint interventions. *Pain Physician* 2005; 8:115-125.
58. Schwarzer AC, Aprill CN, Bogduk N. The sacroiliac joint in chronic low back pain. *Spine* 1995; 20:31-37.
59. Maigne JY, Aivakiklis A, Pfefer F: Results of sacroiliac joint double block and value of sacroiliac pain provocation test in 54 patients with low back pain. *Spine* 1996; 21: 1889-1892.
60. Manchikanti L, Singh V, Pampati V, Dam-

ron KS, Barnhill RC, Beyer CD, Cash KA. Evaluation of the relative contributions of various structures in chronic low back pain. *Pain Physician* 2001; 4:308-316.

61. Boswell MV, Shah RV, Everett CR, Sehgal N, McKenzie-Brown AM, Abdi S, Bowman RC, Deer TR, Datta S, Colson JD, Spillane WF, Smith HS, Lucas-Levin LF, Burton AW, Chopra P, Staats PS, Wasserman RA, Manchikanti L. Interventional techniques in the management of chronic spinal pain: Evidence-based practice guidelines. *Pain Physician* 2005; 8:1-47.
62. Merskey H, Bogduk N (eds), *Classification of chronic pain. In: Descriptions of Chronic Pain Syndromes and Definition of Pain Terms,* 2nd edition. IASP Press, Seattle, 1994, pp 180-181.
63. Dreyfuss P, Michaelsen M, Pauza K. The value of medical history and physical examination in diagnosing sacroiliac jont pain. *Spine* 1996; 21:2594-2602.
64. Laslett M, Young SB, Aprill CN, McDonald B. Diagnosing painful sacroiliac joints: A validity study of a McKenzie evaluation and sacroiliac provocation tests. *Aust J Physiother* 2003; 49:89-97.
65. Dreyfuss P, Dryer S, Griffi n J, Hoffman J, Walsh N. Positive sacroiliac screening tests in asymptomatic adults. *Spine* 1994; 19:1138-1143.
66. Slipman CW, Sterenfeld EB, Chou LH, Herzog R, Vresilovic E. The predictive value of provocative sacroiliac joint stress maneuvers in the diagnosis of sacroiliac joint syndrome. *Arch Phys Med Rehab* 1998; 79:288-292.
67. Broadhurst NA, Bond MJ. Pain provocation tests for the assessment of sacroiliac joint dysfunction. *J Spin Disord* 1998; 11:341-345.
68. Greenman PE. Innominate shear dysfunction in the sacroiliac syndrome. *J Man Med* 1986; 2:114-121.
69. Mitchell SL, Moran PS, Pruzzo NA. An Evaluation and Treatment Manual of Osteopathic Muscle Energy Procedures. Mitchell, *Moran and Pruzzo Assoc*., Manchester, 1979.
70. Farfan HF. The scientific basis of manipulative procedures. *Clin Rheum Dis* 1980; 6:4.
71. Haldeman S. Spinal manipulative therapy and sports medicine. *Clin Sports Med* 1986; 5:277-293.
72. Fortin JD. Sports specific stabilization: Figure skating. In White HA (ed), Basic science in the Diagnosis and Treatment of Degenerative Diseases of the Spine. Volume I. *CV Mosby Year-Book,* Chicago, 1995.
73. Saal JA. Rehabilitation of sports related lumbar spine injuries. In Belfus LC (ed), *Physical Medicine and Rehabilitation, State Art Rev*, Volume 1(4). Hanley and Belfus, Philadelphia, 1987, pp 613-618.
74. Chu DA. Jumping into Plyometrics. *Leisure Press*, Champagne, 1992.
75. Buyruk HM. Effect of pelvic belt application on sacroiliac joint mobility. In Vleeming A, Snyders CJ, Stoeckart R (eds), *Progress in Vertebral Column Research: First International Symposium on the Sacroiliac Joint: Its Role in Posture and Locomotion*. ECO, Rotterdam, 1991, pp 94-95.
76. Vleeming A, Buyruk HM, Stoeckart R, Karamursel S, Snijders CJ. An integrated therapy for peripartum pelvic instability: A study based on biomechanical effects of pelvic belts. In Vleeming A, Snyders CJ, Stoechart R (eds), *Progress in Vertebral Column Research: First International Symposium on the Sacroiliac Joint: Its Role in Posture and Locomotion.* ECO, Rotterdam, 1991, pp 86-92.
77. Hoyt WH, Bard DA, Shaffer F. Experience with an antigravity leverage device for chronic low back pain: A clinical study. *JAOA* 1982; 80:474-479.
78. Steindler A, Luck J. Differential diagnosis of pain lower in the back allocation of the source of pain by the procaine hydrochloride method. *J Am Med Assoc* 1938: 110: 106-113.
79. Aprill C, Dwyer A, Bogduk N. Cervical zygapophyseal joint pain patterns. Part II: A clinical evaluation. *Spine* 1990; 15:458-461.
80. Dwyer A, Aprill C, Bogduk N. Cervical zygapophyseal joint pain patterns. Part I: A study in normal volunteers. *Spine* 1990; 15:453-457.
81. Schwarzer AC, Aprill CN, Derby R. Clinical features of patients with pain stemming from the lumbar zygapophyseal joints. *Spine* 1994; 19:1132-1137.
82. Fortin JD. Sacroiliac joint injection and arthrography with imaging correlation. In Vleeming A, Mooney V, Dorman T (eds), *The Integrated Function of the Lumbar Spine and Sacroiliac Joint*. Part II. ECO, Rotterdam, 1995, pp 533-544.
83. Cole AJ, Dreyfuss P, Pauza K. Sacroiliac joint techniques. In Vleeming A, Mooney V, Dorman T (eds), The Integrated Function of the Lumbar Spine and Sacroiliac Joint. Part II. ECO, *Rotterdam*, 1995, pp 569-597.
84. Kissling RO. Zur arthrographies des iliosacralgelenks. *Zeitschrift fur Rheumatologic* 1992; 51:183-187.
85. Hansen, H. Is fluoroscopy necessary for sacroiliac joint injections? *Pain Physician* 2003; 6:155-158.
86. Rosenberg JM, Quint TJ, de Rosayro AM. Computerized tomographic localization of clinically-guided sacroiliac joint injections. *Clin J Pain* 2000; 16:18-21.
87. Maugars Y, Mathis C, Berthelot JM, Charlier C, Prost A. Assessment of the efficacy of sacroiliac corticosteroid injections spondyloarthropathies: A double blind study. *Br J Rheumatol* 1996; 35:767-770.
88. Hanly JG, Mitchell M, MacMillan L, Mosher D, Sutton E. Efficacy of sacroiliac corticosteroid injections in patients with inflammatory spondyloarthropathy: Results of a 5 month controlled study. *J Rheum* 2000; 27:719-722.
89. Slipman CW, Lipetz JS, Plastaras CT, Jackson HB, Vresilovic EJ, Lenrow DA, Braverman DL. Fluoroscopically guided therapeutic sacroiliac joint injections for sacroiliac joint syndrome. *Am J Phys Med Rehabil* 2001; 80:425-432.
90. Ferrante FM, King LF, Roche EA, Kim PS, Aranda M, Delaney LR, Mardini IA, Mannes AS. Radiofrequency sacroiliac joint denervation for sacroiliac syndrome. Req Anesth *Pain Med* 2001; 26:137-142.
91. Yin W, Willard F, Carreiro J. Sensory stimulation guided sacroiliac joint radiofrequency neurotomy: Technique based on neuroanatomy of the dorsal sacral plexus. *Spine* 2003; 28:2419-2425.
92. Myers A. Prolotherapy treatment of low back pain and sciatica. *Bulletin of the Hospital for Joint Diseases* 1961(12).
93. Dorman T. Pelvic mechanics and prolotherapy. In Vleeming A, Mooney V, Dorman T, Snijders C, Stoeckart R (eds), *Movement, Stability, and Low Back Pain: The Essential Role of the Pelvis.* Churchill Livingstone, New York, 1997, pp 501-522.
94. Gedney EH. Hypermobile joint. *Osteopath Prof* 1937; 4:30-31.
95. Hackett GS. *Ligament and Tendon Relaxation Treated by Prolotherapy*, 3rd edition. Hemwall G. Institute, Illinois, 1958.
96. Linetsky FS, Manchikanti L. Regenerative injection therapy for axial pain. Tech Reg *Anesth Pain Manage* 2005; 9:40-49.
97. Kim PS, Ferrante FM. Cryoneurolysis in a pain practice. *Prog Anesthesiol* 2001; 15: 127-137.
98. Trescot AM. Cryoanalgesia in interventional pain management. *Pain Physician* 2003; 6:345-360.
99. Moore MR. Surgical treatment of chronic painful sacroiliac joint dysfunction. In Vleeming A, Mooney V, Dorman T, Snijders C, Stoeckart R (eds), *Movement, Stability, and Low Back Pain: The Essential Role of the Pelvis.* Churchill Livingstone, New York, 1997, pp 563-572.
100. Keating JG, Dims V, Avillar M. Sacroiliac joint fusion in a chronic low back pain population. *The Integrated Function of the Lumbar Spine and Sacroiliac Join*t. Part I. ECO, Rotterdam, 1995, pp 361-365.