

Case Report

Cooled Sacroiliac Radiofrequency Denervation for the Treatment of Pain Secondary to Tumor Infiltration: A Case-Based Focused Literature Review

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Background: The sacroiliac (SI) joint is a common cause of low back pain, for which radiofrequency (RF) denervation has been shown to provide long-term relief. However, controversy exists surrounding the innervation, which treatment paradigm to utilize, and how best to select patients who might benefit.

Objective: To describe a patient with terminal breast cancer and tumor infiltration of the sacroiliac joint who was treated with cooled RF of the sacral lateral branches as an end-of-life palliative measure. The objectives of this review are to provide insight into the innervation of the SI joint; address controversial issues surrounding the targeted nerves in a patient with transitional anatomy; outline risk-mitigation strategies; and highlight the need for individually tailored treatment plans.

Methods: Case-based focused literature review in a patient treated with cooled RF ablation of the L4-S3 primary dorsal rami and lateral branches.

Results: Treatment was tailored to facilitate the rapid treatment of this terminal patient by performing the prognostic blocks and RF ablation at the same visit. Until her death 5 days post-procedure, the patient reported significant pain relief and began to ambulate and use the bathroom on her own, activities she could not do before treatment. In addition to functional improvement, she was also able to significantly reduce her opioid intake.

Conclusion: This is the first report of cooled SI joint RF ablation to treat cancer pain. Our patient's positive response to the procedure suggests the possibility that the lateral branches innervate not only the posterior ligaments, but also the bony articulation. The decision to proceed with RF ablation on the same day as a prognostic lateral branch block was based on our patient's terminal condition, and the fact that cooled RF does not require sensory stimulation to ensure proximity to the target nerves. Because of her transitional anatomy, we elected to target L4.

Key words: Cancer, denervation, innervation, radiofrequency, sacroiliac joint, transitional anatomy

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Bone metastases occur in 60% of patients with cancer (1), and are a major cause of cancer related pain (2). Pain associated with bone metastases reduces the likelihood of good pharmacological pain control and is a negative prognostic factor (3). The release of chemical mediators, increased pressure within

bone, microfractures, stretching of nociceptor-imbued periosteum, reactive muscle spasm, and compression of nerves and/or nerve roots by collapsed vertebrae are all possible mechanisms by which bone metastases can cause pain (4). Classically exacerbated by movement, pain secondary to bone metastases can be notoriously

difficult to treat with conventional analgesics. Radiation therapy is considered the reference standard for the management of painful bony metastases (5); however, not all patients will tolerate or benefit from this treatment. In such a population, interventional procedures such as radiofrequency ablation (RFA) of the sensory nerves innervating structures invaded by the tumor, or even ablation of the tumor itself, may be viable treatment options.

The basis for pain improvement following RFA appears to be multifactorial. Possible mechanisms include physical destruction of sensory nerve fibers innervating the periosteum and cortex of bone; mechanical decompression of tumor volume resulting in decreased stimulation of sensory nerves; direct destruction of tumor cells resulting in decreased cytokine release, which in turn may reduce peripheral sensitization; and finally inhibition of osteoclast activity (6-8).

Consequently, RFA may play an adjunctive role to the use of radiation therapy for palliation of painful metastatic lesions. The objective of this case-based review is to report the first case describing RFA of the lateral branches as a treatment for metastatic SI joint pain in a patient with stage IV breast cancer, and to explore the myriad issues surrounding its use. These issues include the utility of "prognostic" nerve blocks in this context and the need to tailor treatment paradigms on an individualized basis, the potential for "seeding" the tumor in unaffected areas; and questions surrounding which structures of the heterogeneous joint complex are innervated by the lateral branch nerves amenable to denervation.

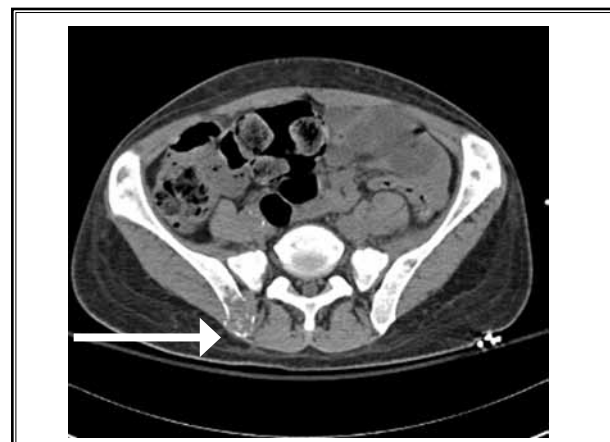


Fig. 1. Axial computed tomography (CT) image through the sacral spine. The white arrowhead shows a right iliac expansile metastatic lesion with a soft tissue component extending into the dorsal aspect of the right sacroiliac joint.

CASE DESCRIPTION

The patient was a 54-year-old with stage IV breast carcinoma with metastases to her liver, lung, and spine, who was admitted for shortness of breath and worsening right-sided buttock pain.

Her initial diagnosis was made 2 years previously at which point a tumor was found on palpation of her left breast. The treatments she underwent included several courses of naturopathic therapy, pharmacotherapy with non-steroidal anti-inflammatory drugs (NSAIDs), opioids, and multiple adjuvants (e.g. gabapentin, antidepressants); vaccine therapy; and 4 cycles of chemotherapy over a 3-month period, all with no improvement.

She was admitted to the hospital with a chief complaint of right-sided buttock pain of 3 weeks duration, for pain control. She was incidentally found to have bilateral ground glass opacities in her lungs on CT scan consistent with pneumonia, which was treated with broad coverage antibiotics. Work-up revealed metastatic disease to her liver, lung, and spine.

The patient's initial numerical rating scale (NRS) pain score was 10/10 in her right buttock region. She described her pain as continuous, sharp, and penetrating, with no radiation. She denied lumbar pain, weakness, or symptoms of incontinence. Her physical exam was remarkable for marked tenderness over the right SI joint and positive Patrick's (pain with flexion, abduction and external rotation of the ipsilateral hip) and Gaenslen's (extending the ipsilateral hip with the contralateral hip flexed) tests. She was unable to ambulate because of pain. Her CT scan was notable for multiple enhancing expansile lesions involving the posterior aspect of the right iliac bone, extending into the dorsal aspect of the SI joint (Fig. 1).

During our initial evaluation, she was on an analgesic regimen consisting of acetaminophen, extended-release morphine sulfate 60 mg every 12 hours, and intravenous morphine sulfate 4 mg every 3 hours as needed, with little benefit. Based on the patient's terminal condition and discussions with the patient and primary team, a collective decision was made to perform a prognostic right-sided lateral branch (SI joint nerve) block with lidocaine, followed by RFA if the patient reported meaningful benefit.

Sedation was withheld during the prognostic blocks to minimize the risk for a false positive result (9). Three 22-gauge 3.5-inch finder needles were placed under fluoroscopic guidance into the foramina of S1, S2, and S3, and withdrawn to the posterior bony cortex to

serve as landmarks. At each one of these sites, 22-gauge spinal needles were placed approximately 5 mm lateral to the finder needles at the 2:00 and 5:00 positions on the face of the clock to anesthetize the lateral branches. Additional needles were also placed in between the sacral ala and articular process to block the L5 dorsal ramus, and at the medial aspect of the junction between the L5 superior articular and transverse processes for L4, in light of the fact that the patient had an anomalous connection of L5 to the iliac crest as well as a rudimentary disc at that level (i.e. sacralization of L5) (Fig. 2). After negative aspiration, 0.5 ml of lidocaine 2% was injected at each site at varying depths. Following a 20-minute interval, the patient reported a reduction in her pain from a 10/10 to a 5/10. At this point, we elected to perform cooled RF of the SI joint after further discussion with the patient. The decision to utilize cooled RF was based on 2 factors: 1) the large lesion size enhances the likelihood of success for a condition in which the number and location of nerves innervating the SI joint exhibit significant variability even in the absence of anatomical derangement; and 2) the large lesion size obviates the need for sensory stimulation to identify the nerves, which was no longer possible after anesthetizing the nerves during the prognostic block.

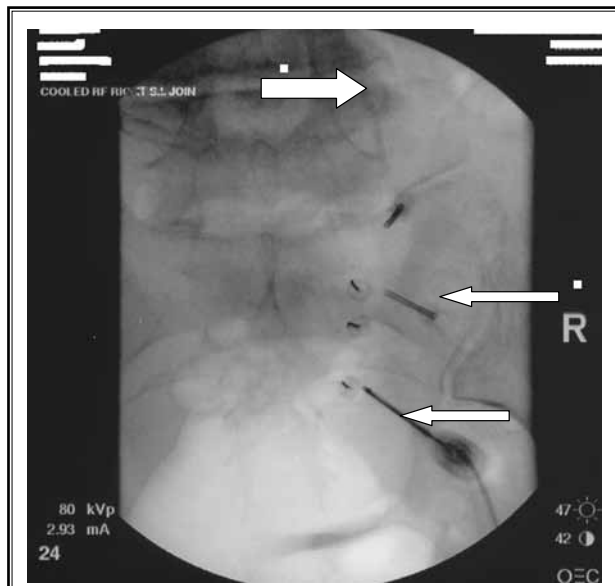


Fig. 2. Antero-posterior image of the lumbar spine. The large white arrow head demonstrates the lumbosacral transitional vertebrae. The small white arrow heads show the needle tips situated at the 3:30 positions (on the face of a clock) lateral to the S1 and S3 foramina. The black arrows indicate the 22-gauge finder needles placed into the S1-S3 neural foramina to guide electrode placement.

Lesioning of the L4 and L5 primary dorsal rami was accomplished by inserting 17-gauge cooled electrodes with 4-mm active tips (Baylis Medical, Montreal, Quebec, Canada) parallel to the course of the nerves until bone was contacted at the junction between the superior border of the transverse and superior articular processes of the sacralized L5 vertebral body for the L4 dorsal ramus, and in the groove between the sacral ala and articular process for L5. For S1-S3 lateral branch denervation, the cooled electrodes were sequentially inserted perpendicular to the bone 8 - 10 mm from the perimeter of the foramina in a semicircumferential pattern. At S1 and S2, 3 lesions were created at 1:30, 3:30, and 5:30 on the face of a clock (Fig. 3). For S3, 2 lesions were created at the 1:00 and 3:30 positions based on the spatial relationship between the foramen and lower part of the SI joint. Prior to lesioning, the absence of leg contractions was verified with electrical stimulation at 2 Hz. Once electrode placement was deemed satisfactory, 1 mL of lidocaine 2% mixed with 5 mg of methylprednisolone was injected through each cannula to reduce thermal pain, prevent neuritis, and

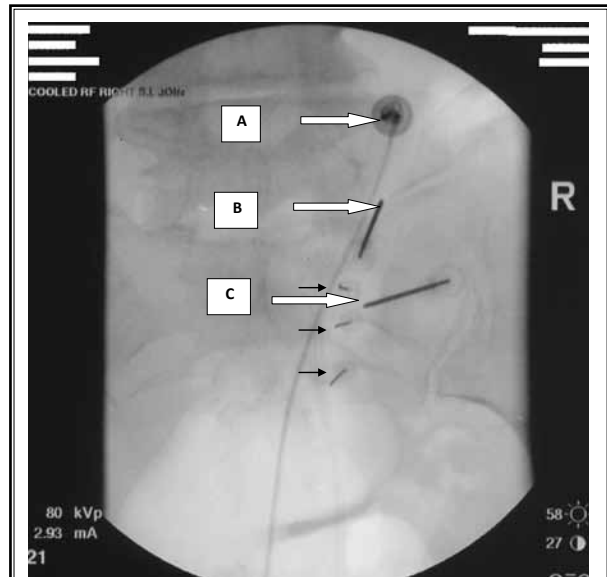


Fig. 3. Antero-posterior image of the lumbar spine demonstrating electrode placement. Arrowhead A illustrates the lumbosacral transitional vertebrae, with the needle tip at the junction of the L5 transverse and superior articular processes, targeting the L4 dorsal ramus. Arrowhead B demonstrates the needle tip at the right sacral ala, targeting the L5 dorsal ramus. Arrowhead C shows the electrode tip on the right side of S1 at the 5:30 position (on the face of a clock). The black arrows show the locations of the 22-gauge finder needles inserted into the foramina of S1, S2, and S3, used as landmarks to guide electrode placement.

enhance lesion size (10,11), after which lesions were created over a 2.5-minute period using a water-cooled heating system (Pain Management SInergy System; Baylis Medical).

On postprocedure day ONE, the patient was able to ambulate with assistance and cooperate with her physical therapy program, activities she had previously been unable to do. Her pain scores ranged between 3 and 5 out of 10. Her opioid requirements declined by 52%. She was able to use the bathroom on her own. Her physical activity continued to improve significantly until postprocedure day 3, when she started to experience increasing dyspnea and increased oxygen requirements secondary to worsening pneumonia. On postprocedure day 5, the patient expired secondary to respiratory failure, with little pain according to her nurses.

Discussion

The results of this case provide insight into the complex innervation of the SI joint complex, as well as controversial issues surrounding how to best select candidates for RFA.

Insights into Innervation

The reason we elected to perform prognostic blocks prior to denervation is because the innervation of the bony articulation of the sacroiliac joint is not well known. Only the anterior, inferior one-third of the interface between the sacrum and the ilium is a true synovial joint; the remainder of the junction is composed of an intricate set of ligamentous connections, which is more extensive posteriorly (12). The innervation of the SI joint is a subject of considerable debate.

The lateral branches of the L4-S3 dorsal rami are often cited as composing the major sensory nerve supply to the posterior SI joint (13). However, the contribution of L4 is based on older studies performed in the late 19th and early 20th centuries that have not been subsequently replicated (14). Moreover, recent cadav-

eric studies suggest that S4 may innervate the SI ligaments in 59% of individuals (15). The innervation of the anterior joint is even more ambiguous, with literature suggesting innervation arising from the L4-S2 ventral rami (16,17). The contention that both intra- and extra-articular structures can be sources of SI joint pain is indisputable (18).

Complicating the picture is the fact that neither historical nor physical exam features can reliably discriminate between intra- and extra-articular pathology (19-21). Table 1 outlines the various causes of intra-articular and extra-articular SI joint pain. The reason this is clinically relevant is because experimental human studies have determined that blockade of the lateral branches amenable to RF denervation reliably stop nociceptive input from the SI joint ligaments but not the joint capsule, making ablative techniques more likely to be effective for extra-articular pathology (22). Our patient’s positive response to the procedure suggests that lateral branches may provide innervation to the bony structures of the SI joint complex, and possibly even fed into the tumor mass.

Transitional Lumbosacral Vertebrae

The rationale for targeting the L4 dorsal ramus stems from the observation that sacralization of L5 typically results in a more cephalad border of the SI joint that extends past the L4 spinal nerve, and that our patient’s pain was diffusely located throughout the SI region. The frequency of transitional vertebra in the general population has been reported to be as high as 30% (23). Studies have shown that the L4 spinal nerve serves the usual function of the L5 nerve root in patients with a sacralized L5 (24). In addition to predisposing individuals to lumbar axial back pain, lumbosacral transitional vertebrae may also present as ipsilateral sacroiliac joint pain secondary to pseudoarthrosis with the infra-adjacent ala of the sacrum, resulting in both radicular pain from L5 and mechanical pain from biomechanical alterations (25). Although cooled RF has been performed many times in the lumbar spine, precautions in the form of imaging the electrode in multiple planes and motor stimulation must be taken to avoid the increased chance of inadvertently lesioning a spinal nerve.

Decision to Perform a Lateral Branch Block

It is well-recognized that the reference standard to identify a painful SI joint is via SI joint blocks (20,21). However, studies utilizing “confirmatory blocks” performed with a short- and long-acting local anesthetic

Table 1. Causes of Intra-articular and Extra-articular Sacroiliac Joint Pain

Intra-articular Pain	Extra-articular Pain
<input type="checkbox"/> Arthritis	<input type="checkbox"/> Ligamentous injury
<input type="checkbox"/> Spondyloarthropathy	<input type="checkbox"/> Bone Fractures
<input type="checkbox"/> Malignancies	<input type="checkbox"/> Malignancies
<input type="checkbox"/> Trauma	<input type="checkbox"/> Myofascial pain
<input type="checkbox"/> Infection	<input type="checkbox"/> Enthesopathy
<input type="checkbox"/> Cystic disease	<input type="checkbox"/> Trauma
	<input type="checkbox"/> Pregnancy

suggest that single blocks are characterized by a high false-positive rate (26-29). In addition, SI joint blocks are inherently non-specific. Periarticular blocks may fail to anesthetize the full extent of posterior soft-tissue structures, and the extravasation of injectate into the surrounding musculature and through the joint capsule during intra-articular blocks can undermine one's ability to distinguish between intra- and extra-articular pathology (30,31); yet, only the latter will likely respond to RFA. In this context, the main purpose of performing a preliminary block before RF in this patient was for prognostic rather than diagnostic purposes, since the radiological evidence of SI joint infiltration was irrefutable. Consequently, the best means to predict whether neuroablation might afford benefit is to first determine whether anesthetizing those nerves (i.e., the lateral branches) provides pain relief. For facet joint pain, controlled studies that selected subjects based on medial branch blocks are almost all positive (32-34), whereas those that selected patients via intra-articular injections have yielded either negative or equivocal results (35,36).

0, 1, or 2 Blocks

Performing multiple diagnostic blocks is often advocated as the best means to reduce the false-positive rate (37). But this reason is only valid when one is using the blocks as a diagnostic tool, and is probably the best treatment paradigm to utilize when designing efficacy studies (38). In view of the patient's terminal condition and the fact that performing 2 blocks decreases the overall chances of a successful outcome, ostensibly by increasing the false-negative rate (39), we never considered utilizing double-blocks. Based on a multicenter randomized study which demonstrated that proceeding straight to RFA is associated with the highest chance of a successful treatment result, one might reasonably contend that we should have foregone prognostic blocks altogether (40). However, this study was performed utilizing conventional RF for suspected lumbar facet joint pain, which is less invasive, less expensive, and associated with lower risk than SI joint cooled RF denervation. Although higher RF denervation success rates were observed in the group that received 2 diagnostic blocks because of the stringency of the selection criteria, the overall success rate was higher in the group that received no blocks, presumably because no false-negative patients were excluded, and the treatment group included placebo-responders. Balancing the relatively invasive nature of multilevel

cooled RF (which bolsters the argument for performing prognostic blocks) and the desire to minimize the chance of a false-negative result, we elected to utilize a single prognostic screening test in our patient. In addition, the use of lateral branch blocks provided us with valuable insight into the innervation pattern of the SI joint complex.

Performing Lateral Branch Blocks and RFA at the Same Visit

There was an urgent need for rapid treatment in this woman with a short life expectancy. Hence, the decision was made to start with a prognostic block of the lateral sacral branches, wait a short period time to assess her response, and then consider RF denervation at the same visit. The drawback to this is that blockade of the lateral branches would render sensory stimulation unreliable. Hence, in ordinary circumstances performing prognostic blocks and RF ablation at the same visit is not acceptable. What makes this even possible in our patient is that sensory stimulation is not necessary for SI joint cooled RF. The sacral lateral branches form a complex arcade of small nerve fibers anastomosing with multiple dorsal rami, rendering the location of the nerves unpredictable from patient-to-patient, side-to-side, and level-to-level (41). Anatomic and fluoroscopic correlational analysis have determined that the precise locations of the lateral branch nerves are inconsistent relative to identifiable bony landmarks (17,41,42). The main advantage of cooled RF technology is that it doubles the lesion diameter and enhances the volume by a factor of 8, making it more likely to interrupt the nociceptive input from the SI joint (43). In light of the fact that there are multiple lateral branches that vary in their locations, eliciting low sensory stimulation at one site does not guarantee severing all nociceptive input at any given spinal level. When the electrodes are strategically positioned around the foramen, the size and orientation of the cooled RF lesions are such that a continuous strip lesion will be formed, obviating the need for sensory testing (43). Even in the lumbar spine, studies have shown no significant correlation between sensory stimulation and RF outcome (44). Motor stimulation was performed in our patient to avoid neuroablation of spinal nerves, as increasing the voltage output to high levels can override low-volume sensory blockade. Furthermore, the purpose of prognostic lateral branch blocks is to block the nociceptive input from the SI joint, not the spinal nerves, which should render motor stimulation valid.

Risk Mitigation

Complications reported with RFA to treat cancer include second degree skin burns at the grounding pad site, transient bowel and bladder incontinence following treatment of sacral metastases, and fracture of the acetabulum following RFA of an acetabular lesion (4,45). Bowel and bladder incontinence have occurred following SI joint cooled RF, and are likely due to inadvertent lesioning of the S2-4 spinal nerves. Intercessions that were used to prevent this complication included the placement of the electrodes > 7 mm from the intraforaminal "finder needles," which is considered to be the minimal safe distance necessary to prevent neurolytic (> 45 deg C) temperatures within the foramina, utilizing supra-threshold motor stimulation at > 3 volts to ensure absence of sphincter and leg contraction, and checking needle position in the lateral fluoroscopic view. Neoplastic needle track seeding into unaffected areas following percutaneous radiofrequency tumor ablation is exceedingly rare (45). This complication is even less of a concern in patients with widely metastatic disease. Strategies used to reduce this risk even further included reinserting our stylet before withdrawing the electrodes. Injecting fluid through the needle during real-time fluoroscopic withdrawal, such as recommended in vertebroplasty, can also be considered.

LIMITATIONS

The main limitations are the very short follow-up period because of death from the primary cancer and the uncontrolled nature of our results. However, the infrequency with which this situation arises precludes the performance of a prospective clinical trial. Whereas some patients might obtain prolonged relief from local anesthetic injections (46), especially in the lumbar spine (47,48), most previous studies have failed to demonstrate any prolonged benefit from lateral branch blocks done with local anesthetics alone (49-51). Nevertheless,

prolonged relief from the local anesthetic and steroid could possibly have contributed to our patient's results, though this would still support the contention that the lateral branches innervate the bony structures of the SI joint. Despite the observation that the patient did not respond to multiple analgesic medications, one might speculate that the strong placebo response with interventions could partially explain her relief. However, a single-blind randomized trial comparing a placebo device to a placebo pill found no evidence for an enhanced effect with placebo devices compared with pills during the 2-week run-in period, though the superior effect for the intervention did become evident in participants who remained on placebo during the subsequent trials of active treatment (52). Our patient's short-term response does not definitively prove that the lateral branches innervate bone, but does represent a possible mechanism to explain her short-term pain relief. Whereas the therapeutic utility of a diagnostic intervention in a low disease prevalence condition is difficult to prove with a controlled study, our hypothesis does warrant more detailed exploration.

CONCLUSION

This is the first report of RFA of nerves being used to treat cancer pain. Our patient's positive response to the procedure suggests that the lateral branches may possibly innervate not only the posterior ligaments, but possibly also the bony structures of the SI joint. The decision to proceed with RFA on the same day as a prognostic lateral branch block was based on our patient's terminal condition and the fact that cooled RF does not require sensory stimulation to ensure proximity to the target nerves. Because there are many potential confounding factors that can affect interpretation of our results, including the short-term follow-up and a prolonged response from the local anesthetic and steroid, caution should be exercised when interpreting them.

REFERENCES

1. Mercadante S. Malignant bone pain: Pathophysiology and treatment. *Pain* 1997; 69:1-18.
2. Twycross RG, Fairfield S. Pain in far-advanced cancer. *Pain* 1982; 14:303-310.
3. Mercadante S, Maddaloni S, Roccella S, Salvaggio L. Predictive factors in advanced cancer pain treated only by analgesics. *Pain* 1992; 50:151-155.
4. Tam A, Ahrar K. Palliative interventions for pain in cancer patients. *Semin Intervent Radiol* 2007; 24:419-429.
5. Jeremic B, Shibamoto Y, Acimovic L, Milicic B, Milisavljevic S, Nikolic N, Aleksandrovic J, Igrutinovic I. A randomized trial of three single-dose radiation therapy regimens in the treatment of metastatic bone pain. *Int J Radiat Oncol Biol Phys* 1998; 42:161-167.
6. Mannion RJ, Woolf CJ. Pain mechanisms and management: A central perspective. *Clin J Pain* 2000; 16:S144-S156.
7. Honore P, Luger NM, Sabino MA, Schwei MJ, Rogers SD, Mach DB, O'Keefe PF, Ramnaraine ML, Clohisy DR, Mantyh MW. Osteoprotegerin blocks bone cancer-induced skeletal destruction, skeletal pain and pain-related neurochemical reorganization of the spinal cord. *Nat Med* 2000; 6:521-528.
8. Woolf CJ, Allchorne A, Safieh-Garabedian B, Poole S. Cytokines, nerve growth factor and inflammatory hyperalgesia: The contribution of tumour necro-

- sis factor alpha. *Br J Pharm* 1997; 121:417-424.
9. Manchikanti L, Pampati V, Damron KS, McManus CD, Jackson SD, Barnhill RC, Martin JC. The effect of sedation on diagnostic validity of facet joint nerve blocks: an evaluation to assess similarities in population with involvement in cervical and lumbar regions. *Pain Physician* 2006; 9:47-51.
 10. Provenzano DA, Flusilla HC, Somers D. The effect of fluid injection on lesion size during radiofrequency treatment. *Reg Anesth Pain Med* 2010; 35:338-342.
 11. Dobrogowski J, Wrzosek A, Wordliczek J. Radiofrequency denervation with or without addition of pentoxifylline or methylprednisolone for chronic lumbar zygapophysial joint pain. *Pharmacol Rep* 2005; 57:475-480.
 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. Bernard TN, Cassidy JD. The sacroiliac syndrome. Pathophysiology, diagnosis and management. In: Frymoyer JW (ed). *The Adult Spine: Principles and Practice*. Raven, New York, 1991, pp. 2107-2130.
 14. Cunningham DK. *Cunningham's Text-Book of Anatomy*. Oxford University Press, New York, 1931.
 15. McGrath MC, Zhang M. Lateral branches of dorsal sacral nerve plexus and the long posterior sacroiliac ligament. *Surg Radiol Anat* 2005; 27:327-330.
 16. Pitkin HC, Pheasant HC. Sacroarthrogenic telalgia I: A study of referred pain. *J Bone Joint Surg* 1936; 18:111-133.
 17. Solonen KA. The sacroiliac joint in the light of anatomical, roentgenological and clinical studies. *Acta Orthop Scand* 1957; 27(suppl):1-27.
 18. Cohen SP. Sacroiliac joint pain: A comprehensive review of anatomy, diagnosis, and treatment. *Anesth Analg* 2005; 101:1440-1453.
 19. Szadek KM, van der Wurff P, van Tulder MW, Zuurmond WW, Perez RS. Diagnostic validity of criteria for sacroiliac joint pain: A systematic review. *J Pain* 2009; 10:354-368.
 20. Hancock MJ, Maher CG, Latimer J, Spindler MF, McAuley JH, Laslett M, Bogduk N. Systematic review of tests to identify the disc, SIJ or facet joint as the source of low back pain. *Eur Spine J* 2007; 16:1539-1550.
 21. Rupert MP, Lee M, Manchikanti L, Datta S, Cohen SP. Evaluation of sacroiliac joint interventions: A systematic appraisal of the literature. *Pain Physician* 2009; 12:399-418.
 22. Dreyfuss P, Henning T, Malladi N, Goldstein B, Bogduk N. The ability of multi-site, multidepth sacral lateral branch blocks to anesthetize the sacroiliac joint complex. *Pain Med* 2009; 10:679-688.
 23. Delpont EG, Cucuzzella TR, Kim N, Marley J, Pruitt C, Delpont AG. Lumbosacral transitional vertebrae: Incidence in a consecutive patient series. *Pain Physician* 2006; 9:53-56.
 24. Kim YH, Lee PB, Lee CJ, Kim YC, Huh J. Dermatome variation of lumbosacral nerve roots in patients with transitional lumbosacral vertebrae. *Anesth Analg* 2008; 106:1279-1283.
 25. Paraskenas G, Tzaveas A, Koutras G, Natsis K. Lumbosacral transitional vertebra causing Bertolotti's syndrome: A case report and review of the literature. *Cases J* 2009; 2:8320.
 26. van der Wurff P, Buijs EJ, Groen GJ. A multitest regimen of pain provocation tests as an aid to reduce unnecessary minimally invasive sacroiliac joint procedures. *Arch Phys Med Rehabil* 2006; 87:10-14.
 27. Manchikanti L, Singh V, Pampati V, Damron K, Barnhill R, Beyer C, Cash K. Evaluation of the relative contributions of various structures in chronic low back pain. *Pain Physician* 2001; 4:308-316.
 28. 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.
 29. 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.
 30. Rosenberg JM, Quint DJ, de Rosayro AM. Computerized tomographic localization of clinically-guided sacroiliac joint injections. *Clin J Pain* 2000; 16:18-21.
 31. Schwarzer AC, Aprill CN, Bogduk N. The sacroiliac joint in chronic low back pain. *Spine* 1995; 20:31-37.
 32. van Kleef M, Barendse GA, Kessels A, Voets HM, Weber WE, de Lange S. Randomized trial of radiofrequency lumbar facet denervation for chronic low back pain. *Spine* 1999; 24:1937-1942.
 33. Nath S, Nath CA, Pettersson K. Percutaneous lumbar zygapophysial (facet) joint neurotomy using radiofrequency current, in the management of chronic low back pain: A randomized double-blind trial. *Spine* 2008; 33:1291-1297.
 34. Lord SM, Barnsley L, Wallis BJ, McDonald GJ, Bogduk N. Percutaneous radiofrequency neurotomy for chronic cervical zygapophysial-joint pain. *N Engl J Med* 1996; 335:1721-1726.
 35. Leclaire R, Fortin L, Lambert R, Bergeron YM, Rossignol M. Radiofrequency facet joint denervation in the treatment of low back pain. A placebo-controlled clinical trial to assess efficacy. *Spine* 2001; 26:1411-1417.
 36. Van Wijk RM, Geurts JW, Wynne HJ, Hammink E, Buskens E, Lousberg R, Knape JT, Groen GJ. Radiofrequency denervation of lumbar facet joints in the treatment of chronic low back pain: A randomized, double-blind, sham lesion controlled trial. *Clin J Pain* 2005; 21:335-344.
 37. Bogduk N. Evidence-informed management of chronic low back pain with facet injections and radiofrequency neurotomy. *Spine J* 2008; 8:56-64.
 38. Cohen SP, Huang JH, Brummett C. Facet joint pain - advances in patient selection and treatment. *Nat Rev Rheumatol* 2012; Nov. 20 (ePub ahead of print).
 39. Lord SM, Barnsley L, Bogduk N. The utility of comparative local anesthetic blocks versus placebo-controlled blocks for the diagnosis of cervical zygapophysial joint pain. *Clin J Pain* 1995; 11:208-213.
 40. Cohen SP, Williams KA, Kurihara C, Nguyen C, Shields C, Kim P, Griffith SR, Larkin TM, Crooks M, Williams N, Strassels SA. Randomized, comparative cost-effectiveness study comparing 0, 1 and 2 medial branch blocks before lumbar facet radiofrequency denervation. *Anesthesiology* 2010; 113:395-405.
 41. Yin W, Willard F, Carreiro J, Dreyfuss P. Sensory stimulation-guided sacroiliac joint radiofrequency neurotomy: Technique based on neuroanatomy of the dorsal sacral plexus. *Spine* 2003; 28:2419-2425.
 42. Ikeda R. Innervation of the sacroiliac joint. Macroscopic and histological studies. *J Nippon Med School* 1991; 58:587-596.
 43. Cohen SP, Hurley RW, Buckenmaier CC 3rd, Kurihara C, Morlando B, Dragovich A. Randomized placebo-controlled study evaluating lateral branch radiofre-

- quency denervation for sacroiliac joint pain. *Anesthesiology* 2008; 109:279-288.
44. Cohen SP, Strassels SA, Kurihara C, Lesnick IK, Hanling SR, Griffith SR, Buckenmaier CC 3rd, Nguyen C. Does sensory stimulation threshold affect lumbar facet radiofrequency denervation outcomes? A prospective clinical correlational study. *Anesth Analg* 2011; 113:1233-1241.
 45. Thacker PG, Callstrom MR, Curry, TB, Mandrekar JN, Atwell TD, Goetz MP, Rubin J. Palliation of painful metastatic disease involving bone with imaging-guided treatment: Comparison of patients' immediate response to radiofrequency ablation and cryoablation. *Am J Roentgenol* 2011; 197:510-515.
 46. Hansen H, Manchikanti L, Simopoulos TT, Christo PJ, Gupta S, Smith HS, Ha-meed H, Cohen SP. A systematic evaluation of the therapeutic effectiveness of sacroiliac joint interventions. *Pain Physician* 2012; 15:E247-278.
 47. Manchikanti L, Singh V, Falco FJ, Cash KA, Pampati V. Lumbar facet joint nerve blocks in managing chronic facet joint pain: One-year follow-up of a randomized, double-blind controlled trial: Clinical Trial NCT00355914. *Pain Physician* 2008; 11:121-132.
 48. Manchikanti L, Singh V, Falco FJ, Cash KA, Fellows B. Comparative outcomes of a 2-year follow-up of cervical medial branch blocks in management of chronic neck pain: A randomized, double-blind controlled trial. *Pain Physician* 2010; 13:437-450.
 49. Cohen SP, Abdi S. Lateral branch blocks as a treatment for sacroiliac joint pain: A pilot study. *Reg Anesth Pain Med* 2003; 28:113-119.
 50. Patel N, Gross A, Brown L, Gekht G. A randomized, placebo controlled study to assess the efficacy of lateral branch neurotomy for chronic sacroiliac joint pain. *Pain Med* 2012; 13:383-398.
 51. Burnham RS, Yasui Y. An alternate method of radiofrequency neurotomy of the sacroiliac joint: A pilot study of the effect on pain, function, and satisfaction. *Reg. Anesth Pain Med* 2007; 32:12-19.
 52. Kaptchuk TJ, Stason WB, Davis RB, Legedza AR, Schnyer RN, Kerr CE, Stone DA, Nam BH, Kirsch I, Goldman RH. Sham device v inert pill: Randomised controlled trial of two placebo treatments. *BMJ* 2006; 332:391-397.