



# Medial branch blocks and facet joint injections as predictors of successful radiofrequency ablation

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Zygapophyseal (z) joints (or facet joints) are a potential source of pain in nearly 15-45% of patients suffering from chronic spinal pain. There are no clinical features or imaging techniques pathognomonic for z-joint pain. Blockade of the medial branch of the spinal nerve primary posterior ramus, using fluoroscopic guidance to ensure positioning of the needle tip and low volumes of local anesthetic, are accepted methods for diagnosing z-joint pain. This is based on the assumption that anesthetizing either the facet joint capsule containing the nerve endings or the main branch innervating it would result in complete or significant pain relief. A positive result presumably means that the z-joint is the anatomical structure where pain originates from. These techniques inherently carry high false-positive rates. The current practice of 2 consecutive positive blocks reduces the false-positive rate. However, the criterion of 2 positive blocks results in an increase of the false-negative rate, which could result in withholding radiofrequency ablation of medial branch. Despite limitations of medial branch blockade, these interventions are crucial in guiding decision on performing treatment modalities such as radiofrequency ablation of the medial branch blocks for chronic spinal pain. Diagnostic facet joint and medial branch blocks are safe, valid, and relatively reliable. There is strong evidence that controlled diagnostic blocks distinguish painful from painless facet joints in the diagnostic workup of chronic spinal pain. Standardization and scientific validation of (controlled) diagnostic medical branch blocks are highly needed to identify its real value in clinical practice.

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Zygapophyseal joints (z-joints) are a common cause of chronic spinal pain. It is accepted that the lumbar z-joints are a potential source of low back and referred leg pain.<sup>1-3</sup> According to the International Association for the Study of Pain, facet joints are the source of chronic low back pain in 15% to 45% of patients.<sup>4</sup> Review of current literature provides prevalence estimates for lumbar, thoracic, and cervical facet joint pain. Various studies suggest facet joints as a

source of chronic spinal pain in 15% to 45% of patients with chronic low back pain,<sup>5,6</sup> 34% to 48% of patients with thoracic pain,<sup>4,7</sup> and 36% to 67% of patients with chronic neck pain.<sup>3,8</sup> These figures were based on responses to controlled diagnostic facet injection and medial branch blocks (MBB) performed in accordance with the criteria established by the International Association for the Study of Pain. As a clinical entity, facet syndrome remains poorly defined. Hence, the extent and significance of its contribution to spinal pain remain a subject of ongoing debate.<sup>9-11</sup> Since neither clinical algorithms nor imaging techniques have been shown to be specific in the diagnosis of axial spinal pain,<sup>1,3,12,13</sup> diagnostic medial nerve blocks have

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been employed to isolate the pain generator.<sup>14-24</sup> While the technique is not standardized, it is widely accepted that the only method for definite diagnosis of z-joint as the pain generator is either through facet joint intra-articular injection or block of the medial branch (MB) and L5 primary dorsal ramus block.<sup>25-28</sup>

## Zygapophyseal joint anatomy and innervation

Chronic spinal pain is difficult to treat since identifying the pain source could be challenging. Multiple anatomical structures in the spine including muscle, ligament, joints, disk, and nerve roots are identifiable sources of spine pain. Kuslich et al performed a pain-provocation study<sup>29</sup> in awake patients undergoing decompressive lumbar spine surgery for disk herniation and/or spinal stenosis under progressive local anesthesia using 1% lidocaine. He found out that disk and nerve roots were the main sources of pain; however, 54% of patients had enhanced sensation when the facet capsule was stimulated and 20% had significant pain.<sup>29</sup>

The z-joint is a synovial joint composed of a superior and an inferior articular process and a surrounding capsule defining a 1-1.5 mL space filled with synovial fluid. Facet joint capsule and the surrounding structures are richly innervated by nociceptors that fire when the capsule is stretched or subjected to compressive forces.<sup>30,31</sup> Using electrophysiology methods, Yamashita et al identified the mechanosensitive afferent units in the inferio-medial aspect of the facet joint capsule in rabbit joints.<sup>32</sup> Similar findings in humans where free nerve endings were detected in the mediolateral and inferior part of the capsule suggest that pinching of the nerves can result from spinal extension causing pain sensation.<sup>33-35</sup> The afferent supply of the facet joint is derived from the MB of posterior primary ramus.<sup>36-39</sup> Facet joints are innervated by medial branches arising from posterior primary rami at both the same level and the level above the z-joint. Exception to this anatomy is the L5-S1 joint, which is innervated by the dorsal ramus itself running at the junction of the sacral ala and superior articular process.<sup>36,40</sup> In a dissection study, Bogduk et al described in detail the path of medial branches in the lower back.<sup>26</sup> He reiterated that the spinal nerve emerges from intervertebral foramen and enters the posterior compartment of the back by coursing around the neck of the superior articular process below the foramen. Sliding at the neck of the superior articular process, the MB passes caudally to disappear under the mamillo-accessory ligament.<sup>41</sup> At the L5 level, L5 dorsal ramus is much longer and runs along the groove formed between the ala of the sacrum and the root of the S1 superior articular process.<sup>26</sup>

The mamillo-accessory ligament courses between the mamillary and accessory processes of each lumbar vertebra. These ligaments create a tunnel in the proximal course of the MB in relation to the neighboring osseous structures.<sup>41</sup> This predictability allows reliable reproduction of ap-

proaches of denervating these nerves. This fixed and close relationship, however, can lead to pathologic states because of ossification and potential entrapment. Beneath the ligament, the nerve hooks medially around the caudal aspect of the root of the superior articular process to enter the multifidus muscle.<sup>39,42,43</sup> Other branches run caudally and laterally across the transverse process into the longissimus and iliocostalis muscles, respectively.

## Pathophysiology and diagnosis of z-joint pain

Based on the biomechanics of the vertebral column, the spinal functional unit comprises superior and inferior facet joints with the intervertebral disk. In most cases the cause of lumbar facet joint pain is not known. Facet joint osteoarthritis is common; however, it is rare to find other definite recognizable pathology affecting the z-joints such as systemic inflammatory arthropathy, facet joint fracture, or infection. It has been demonstrated that facet joint degeneration almost invariably follows disk degeneration at the same level. However, Schwarzer et al evaluated patients by provocative discography and facet joint blocks and concluded that it was rare to suffer symptomatic disk degeneration in combination with symptomatic facet joints.<sup>1</sup> The hypertrophic changes of the z-joints secondary to injury or inflammatory changes and disk degeneration may lead to lumbar spinal nerve irritation and may cause low back pain. Low back pain can present with buttock pain, radicular-type pain, or pain in the posterior thigh or inguinal region. It is common to find paravertebral tenderness corresponding to z-joints, and aggravation of pain from maneuvers that maximally irritate the joints. Such maneuvers or transitional movements (eg, getting up or standing from sitting positions) were characterized as “facet syndrome.”<sup>9,10,44,45</sup>

The diagnosis of z-joint pain is made clinically and by excluding other origins of low back pain. Although one study reported a collection of symptoms and signs that increased the probability of a patient having z-joint pain, this has been refuted recently. Common imaging techniques such as plain radiographs, magnetic resonance imaging, computed tomography, and bone single photon emission computed tomography cannot discern which patients have z-joint pain either.<sup>46-48</sup> All imaging techniques have low sensitivity for facet joint pain and as such are not clinically useful as a screening tool.<sup>49-51</sup> The most useful test for confirmatory diagnosis is diagnostic facet injection or blockade of the innervating nerves (MB of the posterior primary ramus).

## Medial branch block

It is generally accepted in clinical practice that diagnostic MBB are the most reliable means for diagnosing z-joints as a pain source.<sup>20,52,53</sup> Local anesthetic injected accurately onto the correct target points selectively infiltrates the target

nerve and does not anesthetize adjacent structures that might be an alternative source of pain. MBB and facet intra-articular injections have been validated as a diagnostic technique. Various systematic reviews have asserted that there is evidence to suggest that intra-articular injections and MBB are equally effective in diagnosing z-joint pain.<sup>20,52,53</sup>

The purpose of a diagnostic block is to identify unequivocally the source of pain. Many studies have shown that it is clinically difficult to diagnose lumbar z-joint pain without the use of controlled diagnostic blocks. Although controlled diagnostic blocks remain the best way of diagnosing z-joint pain, they are not infallible and care must be taken to assure a correct diagnosis. Various practices with significant differences in sensitivity and specificity have been described. The following algorithms have been described:

- a. Double-blind (or single-blind) placebo-controlled injections. This is the best technique to sort out the false-positive responder and maximize the positive-predictive value. Performing double-blind injections actually would be ideal to identify the true facet joint pain. However, ethical impediments of performing diagnostic placebo injections precluded this technique from being viable.
- b. Comparative local anesthetic techniques rely on the patient having a longer duration of pain relief with bupivacaine than with lidocaine and require at least 2 separate injections for confirmation. This increases specificity greatly, but excludes nearly one third of patients with true z-joint pain who exhibit a “discordant response,” that is, a longer duration of relief with lidocaine than bupivacaine.
- c. Consecutive local anesthetic injections. This is the prevailing technique. Two consecutive positive responses to lidocaine would confirm the diagnosis of z-joint pain.

Ideally a positive response would be considered a complete pain relief (100%) post injection. However, significant pain relief (80%) has been accepted as the more stringent criterion. There could be concomitant degenerative changes, muscle- or ligament-associated nociception that can escape the MB innervation field or intra-articular injection resulting in incomplete pain relief.

In light of establishing a long term treatment strategy and in particular for predicting a higher success rate of radiofrequency ablation (RFA) of MBs, the following parameters are still under review for validation:

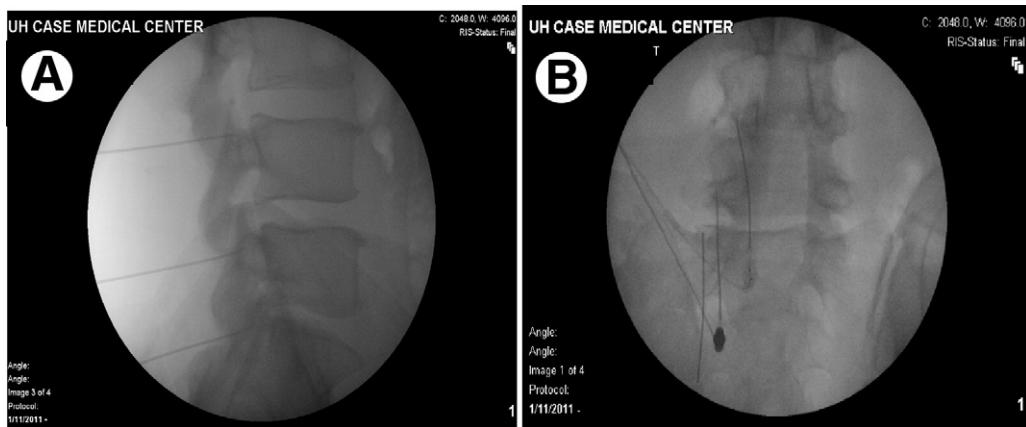
1. Clinically significant pain relief to consider a diagnostic procedure to be positive: 50% vs 80% pain relief post block. Subsequent studies demonstrated that the specificity improved by requiring 80% pain relief to secure the diagnosis; the false-positive rate fell to 27% and the positive-predictive value rose from 31% to 63%. However, the increase of false-negative results would lead to withholding treatment in a group of patients who would likely benefit from RFA of MB. Perhaps most significant is that in almost all the prospective studies using greater

than or equal to 80% pain relief as the cutoff value, placebo-controlled or comparative local anesthetic blocks were used to minimize the high false-positive rate of uncontrolled z-blocks, estimated at between 25% and 40%. The benefits of RFA are realized mostly in patients who obtained nearly complete pain relief from diagnostic blocks. The question as to what the optimal cutoff should be before proceeding to RFA is still unknown from a clinical point of view: withholding a definitive treatment from someone who reports only partial pain relief from z-blocks but is nevertheless likely to benefit may potentially lead to misdiagnosis, increased disability, unnecessary interventions, and amplified costs. By contrast, performing RFA on patients who experience partial pain relief from diagnostic blocks and are consequently predisposed to treatment failure exposes them to unnecessary risks, wastes valuable resources, and reduces the viability of RFA because it undermines the very concept of the procedure.

2. Before proceeding to definitive therapy, should single or two positive blocks be required? The high rate of false-positive z-blocks has led numerous experts to advocate performing 2 blocks, either using the same local anesthetic in both times or changing it from session to session (lidocaine to bupivacaine). In this instance, the stringency of the criteria would reflect again the rate of false-positive vs false-negative results. Schwarzer et al showed that a single z-joint injection resulted in a 38% false-positive rate.<sup>17</sup>
3. The volume of injectate: in studies by Kaplan et al and Cohen et al for lumbar z-joint and cervical z-joints,<sup>54,55</sup> it has been shown that to minimize the spread of local anesthetics to adjacent structures one needs to reduce the volume of the injectate to 0.25 mL in cervical and 0.5 mL in lumbar z-joint to increase the specificity of the MBB.
4. To address the ethical dilemma of exclusion of appropriate patients following a true comparative anesthetic protocol, the approach that has become popular is the modified comparative anesthetic protocol. With this protocol, a patient is required to have >1-2 hours of over 80% pain relief with lidocaine, and >2-3 hours of pain relief with bupivacaine. Using this protocol, Dreyfuss et al achieved a 90% success rate with subsequent RFA.<sup>56</sup>

## MBB as a predictor of outcomes post radiofrequency ablation of MB

The goal of diagnostic blocks is to select patients with facet joint pain who are supposed to benefit mostly from the use of RFA. Radiofrequency denervation of the nerves innervating the z-joints has generally been considered the gold standard to provide long-term relief of pain in these joints. One of the crucial determinants of a successful outcome is patient selection. Patient selection is directly related to an appropriately performed diagnostic test.



**Figure 1** Radiofrequency ablation of the L3, L4 medical branch, and L5 posterior branch. (A: lateral view of the RF needle positioning and B: AP view for the target). RF canules are positioned between one third and two thirds of the SAP at the L4 and L5 and lateral to the S1 SAP.

Shealy was the first to use RFA for denervation of the lumbar facet joints.<sup>57</sup> Since then, fluoroscopic-guided RFA of the MB has been commonly used as an effective treatment for chronic back pain of such type. The treatment technique has been advanced and modified since then. Most currently, Bodguk et al has described in detail the correct technique as illustrated in Figure 1 based on surgical anatomy of the MBB in the lumbar spine.<sup>26</sup>

The predictability of RFA success by diagnostic nerve blocks can be demonstrated by randomized controlled trials of RFA.<sup>58-64</sup> Leclaire et al used intra-articular injections as a diagnostic tool for patient selection. Significant relief of low back pain for at least 24 hours during the week after intra-articular facet steroid injections was considered positive for facet pain. This was a heterogeneous group of patients due to the weak selection criteria (conforming to current understanding) who may not have had facet joint pain. Not surprisingly there was not a statistically significant effect in the post RFA group. The lesioning techniques were not described well and there were no measures of real denervation.<sup>58</sup> Gallagher et al<sup>62</sup> in 1994 included 60 patients who were selected on clinical grounds to have symptoms of low back pain suggestive of facet joint origin. Forty-one patients reported improvement or were equivocal in their response following injection of local anesthetic. Block technique involved an injection into and around the facet joints. Patients were randomized to undergo either radiofrequency facet joint denervation or a sham procedure using the Shealy technique (invalid based on the current understanding of surgical anatomy).<sup>26</sup> The improvement in symptoms was noted in patients who had a clear improvement following diagnostic facet joint injections compared to patients who were equivocal in their response to the diagnostic injections. Results evaluated at 6 months were still statistically significant. In a large study evaluating RFA, van Wijk et al<sup>59</sup> found that the only difference between the treatment and control group at 3 months was that more RFA patients reported a 50% or greater decrease in back pain than sham patients (62% vs 39%). No differences were noted in mean

reduction in visual analog scale (VAS) pain scores, change in analgesic intake, and functional assessments. Intra-articular facet injections were used for patient selection.

Van Kleef et al<sup>63</sup> reported the results of 31 patients with chronic low back pain selected on the basis of pain relief following diagnostic blockade of the MB of the posterior primary rami: the technique of lesion production was similar to the technique advocated by Bodguk.<sup>26</sup> At least 50% pain relief following MBB was required to be eligible to enter the study and then patients were randomized to undergo either RFA or a sham procedure. Final analysis indicated that results were superior in patients that had reported complete relief of pain with diagnostic nerve blocks compared to those with only had partial relief of pain. Statistical analysis at 3, 6, and 12 months following treatment showed significant improvement in pain and functional disability in the treatment group.<sup>63</sup> In a study by Kroll et al,<sup>64</sup> the efficacy of conventional RFA was compared to that of pulsed radiofrequency in the treatment of lumbar facet syndrome. Target facet joints were identified with oblique radiographic views. VAS pain assessment and Oswestry Low Back Pain and Disability Questionnaire were administered at baseline and then at 3 months. Patients were identified by comparative lidocaine/bupivacaine blocks and >80% pain relief was considered as criterion for patient selection.<sup>64</sup> There was improvement in long-term outcomes in the treatment of lumbar facet syndrome in both groups; a greater improvement was noted within the RFA group. Tekin et al<sup>60</sup> studied the effects of RFA and pulsed radiofrequency denervation of medial branches of dorsal rami in the treatment of facet joint pain. Patients with continuous low back pain were selected by diagnostic blocks with 0.3 mL of lidocaine and >50% pain relief as criterion for determining a positive block. Pain relief was evaluated by VAS and Oswestry Disability Index at preprocedure, at procedure, at 6 months, and 1 year after the procedure. There was a significant decrease in the pain score at 6 months and 1 year.<sup>60</sup> To study the possible beneficial effect of percutaneous RFA in reducing pain and physical impairment in patients selected

after repeated diagnostic blocks, Nath et al<sup>61</sup> performed a randomized controlled study: percutaneous RFA was conducted in 40 patients with chronic low back pain (20 active and 20 controls). Inclusion criteria were 3 separate positive facet blocks. Three consecutive diagnostic blocks with local anesthetics were used to select patient and >80% pain relief was used as a clinically significant criteria.<sup>61</sup> The active treatment group showed statistically significant improvement in back and leg pain. None of the patients had any complication other than transient postoperative pain that was easily managed. The 3 above-mentioned studies indicate the validity of diagnostic MBB as a predictor of long-term benefits from either mode of RFA.

## Conclusions

Diagnostic MBB and intra-articular facet joint injection with local anesthetic are valid and reliable tools to diagnose z-joint pain. Single diagnostic blocks carry a high false-positive rate. Therefore, to be valid, they have to be controlled. Comparative local anesthetics have been used in the past but doubts have been raised about their validity; even comparative nerve blocks have still substantial false-positive rates. In the study by Cohen et al,<sup>65</sup> 64% of the patients treated after 2 diagnostic blocks and 39% of the patients treated after 1 block had successful outcome. Algorithms for appropriate use of blocks have been described; however, better validation is necessary. The goal of diagnostic blocks is to select patients with facet joint pain who are supposed to benefit mostly from the use of radiofrequency facet denervation. Performing 2 diagnostic blocks would decrease the false-positive rate, but unfortunately the false-negative rate will increase, thus increasing the risk of withholding an active treatment from patients. Moreover, aberrant MB innervations demonstrated in 11% of patients<sup>66,67</sup> pose an additional risk for false-negative blocks. The second concern is related to the balance of the burden of multiple interventions vs the potential benefit.

Diagnostic facet joint blocks are safe, valid, and reliable. Based on review of available studies, there is strong evidence that controlled diagnostic blocks distinguish painful from painless facet joints in the diagnostic workup of chronic spinal pain and are good predictors of the success of MB RFA and long-term pain relief.

## References

1. Schwarzer AC, April CN, Derby R, et al: The relative contributions of the disc and zygapophyseal joint in chronic low back pain. *Spine (Phila PA 1976)* 19(7):801-806, 1994
2. Schwarzer AC, April CN, Derby R, et al: Clinical features of patients with pain stemming from the lumbar zygapophysial joints. Is the lumbar facet syndrome a clinical entity? *Spine (Phila PA 1976)* 19(10): 1132-1137, 1994
3. Bogduk N, Marsland A: The cervical zygapophysial joints as a source of neck pain. *Spine (Phila PA 1976)* 13(6):610-617, 1988
4. Merskey H, Merskey BN, H, et al: Thoracic zygapophysial joint pain. Classification of chronic pain. Descriptions of chronic pain syndromes and definition of pain terms. Task Force on Taxonomy of the International Association for the Study of Pain, Seattle, WA, IASP Press, 1994
5. Bogduk N: Low back pain. *Aust Fam Physician* 14:1172, 1985
6. Manchikanti L, Pampati V, Fellows B, et al: Prevalence of lumbar facet joint pain in chronic low back pain. *Pain Physician* 2:59-64, 1999
7. Manchikanti L, Singh V, Pampati V, et al: Evaluation of the prevalence of facet joint pain in chronic thoracic pain. *Pain Physician* 5:354-359, 2002
8. April C, Bogduk N: The prevalence of cervical zygapophyseal joint pain. A first approximation. *Spine (Phila PA 1976)* 17(7):744-747, 1992
9. Lippitt AB: The facet joint and its role in spine pain. Management with facet joint injections. *Spine (Phila PA 1976)* 9(7):746-750, 1984
10. Cavanaugh JM, Lu Y, Chen C, et al: Pain generation in lumbar and cervical facet joints. *J Bone Joint Surg Am* 88(suppl 2):63-67, 2006
11. Cabraja M, Abbushi A, Woiciechowsky C, et al: The short- and mid-term effect of dynamic interspinous distraction in the treatment of recurrent lumbar facet joint pain. *Eur Spine J* 18:1686-1694, 2009
12. Bogduk N, April C: On the nature of neck pain, discography and cervical zygapophysial joint blocks. *Pain* 54:213-217, 1993
13. Bogduk N: Diagnostic nerve blocks in chronic pain. *Best Pract Res Clin Anaesthesiol* 16:565-578, 2002
14. Bogduk N: Neck pain. *Aust Fam Physician* 13:26-30, 1984
15. Revel ME, Listrat VM, Chevalier XJ, et al: Facet joint block for low back pain: identifying predictors of a good response. *Arch Phys Med Rehabil* 73:824-828, 1992
16. Barnsley L, Lord S, Bogduk N: Comparative local anaesthetic blocks in the diagnosis of cervical zygapophysial joint pain. *Pain* 55:99-106, 1993
17. Schwarzer AC, April CN, Derby R, et al: The false-positive rate of uncontrolled diagnostic blocks of the lumbar zygapophysial joints. *Pain* 58:195-200, 1994
18. Bogduk N: International Spinal Injection Society guidelines for the performance of spinal injection procedures. Part 1: Zygopophysial joint blocks. *Clin J Pain* 13:285-302, 1997
19. Manchikanti L, Manchikanti KN, Damron KS, et al: Effectiveness of cervical medial branch blocks in chronic neck pain: a prospective outcome study. *Pain Physician* 7:195-201, 2004
20. Sehgal N, Shah RV, McKenzie-Brown AM, et al: Diagnostic utility of facet (zygapophysial) joint injections in chronic spinal pain: a systematic review of evidence. *Pain Physician* 8:211-224, 2005
21. Boswell MV, Colson JD, Spillane WF: Therapeutic facet joint interventions in chronic spinal pain: a systematic review of effectiveness and complications. *Pain Physician* 8:101-114, 2005
22. Ackerman WE, 3rd, Ahmad M: Pain relief with intraarticular or medial branch nerve blocks in patients with positive lumbar facet joint SPECT imaging: a 12-week outcome study. *South Med J* 101:931-934, 2008
23. Cohen SP, Stojanovic MP, Crooks M, et al: Lumbar zygapophysial (facet) joint radiofrequency denervation success as a function of pain relief during diagnostic medial branch blocks: A multicenter analysis. *Spine J* 8:498-504, 2008
24. Van Zundert J, Mekhail N, Vanelderen P, et al: Diagnostic medial branch blocks before lumbar radiofrequency zygapophysial (facet) joint denervation: benefit or burden? *Anesthesiology* 113:276-278, 2010
25. Bogduk N, Colman RR, Winer CE: An anatomical assessment of the "percutaneous rhizolysis" procedure. *Med J Aust* 1:397-399, 1977
26. Lau P, Mercer S, Govind J, et al: The surgical anatomy of lumbar medial branch neurotomy (facet denervation). *Pain Med* 5:289-298, 2004
27. Bogduk N: A narrative review of intra-articular corticosteroid injections for low back pain. *Pain Med* 6:287-296, 2005

28. Bogduk N: On diagnostic blocks for lumbar zygapophysial joint pain. *F1000 Med Reproduction* 2:57, 2010

29. Kuslich SD, Ulstrom CL, Michael CJ: The tissue origin of low back pain and sciatica: A report of pain response to tissue stimulation during operations on the lumbar spine using local anesthesia. *Orthop Clin North Am* 22:181-187, 1991

30. Stilwell DL Jr: The nerve supply of the vertebral column and its associated structures in the monkey. *Anat Rec* 125:139-169, 1956

31. Cavanaugh JM, Ozaktay AC, Yamashita HT, et al: Lumbar facet pain: biomechanics, neuroanatomy and neurophysiology. *J Biomech* 29: 1117-1129, 1996

32. Yamashita T, Cavanaugh JM, Ozaktay AC, et al: Effect of substance P on mechanosensitive units of tissues around and in the lumbar facet joint. *J Orthop Res* 11:205-214, 1993

33. McLain RF, Pickar JG: Mechanoreceptor endings in human thoracic and lumbar facet joints. *Spine (Phila PA 1976)* 23(2):168-173, 1998

34. Sato S, Oguma H, Murakami G, et al: Morphometrical study of the joint surface and capsule of the lumbar zygapophysial joint with special reference to their laterality. *Okajimas Folia Anat Jpn* 79:43-53, 2002

35. Tanno I, Oguma H, Murakami G, et al: Which portion in a facet is specifically affected by articular cartilage degeneration with aging in the human lumbar zygapophysial joint? *Okajimas Folia Anat Jpn* 80:29-34, 2003

36. Pedersen HE, Blunck CF, Gardner E: The anatomy of lumbosacral posterior rami and meningeal branches of spinal nerve (sinu-vertebral nerves); with an experimental study of their functions. *J Bone Joint Surg Am* 38-A:377-391, 1956

37. Bogduk N, Long DM: The anatomy of the so-called "articular nerves" and their relationship to facet denervation in the treatment of low-back pain. *J Neurosurg* 51:172-177, 1979

38. Bucknill AT, Coward K, Plumpton C, et al: Nerve fibers in lumbar spine structures and injured spinal roots express the sensory neuron-specific sodium channels SNS/PN3 and NaN/SNS2. *Spine (Phila PA 1976)* 27(2):135-140, 2002

39. Kang YM, Choi WS, Pickar JG: Electrophysiologic evidence for an intersegmental reflex pathway between lumbar paraspinal tissues. *Spine (Phila PA 1976)* 27(3):E56-63, 2002

40. Bogduk N. Anatomy of the Lumbar Spine and Sacrum (ed 3). Edinburgh, Churchill Livingstone, 1997. p 197

41. Bogduk N: The lumbar mamillo-accessory ligament. Its anatomical and neurosurgical significance. *Spine (Phila PA 1976)* 6(2):162-167, 1981

42. Chua WH, Bogduk N: The surgical anatomy of thoracic facet denervation. *Acta Neurochir [Wien]* 136(3-4):140-144, 1995

43. Indahl A, Kaigle A, Reikeras O, et al: Electromyographic response of the porcine multifidus musculature after nerve stimulation. *Spine (Phila PA 1976)* 20(24):2652-2658, 1995

44. Mehta M, Parry CB: Mechanical back pain and the facet joint syndrome. *Disabil Rehabil* 16:2-12, 1994

45. Cohen SP, Raja SN: Pathogenesis, diagnosis, and treatment of lumbar zygapophysial (facet) joint pain. *Anesthesiology* 106:591-614, 2007

46. Cramer GD, Tuck NR Jr, Knudsen JT, et al: Effects of side-posture positioning and side-posture adjusting on the lumbar zygapophysial joints as evaluated by magnetic resonance imaging: A before and after study with randomization. *J Manipulative Physiol Ther* 23:380-394, 2000

47. Hancock MJ, Maher CG, Latimer J, et al: Systematic review of tests to identify the disc, SIJ or facet joint as the source of low back pain. *Eur Spine J* 16:1539-1550, 2007

48. Friedrich KM, Nemec S, Peloschek P, et al: The prevalence of lumbar facet joint edema in patients with low back pain. *Skeletal Radiol* 36:755-760, 2007

49. Schwarzer AC, Wang SC, O'Driscoll D, et al: The ability of computed tomography to identify a painful zygapophysial joint in patients with chronic low back pain. *Spine (Phila PA 1976)* 20(8):907-912, 1995

50. Dolan AL, Ryan PJ, Arden NK, et al: The value of SPECT scans in identifying back pain likely to benefit from facet joint injection. *Br J Rheumatol* 35:1269-1273, 1996

51. Cramer GD, Cantu JA, Pocius JD, et al: Reliability of zygapophysial joint space measurements made from magnetic resonance imaging scans of acute low back pain subjects: comparison of 2 statistical methods. *J Manipulative Physiol Ther* 33:220-225, 2010

52. Boswell MV, Colson JD, Sehgal N, et al: A systematic review of therapeutic facet joint interventions in chronic spinal pain. *Pain Physician* 10:229-253, 2007

53. Sehgal N, Dunbar EE, Shah RV, et al: Systematic review of diagnostic utility of facet (zygapophysial) joint injections in chronic spinal pain: an update. *Pain Physician* 10:213-228, 2007

54. Kaplan M, Dreyfuss P, Halbrook B, et al: The ability of lumbar medial branch blocks to anesthetize the zygapophysial joint. A physiologic challenge. *Spine (Phila PA 1976)* 23(17):1847-1852, 1998

55. Cohen SP, Strassels SA, Kurihara C, et al: Randomized study assessing the accuracy of cervical facet joint nerve (medial branch) blocks using different injectate volumes. *Anesthesiology* 112:144-152, 2010

56. Dreyfuss P, Halbrook B, Pauza K, et al: Efficacy and validity of radio frequency neurotomy for chronic lumbar zygapophysial joint pain. *Spine (Phila PA 1976)* 25(10):1270-1277, 2000

57. Shealy CN: Percutaneous radiofrequency denervation of spinal facets. Treatment for chronic back pain and sciatica. *J Neurosurg* 43:448-451, 1975

58. Leclaire R, Fortin L, Lambert R, et al: Radio frequency facet joint denervation in the treatment of low back pain: A placebo-controlled clinical trial to assess efficacy. *Spine (Phila PA 1976)* 26(13):1411-1416; discussion 1417, 2001

59. van Wijk RM, Geurts JW, Wynne HJ, et al: 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* 21:335-344, 2005

60. Tekin I, Mirzai H, Ok G, et al: A comparison of conventional and pulsed radiofrequency denervation in the treatment of chronic facet joint pain. *Clin J Pain* 23:524-529, 2007

61. Nath S, Nath CA, Pettersson K: Percutaneous lumbar zygapophysial (facet) joint neurotomy using radio frequency current, in the management of chronic low back pain: A randomized double-blind trial. *Spine (Phila PA 1976)* 33(12):1291-1297; discussion 1298, 2008

62. Gallagher J, Petriccione di Vadi PL, Wesley JR, et al: Radio frequency facet joint denervation in the treatment of low back pain—a prospective controlled double-blind study to assess its efficacy. *Pain Clin* 7:193-198, 1994

63. van Kleef M, Barendse GA, Kessels A, et al: Randomized trial of radio frequency lumbar facet denervation for chronic low back pain. *Spine (Phila PA 1976)* 24(18):1937-42, 1999

64. Kroll HR, Kim D, Danic MJ, et al: A randomized, double-blind, prospective study comparing the efficacy of continuous versus pulsed radiofrequency in the treatment of lumbar facet syndrome. *J Clin Anesth* 20:534-537, 2008

65. Speldewinde GC: Outcomes of percutaneous zygapophysial and sacroiliac joint neurotomy in a community setting. *Pain Med* 12(2):209-218, 2011

66. Zhang J, Tsuzuki N, Hirabayashi S, et al: Surgical anatomy of the nerves and muscles in the posterior cervical spine: A guide for avoiding inadvertent nerve injuries during the posterior approach. *Spine (Phila PA 1976)* 28(13):1379-1384, 2003

67. Masini M, Paiva WS, Araújo AS Jr: Anatomical description of the facet joint innervation and its implication in the treatment of recurrent back pain. *J Neurosurg Sci* 49:143-146, discussion 146, 2005