

Selective Nerve Root Injections Can Predict Surgical Outcome for Lumbar and Cervical Radiculopathy: A Retrospective Review with Comparison to Magnetic Resonance Imaging

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Study Design: Diagnostic selective nerve root injections (SNIs) performed in patients who underwent lumbar or cervical decompression for radiculopathy were retrospectively analyzed and compared with surgical outcome. A comparison was also made between magnetic resonance imaging (MRI) and SNI results regarding their ability to determine surgical outcomes.

Objectives: To correlate our SNI data on the affected level with the level operated by the surgeon; to independently examine SNI and MRI results and compare to 1-year surgical outcome in patients undergoing cervical and lumbar decompression for radiculopathy.

Methods: A group of patients who had cervical or lumbar surgery with preoperative discrepancies between presenting exam and radiological imagery underwent selective nerve root injections prior to surgery. Strict criteria were adhered to in performing the SNIs, including use of fluoroscopy with contrast, nerve stimulation, concordance of stimulation and limited volume of local anesthetic. The SNI was considered a positive test if >90% pain relief occurred. Evidence used to support a positive SNI response included concordance, if any, of nerve stimulation, reduced anxiety levels due to the abolition of pain, and absence of overt pain behavior.

Results: In a database of 573 patients who had SNI(s) before lumbar or cervical SNIs, there were 101 patients who subsequently underwent surgical decompression with post-surgical follow-up of > 12 months available for review. Differences in surgical outcome between patients who had surgery at a positive vs. negative SNI level were statistically significant ($p=0.05$). Patients having surgery on positive SNI levels were 9.1 times more likely to have good outcomes versus those that had surgery on negative SNI levels ($p=0.01$). Differences in surgical outcome by results from pre-operative MRI were not significant ($p=0.65$).

Conclusion: Using neurography and stimulation for nerve root identification, meticulous low volume local anesthetic instillation for nerve root block, and strict criteria in assessing pain relief, we have found that SNIs can be performed safely and accurately to discern the presence or absence of lumbar and cervical radiculopathy in patients with otherwise equivocal imagery. [Key Words: selective nerve root injection, radiculopathy, nerve root compression, nerve root stimulation, cervical, lumbar]

Introduction

To ensure a successful surgical outcome in nerve root decompression surgery, it is of paramount importance to have a precise preoperative diagnosis. There is risk and considerable frustration, however, when surgical patients do not improve and/or require further surgery despite a well-planned initial procedure. The re-operation rates after lumbar discectomy range are reported at rates ranging from 5 to 50%, with an average estimate of 15%. [1],[2],[3]

The literature indicates that lack of improvement and repeated surgeries may be secondary to the inexact methods that are presently used to determine surgical localization. [4] Indeed, it is commonly observed that static imaging studies and laboratory findings do not correspond with clinical signs or symptoms. Confounding factors may include patients with equivocal, multilevel or extraforaminal pathology as determined by imaging/electrodiagnostic studies, and nerve root anomalies. "Positive findings" on MRI occur in up to 60% of asymptomatic subjects, [5],[6],[7] and it is well accepted that the presence of mechanical compression is not always associated with painful radiculopathy. In addition, radiculitis due to inflammation from a discogenic source may occur without evidence of nerve root compression. [8],[9]

All of these factors may make it difficult for the surgeon to determine the best approach. Equivocal or multilevel pathology on imaging studies may result in a decision to do surgery at multiple levels despite a singularly painful lesion. However, pain emanating from multiple spinal sources at the same time is uncommon. [10] Although multilevel surgery may result in an initially "good" surgical outcome, these patients have a higher predisposition to instability from a multilevel laminectomy, (and in instances of fusion), adjacent level degeneration and pseudoarthrosis. [11]

When careful evaluation and imaging do not make the diagnosis clear in patients presenting with radicular or radicular-like symptoms, some clinicians consider a selective nerve root injection (SNI) to be a pivotal diagnostic test in making a determination for surgery. SNI is the only study that uses pain relief as a diagnostic endpoint in attempting to detect presence of radiculopathy. In SNI, a local anesthetic is delivered in direct proximity of a putatively painful nerve root. If pain relief occurs, the SNI result ostensibly indicates the presence of pain transmission within the distribution of the nerve root examined and, in most cases of nerve pain, the presence of radiculopathy.

In our practice, we have developed stringent SNI criteria in an effort to delineate the presence and level of cervical or lumbar radiculopathy. We retrospectively analyzed our results of diagnostic SNIs performed in patients who underwent lumbar and cervical decompression for radiculopathy. Our objectives were: to correlate our SNI data on the affected level with the level operated by the surgeon, and to independently examine SNI and MRI results and compare to 1-year surgical outcomes in patients undergoing cervical and lumbar decompression for radiculopathy.

Methods and Materials

The patient population studied was selected from a 1996-99 database. In this database, there were 573 patients who had been referred (by one of 8 neurosurgeons or 2 orthopedic spine surgeons) for SNIs due to known or suspected cervical/lumbar radiculopathy. (Figure 1) All of these patients underwent SNI procedures, of which there were 104 patients who subsequently underwent surgical decompression. Two of the 104 were lost to follow-up and 1 patient had spinal trauma 8 months after surgery. Therefore, there were 101 patients with post-surgical follow-up >12 months available for review.

To be included in the study, patients had to have provided informed consent, undergone SNI, and undergone nerve root decompression surgery. In those who had an SNI, the following technique was used: patient's history, physical exam, review of imaging and electrodiagnostic studies and informed consent initially were completed. Pre-procedural numerical rating scale (NRS, 0-10) scores measuring leg pain intensity were obtained and pain-provoking maneuvers (i.e., straight leg raise, walking) were used. Patients did not get diagnostic SNIs, and were thus excluded from the study, if they had pre-procedural NRS scores of less than 4, due to difficulties in interpreting the post-procedural change in pain relief.

The primary response required for an SNI to be considered positive was an NRS of 0-1, and immediate relief of >90% of the patient's extremity pain, even when pain-provoking maneuvers specific to the patient's "radicular" symptoms were performed. The reduction of anxiety due to pain was also observed in evaluating the overall response. Indeterminate results were those in which pain relief was between 80-90%, or if patient response was judged to be unreliable. In such patients, a comparative block technique was performed.[12] In this technique, the patient is subjected to a repeat nerve block at a later date, using a local anesthetic of a known different duration of action (e.g. lidocaine vs. bupivacaine). The degree and duration of initial pain relief from each of the local anesthetics is compared. If patients had >90% relief of pain on both occasions, and longer-acting relief occurred when the longer-duration agent was used, the SNI response was considered positive.

At the time of analysis, the surgeons' notes and operative dictation were carefully reviewed in regard to whether the SNI and MRI reports affected the surgeons' decision-making process leading up to surgery. To avoid author bias through direct inspection, neuroradiologists' reports (focusing mainly on the presence of intervertebral disc herniation, spinal stenosis, lateral recess and neuroforaminal narrowing, and neural-compromising spondylolisthesis), were reviewed. A positive MRI finding was defined as one that displayed blatant evidence of nerve root compression by disc extrusion and/or severe spinal canal/lateral recess/neuroforaminal compromise. An MRI was considered equivocal in the presence of thecal sac effacement, focal non-compressing disc herniation, mild to moderate spinal canal/lateral recess stenosis or mild to moderate neuroforaminal narrowing.

All of the 101 patients who received diagnostic SNIs for either discrepancies between physical exam and radiologic imagery or to confirm a putative pain generator in equivocal or multilevel pathology. Of these patients, duration of symptoms prior to SNI ranged from 1.5 to 27 months (4.7 months mean); the interval between SNI and surgery was 1-3 months (1.5 month mean); and the post-surgical follow-up ranged from 12 to 26 months (16.2 month mean). There were 18 patients who had cervical and 83 patients who lumbar spine surgery, respectively. (Table 1) Of 20 patients who had histories of previous spinal surgery, 15 had had surgery at the same and/or adjacent level(s) and 5 had had surgery at non-adjacent levels.

The patients undergoing lumbar SNI were placed in the prone position and patients undergoing cervical SNI were placed in the supine position. The procedure was conducted with fluoroscopic guidance and without sedation. The skin was anesthetized with 1% lidocaine. A 2-, 4- or 6-inch (22, 21 or 20 gauge, respectively) stimulating needle (B. Braun Medical) was used in the approach to the selected nerve root with stimulator settings of 0.5-1 milliamps and 2 Hz. In the lumbar area, the needle tip was directed to the anterosuperior aspect of the neuroforamen from a posteroinferior and paramedian approach. In the cervical area, the needle tip was directed tangentially, within the posteroinferior aspect of the neuroforamen from an anterolateral and slightly inferior approach. To avoid penetration of the vertebral artery, the needle was placed, from an AP view, between the lateral aspect and the midpoint of the ipsilateral lateral mass. While the needle was being placed, avoidance of nerve root impalement was attempted by paying close attention to intensity of nerve stimulation. Patients were asked to describe where they feel the stimulation

as the needle approached the target point. The dynamical distribution of nerve stimulation was noted and compared to the patient's usual area of pain. Iohexol (Omnipaque 300) was injected to the minimal amount necessary to confirm visualization of a neurogram (0.25-0.75 ml), and closely observed for epidural or extraradicular spread, or intravascular flow. Hard copy images in the anteroposterior and lateral views were obtained for lumbar SNI (Figure 2). For cervical SNI, there is shown a pre-contrast cervical SNI with concordant stimulation (Figure 3a) and in the anteroposterior and oblique views (Figure 3b) for cervical SNI documentation.

In an effort to obviate spread epidurally or extra-radicularly, 0.5-0.75 ml of 2% lidocaine was injected, taking into consideration the observed amount of contrast needed for neurography. If steroid was used as an adjunctive therapy, 6 mg of betamethasone (Celestone Soluspan) was subsequently injected, waiting at least one minute after the instillation of the local anesthetic. The patient was then observed in a recovery area and assessed for evidence of nerve root block (motor weakness, numbness), changes in NRS, and percentage of pain relief. Particular attention was paid to maneuvers that were observed to provoke pain before the procedure.

To determine surgical outcome, data from the surgeons' follow-up records were collected and reviewed as well as data from follow-up questionnaires and telephone interviews. A good surgical outcome was defined as one in which patients who had residual NRS scores of 2 or less, would do the surgery again and were either satisfied or very satisfied with the surgical outcome at follow-up after 12 months. (Table 2) A bad outcome was defined as one in which patients who had a residual NRS of 3, or greater, would not do surgery again and were either unsatisfied or very unsatisfied at 12 months.

To compare associations between surgical outcomes and pre-surgical diagnostic tests, the positive predictive value (percentage of patients with a positive pre-surgical diagnostic test who had a good surgical outcome) and negative predictive value (percentage of patients with a negative pre-surgical diagnostic test who had a bad surgical outcome) were calculated. Comparison of positive predictive values and negative predictive values and construction of 95% confidence intervals were based on z-score statistics.

To quantify and compare risk factors for 1-year surgical outcomes, a multivariate logistic regression model was constructed using SAS software (SAS/STAT Software, Release 8.1, Cary, NC : SAS Institute Inc., 2000). Risk factors initially considered in the statistical model included gender, age, rheumatoid arthritis, diabetes, history of coronary bypass or vascular surgery, smoking status, rating of pre-surgical pain, cervical surgery, previous adjacent spinal surgery, surgery performed at the same level as SNI findings, and surgery performed at the same level as MRI findings. Variables whose parameter estimates had poor association with surgical outcome ($p > .20$) were removed from the model. Correspondence between pre-surgical diagnostic test findings and level of surgery was forced into the statistical model to obtain final parameter estimates of the odds ratios.

Results

A total of 111 SNIs were performed on the 101 patients in our study. Overall, 88% (89/101) patients had a good surgical outcome. There were no complications from the SNI procedure. Precise technical performance of the procedure was an important factor in SNI's ability to detect radiculopathy and, secondarily, predict a good outcome.

Fourteen patients who had "indeterminate" initial SNI results underwent a repeat SNI at the same level as

part of a comparative block technique. Eight of these resulted in a positive SNI, with the remaining 6 resulting in negatives. Only this second and confirming result was used for tabulating SNI-surgical outcomes data. Of the 101 patients, 91 had positive and 10 had negative SNI test results at the level operated. Of the 91 patients with positive SNIs, 84 had an initial positive test with no further testing prior to surgery. There were 7 patients who had an initial negative SNI at the level requested by the surgeon, followed by a positive SNI at an adjacent level; all had surgery at the positive level. The surgeon's notes in these 7 patients indicated that the SNI was decisive in determining the level operated and all patients had good surgical outcome at 1 year. Overall, 91% (83/91) of patients with positive SNIs had good outcomes.

Of the 10 patients with negative SNIs, 7 had an initial negative with no further testing prior to surgery. The remaining 3 patients who had an initial negative SNI had subsequent negative SNI results at an adjacent level that had surgery at the subsequently tested level. Of these 10 patient records, none of the surgeons' notes mentioned the results of the SNI, or whether the SNI results influenced their decision-making process. Overall, 60% (6/10) of these patients had good outcomes.

An analysis of whether an SNI result could accurately predict surgical outcome was also performed. (Figure 4) Of the 91 patients who had surgery at a positive SNI level, 91% (83) of these patients had good surgical outcome. Of the 8 patients with bad outcome, 75% (6) required more surgery. Of the 10 patients who had surgery at a negative SNI level, 60% (6/10) had good surgical outcome. Of the 4 patients with bad outcome, 100% (4) required more surgery.

The total number of 111 SNIs performed in our patients was used in determining the predictive values of all SNIs. Of the 91 positive SNI results, surgery occurred at the SNI-specified level 100% (91) of the time. The positive predictive value, indicated by the percentage of patients with a positive SNI result who actually had surgery at the same level, was 100%. Of the 20 negative SNI results, surgery occurred at the SNI-specified level 55% (11) of the time. One of these patients was lost to follow-up. The negative predictive value, indicated by the percentage of patients with a negative SNI result who had surgery at the SNI-specified level, was 40%. According to the surgeons' operative notes, all patients had surgical findings at the level(s) operated, and thus no correlation to surgical outcome could be made.

Overall, 18 patients underwent cervical and 83 underwent lumbar/sacral spine surgery. (Table 1) Of the 18 patients who underwent cervical surgery, 94% (15/16) had good outcomes. Of the 83 patients who underwent lumbar/sacral surgery, 87% (74/85) had good outcomes. There was no statistical significance between the two groups ($p=0.68$). The probability of a poor surgical outcome was similar ($OR=1.79$, $0.16-20.2$, $p=0.64$) between cervical and lumbar surgery patients (Figure 5), even after statistically controlling for the potential confounding effects of diabetes and previous surgery.

Ninety-nine of the 101 patients also had pre-operative MRIs. Positive MRI findings (definite nerve root compression) were present in 87% (86) of these patients. Of these 86 patients, 88% (76) had good outcomes. Of the 13 patients who had surgery performed at a level where MRI findings were considered negative or equivocal, 85% (11) had good outcomes. Surgical findings with evidence of nerve root compression were present in all 13 of these patients, which included sequestered disc herniation (4), osteophytic formation at the level of the adjacent superior articular process with concomitant disc bulge (5), and small lateral disc herniation, with definite nerve root compression (4). Differences in surgical outcome based on results from pre-operative MRI were not significant ($p=0.65$).

Surgical outcomes as they relate to SNI versus MRI results and predictive values are presented in Table 3. Positive predictive value (PPV) and negative predictive value (NPV) of SNI versus MRI associated with 1-year surgical outcomes are presented in Table 2. Both the PPV (91.2) and NPV (40.0) of SNI findings were significantly greater than 0 ($p<0.001$ and $p=0.01$, respectively), while only the PPV (88.4) of MRI findings were sig-

nificantly greater than 0 ($p < 0.001$). The NPV of SNI was significantly better than that associated with MRI findings ($z = 2.46, p = 0.01$).

MRI agreed with SNI results (positive MRI findings with positive SNI results + negative MRI findings with negative SNI results) in 85 (86%) out of 99 of patients. (Figure 6) Of the 85 patients who had correlative results, 79 had positive MRI and SNI results; 91% (72/79) of these had a good outcome. Of the 6 patients who had negative MRI and SNI results, 50% (3) had a good outcome. MRI did not agree with SNI results in 14 patients. Of these 14, 11 patients had a negative MRI/positive SNI result, and 91% (10/11) had a good outcome. Of the remaining 3 patients with non-correlative results (in these 3 cases, positive MRI with negative SNI), 66% (2) had a good outcome.

Our analysis seems to show a strong association between positive SNI results and good surgical outcomes. Whether MRI agreed with SNI or not, 91% of patients with positive SNI results had good surgical outcomes. SNI proved to be most useful when MRI results were equivocal, multilevel and/or do not agree with the patients' symptoms.

Independent risk factors, such as comorbid conditions and presurgical diagnostic tests, for patients with bad 1-year surgical outcomes are shown in Figure 7. Subjects with diabetes, both IDDM and NIDDM, were most likely to have incomplete pain relief or dissatisfaction with surgical outcome ($OR = 23.7, _2 = 9.22, p = 0.002$). Subjects with a history of previous spinal surgery either at the same or adjacent level were also at increased risk for incomplete pain relief or dissatisfaction with surgical outcome ($OR = 13.8, _2 = 9.12, p = 0.002$) (Figure 5). With regard to the use of pre-surgical diagnostic findings, only performing surgery at a level different than that indicated by the SNI findings was associated with incomplete pain relief or dissatisfaction with surgical outcome ($OR = 9.1, _2 = 6.19, p = 0.01$). Additionally, surgery performed at a level consistent with MRI findings was not associated with surgical outcome ($_2 = ?, p = 0.52$). Other factors that might have affected outcome (gender, age, smoking status, coronary artery disease and peripheral vascular disease) were not significant in 12-month outcomes.

Discussion

At our institution, the majority of patients with cervical or lumbar radiculopathy who undergo surgical decompression do not undergo SNI prior to their surgery. SNIs are reserved for patients with symptoms refractory to conservative treatment of at least 6 weeks in order to confirm a level of suspicion prior to surgical consideration and/or as an adjunct to their conservative therapy regimen.

In our study, we were able to positively correlate SNI data on affected levels with levels operated by the surgeons, and have demonstrated two pertinent advantages in the use of SNIs for diagnostic purposes. First, we have found it most useful in localizing radicular pain in patients with equivocal MRI findings. Secondly, the diagnostic SNI can in some cases persuade surgeons from operating on an initially suspicious, but incorrect, level of radiculopathy. There were 7 patients who initially had a negative SNI result at the level the surgeon initially suspected as being the level of radiculopathy. Subsequent SNIs at an adjacent level were positive. All of these patients underwent surgery at the subsequently positive level with good surgical outcome. These patients' surgical notes indicated that SNI results did influence the surgeon's decision-making process in all cases.

We found that positive SNI results seemed to be associated with good surgical outcomes most of the time, and were most helpful when MRI results were equivocal, multilevel and/or do not agree with the patient's symptoms. There were 10 patients who underwent surgery at a spinal level with a negative SNI result. The SNI results did not influence the surgeon's decision-making process. However, a good surgical outcome occurred in only 60% (6/10) of these patients; this compares to 88% of all SNI patients. Although the sur-

geons' notes did not indicate why they did not consider the results of the SNI, likely explanations include reliance on other clinical data, and increased false-negative SNI results due to strict definitions of positive results. This probably explains why a good outcome occurred in patients with "negative" SNI results. To our knowledge, SNIs have not been reported as a diagnostic test in cervical surgery. Good outcomes occurred in these patients at rates similar to those of patients who underwent lumbar surgery. While 1 out of 16 (6.2%) cervical surgery patients had a poor surgical outcome, this was similar to 11 out of 85 (12.9%) lumbar surgery patients ($\chi^2=0.57$, $p=0.68$). However, because of the small number of cervical cases and the strong consistency with surgical site and SNI results, the lack of significant differences should not be interpreted to mean there is no difference between surgical regions.

An important difference in predictive values of SNI versus MRI was observed. The NPV is a measure of how well the SNI or MRI works for diagnostic purposes, where the consequences of false positive tests are very important. While an NPV for SNI (40%) was not ideal, it is significantly better than the NPV of MRI (15%). However, the MRI's NPV was not statistically significant (i.e., no greater than 0). This appears to indicate that, in patients with equivocal findings, MRI has very little diagnostic value toward identifying the correct level for surgery. The PPV, shown for completeness, is a measure of how well the SNI or MRI functions for screening. It has little value to the surgeon, as the suspicion of radiculopathy was already present.

Studies that have reported on the diagnostic applicability of SNIs have produced mixed results.[13],[14],[15],[16],[17] Protocols described in these studies include the use of fluoroscopy with or without neurography and a paresthesia technique to identify the nerve, and use of 1-3 ml of local anesthetic to anesthetize the nerve, in which case >50% pain relief or "good relief" is used to assess the result. In 1998, Wetzel sharply criticized the use of SNIs in patients being considered for operative intervention.[18] He based most of his argument on studies demonstrating poor results in patients with chronic radiculopathy who, after SNI was used to identify a putatively painful nerve root, underwent a dorsal rhizotomy procedure.[19],[20],[21] Although these data may be valid for patients who undergo dorsal rhizotomy, a procedure complicated by high failure rates, their results should not be equated to results seen in patients who undergo nerve root decompression. Recently, Apsinall et al. reported on the value of SNIs in the evaluation of sciatica with normal MRI scans.[22] In their study, 40 patients with normal MRIs were further investigated with an SNI. Of 11 patients who had temporary relief after SNI, all of them underwent surgical exploration. In 9 cases compression was identified at the ligamentum flavum and in 2 cases, at the neural foramen. Nine of these patients had complete relief of their symptoms after surgery. In our study, there were 13 patients with "normal" MRIs, all of whom underwent surgical exploration. All 13 had evidence of nerve root compression upon surgical exploration, and 11 had good surgical outcome.

As might be expected, the presence of diabetes and/or previous surgery at the same or adjacent level was associated with poor outcome. In such patients, there was agreement with a negative SNI result. It could be argued that the negative SNI results of these patients may simply represent a superficial look at the true outcomes. However, this regression analysis quite clearly showed that regardless of the patient risk factors for poor surgical outcome, SNI results are accurate (based on negative predictive value) and are an independent measure to predict surgical outcome.

The use of nerve stimulation as an aid to identify needle proximity to a nerve root has not been reported. We believe the nerve stimulator is an excellent tool to identify proximity of the nerve while avoiding deliberate impalement of the nerve root. On rare occasion, a needle puncture can accidentally transect a nerve root.[23] Permanent neuropathies are reported to occur more frequently with the use of the paresthesia technique.[24] This should be of particular concern when taking into consideration the precariousness of the damaged nerve root that is frequently associated with radiculopathy. Also, concordance of nerve stimu-

lation with the area of a patient's pain distribution should serve as corroborative, but not absolute, evidence that the nerve being stimulated is the painful nerve.[25] We have found this technique particularly useful when the patient's pain referral (dynatome) occurs outside a specific nerve root's expected dermatomal distribution and nerve stimulation elicits paresthesias within the same area. It is important to note that the lack of concordance of stimulation with the painful area does not exclude the possibility that the nerve being stimulated is not the painful nerve.

An important component to increasing specificity of a diagnostic SNI is the meticulous use of a low volume anesthetic when anesthetizing the nerve root. Castro et al. demonstrated that diffusion of contrast to the adjacent, ipsilateral nerve root(s), via epidural space or extraforaminally, occurs in the majority of patients when 1 ml or greater is placed on a nerve root.[26] In our literature review, we found that studies investigating diagnostic accuracy of SNIs in a clinical setting typically have used volumes between 1-3 ml, thereby substantially reducing the specificity of the injection.[12-15, [27] The maximum volume of local anesthetic used in our technique is 0.75 ml with a range of 0.5-0.75 ml. The volume is ultimately determined by first observing the nature of contrast spread along the nerve root. Typically, injection of contrast follows along the periradicular sheath before spreading into the epidural space or extraspinally to the plexus or soft tissues. Injection of contrast also ensures avoidance of subsequent intravascular injection of local anesthetic. A pitfall in this technique is the possibility of a false-negative result if not enough anesthetic infiltrates a truly painful nerve root. Hence, the patient's pain would remain unresolved. Although minimal volumes or concentrations of local anesthetic to anesthetize the nerve root have never been reported, objective evidence of sensory and/or motor blockade frequently, but not reliably, occurs with this technique and is noted. Increasing the concentration of local anesthetic while maintaining this minimal volume technique may provide a more reliable anesthetic block. Although this could be recommended for lumbar level SNIs, we would advise against it at the cervical level due to a greater risk of seizure.

Pain relief as a diagnostic tool remains difficult to interpret, regardless of its application. Inherent in any diagnostic study that uses degree of pain relief as a determination of result is the placebo response. Formal studies have shown that 30% of patients ostensibly undergoing lumbar zygapophyseal joint blocks can report complete relief of their back pain following a subcutaneous injection of normal saline.[28] False-positive responses occur in 27-38% after single injections at the facet level.[29],[30] Although false-positive response rates for SNIs have not been specifically studied, one could presume similar response rates would result. Moreover, variable (not complete) degrees of response commonly occur after injection. If such results are considered 'positive', they would lead to reducing the tests' specificity. In a study comparing pain relief after local anesthetic blocks for sciatica of spinal origin to areas of pain referral (facet joint, sciatic nerve and subcutaneous tissue) North et al. concluded that SNIs were not specific in diagnosing radiculopathy.²⁴ However, if greater than 90% relief were applied as a diagnostic criterion, the majority of the SNIs in their study would have been considered positive tests, and the majority of facet joint, sciatic nerve and subcutaneous blocks would have been considered negative tests. Moreover, only patients who underwent SNI sustained complete pain relief for at least one hour ($p < 0.05$). Although the criterion of pain relief for at least one hour was not used in our study, it supports the concept that SNIs can be specific for determining level of radiculopathy when compared with injections anatomically remote from the pathology causing the pain. Also, in the North et al. study, the volume of local anesthetic injected at the nerve root level was 3 ml. This is a relatively large amount and would be expected to consistently spread in an uncontrolled manner to adjacent tissue, thereby reducing specificity.

From our results, the majority of placebo responders, we believe, were screened out through pre- and post-procedural physical examination and change in pain-related anxiety, observation of functional overlay,[31] and the requirement of at least 90% pain relief. If it was felt that a false-positive response or functional

overlay was dominant after the SNI, the authors used to using a comparative local anesthetic nerve block technique.[32] Although this technique was not specifically described for SNIs, its application should be consistent. When tested against placebo blocks, comparative blocks yield valid responses with 85% reliability.[33] Six of the 101 patients included in our analysis underwent a comparative block technique. All were considered to have a positive result.

There are reasons other than the placebo effect that may cause an SNI diagnostic test to be falsely positive. Uncontrolled local anesthetic, spread unknowingly to other “pain-generator” tissue(s), could also be misinterpreted as a positive test. SNIs are not truly “selective” in their ability to anesthetize only the ventral ramus of the nerve root, which comprises the putatively painful component nerve to the extremity. Injection of a local anesthetic immediately outside the neuroforamen, before the dorsal and ventral rami divide, will also block the dorsal ramus. This latter ramus innervates structures of the spinal segment, where radicular-like symptoms may derive. If structures(s) innervated by the spinal segmental nerves are primary or secondary components to the patient’s symptomatology, then anesthetizing the dorsal ramus may result in a falsely positive result. Also, local anesthetic infiltration completely outside the nerve distribution can relieve a patient’s pain. [34] A theoretical explanation for this is that the cell bodies within the spinothalamic tract of the dorsal horn may have lower thresholds for excitation and expanded receptive fields after nerve injury. [35] Normal background afferent excitatory input within these cell bodies may therefore be sensed as pain.[36]

When a high level of specificity is sought, higher false-negative rates may occur. Indeed, it is difficult to categorize patients with a “negative” SNI result after they have experienced a 70-90% reduction of their pain. Other factors that may cause false-negative test results include intravascular uptake, incorrect needle placement and volumes or concentrations of local anesthetic too low to infiltrate the nerve root. Secondary gain issues may result in false-positive or false-negative results.

Other important limitations of SNIs are that they do not contribute information regarding the locality or pathological process that is responsible for inciting pain. Local anesthetic nerve blocks proximal or distal to the “pain generator” area can provide temporary pain relief. For example, a peripheral local anesthetic block in the area where pain is perceived can relieve central pain[37],[38] and radiculopathy can be relieved by an ipsilateral sciatic nerve block.[31],[39],[40] This latter effect is most likely related to the requirement of peripheral input to propagate radiculopathy. Theoretical explanations include non-noxious afferent activity that becomes “amplified” at the site of the injured nerve root or dorsal root ganglia; cross-talk, or non-noxious afferent conduction transfers to pain-relaying nerve tracts;[41],[42] preferential injury of large myelinated afferents resulting in “disinhibition” of unmyelinated nociceptive input; and antidromic activity from injured sensory nerves which may cause peripheral tissue release of substance P and perhaps other substances, (such as bradykinin, histamine, and 5-HT—prostaglandins producing changes in nociceptor sensitivity).[43],[44],[45]

Finally, complications that could occur from SNI include infection, bleeding, allergic reaction, nerve root injury, spinal cord injury, seizure and stroke. Only recently has there been a case report of three patients sustaining serious complications due to lumbar SNI, including paraplegia or paraparesis.[46] Undetected needle penetration and injection of a depot-steroid into a spinal artery or artery of Adamkiewicz resulting in spinal cord infarction were the proposed mechanisms. Indeed, all commonly used depot-steroids used in intraspinal injections are suspensions of particulate material. Accidental vertebral artery puncture during cervical epidural procedure and trigger point block, leading to medullary infarct have been reported. [47] Of particular concern are serious CNS complications after cervical SNI including paralysis, stroke and death.

The precarious arterial supply of the anterior cervical spinal cord, which is supplied by the radicular artery via the vertebral artery, may have an increased propensity for severe vasospasm or direct injection. Although the authors are aware of instances of these catastrophic events by other injectionists, only one case of fatal spinal cord infarction attributed to a transforaminal corticosteroid injection has been reported.[48] Steps we consider important in preventing, but not completely avoiding spinal cord/intramedullary infarction include proper needle placement within the neuroforamen. At the cervical level, this requires placement posteriorly and immediately lateral to the midpoint of the lateral mass from an anteroposterior view. Other steps include injection of contrast under real-time fluoroscopic guidance to observe for intravascular flow; applying a local anesthetic prior to the use of steroid to observe for prodromal CNS toxic local anesthetic effects; and injecting steroid slowly to assure a low pressure head is applied periradicularly.

Conclusion

We found meticulous performance of the procedure can increase accuracy of a diagnostic SNI in detecting the presence or absence of cervical or lumbar radiculopathy. The steps include: 1) clinical examination of the patient including history and physical, imaging studies, observation of anxiety and functional overlay; 2) pre-procedural pain NRS score of >4 with or without pain provoking maneuvers; 3) stimulation of the nerve root, with observation of stimulation distribution relative to the patient's usual pain distribution; 4) a neurogram, with observation of spread relative to volume of contrast injected; 5) injection of local anesthetic (i.e. lidocaine 2%), with a volume in accordance with the amount of contrast needed for a singular neurogram, keeping in a range between 0.5-0.75 ml; 6) $> 95\%$ reduction in extremity pain, with residual NRS = 0-1; 7) absence of pain caused by physical maneuver(s) that was/were present prior to the procedure (i.e., straight leg raise); 8) utilization of comparative blocks if substantial false-positive response or functional overlay is suspected.

When comparing SNI results with MRI, we found that SNI is no more predictive of the level of the offending lesion when it is obvious on MRI. Since imaging is important in understanding the pathological process that causes radiculopathy, we recommend against the use of SNI as a diagnostic tool in single level, clear-cut causes of radiculopathy. However, in cases where MRI findings are equivocal, multilevel and/or do not agree with the patient's symptoms, the result of a negative diagnostic SNI, (i.e., lack of presence of radiculopathy), becomes superior in predicting the absence of an offending lesion.

Although we agree that SNIs should never be relied upon "as the sole...diagnostic maneuver,"⁷ we have found SNIs can be performed with accuracy and can be considered a pivotal test in determining the presence or, in particular, the absence of radiculopathy. This important finding could potentially reduce the number of operated levels when spinal surgery is planned.

END

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