Medical Sciences

Does Electrodiagnostic Confirmation of Radiculopathy Predict Pain Reduction after Transforaminal Epidural Steroid Injection? A Multicenter Study.

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Objective: **Minimal definitive literature identifies patients with radicular pain who would benefit most from epidural steroid injection (ESI). This study investigated if electromyographic (EMG) confirmation of radiculopathy with active or chronic denervation predicts a positive treatment outcome following ESI.**
Design: **Longitudinal cohort study of adults who underwent EMG and subsequent transforaminal ESI within 6 months. The proportion of individuals who experienced >50% pain relief and mean change in daily morphine equivalents (DME) were calculated.**
Results: **170 individuals with respective mean (Standard Deviation) age and duration of symptoms of 55 (15) years and 36 (56) months were included. Mean time to <30 day and >30 day follow-up post-injection were 18 (6) and 99 (130) days, respectively. At >30 day follow-up, a larger proportion of EMG-confirmed individuals (37.7%) reported >50% pain reduction compared to EMG-negative individuals (17.8%) (p=0.03). This was significant for lumbosacral (40% vs. 15%, p=0.01) but not cervical symptoms (p>0.05). Mean decrease in DME at long-term follow-up in EMG-confirmed compared to EMG-negative individuals trended toward significance (-4 vs. -1, p=0.11). There was no significant relationship between myotomal spontaneous activity and pain or opioid use.**
Conclusions: **Needle EMG predicts long-term pain reduction from transforaminal ESI in patients with lumbosacral radiculopathy, regardless of the presence of active denervation.**
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Electromyography | Prediction tool | epidural | radiculopathy | pain | cervical | lumbar | lumbosacral

Lumbar and cervical spine pathologies are a major public health and economic problem affecting over 100 million adults per year and leading to over $100 billion in healthcare expenditure in the United States [1]. Epidural steroid injections (ESIs) are effective in providing clinically-significant pain reduction, functional improvement, and preventing spinal surgery in some patients with lumbosacral radicular pain [2-11]. While less robust, there is also evidence that a portion of patients with cervical radicular pain can be effectively treated with cervical ESI [12-15]. Determining which patients are most likely to benefit from an ESI is important for both patient care and for managing healthcare expenditures.

Beyond the diagnosis of disc herniation versus spinal stenosis [7,11,16-19], there is minimal definitive literature that identifies those patients with radicular pain who would benefit most from ESI [20-27]. Needle electromyography (EMG) is the only objective means of detecting functional nerve root dysfunction [28,29] and is often used to confirm a diagnosis of radiculopathy or to define the specific nerve root affected [31-34]. Thus, electromyography may have some utility in identifying appropriate patients for ESI treatment. However, there has been limited data investigating the use of EMG for directing ESI interventions and for predicting efficacy of this intervention. There is no literature on whether the outcomes of patients with cervical radicular symptoms who show EMG evidence for radiculopathy differ from those without such changes. Additionally, there has been little research on the prognostic value of EMG confirmation of radiculopathy with regard to specific clinical outcomes after an epidural steroid injection [35-38]. The current literature is comprised of studies with small sample sizes and heterogeneous ESI techniques. Finally, no study has determined if the presence of active denervation versus only chronic denervation in either cervical or lumbosacral radiculopathy has any effect on the predictive value of EMG.

This study aimed to determine if EMG confirmation cervical or lumbosacral radiculopathy, with active versus chronic denervation, predicts a positive treatment outcome following an ESI, as measured by improved pain or decreased opiate consumption at short- and long-term follow up.

Methods

This was a multicenter, longitudinal cohort study approved by the Institutional Review Board at Northwestern University and at the University of Pennsylvania. The study was conducted at Physical Medicine and Rehabilitation outpatient interventional spine centers in two urban tertiary academic medical centers. Individuals seen at Northwestern/The Rehabilitation Institute of Chicago between May 2007 and December 2013; and those seen at The University of Pennsylvania between September 2009 and July 2010 were included in the study. At Northwestern/The Rehabilitation Institute of Chicago, data were obtained by retrospective query of the electronic medical record. At The University of Pennsylvania, data were obtained by interrogation of a discrete, structured clinical database (RICPLAS©) of individuals who were studied prospectively. This prospective clinical database has been further described in previous studies [27,39-43]. Consecutive individuals 18 years of age or older who underwent an EMG to evaluate radiculopathy and also underwent a transforaminal ESI (TFESI) within 6 months of the EMG to treat radicular pain were included. Exclusion criteria were: history of cervical or lumbar surgery and administration of ESI more than 6 months after the EMG was performed. For all individuals, the following data were collected: clinical history, pain diagram, 0-10 point Numeric Rating Scale (NRS) pain scores, physical examination findings (sensory, motor or reflex abnormalities), indication for EMG, and ESI procedural details. Opioid use data was collected only at the Northwestern University/Rehabilitation Institute of Chicago study sites (Table 1). An EMG was ordered at the discretion of the treating physician, and was typically done to clarify or confirm the diagnosis. EMG-confirmation of the diagnosis of radiculopathy was defined as 2 or more muscle abnormalities in the same myotome, with different peripheral nerve distributions, on a 6-muscle screen with changes consistent with denervation [32,33].

Conflict of interest: Dr. Plastaras has a patent RICPLAS licensed. None of the other authors report any conflict of interest.

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Table 1. Study Sample Characteristics

	Data Available n	All Individuals Mean (SD) or % (n)	EMG-confirmed Mean (SD) or % (n)	EMG-negative Mean (SD) or % (n)	Comparison of EMG-N vs. EMG-C groups P value
Demographics					
Age, years	170	55 (15)	56 (15)	54 (15)	0.25
Gender	170				
Male		45% (77)	47% (42)	43% (34)	
Female		55% (93)	53% (47)	57% (46)	0.53
BMI	115	29 (6)	30 (7)	28 (5)	0.21
Duration of symptoms, months	141	36 (56)	46 (68)	25 (53)	0.14
>3 drinks/day	64				
Yes		2% (1)	3% (1)	0% (0)	
No		98% (63)	97% (36)	100% (30)	0.60
Smoker	134				
Yes		16% (22)	17% (12)	16% (10)	
No		84% (112)	83% (60)	84% (52)	0.93
Worker's compensation	156				
Yes		6% (10)	6% (5)	7% (5)	
No		94% (146)	94% (78)	93% (73)	0.83
MVC caused symptoms	154				
Yes		8% (13)	6% (5)	11% (8)	
No		92% (141)	94% (77)	89% (64)	0.26
Disability	144				
Yes		4% (6)	4% (3)	4% (3)	
No		96% (138)	96% (69)	96% (69)	1.00
Time to "short-term follow-up" (<30 days)	160	18 (6)	17 (6)	18 (7)	0.70
Time to "long-term follow-up" (>30 days)	106	99 (130)	84 (54)	117 (184)	0.19
Reason for EMG	88				
Clarifying diagnosis		90% (79)	90% (45)	92% (35)	0.80
Clarifying level of affected nerve root		32% (28)	36% (18)	24% (9)	0.48
Considering surgery		2% (2)	6% (3)	0% (0)	0.15
Clarifying level for surgery		1% (1)	2% (1)	3% (1)	0.78
Injection Procedure Details					
Steroid type	168				
Triamcinolone		24% (41)	29% (26)	19% (15)	
Betamethasone		19% (31)	16% (14)	22% (17)	
Dexamethasone		57% (96)	56% (50)	59% (46)	0.28
Number of times injection was repeated	168	0.4 (0.7)	0.5 (0.8)	0.4 (0.6)	0.30
Level of Injection	178*				
C5-C6		4% (7)	Cervical	Cervical	
C6-C7		6% (10)	13% (10)	13% (12)	
C7-T1		3% (5)			
L2-L3		2% (3)	Lumbar	Lumbar	
L3-L4		7% (12)	88% (70)	87% (78)	
L4-L5		24% (43)			
L5-S1		40% (71)			
S1-S2		15% (27)			0.87
Pain and Opioid Use					
NRS prior to injection	167	5.9 (2.3)	5.9 (2.4)	6.0 (2.4)	0.77
NRS immediately post-injection	155	2.7 (2.8)	2.8 (2.9)	2.5 (2.7)	0.49
Morphine equivalents prior to injection	84	5 (11)	6 (14)	4 (8)	0.44
Pre-injection Electromyography					
Radiculopathy	160				
Yes		53% (90)	100% (90)	-	-
No		47% (80)			
Location of Radiculopathy	90				
Cervical		16 % (14)	16 % (14)		
Lumbar		84% (76)	84% (76)	-	-

*8 bilateral injections
BMI – body mass index
EMG-C – EMG-confirmed radiculopathy
EMG-N – EMG-negative for radiculopathy
MVC – motor vehicle accident
NRS – numerical rating scale

Table 2. Pain and Opioid Use Outcomes after TFESI

Pain and Opioid Use	Data Available n	Mean (SD) or % (n)
NRS prior to injection	167	5.9 (2.3)
NRS immediately post-injection	155	2.7 (2.8)
NRS at short-term follow-up	152	4.3 (2.8)
NRS at long-term follow-up	98	4.4 (2.6)
>50% NRS improvement from pre-injection to short-term follow-up	151	
Yes		28% (43)
No		72% (108)
>50% NRS improvement from pre-injection to long-term follow-up	98	
Yes		29% (28)
No		71% (70)
DME prior to injection	84	5 (11)
DME at short-term follow-up	73	2 (10)
DME at long-term follow-up	48	2 (11)
Opioids discontinued by short-term follow-up	30	20% (6)
Opioids discontinued by long-term follow-up	24	42% (10)

DME – daily morphine equivalents
NRS – numerical rating scale

The general indication for an epidural steroid injection in this cohort was radicular pain refractory to conservative treatment. Pain was considered to be radicular by history consistent with axial pain radiating to a limb in a dermatomal distribution, potentially supported by physical examination findings suggestive of nerve root irritation (dural tension signs, motor or reflex asymmetry), and/or concordant pathology on magnetic resonance imaging (MRI). Unilateral, single-level ESI was performed using a standard, image-guided transforaminal technique for both lumbar and cervical injections [44]. Steroid (12mg betamethasone [6mg/mL], 80mg triamcinolone [40mg/mL], or 16mg dexamethasone [4mg/mL], equipotent doses [45]) diluted in 1-2 mL of 1% lidocaine, was used for these injections. Dexamethasone was used exclusively for all cervical injections. All injections were performed by board-certified Physical Medicine & Rehabilitation physicians with additional board certification in either Sports Medicine or Pain Medicine.

Data Analysis

Opioid use data was converted to daily morphine equivalents (DME) [46]. Follow-up was categorized as ≤30 days (short term) and >30 days (long term); the mean time to follow-up in these groups was 18 and 99 days, respectively (Table 1).

The primary outcome measure for this study was the proportion of individuals who received >50% pain relief after TFESI. Individuals as were categorized as "responders" and "non-responders" with categorical outcome analysis in order to be consistent with prior studies of clinical outcomes following TFESI [7]. Secondary outcomes included change in mean NRS pain score and change in DME.

Outcomes were compared between individuals who had EMG-confirmed radiculopathy (EMG-C) and those who had radicular pain but no electrophysiologic evidence of radiculopathy on EMG (EMG-N). Outcomes were also compared between EMG-C individuals who had evidence of myotomal spontaneous activity (MSA), i.e. positive sharp waves and/or fibrillation potentials, and EMG-C individuals with no myotomal spontaneous activity (NMSA), i.e. only motor unit action potential recruitment changes in the absence of positive sharp waves and fibrillation potentials.

In order to identify group difference in outcomes based on confirmatory or non-confirmatory EMG evidence for radiculopathy, confounding factors were also included in the analysis.

Statistical Analysis

To illustrate the demographic, radiologic, and procedural characteristics of the study sample, the means and standard deviations for continuous variables and proportions for categorical variables were calculated. Data were checked for normal distributions using summary statistics and graphical displays. X^2 statistic was used to compare outcome groups on categorical variables and used analysis of variance tests to compare groups on numerical variables. Data were analyzed using PSPP version 0.8.3 (Gnu Project, Boston, MA). The level of significance was set at 0.05 for all statistical tests. Two-sided testing was used for all hypothesis testing.

Results

A total of 170 consecutive individuals received an EMG followed by a TFESI for radicular pain during the study time frame. Demographic, clinical, and procedural characteristics of the study population are shown in Table 1. The mean (SD) age was 55 (15) years, and the mean duration of symptoms prior to ESI was 36 (56) months. The mean time to "short term" follow-up post-injection was 18 (6) days and to "long-term" follow-up was 99 (130) days.

There were 90 (53%) EMG-C individuals 14 (16%) of which were cervical and 76 (84%) of which were lumbosacral (Table 1). NRS pain scores were available for 152 (89%) individuals at short-term follow-up and for 98 (58%) of individuals at long-term follow-up.

Demographic, clinical, and procedural characteristics of EMG-C individuals were compared to EMG-N individuals, with no significant between group differences found. (Table 1).

At short-term follow-up, 28% (95% Confidence Interval [CI] 22%, 36%) of all individuals reported >50% improvement in pain and 20% discontinued opioids. At long term follow-up, 29% (95% CI 21%, 38%) reported > 50% improvement in pain and 42% (95% CI 24%, 61%) of those with available data (or 29% [95% CI 17%, 46%] if including those with missing data) had discontinued opioid use for pain control (Table 2).

Table 3 shows NRS pain score improvements in EMG-C individuals compared to EMG-Negative individuals. At long-term follow up, a significantly larger proportion of EMG-Confirmed individuals (38%, 95% CI 26%, 51%) reported >50% pain reduction compared to EMG-negative individuals (18%, 95% CI 8.5%, 31%) (p=0.03). The mean decrease in NRS pain score was 30% in EMG-C individuals compared to only 9% of EMG-negative individuals (p=0.05). There were no significant differences between these two groups with regard to either categorical or mean pain reduction at short-term follow up, and no significant differences in DME at either short- or long-term follow up, though there was a trend toward a greater decrease in DME at long-term follow up in EMG-Confirmed compared to EMG-Negative individuals (p=0.11) (Table 3).

In individuals with cervical radicular pain, (n = 22) no relationship was identified between EMG results with regard to the proportion of individuals who experienced >50% pain reduction or in the mean change in NRS pain score at short (p=0.65, p=0.87) or long term (p=0.50, 0.91) follow-up. In individuals with lumbosacral symptoms (n = 148), there was no significant difference in the proportion of individuals who experienced >50% pain reduction or in the mean change in NRS pain score between the two groups at

Table 3. Pain and Opioid use Outcomes in EMG-C vs. EMG-N Individuals. Positive values indicate an improvement.

	Data Available n	EMG-Confirmed Mean improvement Or % (n) [lower,upper 95% CI]	EMG-Negative Mean improvement Or % (n) [lower,upper 95% CI]	P value
Percent NRS reduction from pre- to immediately post injection	151	53% [44%-63%]	58% [47%-68%]	0.37
Percent NRS reduction from pre-injection to short-term follow-up	151	28% [16%-46%]	16% [-1%-34%]	0.27
Percent NRS reduction from pre-injection long-term follow-up	99	30% [17%-44%]	9% [-9%-27%]	**0.05***
Pre- to immediately post-injection: >50% improvement	155	46% (37)	56% (40)	0.30
Pre-injection to short-term follow-up: >50% improvement	151	30% (25)	27% (18)	0.55
Pre-injection to long-term follow-up : >50% improvement	98	38% (20)	18% (8)	**0.03***
Decrease in DME, Pre-injection to short-term follow-up	73	2 [-2,6]	1 [-2,4]	0.75
Decrease in DME, Pre-injection to long-term follow-up	45	4 [-1,9]	-1 [-3,2]	0.11
Opioids discontinued by short-term follow-up	30	18% (3)	23% (3)	0.71
Opioids discontinued by long-term follow-up	24	39% (5)	46% (5)	0.73

DME – daily morphine equivalents
EMG-C – EMG-confirmed radiculopathy
EMG-N – EMG-negative for radiculopathy
NRS – numerical rating scale
* - statistically significant, as defined by an alpha value of 0.05

short-term follow-up (p = 0.55, p=0.35), but significantly more subjects with EMG-confirmed radiculopathy (40%, 95% CI 27%, 54%) had >50% relief at long-term follow-up compared to those without EMG-confirmed radiculopathy (15%, 95% CI 7%, 29%), p = 0.01. The mean percentage change in pain relief between lumbosacral EMG-C and lumbosacral EMG-N at long-term follow-up was 21% less pain (p = 0.08).

Table 4 shows NRS pain scores and opioid use in EMG-C individuals, comparing those with and those without myotomal spontaneous activity (MSA versus NMSA). There was no significant interaction between myotomal spontaneous activity (MSA vs. NMSA) and NRS pain scores or opioid use at short- or long-term follow up.

In comparing demographic, procedural, and outcome data between the two centers, no significant differences were found (p>0.05). This included age, gender, BMI, duration of symptoms, alcohol consumption, smoking status, worker's compensation involvement, disability, pain related to a motor vehicle accident, baseline NRS pain score, number of times the injection was repeated, decrease in mean decrease in pain scores at short and long-term follow-up, proportion of responders (>50% improvement in pain). Differences in opioid consumption could not be compared between centers, as this data was not available in the RICPLAS clinical database.

Discussion

These data indicate that EMG findings of radiculopathy may predict pain reduction at intermediate to long-term follow-up in individuals with lumbosacral symptoms who undergo a TFESI. No differences in potentially confounding baseline demographic, clinical, or procedural characteristics were apparent in this analysis, thus strengthening this finding.

These results also suggest that EMG predicts pain reduction after TFESI for radiculopathy in both the case of active denervation and when only chronic denervation is present, as there was no difference in pain reduction with regard to the presence or absence of myotomal spontaneous activity. This is the first study to report this finding.

This was also the first study to examine cervical radiculopathy outcomes after an ESI. No relationship was identified between EMG confirmation of cervical radiculopathy and pain outcomes following TFESI, however the sub-population of individuals with cervical radicular symptoms was small and unlikely to detect significant differences.

Four small studies have investigated the prognostic value of EMG confirmation of radiculopathy in determining clinical outcomes after ESI. Annaswamy et al. [35] found that individuals with EMG findings of radiculopathy with active denervation (myotomal spontaneous activity) were more likely to experience improvements in pain and function 2 and 6 months after ESI, but this study was limited to only 70 individuals with symptoms of lumbosacral radicular pain. In another study, Marchetti et al. [36] found no differences in pain relief 6 weeks after an ESI in patients with EMG evidence of lumbosacral radiculopathy versus those without. This study was limited by its retrospective design, small size, and varied technique of ESI (caudal, interlaminar and transforaminal).

Table 4. Pain and Opioid use Outcomes in EMG-C Individuals with MSA vs. NMSA. Positive values indicate an improvement.

	Data Available n	Myotomal Spontaneous Activity Mean improvement Or % and n [lower,upper 95% CI]	No Spontaneous Activity Mean improvement Or % and n [lower,upper 95% CI]	P value
Percent NRS reduction from pre- to immediately post injection	69	56% [44%,68%]	42% [19%, 65%]	0.30
Percent NRS reduction from pre-injection to short-term follow up	72	26% [10%, 43%]	36% [18%, 55%]	0.63
Percent NRS reduction from pre-injection to long-term follow-up	45	28% [11%, 45%]	36% [5%, 67%]	0.66
Pre-injection to short-term follow-up: >50% NRS reduction	72	34% (21)	20% (2)	0.38
Pre-injection to long-term follow-up: >50% NRS reduction	45	39% (14)	33% (3)	0.76
Reduction in DME, Pre-injection to short term follow-up	40	1 [-3,5]	4 [-5,13]	0.50
Reduction in DME, Pre-injection to long-term follow-up	26	3 [-3,10]	6 [-2,15]	0.62
Opioids discontinued by short-term follow-up	19	20% (3)	0% (0)	0.49
Opioids discontinued by long-term follow-up	13	33% (2)	50% (2)	0.57

DME – daily morphine equivalents
EMG-C – EMG-confirmed radiculopathy
MSA – myotomal spontaneous activity
NMSA – no myotomal spontaneous activity
NRS – numerical rating scale

Fish et al. [37] found that patients with EMG-confirmed lumbosacral radiculopathy who received an an ESI showed greater functional improvement at 3 months as compared to those with radicular pain but no EMG evidence of radiculopathy. In contrast, Cosgrove et al. [38] found no relationship between EMG findings and pain or functional improvement 6 weeks after interlaminar ESI, but was underpowered with only 17 participants.

The findings in this present study are thus in agreement with those of Annaswamy et al. and Fish et al., which demonstrated the value of EMG as a predictor of outcomes after epidural steroid injection. Also of note, the only two studies to investigate the transforaminal approach to ESI exclusively – this study and that of Fish et al. – both demonstrate the prognostic value of EMG.

These findings should only be interpreted in the context of the characteristics of the study sample. In this sample, EMGs had been obtained for the purpose of clarifying or confirming the diagnosis of radiculopathy in approximately 90% of both groups (EMG-C and EMG-N), reflecting a cohort of individuals in which some had, perhaps, a questionable diagnosis of radicular pathology. For example, zygapophyseal joint [47,48], shoulder [49], mediastinal [50], hip/sacroiliac joint [51,52], and myofascial trigger-point mediated pain [53,54] can refer in distributions that may appear radicular. Therefore, the finding that EMG confirmation of radiculopathy predicts pain reduction after TFESI may only be relevant in a population with an unclear diagnosis of radiculopathy. EMG may not predict pain outcome after TFESI when a diagnosis of radicular pathology is absolutely clear. Also since this cohort represented a group of patients with a possibly unclear diagnosis that needed an EMG, it may explain the relatively poor response rate of only 29% having a 50% long-term decrement in pain.

Limitations of this study exist. While 49% of the data in this study from individuals treated at The University of Pennsylvania was obtained from the RICPLAS clinical database, the other 51% was collected by retrospective chart review from Northwestern/The Rehabilitation Institute of Chicago. As a hybrid study, these findings are at risk of the possible biases associated with a retrospective study, though less than if all data was gathered retrospectively. Similar baseline characteristics and clinical outcomes of the study samples at the two centers do help to limit possible bias. Due to limitations in the clinical database, information regarding general medical comorbidities that could have affected the results, such as diabetes mellitus, renal disease, thyroid conditions, etc., could not be compared between the EMG-C and EMG-N groups. This represents a possible source of bias.

Another possible limitation was in the selection of patients. Those with clear radiculopathies may have not undergone EMG testing, thus resulting in a selection bias. However, the unclear nature of these patients facilitated the comparison between those with a positive and negative EMG. It does however possibly alter the response rates of the subjects presented, and thus data on the outcomes from ESIs in this cohort must be viewed in this light.

Further study of the prognostic value of EMG in patients with radicular pain is warranted. Larger, prospective studies are needed, and the literature regarding cervical pathology, specifically, must be developed. In addition, beyond pain outcomes, functional measures should be included in future analyses. Functional measures were not available in the datasets used for this study but are of significant interest as an important outcome.

Conclusions

This study demonstrated that EMG predicts long-term pain reduction in patients with lumbosacral radiculopathy, regardless of the presence of active denervation, following TFESI. These findings primarily apply to individuals with questionable radicular symptoms in which clinical assessment requires EMG confirmation.

Acknowledgements

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1. Mafi JN, McCarthy EP, Davis RB, Landon BE. Worsening trends in the management and treatment of back pain. JAMA Intern Med. 2013 Sep 23;173(17):1573-81.
2. Roberts ST, Willick SE, Rho ME, Rittenberg JD. Efficacy of lumbosacral transforaminal epidural steroid injections: a systematic review. PM R. 2009 Jul;1(7):657-68.
3. Boswell M, Hansen H, Trescot A, Hirsch J. Epidural steroids in the management of chronic spinal pain and radiculopathy. Pain Physician, 6 (2003), pp. 319–334.
4. Abdi S, Datta S, Trescot A, Schultz D, Adlaka R, Atluri S, Smith, H.S., Manchikanti L. Epidural steroids in the management of chronic spinal pain: A systematic review. Pain Physician, 10 (2007), pp. 185–212.
5. Riew KD, Yin Y, Gilula L, Bridwell KH, Lenke LG, Lauryssen C, Goette K. The effect of nerve-root injections on the need for operative treatment of lumbar radicular pain. A prospective, randomized, controlled, double-blind study. J Bone Joint Surg Am. 2000 Nov;82-A(11):1589-93.
6. Vad VB, Bhat AL, Lutz GE, Cammisa F. Transforaminal epidural steroid injections in lumbosacral radiculopathy: a prospective randomizedstudy. Spine (Phila Pa 1976). 2002 Jan 1;27(1):11-6.
7. Ghahreman A, Ferch R, Bogduk N. The Efficacy of Transforaminal Injection of Steroids for the Treatment of Lumbar Radicular Pain. Pain Medicine 2010; 11: 1149-1168.
8. MacVicar J, King W, Landers MH, Bogduk N. The effectiveness of lumbar transforaminal injection of steroids: a comprehensive review with systematic analysis of the published data. Pain Med. 2013 Jan;14(1):14-28.
9. Manson NA, McKeon MD, Abraham EP. Transforaminal epidural steroid injections prevent the need for surgery in patients with sciatica secondary to lumbar disc herniation: a retrospective case series. Can J Surg. 2013 Apr;56(2):89-96.
10. Chang-Chien GC, Knezevic NN, McCormick Z, Chu SK, Trescot AM, Candido KD. Transforaminal versus interlaminar approaches to epidural steroid injections: a systematic review of comparative studies for lumbosacral radicular pain. Pain Physician. 2014 Jul-Aug;17(4):E509-24.
11. Kennedy DJ, Plastaras C, Casey E, Visco CJ, Rittenberg JD, Conrad B, Sigler J, and Dreyfuss P. Comparative Effectiveness of Lumbar Transforaminal Epidural Steroid Injections with Particulate Versus Nonparticulate Corticosteroids for Lumbar Radicular Pain due to Intervertebral Disc Herniation: A Prospective, Randomized, Double-Blind Trial. Pain Med. 2014 Apr;15(4):548-55.
12. Benyamin RM, Singh V, Parr AT, Conn A, Diwan S, Abdi S. Systematic review of the effectiveness of cervical epidurals in the management of chronic neck pain. Pain physician. Jan-Feb 2009;12(1):137-157.
13. Stav A, Ovadia L, Sternberg A, Kaadan M, Weksler N. Cervical epidural steroid injection for cervicobrachialgia. Acta anaesthesiologica Scandinavica. Aug 1993;37(6):562-566.
14. Castagnera L, Maurette P, Pointillart V, Vital JM, Erny P, Senegas J. Long-term results of cervical epidural steroid injection with and without morphine in chronic cervical radicular pain. Pain. Aug 1994;58(2):239-243.
15. Saal JS, Saal JA, Yurth EF. Nonoperative management of herniated cervical intervertebral disc with radiculopathy. Spine. Aug 15 1996;21(16):1877-1883.
16. Friedly JL, Comstock BA, Turner JA, Heagerty PJ, Deyo RA, Sullivan SD, Bauer Z, Bresnahan BW, Avins AL, Nedeljkovic SS, Nerenz DR, Standaert C, Kessler L, Akuthota V, Annaswamy T, Chen A, Diehn F, Firtch W, Gerges FJ, Gilligan C, Goldberg H, Kennedy DJ, Mandel S, Tyburski M, Sanders W, Sibell D, Smuck M, Wasan A, Won L, Jarvik JG. A randomized trial of epidural glucocorticoid injections for spinal stenosis. N Engl J Med. 2014 Jul 3;371(1):11-21.
17. Choi SJ, Song JS, Kim C, Shin MJ, Ryu DS, Ahn JH, Jung SM, Park MS. The use of magnetic resonance imaging to predict the clinical outcome of non-surgical treatment for lumbar intervertebral disc herniation. Korean J Radiol. 2007 Mar-Apr;8(2):156-63.
18. Lee JW, Kim SH, Lee IS, Choi JA, Choi JY, Hong SH, Kang HS. Therapeutic effect and outcome predictors of sciatica treated using transforaminal epidural steroid injection. AJR Am J Roentgenol. 2006 Dec;187(6):1427-31.
19. Lee JW, Choi SW, Park SH, Lee GY, Kang HS. MR-based outcome predictors of lumbar transforaminal epidural steroid injection for lumbar radiculopathy caused by herniated intervertebral disc. Eur Radiol. 2013 Jan;23(1):205-11.
20. McCormick Z, Plastaras C. Transforaminal epidural steroid injection in the treatment of lumbosacral radicular pain caused by epidural lipomatosis: a case series and review. J Back Musculoskelet Rehabil. 2014;27(2):181-90.
21. McCormick Z, Plastaras C. Lumbosacral transforaminal epidural steroid injections are equally effective for treatment of lumbosacral radicular pain in the obese compared to non-obese population: a pilot study. J Back Musculoskelet Rehabil. 2013;26(2):183-8.
22. Schiff E, Eisenberg E. Can quantitative sensorytesting predict the outcome of epidural steroid injections in sciatica? A preliminary study. Anesth Analg. 2003 Sep;97(3):828-32.
23. Golish SR, Hanna LS, Bowser RP, Montesano PX, Carragee EJ, Scuderi GJ. Outcome of lumbar epidural steroid injection is predicted by assay of a complex of fibronectin and aggrecan fromepidural lavage. Spine (Phila Pa 1976). 2011 Aug 15;36(18):1464-9.
24. Park CH, Lee SH. Prognostic usefulness of high sensitivity C-reactive protein for transforaminal epidural steroid injection in patients with radicular pain. Pain Med. 2011 Feb;12(2):219-23.
25. Ghahreman A, Bogduk N. Predictors of a favorable response to transforaminal injection of steroids in patients with lumbar radicular pain due to disc herniation. Pain Med. 2011 Jun;12(6):871-9.
26. Inman SL, Faut-Callahan M, Swanson BA, Fillingim RB. Sex differences in responses to epidural steroid injection for low back pain. J Pain. 2004 Oct;5(8):450-7.
27. McCormick Z, Cushman D, Casey E, Garvan C, Kennedy DJ, Plastaras C. Factors Associated With Pain Reduction After Transforaminal Epidural Steroid Injection for Lumbosacral Radicular Pain. Arch Phys Med Rehabil. 2014 Aug 7. pii: S0003-9993(14)00931-9.
28. Braune HJ, Wunderlich MT. Diagnostic value of different neurophysiological methods in the assessment of lumbar nerve root lesions. Arch Phys Med Rehabil 1997;78:518–520.
29. Nardin RA, Patel MR, Gudas TF, Rutkove SB, Raynor EM. Electromyography and magnetic resonance imaging in the evaluation of radiculopathy. Muscle Nerve 1999;22:151–155.
30. Cho SC, Ferrante MA, Levin KH, Harmon RL, So YT. Utility of electrodiagnostic testing in evaluating patients with lumbosacral radiculopathy: An evidence-based review. Muscle Nerve. 2010 Aug;42(2):276-82.
31. Dillingham TR. Electrodiagnostic approach to patients with suspected radiculopathy. Phys Med Rehabil Clin N Am. 2002 Aug;13(3):567-88.
32. Dillingham TR, Lauder TD, Andary M, Kumar S, Pezzin LE, Stephens RT, Shannon S. Identifying lumbosacral radiculopathies: an optimal electromyographic screen. Am J Phys Med Rehabil. 2000 Nov-Dec;79(6):496-503.
33. Dillingham TR, Lauder TD, Andary M, Kumar S, Pezzin LE, Stephens RT, Shannon S. Identification of cervical radiculopathies: optimizing the electromyographic screen. Am J Phys Med Rehabil. 2001 Feb;80(2):84-91.
34. Levin KH. Approach to the patient with suspected radiculopathy. Neurol Clin. 2012 May;30(2):581-604.
35. Annaswamy TM, Bierner SM, Chouteau W, Elliott AC. Needle electromyography predicts outcome after lumbar epidural steroid injection. Muscle Nerve. 2012 Mar;45(3):346-55.
36. Marchetti J, Verma-Kurvari S, Patel N, Ohnmeiss DD. Are electrodiagnostic study findings related to a patient's response to epidural steroid injection? PM R. 2010 Nov;2(11):1016-20.
37. Fish DE, Shirazi EP, Pham Q.The use of electromyography to predict functional outcome following transforaminal epidural spinal injections for lumbar radiculopathy. J Pain. 2008 Jan;9(1):64-70.
38. Cosgrove JL, Bertolet M, Chase SL, Cosgrove GK. Epidural steroid injections in the treatment of lumbar spinal stenosis efficacy and predictability of successful response. Am J Phys Med Rehabil. 2011 Dec;90(12):1050-5.
39. Plastaras C, McCormick Z, Garvan C, Macron, D, Joshi D, Chimes G, Smeal W, Rittenberg J, Kennedy DJ. Adverse Events Associated with Fluoroscopically Guided Lumbosacral Transformaminal Epidural Steroid Injections. The Spine Journal. 2015 June 8. pii: S1529-9430(15)00556-2.
40. Plastaras C, McCormick Z, Macron D, Garvan C, Joshi A, Chimes G, Smeal W, Rittenberg J. Adverse Events Associated with Fluoscopically Guided Zygapophyseal Joint Injections. Pain Physician. 2014 July-August;17(4):297-304.
41. Cushman D, McCormick Z, Casey E, Plastaras C. Discrepancies in Describing Pain: Is There Agreement Between Numeric Rating Scale Scores and Pain Reduction Percentage Reported by Patients with Musculoskeletal Pain after Corticosteroid Injection . Pain Medicine. 2015 Feb 26. doi: 10.1111/pme.12669.
42. McCormick Z, Margolis S, Temme K, Rivers WE, Cameron SA, Smith MA, Rohr A, Zander E, Garvan C, Kennedy DJ, Plastaras CT.

Concordant Pain Provocation during Transforaminal Epidural Steroid Injection for Lumbosacral Radiculopathy: Effect on Pain Outcome and Predictive Factors. Pain Physician. 2015 Jan-Feb;18(1):E19-E26.
43. McCormick Z, Kennedy DJ, Rivers WE, Garvan C, Temme K, Margolis S, Zander E, Rohr A, Smith MA, Plastaras CT. Comparison of Pain Score Reduction Using Triamcinolone vs. Betamethasone in Transforaminal Epidural Steroid Injections for Lumbosacral Radiculopathy. American Journal of Physical Medicine and Rehabilitation. Accepted for publication.
44. April C, Bogduk N, Dreyfuss P, Endres S, Govind J, Kraft M, Pauza K, Rogers K, Tibiletti C, Yin W. Practice Guidelines for Spinal Diagnostic & Treatment Procedures. International Spine Intervention Society, first edition, 2004.
45. Meikle AW and Tyler FH. Potency and duration of action of glucocorticoids. Am J of Med 1977;63;200.
46. Argoff CE, Silvershein DI. A comparison of long- and short-acting opioids for the treatment of chronic noncancer pain: tailoring therapy to meet patient needs. Mayo Clin Proc. 2009 Jul;84(7):602-12.
47. Marks R. Distribution of pain provoked from lumbar facet joints and related structures during diagnostic spinal infiltration. Pain. 1989 Oct;39(1):37-40.
48. Tessitore E, Molliqaj G, Schatlo B, Schaller K. Clinical evaluation and surgical decision making for patients with lumbar discogenic pain and facet syndrome. Eur J Radiol. 2014 Apr 4. pii: S0720-048X(14)00154-5.
49. Bayam L, Ahmad MA, Naqui SZ, Chouhan A, Funk L. Pain mapping for common shoulder disorders. Am J Orthop (Belle Mead NJ). 2011 Jul;40(7):353-8.
50. McCormick Z, Bouffard KJ, Neudorf D, Casey E. A mediastinal mass presenting with unilateral periscapular and arm pain. PM R. 2014 Jun;6(6):560-3.
51. van der Wurff P, Buijs EJ, Groen GJ. Intensity mapping of pain referral areas in sacroiliac joint pain patients. J Manipulative Physiol Ther. 2006 Mar-Apr;29(3):190-5.
52. Laplante BL, Ketchum JM, Saullo TR, DePalma MJ. Multivariable analysis of the relationship between pain referral patterns and the source of chronic low back pain. Pain Physician. 2012 Mar-Apr;15(2):171-8.
53. Fernández-de-las-Peñas C, Gröbli C, Ortega-Santiago R, Fischer CS, Boesch D, Froidevaux P, Stocker L, Weissmann R, González-Iglesias J. Referred pain from myofascial trigger points in head, neck, shoulder, and arm muscles reproduces pain symptoms in blue-collar (manual) and white-collar (office) workers. Clin J Pain. 2012 Jul;28(6):511-8.
54. Simons DG, Travell JG. Myofascial origins of low back pain. 3. Pelvic and lower extremity muscles. Postgrad Med. 1983 Feb;73(2):99-105, 108.