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Injectate Volumes Needed to Reach Specific Landmarks in Lumbar Transforaminal Epidural Injections

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Objectives: To identify the volumes of contrast material needed to reach specific landmarks during lumbar transforaminal epidural injections (L-TFEIs).

Design: Prospective, nonrandomized, observational human study.

Setting: Academic/private pain management practice.

Patients: Sixty-nine patients undergoing L-TFEIs were investigated. Sixty patients were included in this study.

Interventions: L-TFEIs were performed with the use of contrast-enhanced fluoroscopic visualization.

Main Outcome Measurements: After the appropriate spinal needle position was confirmed, up to 5.0 mL of nonionic contrast material was slowly injected. Under biplanar fluoroscopic guidance, contrast volumes were recorded as flow reached specific anatomic landmarks: ipsilateral neural foramen, ipsilateral disks superior and inferior to the injected level, and across the midline of the spinous process.

Results: After 1.1 mL of contrast was injected, 100% of L-TFEIs spread to the medial aspect of the superior pedicle (PED) of the corresponding level of injection. After 2.8 mL of contrast was injected, 95% of L-TFEIs spread to the superior aspect of the superior intervertebral disk (IVD) of the corresponding level of injection. After 3.6 mL of contrast was injected, 95% of L-TFEIs spread to the inferior aspect of the inferior IVD of the corresponding level of injection. After 3 mL of contrast was injected, 88% of L-TFEIs spread to cover both the superior and inferior IVDs of the corresponding level of injection. After 4 mL of contrast was injected, 93% of L-TFEIs spread to cover both the superior and inferior IVDs of the corresponding injection. After 4 mL of contrast was injected, 55% of L-TFEIs spread beyond the midline of the spinous process, but barely.

Conclusion: This study demonstrates injectate volumes needed to reach specific anatomic landmarks in L-TFEIs. A volume of 4.0 mL of injectate reaches both the superior aspect of the superior IVD and the inferior aspect of the inferior IVD 93% of the time.

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INTRODUCTION

The prevalence of low back pain, with or without radicular pain, remains high in industrialized countries [1]. A thorough clinical evaluation includes a detailed history and physical examination and may include imaging and/or serologic studies. Noninvasive treatment options include physical therapy, manual manipulation, behavioral techniques, and medications. Within the realm of percutaneous spinal interventions, therapeutic options include lumbar transforaminal epidural steroid injections (L-TFESIs). L-TFESIs are an integral component of comprehensive, conservative care for radicular pain resulting from disk compression or spinal stenosis [2-9]. The theoretical goal is to place a mixture of concentrated steroid and anesthetic solution at the pathologic site or along the dorsal root ganglion [3,10]. The pathologic site is often determined by clinical, radiographic, and electrodiagnostic studies as part of the comprehensive evaluation in which active pain generators are localized.

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L-TFESIs result in the flow of medication from the needle tip to the dorsal root ganglion, medial to the pedicle (PED) and into the epidural space [11]. To optimize the therapeutic benefit, the goal of L-TFESIs should concentrate injectate flow to the spinal segment(s) that correlate anatomically with the patient's clinical and radiographic presentation. The proposed mechanisms of pain relief include decreasing or diluting inflammatory mediators, reducing edema, interrupting afferent nerve impulses, and possibly providing nerve membrane stabilization. The goal is to maximally concentrate the medication at the suspected pathologic site. To accurately determine the amount of injectate necessary to reach the suspected pathologic level, Bogduk [2] advocates recording the amount of contrast needed to reach the site and then using this volume for the therapeutic injectate. Because steroid solutions have a lower viscosity than the contrast agents, we would expect the injectate solution to reach the same anatomic locations as the contrast, if not beyond them.

Spinal segments have a number of suspected pain generators. Before performing L-TFESIs, physicians typically determine the pathologic spinal segment that corresponds to the patient's symptomatology and functional status via clinical, radiographic, and/or electrodiagnostic evaluations. Figure 1 demonstrates a right L3-TFEI with contrast along the right L3 nerve. There are various potential sites at which the spinal nerve and nerve root can be compromised: L2-3 central stenosis or a right central L2-3 herniated nucleus pulposus (HNP) may encroach along the L3 nerve as it transits inferiorly; an L3-4 lateral recess or foraminal stenosis may contact the exiting L3 nerve root or the L3 dorsal root ganglion; and a "far lateral" (extraforaminal) L3-4 HNP may also affect the exiting L3 spinal nerve. Other common causes for pain include compression from zygapophysial joints, synovial cysts, epidural lipomatosis, and/or postsurgical epidural scarring [12].

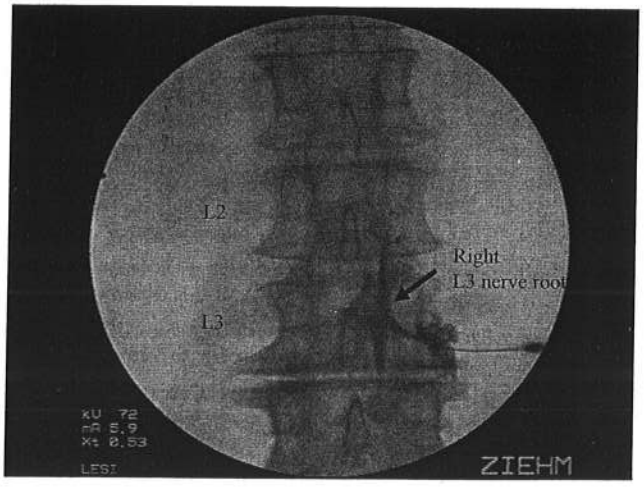

Figure 1. A L-TFEI with contrast along the right L3 nerve demonstrating the potential sites in which a nerve can be compromised. Note that the L3 nerve root "transits" past the L2-3 disk in the right central location, descends inferiorly, and then "exits" at the foramen between L3 and L4, where it can be encroached foraminally or extraforaminally.

Central HNP

As per the classification of lumbar disk pathology by Fardon and Milette [13], patients can develop a right central or left central HNP (previously referred to as paracentral HNP). When treating a right or left central HNP, the physician typically strives to place the injectate at the interface of where the disk contacts the centrally transiting nerve. Most interventionalists will use a "conventional" L-TFESI to inject where the spinal nerve exits the level below the HNP and direct the flow along the exiting spinal nerve and nerve root, and most importantly, superiorly to the transiting nerve–disk interface. However, some physicians use a conventional L-TFESI to inject along the exiting spinal nerve and nerve root at the level above the central HNP and direct the flow inferiorly to the transiting nerve/disc interface inferior to the injected exiting spinal nerve. Although a retrodiskal (ie, "preganglionic") approach has been described [11,14] to place medication directly at the transiting nerve–disk interface, this is not the conventional L-TFEI technique used in this study.

The superior margin of the superior intervertebral disk (IVD) is adjacent to the inferior endplate of the superior vertebral body. The inferior margin of the inferior IVD is adjacent to the superior endplate of the inferior vertebral body (Figure 2A and B). To confirm that the injectate covers the disk–nerve interface, the injectate should travel superiorly to or above the superior IVD (Figure 3A and B). Alternatively, the injection may be performed along the exiting nerve superior to the suspected central HNP. Likewise, to confirm that the injectate covers the disk–nerve interface, the injectate should travel inferiorly to or below the inferior IVD (Figure 4A and B). Theoretically, injectate from one needle may be able to treat both the superior and inferior levels to treat 2 adjacent spinal segments (Figure 5).

Central Stenosis

Central stenosis usually results from a combination of dorsal and ventral compromise of the spinal canal. Pain generators from stenosis may differ from those involved in a central HNP. Dorsal structures that constrict the central canal include the posterior elements such as the zygapophysial joints and the ligamentum flavum. Ventral structures that constrict the central canal include the IVD and the endplate osteophytes. By use of similar logic as described previously for central HNP, to treat the pathologic site, injectate should flow from the needle tip to the central spinal segment located

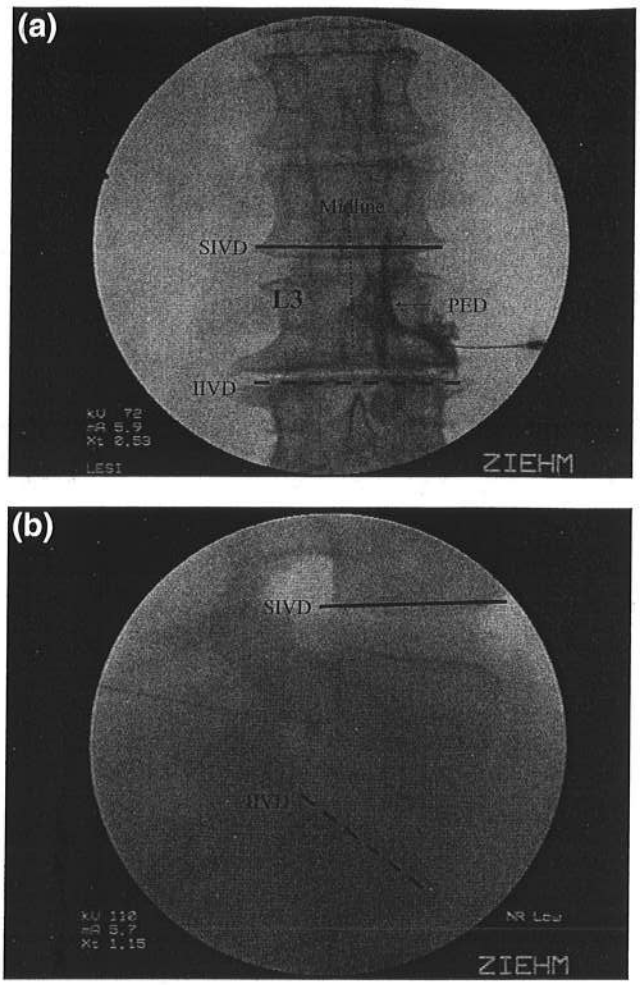

Figure 2. (A) Anteroposterior view of a needle placed for a right L3 TFESI demonstrating the landmarks used for this investigation. Note the superior aspect of the adjacent superior IVD and the inferior aspect of the adjacent inferior IVD. Also, note the contrast flowing along the most medial aspect of the superior pedicle (PED) and the midline of the spinal segment. (B) Lateral view of a needle placed for a right L5 TFESI demonstrating the landmarks used for this investigation. Note the superior aspect of the adjacent IVD and the inferior aspect of the adjacent inferior IVD.

superior, inferior, and/or contralateral to the site of needle tip placement.

Far Lateral HNP

In this study, a "far lateral" HNP refers to extraforaminal disk herniations affecting the spinal nerve/ventral ramus that exit from a specific level. Theoretically, to effectively treat L3 radiculitis from a far lateral L3-4 HNP or from a foraminal stenosis, the injectate needs to be delivered along the exiting L3 spinal nerve through the L3 (L3-4) foramen to the nerve root sheath with minimal flow into the epidural space. The use of contrast-enhanced fluoroscopic visualization may allow for the use of smaller and more concentrated volumes of injectate to the site of the suspected pain generator.

Contralateral Pathology

It is widely accepted that the flow tends to travel ipsilaterally. Specifically, an injection should be performed on the side of pain and pathology because flow barely crosses the midline [15].

Because Whitlock et al [16] have demonstrated no septa in the anterior epidural space at the mid-vertebral level, con-

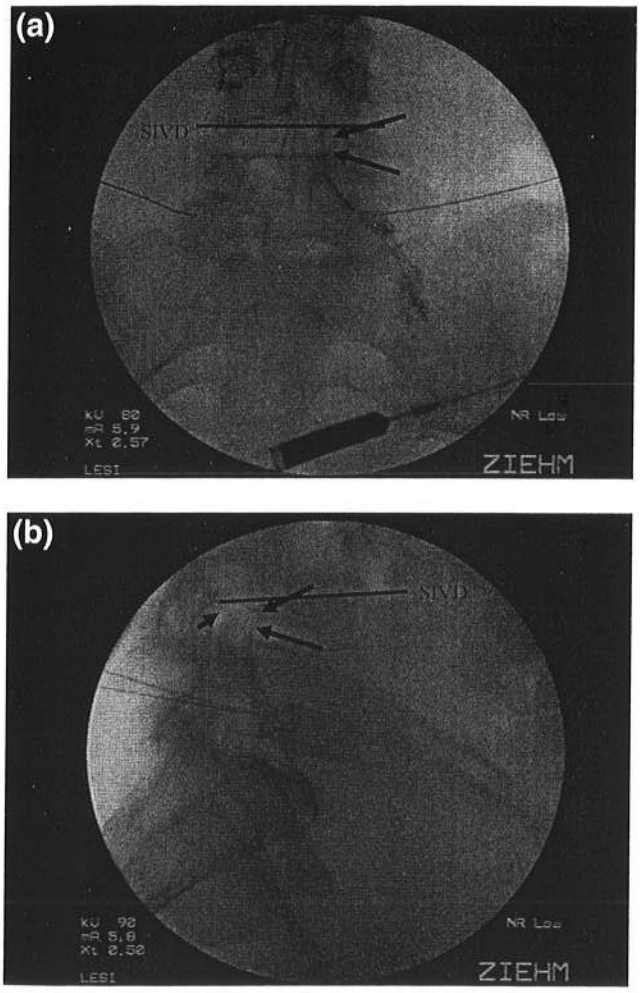

Figure 3. (A) Anteroposterior view of 2 needles placed for bilateral L5 TFESIs. Note the contrast crossing the superior aspect of the L4-5 IVD (solid line) when injected via the right L5 foramen. The flow demonstrates that injectate will cover L4-5 central pathology (solid arrows point to the disk-nerve root interface). (B) Lateral view of 2 needles placed for bilateral L5 TFESIs. Note the contrast crossing the superior aspect of the L4-5 IVD (solid line) when injected via the right L5 foramen. The flow demonstrates that injectate will cover L4-5 central pathology (solid arrows point to the disk-nerve root interface).

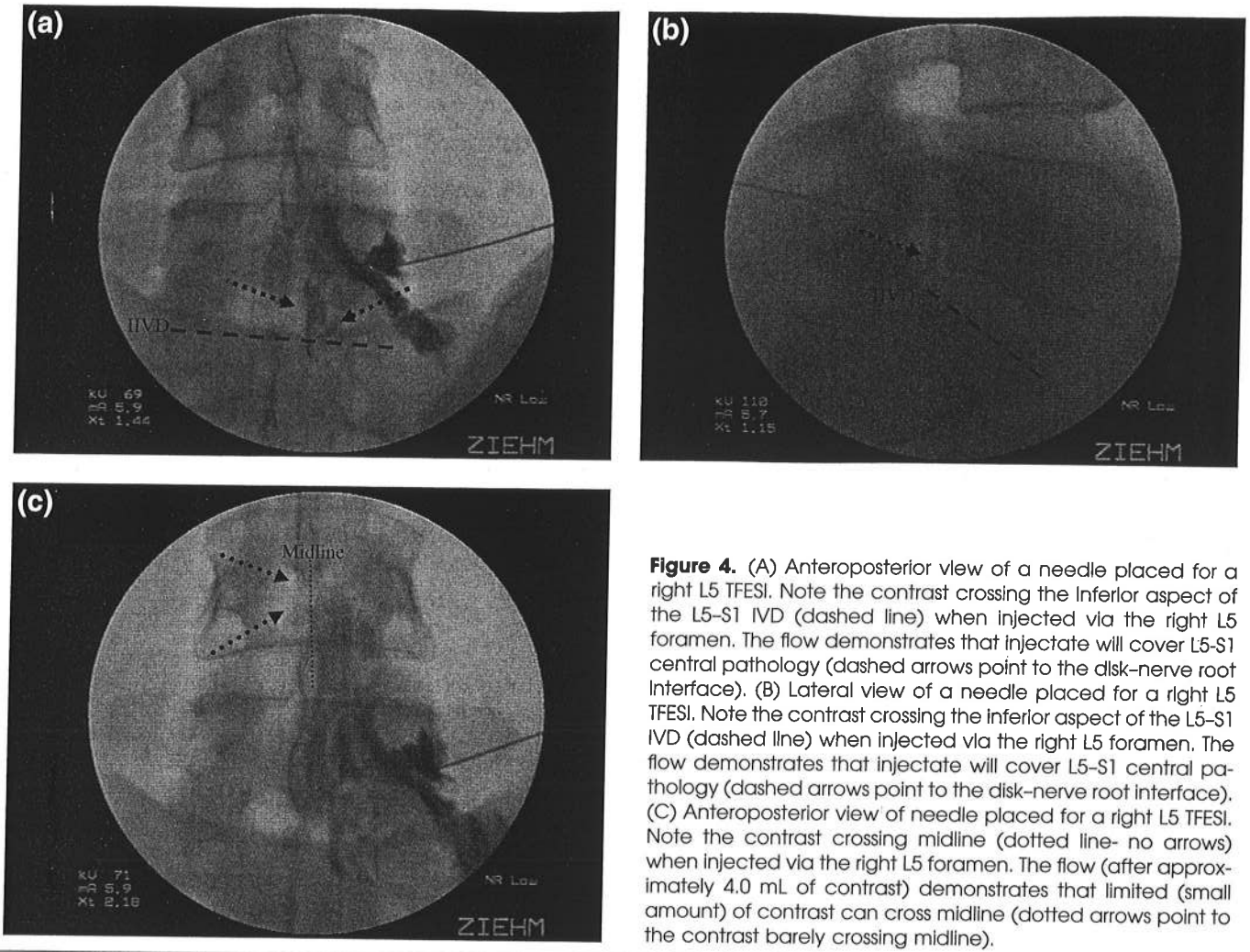

Figure 4. (A) Anteroposterior view of a needle placed for a right L5 TFESI. Note the contrast crossing the inferior aspect of the L5–S1 IVD (dashed line) when injected via the right L5 foramen. The flow demonstrates that injectate will cover L5-S1 central pathology (dashed arrows point to the disk–nerve root interface). (B) Lateral view of a needle placed for a right L5 TFESI. Note the contrast crossing the inferior aspect of the L5–S1 IVD (dashed line) when injected via the right L5 foramen. The flow demonstrates that injectate will cover L5–S1 central pathology (dashed arrows point to the disk–nerve root interface). (C) Anteroposterior view of needle placed for a right L5 TFESI. Note the contrast crossing midline (dotted line- no arrows) when injected via the right L5 foramen. The flow (after approximately 4.0 mL of contrast) demonstrates that limited (small amount) of contrast can cross midline (dotted arrows point to the contrast barely crossing midline).

tralateral spread is not surprising. In those patients in whom contralateral spread was not observed, one can postulate either the presence of a normal midline septum or soft-tissue contours resulting in unilateral contrast flow [17]. The variability in contrast volume that is necessary to reach adjacent segments can be explained by variations in each patient's anatomy and/or pathoanatomy, final needle tip position relative to the segmental level, or other minor procedural nuances. Theoretically, if flow routinely crosses midline, a 1-level (unilateral) injection for bilateral pathology can be performed.

Use of Contrast to Enhance the Therapeutic Benefit of L-TFEIs

Although flow patterns have been investigated, to the authors' knowledge, the quantification of contrast volumes to enhance and to optimize the proposed therapeutic benefit of L-TFEIs has not been investigated [18,19]. Currently reported L-TFESIs volumes range from 2.0 to 5.0 mL to coat the suspected pathologic site with a concentrated anesthetic/steroid solution [2,20]. In this study we investigated L-TFEI contrast flow by recording the volumes needed to reach fluoroscopically visualized spinal landmarks. These radiologic landmarks correspond to specific anatomical spinal targets that correlate with common clinical and radiographic pathological spine pain generators.

Furman et al [15] evaluated contrast flow to determine when injectate volumes are no longer considered diagnostic during L-TFEIs. Because diagnostic and therapeutic procedures have different intentions, our present therapeutic flow study differs from that previous study [15]. In this study we use the superior aspect of the superior IVD and the inferior aspect of the inferior IVD targets to document potential therapeutic coverage respectively for the superior and inferior disks. In the previous diagnostic study, the authors evaluated for flow to the "adjacent" structures by using the landmarks of the inferior (not superior) endplate of the

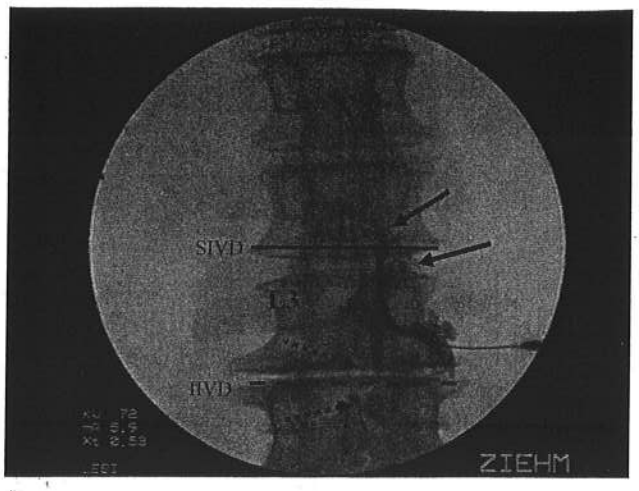

Figure 5. Anteroposterior view of a needle placed for a right L3 TFESI. Note the contrast crossing the superior aspect of the L2-3 superior IVD (solid line) and the inferior aspect of the L3-4 inferior IVD (dashed line) when injected via the right L3 foramen. The flow demonstrates that contrast will cover L2-3 central pathology (solid arrows point to the L2-3 disk-nerve root interface; dashed arrows point to the L3-4 disk nerve root interface). The flow demonstrates that contrast from one needle can cover both the superior and inferior levels to potentially treat 2 adjacent spinal segments.

superior disk and the superior (not inferior) endplate of the inferior disk. Their goal was to determine the volumes at which the flow would no longer be considered diagnostic because it would approach other potential pain generators.

In addition, the injection protocol used in the previous study was different. Instead of injecting contrast volume until a specific landmark was reached (as in this present study), contrast was injected in 0.5-mL aliquots [15]. The previous diagnostic study had included 30 subjects. A power analysis revealed that at least 52 subjects would be necessary to determine whether there were any effects on the different parameters (level injected, smoking history, and the diagnosis of spinal stenosis versus HNP). The authors also noted that if the contrast did not travel medial to the ipsilateral PED and was visualized extraforaminally, it was unlikely that contrast flow would ever flow in that direction (medially) despite the use of greater contrast volumes.

It has been reported that the injectate, when placed transforaminally, can flow to both the superior and inferior spinal segments from only one initial site of insertion [15,21]. In this study we attempted to identify the minimum injectate volumes necessary to reach postulated pathologic target sites for therapeutic lumbar transforminal procedures. In particular, in this study we attempted to quantify the minimum contrast volumes at which these L-TFEI procedures reach the following radiographic landmarks: the most medial aspect of the superior PED, the superior aspect of the adjacent superior IVD, the inferior aspect of the adjacent inferior IVD, and beyond the midline of the contralateral spinal segment.

MATERIALS AND METHODS

Patients who were clinically appropriate for L-TFESIs were recruited. Subjects with single or multilevel lumbar radicular pain (ie, L3, L4, L5, or S1) as the result of disk injury/herniation and/or central spinal stenosis who were deemed candidates for TFESIs were recruited for this study. We only evaluated contrast flow with L-TFEIs and not with sacral TFEIs because the anatomy of S1 is quite different. Pregnant patients or those with contrast allergy were excluded. York Hospital institutional review board approval was obtained, and all subjects underwent an informed consent of risk, benefits, and alternatives to participate in the study.

Sixty-nine patients were consented in the study analysis. The interventionalist or the referring physician determined the appropriate injection level according to the patient's clinical scenario, typically including imaging studies. In addition to the aforementioned volume data, the epidemiological data collected included gender, age, smoking history, diagnosis (eg, stenosis, disk herniation), presence or absence of previous spinal surgery, level of injection, and injection side.

All of the L-TFEIs were performed in a procedure suite at an ambulatory surgery center. The first author (M.B.F.) was present for all procedures performed. All subjects were placed in a prone position, and they were prepared and draped in sterile fashion. A registered nurse monitored vital signs and provided intravenous conscious sedation as needed. For the appropriate spinal segment, the oblique view of the intervertebral foramen was fluoroscopically visualized and optimized. The overlying soft tissue was anesthetized with 1% lidocaine without epinephrine (1% Lidocaine HCL, Hospira, Inc., Lake Forest, IL). A 22-gauge spinal needle was guided inferior to the pars interarticularis and into the intervertebral foramen by a subpedicular approach [2]. With the use of biplanar visualization, the needle was advanced into the "safe triangle," inferior to the PED and superolateral to the exiting spinal nerve [22,23]. In the lateral projection, needle placement was confirmed with the needle tip approximately 1 to 2 mm dorsal to the posterolateral vertebral body.

After needle position confirmation, a 3.0-mL syringe and extension tube system, which was used for injection, was filled and primed with contrast (ISOVUE 320, Bracco Diagnostics, Princeton, NJ). When more than 3.0 mL was injected, the empty 3.0-mL syringe was replaced with a full one. The contrast was injected under real-time continuous fluoroscopy at a consistent rate of 0.5 to 1.0 mL/min, monitored manually. As contrast reached the specified landmarks, the injection was paused and the volume injected was documented.

The images were evaluated for contrast spread to the following areas:

Table 1. *Demographics of study participants*

Demographic	n (%)
Male	22 (37)
Female	38 (63)
Average age	54 years (SD = 16) range, 25-83 years
History of previous surgery	12 (20)
History of smoking	13 (22)

Table 3. *Levels injected*

Level	Frequency	Percent
L L3	2	3
L L4	9	15
L L5	10	17
R L3	3	5
R L4	13	22
R L5	24	38

1. The medial aspect of the superior PED of the corresponding level of injection
2. The superior aspect of the superior IVD of the corresponding level of injection
3. The inferior aspect of the inferior IVD of the corresponding level of injection
4. Beyond the midline of the contralateral spinal segment
5. Both the superior IVD and the inferior IVD

As contrast reached the specified anatomical landmarks, the total contrast volume was recorded. The data from patients whose flow patterns revealed vascular flow (n = 2) were excluded from analysis because we typically reposition the needle tip and reinject contrast for these patients. If epidural flow was not obtained (n = 6), subjects were excluded from the quantitative analysis. A total of sixty patients were included into the final analysis.

RESULTS

Tables 1 to 3 show the subject demographics, their injuries, and the levels injected, respectively. For Tables 4 to 8, the "injected volume" is in the first column. The "frequency" (column 2) refers to the number of patients that required the specified "injectate volume" to reach the fluoroscopically visualized landmarks. The "percent" is calculated by dividing "frequency" by the number of patients. The "cumulative %" is a running percentage of patients that have reached the landmark as more "injectate volume" is placed. Figure 6 is a graph that corresponds to the data in Tables 4 to 8.

The average contrast volume observed to extend to the medial aspect of the superior PED of the corresponding level of injection was 0.33 mL (n = 60, SD = 0.196). The average contrast volume observed to extend to the superior aspect of the SIVD of the corresponding level of injection was 1.31 mL (n = 60, SD = 0.822). The average contrast volume observed to extend to the inferior aspect of the IIVD of the corresponding level of injection was 1.37 mL (n = 57, SD = 0.919). The average contrast volume observed to extend to both the superior and inferior IVDs was 1.85 (n = 56, SD = 0.872). The average contrast volume observed to extend to the contralateral spinal segment was 2.48 mL (n = 34, SD = 1.155).

A cumulative percent analysis was also performed and the results are as follows:

- After injection of 1.1 mL of contrast, 100% of L-TFEIs performed in this study had spread to the medial aspect of the superior PED of the corresponding level of injection.
- After injection of 2.8 mL of contrast, 95% of L-TFEIs performed in this study had spread to the superior aspect of the superior IVD of the corresponding level of injection.
- After injection of 3.6 mL of contrast, 92% of L-TFEIs performed in this study had spread to the inferior aspect of the IIVD of the corresponding level of injection.
- After injection of 3.0 mL of contrast, 85% of L-TFEIs performed in this study had spread to cover both the superior and inferior IVDs.
- After injection of 4.0 mL of contrast, 93% of L-TFEIs performed in this study had spread to cover both the superior and inferior IVDs.
- After injection of 4.0 mL of contrast, 52% of L-TFEIs performed in this study showed contralateral spread, although limited (26/61, or 43%). When there was contralateral spread (crossed the midline of the spinous pro-

Table 2. *Types of injuries of study participants*

Diagnosis	Frequency	Percent
Lumbar disk injury/herniation	31	51.67
Central spinal stenosis (foraminal excluded)	7	11.67
Both lumbar disk injury/herniation and central spinal stenosis	22	36.67
Total	60	100

Table 4. *Observed injectate volumes (mL) to the medial aspect of the superior pedicle of the corresponding level of injection*

Volume	Frequency	Percent	Cumulative Percent
0.1	4	6.67	6.67
0.15	10	16.67	23.33
0.17	1	1.67	25
0.2	10	16.67	41.67
0.25	1	1.67	43.33
0.3	15	25	68.33
0.4	3	5	73.33
0.5	7	11.67	85
0.6	7	1.67	6.67
0.8	1	1.67	98.33
1.1	1	1.67	100
Total	60	100	

Table 5. *Observed injectate volumes (mL) to the superior aspect of the superior IVD of the corresponding level of injection*

Volume	Frequency	Percent	Cumulative Percent
0.3	2	3.33	3.33
0.4	1	1.67	5
0.43	1	1.67	6.67
0.45	1	1.67	8.33
0.5	2	3.33	11.67
0.6	4	6.67	18.33
0.65	1	1.67	20
0.7	4	6.67	26.67
0.75	2	3.33	30
0.8	4	6.67	36.67
1.0	6	10	46.67
1.1	4	6.67	53.33
1.2	4	6.67	60
1.3	1	1.67	61.67
1.4	2	3.33	65
1.5	1	1.67	66.67
1.6	2	3.33	70
1.7	1	1.67	71.67
1.8	3	5	76.67
2.0	3	5	81.67
2.2	3	5	86.67
2.3	1	1.67	88.33
2.5	2	3.33	91.67
2.6	1	1.67	93.33
2.8	1	1.67	95
4.0	2	3.33	98.33
Never	1	1.67	100
Total	60	100	

Never = Despite injecting 5.5 mL of contrast, this landmark was never reached.

cess), it rarely resulted in substantial contrast into the contralateral epidural space (Figure 4C).

- Of note, after injecting only 0.5 mL, the contrast reached the superior IVD in 13% of patients and the inferior IVD in 16% of patients.

When using nonparametric analyses (Mann-Whitney *U* tests), we found no statistically significant differences in regard to the side injected or the level injected for flow volumes to the superior and inferior landmarks ($P = .804$, $P = .652$, $P = .389$, $P = .613$, respectively). Furthermore, an analysis of the diagnoses demonstrated no significant differences for flow volumes to the superior and inferior landmarks ($P = .294$, $P = .950$, respectively). Smokers required larger median flow volumes (1.8 mL) than nonsmokers (1.17 mL) for spread to the superior IVD of the corresponding level of injection ($P = .011$). Smoking had no impact on the injectate volumes for spread to the inferior IVD of the corresponding level of injection ($P = .563$). Those patients who had previous surgery had larger median flow volumes (0.300) than those who did not have surgery (0.275) for spread to the medial aspect of the superior PED of the corresponding level of injection ($P = .031$). Previous surgery had no impact on injectate volume to the inferior landmark ($P = .265$). A Spearman rho test indicated there was a statistically significant relationship noted between age and observing contralateral flow (rho = −0.411, $P = .018$), which indicates that as a subject's age increases, there is less contralateral contrast flow. All other nonparametric analyses performed to determine the impact on the injectate volume to landmarks were statistically insignificant, including the presence or absence of central or foraminal stenosis.

DISCUSSION

L-TFESIs are a validated treatment option within the comprehensive, nonsurgical armamentarium for radicular pain resulting from disk compression or spinal stenosis [2-9]. In these studies, total volumes used for "therapeutic injections" ranged from 0.5 mL to more than 5.0 mL of injectate. Therapeutic response to a TFESI is theoretically determined on the basis of precise localization of the concentrated medication to an anatomical spinal segment that correlates with the patient's clinical and radiographic examinations.

Table 6. *Observed injectate volumes (mL) to the inferior aspect of the inferior IVD of the corresponding level of injection*

Volume	Frequency	Percent	Cumulative Percent
0.2	1	1.67	1.67
0.3	5	8.33	10
0.4	2	3.33	13.33
0.45	1	1.67	15
0.5	2	3.33	18.33
0.6	2	3.33	21.67
0.65	1	1.67	23.33
0.7	3	5	28.33
0.75	1	1.67	30
0.8	6	10	40
0.85	1	1.67	41.67
0.9	1	1.67	43.33
1.0	2	3.33	46.67
1.1	1	1.67	48.33
1.3	2	3.33	51.67
1.4	2	3.33	55
1.5	3	5	60
1.6	3	5	65
1.7	1	1.67	66.67
1.8	2	3.33	70
2.0	3	5	75
2.2	3	5	80
2.3	1	1.67	81.67
2.5	3	5	86.67
2.6	2	3.33	90
2.9	1	1.67	91.67
3.0	1	1.67	93.33
3.6	1	1.67	95
4.3	1	1.67	96.67
Never	2	3.33	100
Total	60	100	

Never = Despite injecting 5.5 mL of contrast, this landmark was never reached.

Table 7. *Observed injectate volumes (mL) to the superior aspect of the superior IVD and the inferior aspect of the inferior IVD of the corresponding level of injection*

Volume	Frequency	Percent	Cumulative Percent
0.3	1	1.67	1.67
0.65	1	1.67	3.33
0.7	2	3.33	6.67
0.75	1	1.67	8.33
0.8	2	3.33	11.67
0.9	1	1.67	13.33
1.0	4	6.67	20
1.1	2	3.33	23.33
1.2	1	1.67	25
1.3	2	3.33	28.33
1.4	3	5	33.33
1.5	2	3.33	36.67
1.6	3	5	41.67
1.7	2	3.33	45
1.8	4	6.67	51.67
2.0	6	10	61.67
2.2	5	8.33	70
2.3	2	3.33	73.33
2.5	4	6.67	80
2.6	2	3.33	83.33
2.8	1	1.67	85
2.9	1	1.67	86.67
3.0	1	1.67	88.33
3.6	1	1.67	90
4.0	2	3.33	93.33
4.3	1	1.67	95
Never	3	5	100
Total	60	100	

Never = Despite injecting 5.5 mL of contrast, this landmark was never reached.

This observational study of TFEIs quantifies the contrast volume needed to reach specific anatomic landmarks. Because steroid injectate is less viscous than contrast [24] we would expect that the therapeutic steroid injectate would flow at least to the same landmarks, if not beyond them. When interventionalists are performing therapeutic TFESIs, their goal is typically to reach certain anatomic landmarks with their injectate. These data may help guide volumes of injectate needed to potentially reach these target landmarks.

Of course, many variables likely influence flow patterns and the response to therapeutic L-TFESIs, including but not limited to anatomical variations (size of foramen and central canal, postsurgical changes and/or scarring), coexisting spinal pathology (stenosis and disk pathology, multi-root involvement), and patient's medical history.

Central Landmarks

This study demonstrated that 3.0 to 3.6 mL of contrast will cover the superior IVD. Not all subjects achieved flow to both the superior IVD and inferior IVD; however, 4.0 mL of contrast will reach both the superior IVD and inferior IVD 93% of the time.

Conventional wisdom has been to inject inferior to the central pathology with the goal of placing the therapeutic injectate along the exiting spinal nerve into the foramen and along the medial aspect of the PED to the disk–nerve interface. Interestingly, our data demonstrate that contrast flow not only reaches these landmarks but also travels inferiorly to the disk–nerve interface immediately inferior to the needle tip. We have demonstrated that contrast from one needle will be able to cover central pathology immediately superiorly and inferiorly. On the basis of our data, interventionalists may consider a 1-level instead of a 2-level injection for 2-level central pathology or for patients with a bleeding risk (ie, anticoagulation, bleeding diathesis). For those patients with multilevel radicular pain, the interventionalist may consider injecting 2 nonadjacent levels (eg, right L3 [right L3-4 intervertebral foramen] and right L5 [right L5-S1 intervertebral foramen] to potentially cover the L2 through S1 levels).

Foraminal Landmarks

This study demonstrates that in all subjects after 1.1 mL of contrast was injected, the contrast spread to the medial aspect of the superior PED of the corresponding level of injection. Therefore, when one performs L-TFEIs for suspected pathology that may involve foraminal stenosis and/or a far lateral HNP, a therapeutic injection that uses injectate

Table 8. *Observed injectate volumes (mL) to beyond the midline of the spinous process of the corresponding level of injection*

Volume	Frequency	Percent	Cumulative Percent
0	1	1.67	1.67
0.75	1	1.67	3.33
1.0	3	5	8.33
1.25	1	1.67	10
1.6	2	3.33	13.33
1.7	1	1.67	15
1.8	2	3.33	18.33
2.0	2	3.33	21.67
2.1	1	1.67	23.33
2.2	1	1.67	25
2.25	1	1.67	26.67
2.3	1	1.67	28.33
2.7	2	3.33	31.67
2.8	3	5	36.67
3.0	1	1.67	38.33
3.1	2	3.33	41.67
3.2	1	1.67	43.33
3.3	1	1.67	45
3.6	1	1.67	46.67
4.0	3	5	51.67
4.3	1	1.67	53.33
5.4	1	1.67	55
Never	27	45	100
Total	60	100	

Never = Despite injecting 5.5 mL of contrast, this landmark was never reached.

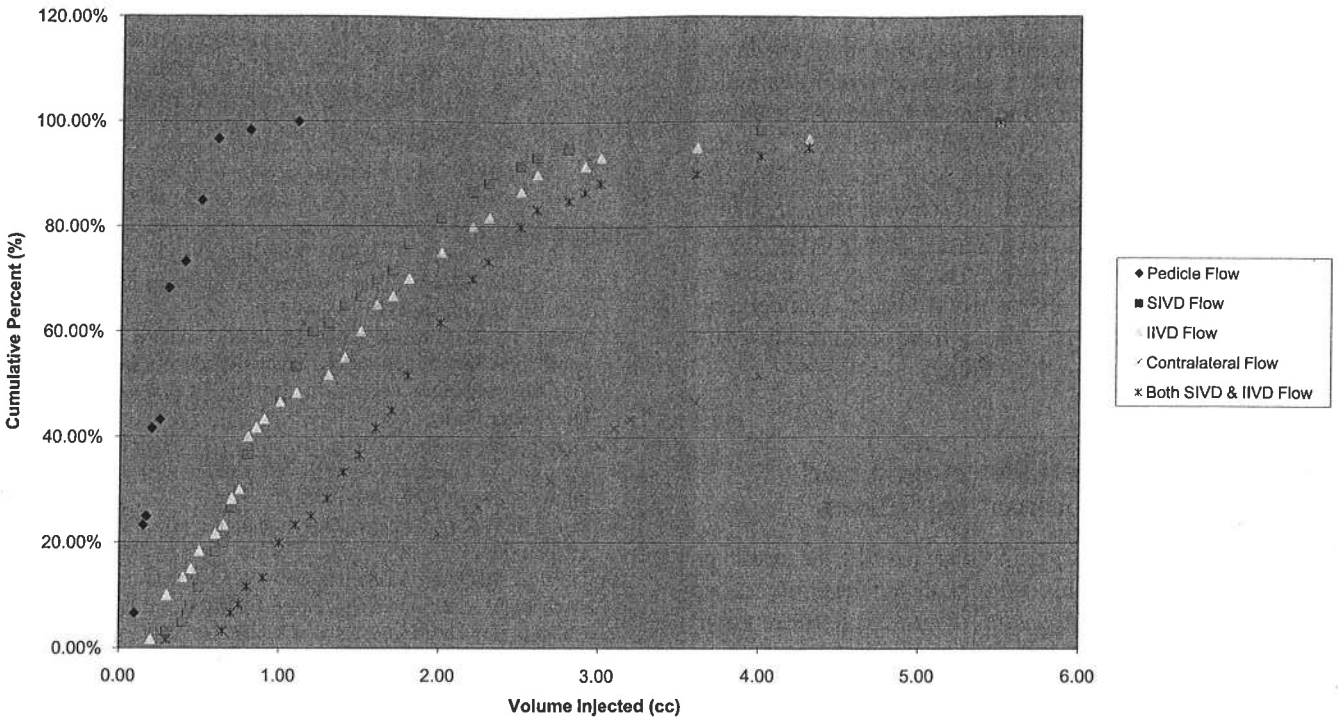

Figure 6. Cumulative percent flow to specific landmarks. SIVD = superior intervertebral disk, IIVD = inferior intervertebral disk.

volumes as little as 1.1 mL will most likely reach the same landmarks and the suspected pathologic site.

Contrast Flow Across Midline to Treat Contralateral Pathology

Theoretically, if flow routinely crosses midline, a 1-level (unilateral) injection for bilateral pathology can be performed. As previously demonstrated [15] this study also showed that only approximately one half of the patients (n = 33) demonstrated contrast flow across midline. Even when flow crossed the midline, it rarely completely bathed the contralateral side (Figure 4C). Therefore, assuming that injectate flow will be similar to contrast flow results, physicians should not rely on treating bilateral pathology with a unilateral procedure.

Limitations

One of this study's potential limitations is that contrast, anesthetic, and steroid solutions have different viscosities and may potentially have different epidural flow characteristics. As discussed, we would anticipate that because steroid injectate is less viscous than contrast [25] that it would flow at least to the same landmarks, if not beyond them (Table 9).

Another limitation is that we did not monitor the different flow patterns at various time frames after injection. One would assume that selectivity would decrease with time as the injectate diffuses into the soft tissues and other structures. With more time, we would again anticipate that the therapeutic steroid injectate would flow at least to the same landmarks, if not beyond them.

Careful attention was made for any visual evidence of extraforaminal flow of injectate. However, another limitation in this study is that some of the contrast may have traveled extraforaminally thus artificially increasing the amount of injectate needed to reach a target landmark.

Effect of Other Variables on Contrast Flow Volume

Our results suggest a possible relationship between age and contralateral flow, as well as between smoking and superior

Table 9. *The viscosities of different injectates*

Injectate (24-26)	Viscosity (centipoise)
Saline	1.0
1% Lidocaine	<1.5
Triamcinalone 40 mg/mL, 80 mg/mL	14
Triamcinalone (2 mL of 40 mg/mL) diluted to 6 mL with saline or 1% Lidocaine	~5.3-5.7
Triamcinalone (1 mL of 80 mg/mL) diluted to 3 mL with saline or 1% Lidocaine	~5.3-5.7
Omnipaque	6.3

flow. However, because of the small number, the statistically significant relationships noted in the results should be interpreted with caution. Otherwise, almost none of the variables demonstrated a statistically significant change on the injectate volumes needed to reach specific landmarks. Further research on the contrast flow when performing L-TFEIs can be performed to further elucidate a possible relationship between age and contralateral flow as well as between smoking and superior flow. Interestingly, larger flow volumes were needed for medial flow in patients who had undergone previous surgery. It is postulated that postsurgical tissue changes can contribute to this finding.

Difference Between Diagnostic and Therapeutic "Selective" Injections

The term "selective" has been used to describe diagnostic or therapeutic specificity. This commingling of the terms creates confusion in our field. A classic "diagnostic selective nerve block" typically implies injecting a low-volume anesthetic to anesthetize a discrete pathologic structure and to determine whether this is a pain generator. The term "therapeutically selective" is sometimes used to describe injecting the suspected pathologic site (ie, disk–nerve interface, central or foraminal stenosis attributable to bony or disk pathology) with an optimally concentrated therapeutic solution.

Although not the intent of this study, the present data demonstrate that TFEIs are not diagnostically selective. After only 0.5 mL was injected the contrast reached the superior IVD in 13% of patients and the inferior IVD in 16% of patients, clearly covering other pain-generating structures. Therefore, this study confirms the previous finding that even these low-volume injections are frequently not diagnostically selective [15].

CONCLUSIONS

This study demonstrates injectate volumes needed to reach specific anatomic landmarks in L-TFEIs. We found that 4.0 mL of contrast reaches both the superior aspect of the superior IVD and the inferior aspect of the inferior IVD 93% of the time.

Our study has the following implications for therapeutic L-TFESIs. Assuming that injectate flow will be similar to our contrast flow results:

1. Interventionalists should not rely on treating bilateral pathology with a unilateral procedure.
2. Interventionalists may consider a 1-level instead of a 2-level injection for patients with a bleeding risk or for 2-level central pathology.
3. Interventionalists may consider injecting 2 nonadjacent levels for multilevel radicular pain.

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