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Cross-sectional CT Assessment of the Extent of Injectate Spread at CT Fluoroscopy–guided Cervical Epidural Interlaminar Steroid Injections

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Background: Previous studies analyzed contrast agent spread during cervical interlaminar epidural steroid injections (CILESIs) by using planar fluoroscopy and reported wide variance of the rate of spread to the ventral epidural space (VES). Cross-sectional CT allows for direct viewing of contrast agent in the VES, providing improved spread assessment and thereby informing needle placement decisions when targeting pain generators.

Purpose: To determine the extent of injectate spread at CT fluoroscopy–guided CILESI, with particular attention to the VES and bilateral neuroforamina, by using cross-sectional CT.

Materials and Methods: This study reviewed 83 consecutive CT fluoroscopy–guided CILESIs at which a postprocedural cervical spine CT was performed (June 2016 to December 2017). All procedures used the same injectate (2 mL corticosteroid, 3 mL contrast agent). Postprocedural CT scans were reviewed for the presence of contrast within the VES, dorsal epidural space, ipsilateral neuroforamen, and contralateral neuroforamen in every cervical interlaminar level. Descriptive data are presented as frequencies or means. McNemar tests or hierarchical logistic models were used to assess associations between covariates and contrast agent spread to particular locations.

Results: The study cohort included 73 individual patients (59% women; 43 of 73) (mean patient age, 57.6 years ± 11.5 [standard deviation]). Mean number of levels of cranial spread were 0.6 level for VES, 1.9 levels for contralateral neuroforamen, 2.1 levels for ipsilateral neuroforamen, and 3 levels for dorsal epidural space. No VES spread in any level was found with 35% (29 of 83) of injections. VES spread was more likely to occur in the level of needle placement (43%; 36 of 83) than in other interlaminar levels (19.5%; 97 of 498; $P < .001$). Spread was more likely to occur in the neuroforamen ipsilateral to the needle approach compared with contralateral ($P < .001$).

Conclusion: Cervical interlaminar epidural steroid injections have injectate spreads with a mean of less than one level cranially in the ventral epidural space (VES) and approximately two levels in the neuroforamen. VES spread occurs more frequently at the level of needle placement and within the ipsilateral neuroforamen.

Cervical interlaminar epidural steroid injections (CILESIs) are common procedures that work via delivery of medication to a pain generator and are therefore targeted to specific locations on the basis of symptoms in the patient and findings at imaging (1–4). The required accuracy of this targeting is dependent, in part, on the extent of medication spread, with more extensive spread allowing for a needle placement more remote from the pain generator (4,5). Determining the extent of medication spread within the ventral epidural space (VES) and the neuroforamen in the cervical spine is particularly important because these locations are common origins for discogenic pain, cervicogenic radiculopathy, and cervicogenic headache (6–8).

The majority of CILESIs is performed by using planar fluoroscopy guidance. Therefore, previous studies (9–14) have used planar fluoroscopic images to analyze the extent of spread of contrast agent during the CILESI epidurography as a surrogate for medication spread. These studies (9–12,14) reported a wide range of rates of spread to the VES (range, 0%–93.3%). This wide variance may be because planar imaging cannot directly image contrast agent flow within the VES, which limits assessment. To our knowledge, no previous studies have determined the extent of contrast agent spread by using cross-sectional CT.

In 2015, the Multisociety Pain Workgroup (MPW; a consortium of 14 medical societies) published recommendations regarding epidural steroid injections including CILESI (15). They recommended that CILESI be performed in the C7/T1 interlaminar space and never superior to C6/C7. However, these recommendations were made with consideration of planar fluoroscopy guidance and not CT guidance. In an effort to more closely target pain generators, our group has been successfully performing CT fluoroscopy–guided CILESI at all levels of the cervical spine since 2009 (16).

Abbreviations

CILESI = cervical interlaminar epidural steroid injection, MPW = Multisociety Pain Workgroup, VES = ventral epidural space

Summary

Cranial spread of medication during cervical interlaminar epidural steroid injections is limited in its extent, particularly within the ventral epidural space and neuroforamen; therefore, injections more directly targeted to the pain generator will provide better delivery.

Key Points

- During cervical interlaminar epidural steroid injections (CILESIs), injectate spreads cranially from the needle site with a mean of 0.5 vertebral level in the ventral epidural space (VES), 1.9 levels in the contralateral neuroforamen, and 2.1 levels in the ipsilateral neuroforamen.
- During CILESIs, medication is significantly more likely to spread to the ipsilateral neuroforamen than the contralateral neuroforamen ($P < .001$).
- Spread to the VES is significantly more likely to occur in the level of the needle placement (43.4%) than in other interlaminar levels (19.5%) ($P < .001$).

The cross-sectional images acquired at CT allow for direct viewing of contrast agent within the VES and the bilateral neuroforamen resulting in improved assessment of the extent of spread during CILESI. This is important because it may help to inform decisions regarding needle placement when targeting specific pain generators. Previous studies (16,17) have demonstrated that CILESI can be performed in any interlaminar space throughout the cervical spine by using CT guidance. Therefore, needle placements closer to pain generators in the middle and superior cervical spine are possible, allowing for more accurate targeting. We hypothesize that injectate spread to the VES may be more limited in extent than previously reported. Thus, the purpose of our study was to determine the extent of injectate spread throughout the cervical spine in the immediate postprocedure period after CILESI, with particular attention to the VES and the bilateral neural foramina, by using cross-sectional CT.

Materials and Methods

This institutional review board–approved study was Health Insurance Portability and Accountability Act compliant and a waiver of written informed consent was granted. None of the authors are industry employees or consultants. The authors of this manuscript retained control of the data and information submitted for publication.

Study Cohort

This is a retrospective observational study that reviewed CT fluoroscopy–guided CILESI performed at a single tertiary referral academic institution from June 2016 to December 2017. We included consecutive patients who underwent postprocedural CT of the cervical spine. We acquired these immediate postprocedure scans to confirm that medication had spread to a target location specified by the referring clinician. We identified eligible patients by using the electronic medical record, picture archiving and communications system (Centricity, version 4.2; GE Healthcare, Waukesha, Wis), and departmental procedure schedules. Exclusion criteria were contraindication to the procedure or a nondiagnostic CT examination. No patients were excluded. Patient demographics were recorded.

Procedural Details and CT Technique

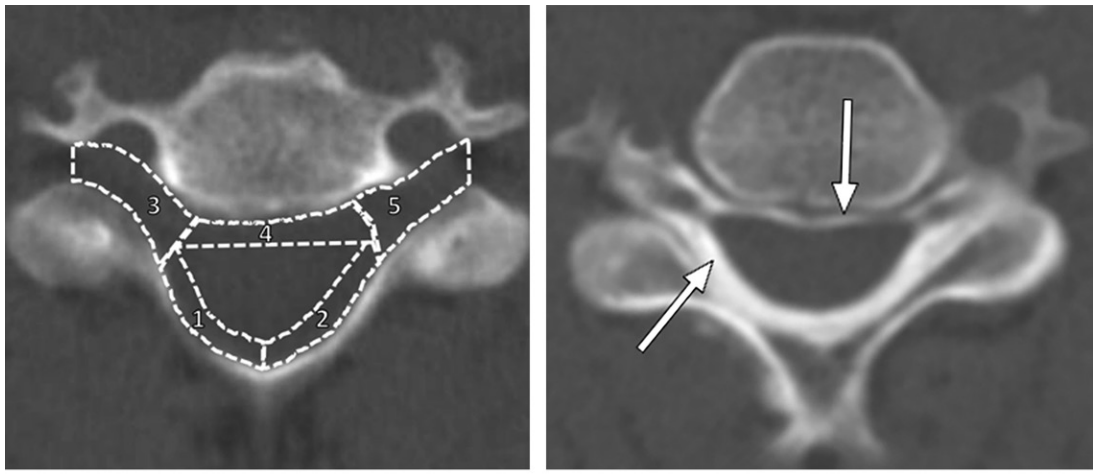
One of two neuroradiologists (T.A. and P.K., with 6 and 9 years of experience, respectively) performed all CT fluoroscopy–guided CILESI procedures by using previously described techniques (18).

As part of routine practice at our institution, we use a standard volume of injectate for all procedures, confirmed by a review of the procedural reports. On placement of the needle in the dorsal epidural space, appropriate positioning was confirmed with approximately 0.2 mL of contrast material (iopamidol; Isovue-M 200, Bracco Diagnostics, Princeton, NJ). Subsequently, a mixture of 2 mL of corticosteroid (betamethasone 6 mg/mL; Celestone Soluspan, Schering, Kenilworth, NJ) and 3 mL of contrast material was injected. It is established that larger volumes of contrast agent result in farther extent of spread throughout the epidural space (12–14,19,20). However, we chose 3 mL of contrast material because we felt it best reflected the volumes of medication typically delivered in clinical practice and because it was the most common volume previously examined in the planar fluoroscopy literature (11,12,14,21,22). Additionally, larger volumes of contrast material dilute the concentration of delivered steroid, which could reduce therapeutic efficacy.

A single 16 multi–detector row CT scanner (LightSpeed 16; GE Healthcare) equipped with CT fluoroscopy was used to perform all procedures and all postprocedure examinations. Each CT examination was performed in the immediate postprocedural period with the patient positioned supine by using the following standard protocol: 120 kVp; fixed tube current of 200 mA; field of view, 25 mm; contiguous 2.5-mm axial sections acquired from the skull base to T1.

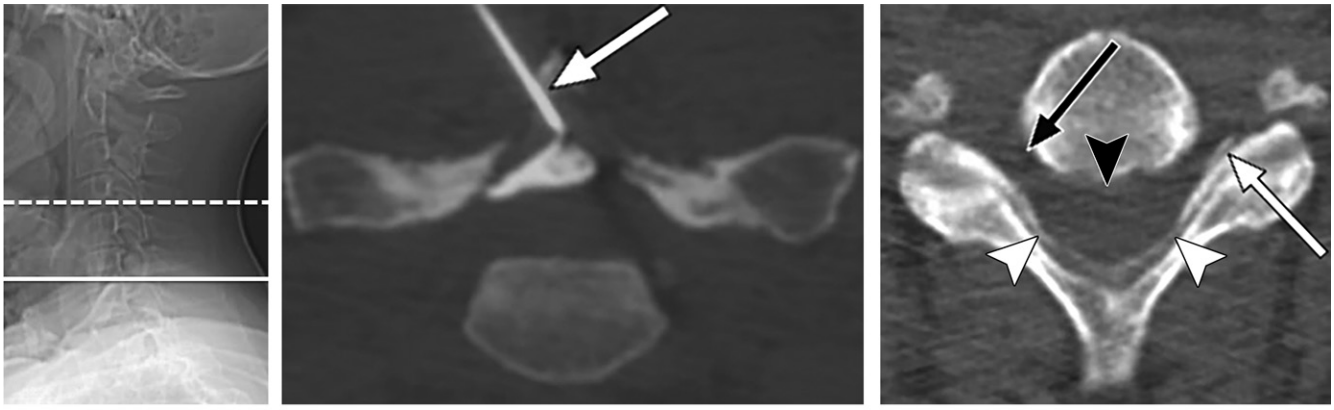
Image Analysis

Two neuroradiology fellows (P.P. and S.V., each with 1 year of experience) were blinded to the clinical indication for the examination and the radiologist that performed the procedure independently reviewed postprocedural CT scans to assess the extent of injectate spread. The level of the injection and the obliquity of the approach to the interlaminar space (ie, left or right) were recorded from intraprocedural images. On the postprocedure epidurogram, contrast flow extent was assessed for every interlaminar level throughout the cervical spine and the presence or absence of contrast material was recorded for each of the following locations: *(a)* ipsilateral dorsal epidural space, defined as the epidural space dorsal to the thecal sac extending from midline to the medial aspect of the ipsilateral facet joint; *(b)* contralateral dorsal epidural space, the epidural space dorsal to the thecal sac extending from midline to the medial aspect of the contralateral facet joint; *(c)* ipsilateral neuroforamen, the perineural epidural space surrounding the ipsilateral nerve root lateral to the medial aspect of the ipsilateral facet joint;



a. b.

Figure 1: Axial CT images in a 55-year-old woman with neck pain and bilateral upper extremity radicular pain, right side greater than left side. Cervical interlaminar epidural steroid injection was performed on the right side in vertebrae C3/C4. **(a)** Preprocedural noncontrast-enhanced image in vertebrae C4/C5 shows a classification scheme for location of injectate spread. Regions include ipsilateral dorsal epidural space (zone 1), contralateral dorsal epidural space (zone 2), ipsilateral neuroforamen (zone 3), ventral epidural space (zone 4), and contralateral neuroforamen (zone 5). **(b)** Postprocedural image in vertebrae C4/C5 shows epidurography contrast material (arrows) spread to all zones.



a. b. c.

Figure 2: Axial CT images in a 47-year-old man with neck pain and left upper extremity radiculopathy. Cervical interlaminar epidural steroid injection was performed on the left in vertebrae C6/C7. **(a)** Preprocedural lateral scout image. Horizontal solid white line indicates level of injection in **b** and dashed white line indicates the level of image in **c**. **(b)** Axial CT fluoroscopy image acquired during eccentric left needle (arrow) placement in vertebrae C6/C7. **(c)** Axial CT in vertebrae C4/C5 acquired during postprocedure imaging. Note the presence of contrast material within the bilateral dorsal epidural spaces (white arrowheads) and the ipsilateral neuroforamen (white arrow). Contrast agent is not present in the ventral epidural space (black arrowhead) or the contralateral neuroforamen (black arrow).

(d) VES, the epidural space ventral to the thecal sac extending between the medial aspects of the bilateral facet joints; and *(e)* contralateral neuroforamen, the perineural epidural space surrounding the contralateral nerve root lateral to the medial aspect of the contralateral facet joint (Figs 1, 2). There were disagreements between the primary readers (P.P. and S.V.) in 11.7% (339 of 2905) of locations, which were adjudicated by a board-certified radiologist (T.A., with a certificate of added qualification in neuroradiology and 6 years of experience performing CT fluoroscopy–guided CILESI).

Image acquisition time stamps were reviewed on a picture archiving and communication station (Centricity, version 4.2; GE Healthcare) by a single radiologist (T.A.) to determine the duration of time between injection of injectate and the performance of the postprocedural CT.

Statistical Analysis

We used descriptive statistics including means and standard deviations to present patient demographics and frequencies of injections at cervical interlaminar level and extent of contrast agent spread. We used a McNemar test to assess for associations between needle laterality and spread to the neuroforamen. Hierarchical logistic mixed-effects models were used to evaluate ventral epidural spread in the level of needle placement versus in other interlaminar levels, and for differences in the extent to spread to different zones at C2/C3 between the MPW (C6/C7

Table 1: Patient Demographic Information

Parameter	Total
Mean age at procedure (y)*	57.6 ± 11.5 (33.8–85.6)
No. of men†	30/73 (41)

Note.—Mean data are ± standard deviation. Only the first procedure is included. There was a total of 73 patients.

* Data in parentheses are age range.

† Data are numerator/denominator; data in parentheses are percentage.

Table 2: Distribution of Needle Placements by Cervical Interlaminar Level

Interlaminar Level	No. of Needle Placements
C1/C2	0
C2/C3	0
C3/C4	5 (6)
C4/C5	11 (13)
C5/C6	37 (45)
C6/C7	24 (29)
C7/T1	6 (7)
Total needle placements	83

Note.—Data in parentheses are percentages.

and C7/T1 injection levels) and non-MPW groups (C1/C2 through C5/C6 injection levels).

For statistical analysis, we used commercially available software (SAS 9.4; SAS Institute, Cary, NC), and *P* values less than .05 indicated statistical significance.

Results

Study Cohort

We identified a total of 83 procedures in 73 individual patients (59% women; 43 of 73 patients) with a mean age of 57.6 years ± 11.5 (standard deviation; Table 1). The distribution of needle placements by interlaminar level is listed in Table 2. There was a nearly even distribution of needle approaches with respect to laterality (57%, right side; 47 of 83). There were no immediate complications.

Image Analysis

Postprocedural CT images were obtained at an average of 6:29 minutes ± 1:18 after injection.

Table 3 shows the mean number of vertebral interspace levels of contrast agent spread for each anatomic zone. We found no ventral spread in any level in 35% (29 of 83) of injections. Spread to the VES was more likely to occur in the level of the needle placement (43%; 36 of 83) than in interlaminar levels other than where the needle was placed (19.5%; 97 of 498; $P < .001$). Needle approach laterality was associated with spread to ipsilateral neuroforamen (60.9%; 354 of 581) compared with the contralateral neuroforamen (52.0%; 302 of 581; $P < .001$).

Table 4 shows the frequency of the extent of cranial contrast agent spread away from the level of injection. For injections in

Table 3: Number of Levels of Contrast Agent Spread by Anatomic Zone

Anatomic Zone	Levels of Contrast Agent Spread	Levels of Cranial Contrast Agent Spread	Levels of Caudal Contrast Agent Spread
VES	1.6 ± 1.6	0.6 ± 1.1	0.7 ± 0.9
CNF	3.6 ± 1.8	1.9 ± 1.4	1.2 ± 0.9
INF	4.3 ± 1.7	2.1 ± 1.3	1.4 ± 0.9
DES	5.5 ± 1.2	3 ± 1	1.7 ± 0.9

Note.—Data are mean number of levels ± standard deviation. CNF = contralateral neuroforamen, DES = dorsal epidural space (contralateral and ipsilateral dorsal epidural spaces were combined), INF = ipsilateral neuroforamen, VES = ventral epidural space.

C7/T1, which is the interlaminar level recommended by the MPW, the mean number of levels of cranial spread was as follows: in the VES, 0.5 levels ± 0.8 (range, 0–2); in the contralateral neuroforamen, 1.7 levels ± 2 (range, 0–5); and in the ipsilateral neuroforamen, 1.2 levels ± 0.4 (range, 1–2).

Because the MPW recommends that CILESI not be performed superior to C6/C7, injection locations at non-MPW-recommended levels therefore included C1/C2 through C5/C6 (15). By examining the rate of spread to C2/C3, a level responsible for cervicogenic headache, we found a trend toward a greater probability of covering the C2/C3 ipsilateral and contralateral neuroforamen in injections performed in the non-MPW levels compared with the MPW levels ($P = .12$ and $P = .06$, respectively) (Table 5). We found no significant difference in the probability of covering the C2/C3 VES between the two groups ($P = .94$).

Discussion

The therapeutic efficacy of cervical interlaminar epidural steroid injection (CILESI) depends on medication delivery to the target pain generator. Contrast agent spread represents a visual surrogate for medication delivery and thereby informs how close the injection site should be to the target. We found that cranial spread of injectate is relatively limited within the ventral epidural space (VES) and neuroforamen. Contrast material extends only a mean of 0.6 cervical levels in the VES, 1.9 levels in the contralateral neuroforamen, and 2.1 levels in the ipsilateral neuroforamen. To our knowledge, our study is the first to evaluate the extent of contrast agent spread during CILESI by using CT. Our data showed no contrast agent spread to the VES at any level in 35% (29 of 83) of injections. Contrast agent spread was more likely to occur within the foramen ipsilateral (60.9%; 354 of 581) to the needle placement than within the contralateral foramen (52.0%; 302 of 581).

The relatively small mean number of levels of cranial contrast agent spread at immediate postprocedural imaging suggests that injections in the inferior cervical spine (ie, C6/C7 or C7/T1) may not provide adequate delivery to the VES and neuroforamen in the middle and superior cervical spine. Our results show that injections should be within one to two interlaminar spaces from the target to achieve adequate medication delivery. When

Table 4: Frequency of Cranial Spread of Contrast Agent at Specified Number of Levels Away from Injection Site Categorized by Anatomic Zone

Cranial Spread	VES (*n* = 83)	CNF (*n* = 83)	INF (*n* = 83)	DES (*n* = 83)
Level of injection	65% (54)	93% (77)	100% (83)	100% (83)
One level	32% (27)	81% (67)	90% (75)	100% (83)
Two levels	17% (14)	55% (46)	63% (52)	92% (76)
Three levels	8% (7)	39% (32)	41% (34)	72% (60)
Four levels	5% (4)	13% (11)	17% (14)	35% (29)
Five levels	1% (1)	2% (2)	1% (1)	5% (4)
Six levels	0	0	0	1% (1)

Note.—Data in parentheses are number of injections. CNF = contralateral neuroforamen, DES = dorsal epidural space (contralateral and ipsilateral dorsal epidural spaces were combined), INF = ipsilateral neuroforamen, VES = ventral epidural space.

Table 5: Frequency of Spread to C2/C3 by Anatomic Zone

Anatomic Zone	All Injections (%)	MPW Levels (C6/C7 and C7/T1) (%)	Non-MPW Levels (C1/C2–C5/6) (%)
VES	10 (8/83)	10 (3/30)	9 (5/53)
CNF	41 (34/83)	27 (8/30)	49 (26/53)
INF	35 (29/83)	20 (6/30)	43 (23/53)
DES	74 (61/83)	50 (15/30)	87 (46/53)*

Note.—Data in parentheses are numerator/denominator. CNF = contralateral neuroforamen, DES = dorsal epidural space (contralateral and ipsilateral dorsal epidural spaces were combined), INF = ipsilateral neuroforamen, MPW = Multisociety Pain Workgroup, VES = ventral epidural space.

* Statistically significant difference between Multi-Society Pain Workgroup and non–Multi-Society Pain Workgroup groups.

targeting pain generators within the VES, the needle should be placed at the same level as the target because VES contrast agent spread is more likely in the level of injection (43%; 36 of 83) than in levels removed from the needle (19.5%; 97 of 498). Finally, for patients with unilateral pain, injections should be performed ipsilateral to the side of the pain generator.

Previous studies (9–14) purport adequate medication coverage throughout the entire cervical spine during CILESI with a needle placement in either C6/C7 or C7/T1 (Table 6). These investigations (9–12,14) report a wide range of rates of contrast agent spread to the VES (0%–93.3%). This may reflect uncertainty regarding spread to this location on review of planar fluoroscopy images, most commonly anteroposterior and lateral views. Small volumes of contrast agent may not be visible with planar fluoroscopy. Furthermore, overlapping contrast agent may result in a false-positive appearance of contrast agent within the VES or neuroforamen (23,24). The cross-sectional imaging in our study provides direct viewing and is a more accurate method for determining three-dimensional spread. In many of these previous studies, the radiographic criteria for VES contrast agent spread are not clearly defined. Our study includes clear definitions for spread on the basis of anatomic zones, greatly reducing ambiguity.

Previous reports (10–13) regarding the extent of craniocaudal contrast agent spread during CILESI are also wide ranging (2.9–13.6 levels). This variability is in part because disparate volumes of contrast agent were injected in the different studies. Three previous investigations are similar to our study because they also injected 3 mL of contrast agent, and reported craniocaudal contrast agent spread of 3.6, 6.9, and 11 levels, respectively (11–13). We found a mean of 5.5 levels of craniocaudal contrast agent spread within the dorsal epidural space, concordant with previous literature. Medication delivery to the dorsal epidural space is of limited use, however, because most pain generators are present within the VES or neuroforamen.

The 2015 MPW recommendations limiting CILESI to C6/C7 or C7/T1 reflects a belief that these injections can still provide adequate medication delivery to the middle and superior cervical spine (15). Recent publications (16,17) demonstrate that CT fluoroscopy–guided CILESI can be performed in all interlaminar spaces throughout the cervical spine. Our results confirm a greater probability of covering the middle and superior cervical spine, including the bilateral neuroforamen in C2/C3 (a level responsible for cervicogenic headache), with injections above the MPW recommended levels (8).

Cervical transforaminal epidural steroid injection, or CTFESI, offers an alternative approach for achieving injectate spread to a target pain generator. CTFESI could result in improved coverage to the VES and ipsilateral neuroforamen. However, spread into the spinal canal during CTFESI is often limited by neuroforaminal stenosis. A detailed review of the comparative efficacy and safety of CTFESI and CILESI is beyond the scope of this study, but can be found elsewhere (25,26). Future studies could examine injectate spread by comparing CTFESI with CILESI.

Our study had several limitations. First, and most importantly, we did not assess the clinical efficacy of CILESIs. Immediate postprocedural spread of injectate to the intended target, an imaging observation, is not an established surrogate for clinical outcome. Second, we acquired images only at one point, immediately after the injection. It is possible that there may be further spread of injectate at later points, including spread to middle and superior cervical spine pain generators after injection at C7/T1. Finally, larger volumes of contrast agent would presumably result in further spread.

Our study demonstrated that injectate spread during cervical interlaminar epidural steroid injections extended in the ventral epidural space (VES) a mean of less than one level cranially from the injection site and a mean of approximately two levels in the bilateral neuroforamina. Additionally, spread to the VES was more likely to occur in the level of the needle placement and in the neuroforamen ipsilateral to the needle. Overall, our findings suggest that needle placement closer in

Table 6: Characteristics of Studies that Assessed Contrast Agent Spread in Cervical Interlaminar Epidural Steroid Injections

Study Author	No. of Injections	Injection Locations	Imaging Method	Volume of Injectate (mL)	Anatomic Zone Definition	Rate of Spread to VES (%)	Mean No. of Vertebral Levels of Total Craniocaudal Spread	Mean No. of Vertebral Levels of Cranial Spread	Mean No. of Vertebral Levels of Caudal Spread
Goel et al (11)	65	C6/C7 or C7/T1	AP and lateral planar fluoroscopy	2, 3, or 4	Not defined	44.6*	NS	3.61–3.88	NS
Kim et al (12)	90	C6/C7	AP and lateral planar fluoroscopy		Not defined		NS		
A				1		56.7*		2.40 ± 1.16	2 ± 1.05
B				2		90*		3.46 ± 1.04	2.10 ± 1.21
C				3		93.3*		3.96 ± 1.09	2.90 ± 1.29
Lee et al (13)	126	C7/T1	AP and lateral planar fluoroscopy		Defines craniocaudal spread only	NS			
A				2.5			8.3 ± 3.1†	4.0 ± 2.1	4.3 ± 2.3
B				5			11.0 ± 3.7	5.5 ± 1.3	5.2 ± 3.6
C				10			13.6 ± 5.1	6.0 ± 1.3	6.9 ± 4.3
Choi et al (9)	31	NS	AP and lateral planar fluoroscopy	2	Defines VES only	90.3‡	NS	NS	NS
Park et al (14)	80	C7/T1	AP and CLO planar fluoroscopy; fluoroscopic 3D reconstructions		Not defined		NS	NS	NS
A				3		78.9			
B				4.5		84.6			
C				6		85.7			
Gill et al (10)	24	C6/C7 or C7/T1	AP, lateral, and multiple CLO views planar fluoroscopy	0.5–3 (1.5)§	Clearly defined	0	NS	1.54 ± 0.88	1.38 ± 0.88

Note.—Mean data are ± standard deviation. The anatomic space used to assess cranial and caudal spread was not clearly specified in the studies by Kim et al (12), Goel et al (11), and Gill et al (10), but is presumed to be the dorsal epidural space. A, B, and C indicate separate groups on the basis of total volume of injectate. 3D = three dimensional, AP = anteroposterior, CLO = contralateral oblique, NS = not specified, VES = ventral epidural space.

* Ventral epidural spread not defined; uncertain if this is at level of needle placement only or further extent.

† Lee et al (13) assessed craniocaudal spread in the dorsal epidural space.

‡ Ventral epidural spread rate is for level of needle placement only.

§ Data in parentheses are median.

proximity to the target pain generator results in more reliable medication delivery. Further study is warranted to determine if patient outcomes are improved with more direct targeting of middle and superior cervical spine pain generators by using CT fluoroscopy guidance.

Author contributions: Guarantor of integrity of entire study, T.J.A.; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; approval of final version of submitted manuscript, all authors; agrees to ensure any questions related to the work are appropriately resolved, all authors; literature research, T.J.A., P.P., P.G.K.; clinical studies, T.J.A., S.V., P.P., P.G.K.; statistical analysis, T.J.A., E.B., S.V., P.P., R.L., S.L.; and manuscript editing, T.J.A., E.B., P.G.K.

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