J Chin Med Assoc

ORIGINAL ARTICLE

Usefulness of cone-beam computed tomography-reformatted epidurography in percutaneous epidural adhesiolysis: A pilot study

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Abstract

Background: Conventional epidurography (CE) is thought to have insufficient usefulness on percutaneous epidural adhesiolysis (PEA). We aimed to evaluate the association between the outcome of PEA and cone-beam computed tomography-reformatted epidurography (CBCT-RE).

Methods: After ethics board approval and written informed consent were obtained, we performed 30 PEA in 26 participants, and evaluated their post-PEA image findings. Two independent radiologists categorized and recorded the occurrence of contrast in the intracanal ventral and extraforaminal regions on CE, and in the dorsal canal (DC), ventral canal (VC), dorsal foramen (DF), and ventral foramen (VF) on CBCT-RE. Reproducibility was assessed using intraclass correlation coefficients (ICCs). Baseline characteristics along with contrast distribution patterns of CE and CBCT-RE were analyzed in terms of their association with symptom relief at 1 month after PEA.

Results: The rate of patients with symptoms relief >50% after PEA was 63.3%. The inter-reader agreement was higher for CBCT-RE (ICC = 0.955) than for CE (ICC = 0.793). Participants with contrast coexisting in VC and DF adjacent to the irritated nerve root on CBCT-RE ($p = 0.015$) had a significantly better response after PEA than those without contrast at these locations on CBCT-RE, independent of baseline characteristics (adjusted odds ratio: 11.414 [$p = 0.012$]).

Conclusion: CBCT-RE with identifying contrast distribution patterns is useful for predicting outcome of PEA.

Keywords: Cone-beam computed tomography-reformatted epidurography; Conventional epidurography; Failed back surgery syndrome; Percutaneous epidural adhesiolysis; Spinal stenosis

1. INTRODUCTION

Percutaneous epidural adhesiolysis (PEA) is performed to treat failed back surgery syndrome (FBSS) and spinal stenosis (SS) that are refractory to more conventional treatments, such as epidural steroid injections.[1,2] There is strong evidence for the short-term (<3 months) and moderate evidence for the mid-to-long-term (>3 months) efficacy of PEA.[3] As the rate of spinal surgery continues to rise, PEA has emerged as a popular treatment for FBSS.

In participants with FBSS and SS, conventional epidurography (CE) is a very common and effective method for the identification of epidural adhesions, and is used to predict the outcome of PEA.[4–6] However, some reports have shown that CE has low clinical credibility because of a lack of significant correlation between the filling defects on CE and area treated using PEA.[7,8] The cause of this discrepancy is probably the inability of CE to clearly identify the locations (dorsal, ventral, foraminal) of filling defects and concomitant pathologies (herniated disks, SS).[8] Hence, more detailed anatomical information is required to make epidurography reliable for use with PEA.

Three-dimensional (3D) rotational myelography using cone-beam computed tomography (CBCT) was described and clinically applied by Kufeld et al.[9] Multiplanar reformatting allows radiologists to easily interpret images, obtaining coronal, axial, paraxial sagittal, and parasagittal reconstructions with different degrees of obliquity. Moreover, the initial results of El-Sheik et al[10] indicated that the artifacts caused by metal implants may influence CBCT images less than conventional radiographs and CT images. To the best of our knowledge, the application of 3D reformatted images of epidurography to anatomic structures other than cerebral arteries has not been reported previously.

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Conflicts of interest: The authors declare that they have no conflicts of interest related to the subject matter or materials discussed in this article.

Journal of Chinese Medical Association. (2024) 87: 131-137.

Received April 29, 2023; accepted September 12, 2023.

doi: 10.1097/JCMA.0000000000001024

The purpose of this study was to evaluate the association between 3D reformatted images from epidurography acquired using CBCT and the outcome of PEA. We refer to this method as CBCT-reformated epidurography (CBCT-RE).

2. METHODS

2.1. Participant selection

This prospective study protocol was approved by the ethics committee (approval number 1-105-05-141), and informed consent was obtained from all subjects. Participants were included in the study only if they met the following conditions: (1) included participants had been diagnosed with FBSS or SS with unilateral radiculopathy. (2) All participants, consecutively referred from clinical physicians, reported a history of discogenic or radicular symptoms that had been refractory to conservative treatments and epidural steroid injection for a minimum of 6 weeks. (3) Each participant received an epidural steroid injection, and if symptoms persisted or relief was insufficient, the participant underwent PEA at least 6 weeks later. (4) A positive provocative test during PEA was used to confirm the affected spinal level.[11] (5) All participants underwent CE before PEA, and both CE and CBCT-RE after PEA. We excluded the participants who had any of the following conditions: (1) participants with a history of cauda equina syndrome, bleeding diathesis, comorbid somatic or psychiatric disease, vertebral fractures, pregnancy, tumors, or other underlying systemic diseases that could significantly influence the procedural outcomes. (2) Magnetic resonance imaging (MRI) and/or CT performed before PEA was used to rule out diagnoses other than FBSS. (3) Participants with bilateral symptoms who lacked a reaction to the provocation during PEA. The investigators analyzed the medical and radiographic records of the participants who underwent lumbar PEA at a single university hospital.

2.2. PEA procedure

A 1-day PEA procedure was standardized in all participants, as previously described,[1,2] and performed by one radiologist (Y.C.H). On confirmation of the target, an angiographic catheter (Cobra 4-Fr; Cordis, Miami Lakes, FL) and/or coaxial supporting catheter (Chiba 6-Fr; Cook, Bloomington, IN) was inserted toward the target site. When the target site was reached, CE (Omnipaque; GE Healthcare, Carrigtohill, Co. Cork, Ireland) was performed by injecting 3 mL of the contrast agent for the identification of filling defects surrounding the target area. Anteroposterior, right and left oblique, and lateral fluoroscopic views were obtained. The investigators chose the target roots for PEA by clinical dermatome involvement and provocation tests. The catheter tip was positioned at the ventral epidural space of the target site or at the opening of the foramen in participants with foraminal diseases.[12] Participants were asked to report provoked symptoms when the tip of the catheter touched the target site or the contrast agent exerted pressure on the lesion. Mechanical and fluid adhesiolysis were performed. Immediately following PEA, CE, and CBCT-RE were repeated. Although inadequate contrast filling at the target area could be seen on some post-PEA imaging, we did not perform further interventional procedures. Because excessive manipulation during PEA may lead to serious complications, such as dural puncture, catheter cutting, and hematoma.[3] All CE and CBCT-RE images were saved in the Digital Imaging and Communications in Medicine (DICOM) format. Finally, once imaging was completed, a 40 mg triamcinolone acetonide (Yung Shin, Taichung, ROC) was slowly injected into the epidural space.

2.3. CBCT-RE technique

After PEA, CBCT-RE was performed using a digital bi-plane angiography system (Allura Xper, Philips, Best, The Netherland). A 240° rotation of the tube-camera unit forward and backward around the participant's longitudinal axis was performed within 4 seconds using an acquisition matrix of 1024 × 1024 pixels, resulting in 120 radiographs. Raw data were exported to a dedicated workstation (Philips Xtra vision workstation). The reconstruction time was 30 seconds. Detailed information regarding technical performance and reconstruction procedure has been reported.[13]

2.4. CE and CBCT-RE contrast distributions

Post-PEA CE contrast patterns were defined and classified into two types: limited intracanal ventral spread (ICV) and extended extraforaminal spread (EF) (Fig. 1).[4,6] For CBCT-RE, the investigators divided the contrast distributions into four areas: dorsal canal (DC), ventral canal (VC), dorsal foramen (DF), and ventral foramen (VF) (Fig. 2). Two blinded musculoskeletal radiologists (Y.C.H, G.S.H) analyzed the CE and CBCT-RE images. The investigators reached a consensus on whether a discrepancy existed between the analyses of these images.

2.5. Data collection

All participants were clinically evaluated before and 1 month after PEA by a pain specialist nurse who blinded to the treatment details. The intensity of leg and back pain before PEA was assessed using a subjective visual analog scale (VAS) calibrated from 0 to 10 (0 = no pain; 10 = the worst pain imaginable). For the comparison of clinical outcomes according to symptom relief, responses were dichotomized to ≥50% or <50% symptom relief. To understand radiation exposure in PEA, simulations were performed with participant-specific input parameters (weight and length) and the actual CBCT-RE system settings for each frame, including the automatic modulation of beam energy, dose level, and collimation. The effective dose was calculated using the latest International Commission on Radiological Protection (ICRP) 103 weighing factors.[14]

2.6. Statistical analysis

Age, discomfort duration before PEA, and VAS scores were expressed as mean ± SD. Inter-reader agreement was evaluated using intraclass correlation coefficients (ICCs), calculated for the contrast distribution of CE and CBCT-RE.[15] Demographic data and the contrast distribution of CE and CBCT-RE were compared using the Chi-square test, Fisher exact test, or unpaired *t* test. Logistic regression analysis was used to predict the outcome of PEA. All statistical analyses were performed using SPSS (v. 22; SPSS, Inc. Chicago, IL). $p < 0.05$ was considered statistically significant.

3. RESULTS

During a 21-month period (December 2017 to August 2019), 35 participants had been performed PEA, CE, and CBCT-RE. Of these participants, four had bilateral symptoms, and five did not have provocation symptoms during PEA were excluded. Finally, 30 PEA procedures were performed in 26 participants (mean age, 71 ± 11 years; 12 women) successfully included (Fig. 3). Three participants with SS had no previous history of lower back surgery. The PEA procedures were performed in the preoperative target nerve roots (two nerve roots in 14 procedures and one nerve root in 12 procedures). Each participant had provoked symptoms in one nerve root during PEA. Repeat PEA was performed in four of 26 participants because of poor response or recurrent symptoms. The average time interval between PEA and evaluation of symptom relief was 1 month.

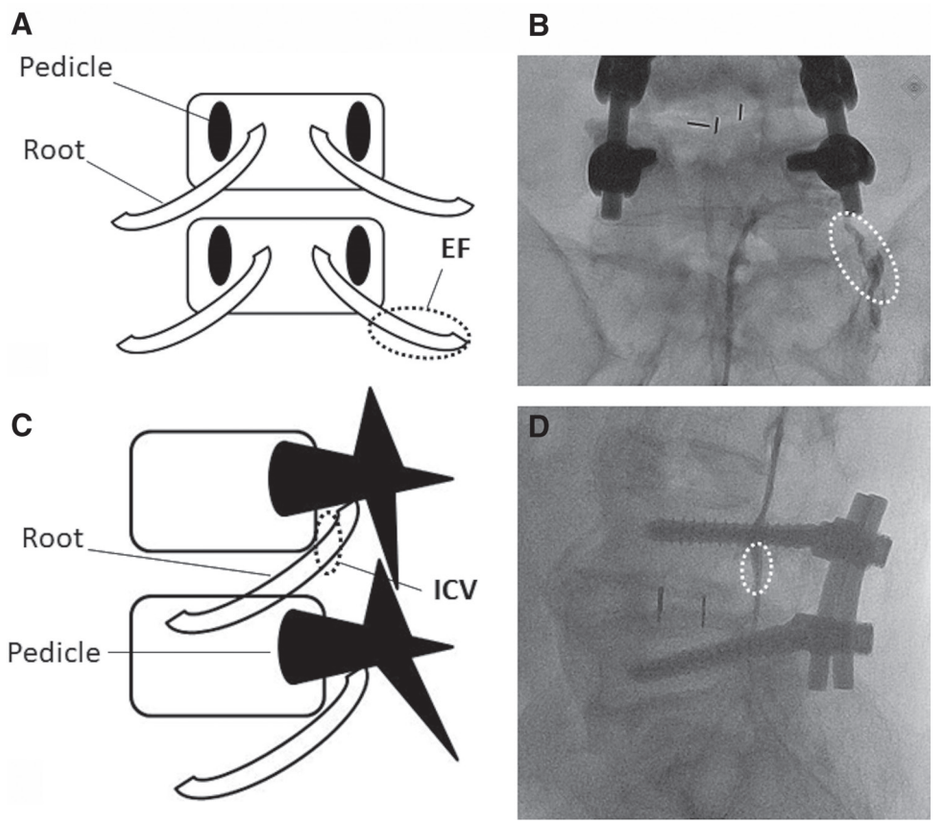

Fig. 1 Classification of CE contrast pattern. A, Small black dot encircles the area classified as the EF space on the schematic diagram of the anteroposterior view of lumbar vertebrae. B, Contrast (small white dot circle) spread to the EF space on the anteroposterior view of CE image during lumbar PEA. C, Small black dot encircles the area classified as the ICV space on the schematic diagram of the lateral view of lumbar vertebrae. D, Contrast (small white dot circle) spread to the ICV space on the lateral view of CE image during lumbar PEA. CE = conventional epidurography; EF = extraforaminal; ICV = intracanal ventral; PEA = percutaneous epidural adhesiolysis.

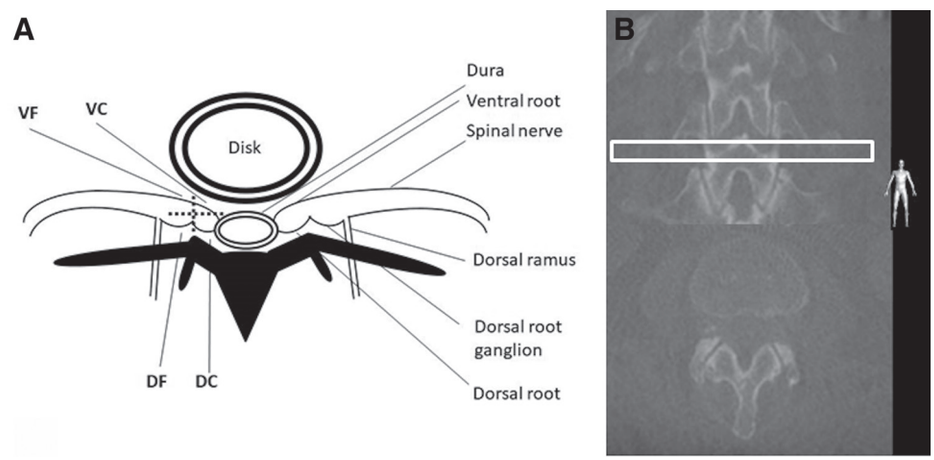

Fig. 2 Classification of CBCT-RE contrast pattern. A, The schematic diagram of the cross-sectional view at the level of the lumbar disk defines the four areas of contrast spread: DC, contrast spread to the dorsal zone of the ipsilateral epidural space not extending to the neural foramen; VC, contrast spread to the ventral zone of the ipsilateral epidural space not extending to the neural foramen; DF, contrast spread to the dorsal zone of the ipsilateral epidural space extending to the neural foramen; VF, contrast spread to the ventral zone of the ipsilateral epidural space extending to the neural foramen. B, The white hollow column illustrated on the coronal view of the CBCT-RE image corresponds to the axial view of the CBCT-RE image at the level of the spinal disk. CBCT-RE = cone-beam computed tomography-reformatted epidurography; DC = dorsal canal; DF = dorsal foramen; VC = ventral canal; VF = ventral foramen.

No other complications, such as intense pain, bleeding, paresthesia, mobility restriction, syncope, allergic reactions, fever, or infection, were observed after the procedure.

At 1 month post-PEA, 63.3% of participants (19/30) experienced at least 50% symptom relief, whereas 36.7% (11/30) experienced <50% symptom relief. Demographic data were

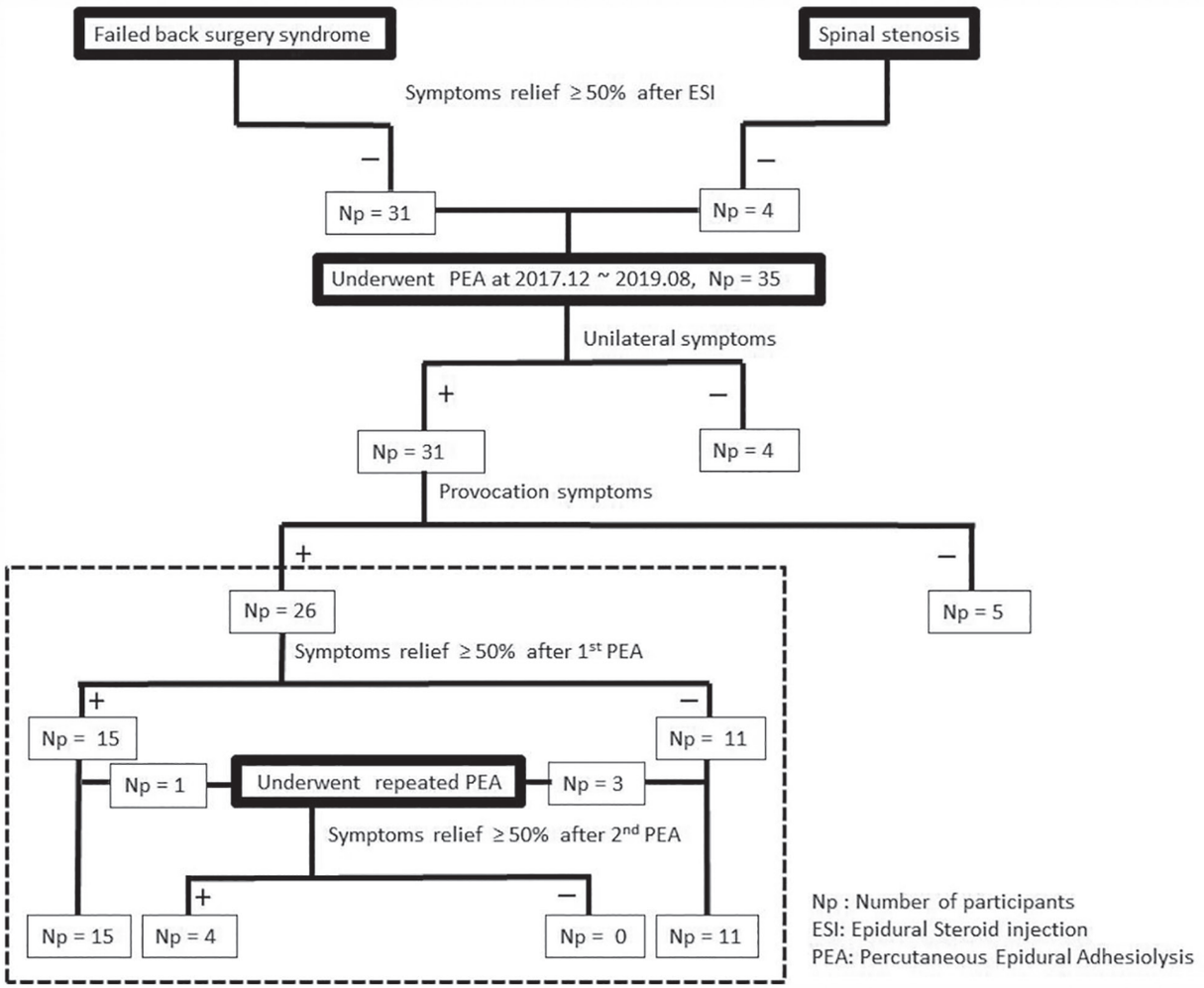

Fig. 3 Flowchart of participant selection.

compared among those with and without at least 50% symptom relief (Table 1). Our data showed no statistically significant intergroup differences with regard to sex, age, side of injection, and the duration of discomfort before PEA.

During PEA, participants received a mean effective dose of 0.44 mSv (±0.20 SD) and 2.72 mSv (±1.17 SD) per CE and CBCT-RE, respectively. Inter-reader agreement was good for the contrast distribution on CE (ICC = 0.793), but was excellent for the contrast distribution on CBCT-RE (ICC = 0.955). The ICCs of contrast distribution at ICV and EF on CE were 0.600 and 0.853, respectively; the ICCs of contrast distribution at DC, VC, DF, and VF on CBCT-RE were 0.965, 0.909, 0.989, and 0.922, respectively. The results of association between imaging parameter and symptoms relief after PEA are shown in Table 2. The analysis demonstrated that successful responses after PEA were significantly associated with the cooccurrence of contrast at VC and DF (p = 0.015) and DC, VC, and DF (p = 0.047). No significant correlation was evident between symptom relief and other regions of contrast distribution on CE or CBCT-RE. Using a logistic regression procedure with adjustment for baseline characteristics, including sex, age, body mass index, VAS score, and duration of discomfort, the coexistence of contrast at DF and VC adjacent to the root that responded to provocation was more strongly associated with a better PEA outcome than the coexistence of contrast at DC, VC, and DF (odds ratio = 11.414 vs 7.742) (Table 3).

4. DISCUSSION

Although the radiation exposure in CBCT-RE was higher than that in CE during PEA, our study demonstrated that CBCT-RE provides more precise imaging of anatomical details than does CE, and may associate with the outcome of PEA. Our results showed higher inter-reader agreement for CBCT-RE than for CE. Inter-reader discrepancies in imaging interpretation on CE commonly occur when a reader determines if the contrast distribution is in the intracanal ventral epidural space (Fig. 4). With multiplanar reformatting, Kufeld et al[9] demonstrated that epidural contrast can be more easily followed and visualized. Moreover, CBCT-RE could provide immediate images of 3D reconstruction without transferring the participant to another imaging unit. In our results, the visualization of contrast in the epidural space was not obviously influenced by metal implants.

Previous studies have demonstrated the critical role of dorsal root ganglion (DRG) in the induction and maintenance of chronic pain.[16–18] Although the location of DRG may be altered

Table 1

Baseline characteristics of participants with or without ≥50% symptoms relief after underwent lumbar PEA

Parameter	≥50% symptoms relief	<50% symptoms relief	*p*
Number of participants	19	11	NA
Sex[a]			0.712
Male	12	6	
Female	7	5	
Age, y			0.580
Range	54-91	42-92	
Mean ± SD	71.16 ± 9.94	69.36 ± 12.99	
Body mass index, kg/m^2			0.556
Range	18.72-30.39	17.63-42.45	
Mean ± SD	25.10 ± 3.21	26.58 ± 7.74	
Visual analog scale			0.548
Range	70-90	70-90	
Mean ± SD	81.59 ± 6.02	80.00 ± 7.75	
Duration of discomfort, mo			0.588
Range	5-72	12-60	
Mean	45.16	40.18	

NA = data not available; PEA = percutaneous epidural adhesiolysis.
[a]Data are shown as the number of participants.

by surrounding structures, previous studies have shown that more than 90% of DRGs for the L4, L5, and S1 lumbar roots are located in the neuroforaminal space and intraspinal space rather than in the extraforaminal space.[19,20] Hence, it is reasonable to assume that the DRG of lower lumbar roots are always located in the ventral region of the intraspinal epidural space (VC in our study) and in the dorsal region of the foraminal epidural space (DF in our study). These anatomical characteristics of DRG may explain why the cooccurrence of contrast at these two locations adjacent to the irritated root was significantly correlated with CBCT-RE findings for our participants who responded well to PEA. The anatomical characteristics of DRG also explain why the presence of contrast at the EF on CE, which was thought to be associated with better symptom relief,[12] was not significant in our participants.

The association between the contrast filling areas or defects on CE and the outcome after PEA has been controversial in previous reports.[4–7] The explanation of the controversy, which has been suggested by Shin[8] attributed these conflicting findings to the fact that CE cannot determine the exact epidural space filled by a contrast agent, which explains why the cooccurrence of contrast at the DF and VC adjacent to the irritated root on CBCT-RE was associated with better pain relief than the observation of contrast in the ICV and EF on CE. Moreover, of the four participants who had undergone a repeat PEA, three had poor responses to the first PEA after which they showed contrast filling in an epidural space of the DF or VC adjacent to the irritated root on CBCT-RE (Fig. 5). These participants responded well to repeat PEA in which contrast filled both the DF and VC adjacent to the irritated root on CBCT-RE, demonstrating the importance of exact identification of epidural contrast filling location for outcome assessment.

The purpose of PEA is to eliminate the barriers in the epidural space that prevent drug delivery through the creation of channels around the target site that can facilitate drug delivery. If the exact lesion location cannot be reached, both PEA and drug delivery will fail, and the target area will remain untreated. However, we cannot determine the target for PEA by identification of contrast filling defects on CE alone. Because a previous report advocated the use of provoked symptoms to determine the source of pain,[4] we chose the target nerve roots for PEA using clinical dermatome involvement and provocation tests when the catheter tip was positioned at the ventral epidural space or at the opening of the neural foramen of the target nerve.[12] As a result,

Table 2

Comparison of substantial response after PEA and occurrence of contrast on CE and CBCT-RE

Examinations	Occurrence of contrast in locations		Number of participants: ≥50% symptoms relief	Number of participants: <50% symptoms relief	*p*
CE	ICV	Yes	17	8	0.327
		No	2	3	
	EF	Yes	13	6	0.696
		No	6	5	
	ICV, EF	Yes	13	5	0.266
		No	6	6	
CBCT-RE	DC	Yes	17	7	0.156
		No	2	4	
	VC	Yes	16	6	0.104
		No	3	5	
	DF	Yes	17	7	0.156
		No	2	4	
	VF	Yes	11	3	0.142
		No	8	8	
	DC, VC	Yes	15	5	0.108
		No	4	6	
	DC, DF	Yes	16	6	0.104
		No	3	5	
	DC, VF	Yes	11	3	0.142
		No	8	8	
	VC, DF	Yes	16	4	0.015*
		No	3	7	
	VC, VF	Yes	10	3	0.259
		No	9	8	
	DF, VF	Yes	11	3	0.142
		No	8	8	
	DC, VC, DF	Yes	15	4	0.047*
		No	4	7	
	DC, DF, VF	Yes	11	3	0.142
		No	8	8	
	VC, DF, VF	Yes	10	3	0.259
		No	9	8	
	DC, VC, DF, VF	Yes	10	3	0.259
		No	9	8	

CBCT-RE = cone-beam computed tomography-reformatted epidurography; CE = conventional epidurography; DC = dorsal canal; DF = dorsal foramen; EF = extraforaminal; ICV = intracanal ventral; PEA = percutaneous epidural adhesiolysis; VC = ventral canal; VF = ventral foramen.
*$p < 0.05$.

Table 3

Logistic regression analysis of the predictive variables related to the post-PEA symptoms relief with adjustment for baseline characteristics

Examinations	Locations	Odds ratio	95% CI: Lower bound	95% CI: Upper bound	*p*
CBCT-RE	VC, DF	11.414	1.703	76.505	0.012*
	DC, VC, DF	7.742	1.296	46.268	0.025*

Baseline characteristics: sex, age, body mass index, visual analog scale, duration of discomfort.
CBCT-RE = cone-beam computed tomography-reformatted epidurography; DC = dorsal canal; DF = dorsal foramen; PEA = percutaneous epidural adhesiolysis; VC = ventral canal; VF = ventral foramen.
*$p < 0.05$.

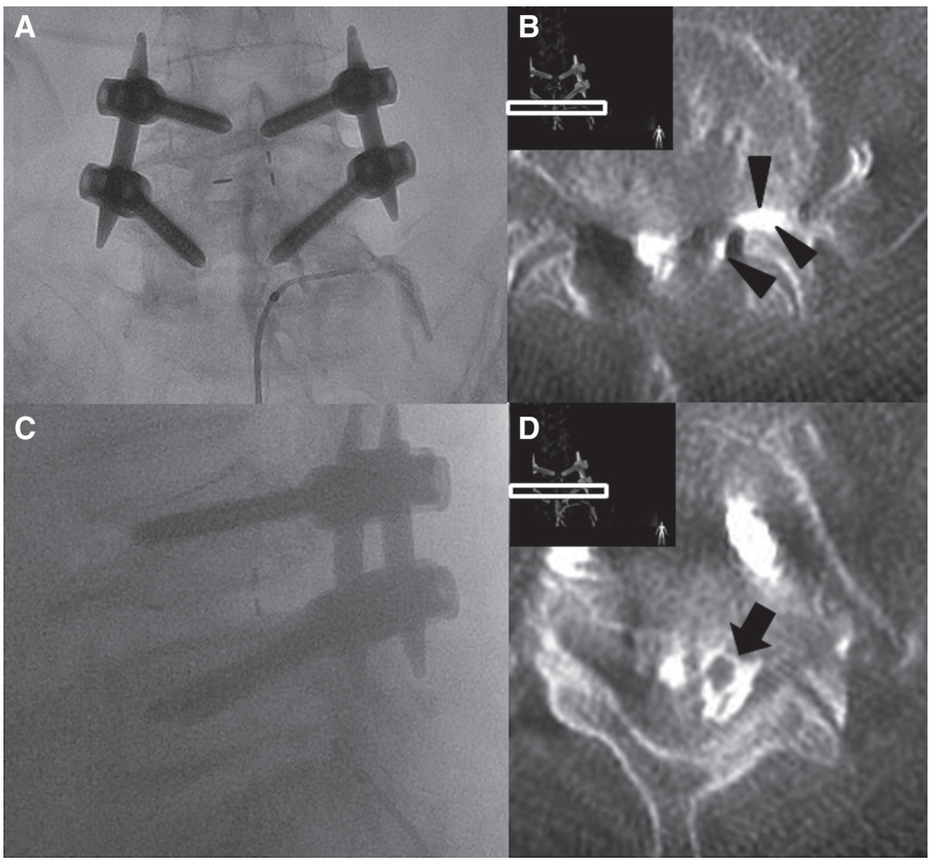

Fig. 4 Representative case of a 69-year old woman with radicular pain corresponding to the left L5 dermatome who had a history of failed back surgery syndrome and underwent lumbar PEA. A and C, The CE showed contrast spread in the EF space but not in the ICV space. The catheter was inserted into the stenotic foramen. B and D, The CBCT-RE showed contrast spread in the DC, DF, and VF spaces (black arrowheads) at disk levels L5/S1 and in the VC space (black arrow) at the level slightly above the disk. The CBCT-RE also showed excellent contrast spread around the left L5 root. The participant exhibited significant pain relief after PEA. CBCT-RE = cone-beam computed tomography-reformatted epidurography; CE = conventional epidurography; DC = dorsal canal; DF = dorsal foramen; EF = extraforaminal; ICV = intracanal ventral; PEA = percutaneous epidural adhesiolysis; VC = ventral canal; VF = ventral foramen.

we could observe the correlation between symptom relief and the contrast distribution pattern along the target nerve using CE and CBCT-RE.

Our study had several limitations that need to be acknowledged. First, the sample size was small, and confirmation of our results in a larger participant cohort is necessary. Second, although the Oswestry Disability Index (ODI) is better method to measure physical functioning,[21] out participants are more able to answer about the degree of symptoms reduction but more difficult to answer the degree of function recovery. Third, we collected clinical data from participants 1 month after PEA because a prior study showed a significant correlation between mid-term response of PEA and that within the first month.[12] We could not search mid-to-long-term effect such as 3 months, 6 months, or 12 months. Therefore, to overcome these limitations in the present study, we are currently conducting a randomized controlled trial to evaluate the association between the contrast distribution pattern of CBCT-RE and long-term physical functional outcome.

In conclusion, readings from CBCT-RE better correlated with participant outcomes than those from CE. CBCT-RE may be recommended to be implemented at the end of PEA to ensure that sufficient effective tunnels have been created for successful PEA.

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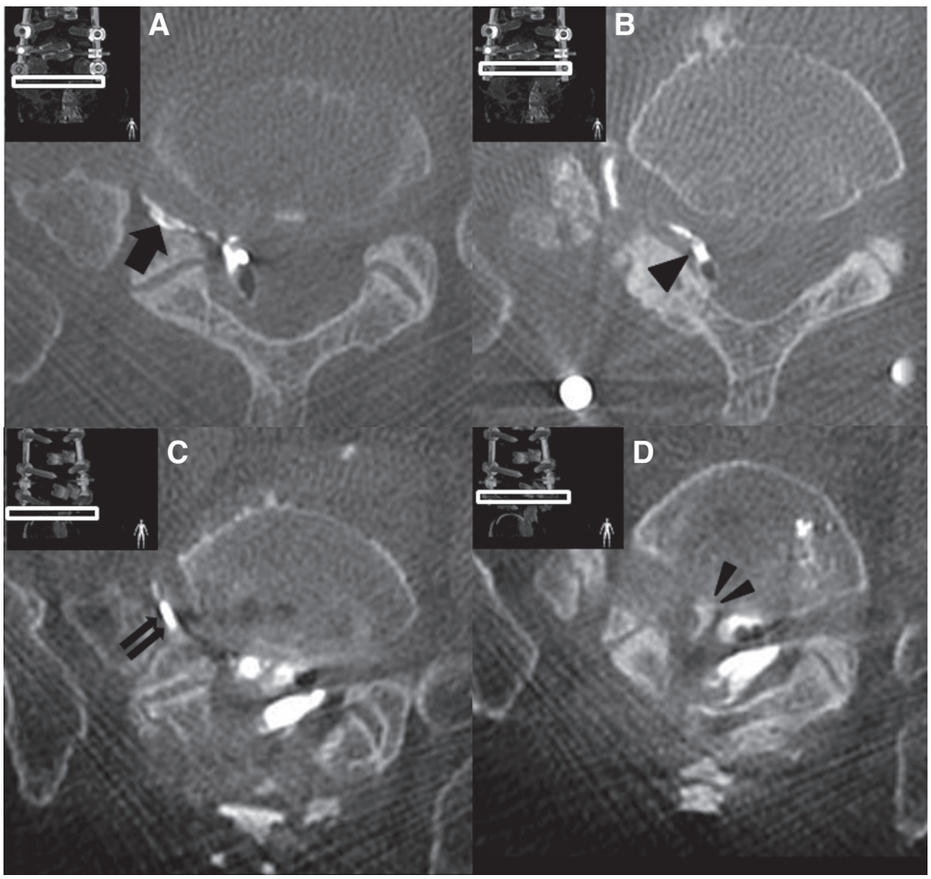

Fig. 5 Representative case of a 68-year old man with radicular pain corresponding to the right L5 dermatome who had a history of failed back surgery syndrome and underwent lumbar PEA. The participant showed no symptom relief after PEA. Nine months later, the participant underwent repeated PEA and exhibited significant pain relief. A and B, In the first PEA, the CBCT-RE showed contrast spread in the DF space (thick arrow) and DC space (thick arrowhead) at the level of the disk and slightly above the disk. B and D, In the repeated PEA, the CBCT-RE showed contrast spread in the DF space (thin arrows) at the disk level of L5/S1 and in the VC space (thin arrowheads) at the level slightly above the disk. The CBCT-RE also showed contrast spread partially around the right L5 root. CBCT-RE = cone-beam computed tomography-reformatted epidurography; DC = dorsal canal; DF = dorsal foramen; PEA = percutaneous epidural adhesiolysis; VC = ventral canal.

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