Real-time CT Fluoroscopy (CTF)-Guided Vertebroplasty in Osteoporotic Spine Fractures

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The purpose of this study was to evaluate the clinical feasibility, benefits, and limitations of CT fluoroscopy (CTF)-guided percutaneous vertebroplasty (PVP). PVP under the guidance of CTF without additional guidance by conventional C-arm fluoroscopy was performed in a total of 29 vertebral bodies in 21 patients with vertebral compression fractures. While monitoring sectional CTF images, the needle was advanced from the skin to the target vertebra. Contrast media and polymethylmethacrylate (PMMA) were injected into the target vertebra with careful monitoring of their distribution. After the procedure, an evaluation was conducted to determine whether extraosseous leakage of PMMA occurred and whether sufficient filling of PMMA had been achieved. Needle placement into the target vertebra was easily achieved with both the transpedicular and posterolateral approaches. Injection of PMMA and venous leakage of contrast media were carefully monitored in all patients, and early detection of PMMA leaking was achieved in 5 patients. Extraosseous leakage that had not been detected during the procedure was not found upon postoperative evaluation. Pain scales were significantly decreased after the procedure, and no obvious complications occurred following the procedure. CTF-guided PVP without the combined use of C-arm fluoroscopy was feasible and showed definite benefits. We believe that, in spite of some limitations, CTF-guided PVP provides an alternative technique appropriate in certain situations.

Key Words: Compression fracture, osteoporosis, vertebroplasty, CT fluoroscopy

INTRODUCTION

Percutaneous vertebroplasty (PVP) is a recently

introduced technique for treating painful vertebral compression fractures by filling polymethylmethacrylate (PMMA) into the compressed vertebral body under image guidance.[1,2] Though there are still no randomized trials to establish long-term clinical outcomes,[3] PVP is being used extensively in many institutes world-wide and has been found to aid many patients by curtailing debilitating pain.[4,5] Imaging modalities are important not only for performing the procedure, but also for arriving at a precise diagnosis before initiating the procedure. Operators should carefully evaluate imaging findings and determine target vertebrae deliberately according to correlations with the physical examination.[1,2] For accurate and safe performance, the availability of high-quality imaging equipment is essential. Such equipment should guarantee precise guidance for needle placement and real-time monitoring of injected contrast media and PMMA. The single- or bi-plane C-arm has been most popular and is widely used for these purposes.[1,2] It is simple to handle, cost-effective, and offers fine images for determining the positional relation of the vertebra and needle, allowing a skilled operator to perform procedures without difficulty in most cases.

CT has also been used in other interventional procedures of the spine, such as periradicular steroid injection, percutaneous laser disc decompression, and facet joint block,[6] although it has not been used independently as an imaging tool in PVP. Real-time monitoring and full profile imaging of the target area are critical in achieving PVP independently. Some authors have reported that a combination of CT and fluoroscopic guidance allows more accurate and safe needle place-

ment and is especially useful in PVP of the cervical and upper thoracic spine;[7,8] however, such combination guidance is not generally adopted in PVP because of its complexity and high cost.[2] Instead, the CT scan is ordinarily part of the postprocedural examination to evaluate adequate filling and extraosseous leaking of PMMA.[1]

CT fluoroscopy (CTF) is a recently introduced imaging modality that permits real-time monitoring of CT images at a rate of 6-8 frames per second. Even though images reconstructed on CTF present a reduced spatial resolution compared to conventional CT, its capacity for continuous sectional image update offers increased efficiency in CT-guided interventional procedures.[9] CTF has already proved very useful in various interventional procedures,[10-12] especially in drainage procedures and in biopsy of the thorax and abdomen. To our knowledge, however, there have been few reports about its application in PVP. We thought that the special capacity of CTF in demonstrating real-time sectional imaging might be useful in PVP in that it could allow for safer needle handling and precise real-time monitoring of PMMA injection. The purpose of this study was to report our clinical experience with CTF-guided PVP and to discuss its feasibility, benefits and limitations.

MATERIALS AND METHODS

Twenty-one patients (5 males and 16 females; mean age 61 ± 11.6 years) with acute painful vertebral compression fracture were included in this study (Table 1). The underlying cause of the

Table 1. Clinical Summary of 21 Patients Treated by PVP Using CTF

Case No	Age/Sex	Fracture level	Post-injury duration(day)	Preop VAS	Postop VAS	Approach	Extraosseous leak
1	66/F	L1	7	8	2	Unilateral transpedicular	-
2	48/F	L2	3	8	0	Unilateral transpedicular	Paraspinal leak
3	74/M	L1,2	14	7	0	Unilateral transpedicular	-
4	65/F	T11	2	9	2	Unilateral transpedicular	Epidural leak
5	52/F	L1	3	9	1	Unilateral transpedicular	Epidural leak
6	68/M	L2	4	9	2	Unilateral posterolateral	-
7	63/F	T6, 9	12	8	3	Unilateral posterolateral	-
8	80/F	T12	7	8	2	Unilateral transpedicular	-
9	76/F	T12, L1,2	3	9	5	Unilateral transpedicular	-
10	57/F	T12	7	8	0	Bilateral transpedicular	-
11	49/F	L1	18	7	3	Unilateral transpedicular	Paraspinal leak
12	60/M	T11	7	9	1	Bilateral transpedicular	-
13	76/M	T12, L2, 3	6	8	0	Unilateral transpedicular	-
14	70/F	T8, 9	3	8	0	Unilateral posterolateral	-
15	73/F	L2	11	8	3	Unilateral posterolateral	-
16	50/F	L2	2	9	2	Unilateral posterolateral	-
17	74/M	T11	19	7	3	Unilateral transpedicular	-
18	68/F	T11	4	9	1	Bilateral transpedicular	Epidural leak
19	56/F	L1	6	9	3	Bilateral transpedicular	-
20	66/F	T5	25	7	2	Unilateral transpedicular	-
21	61/F	L1, 2	20	7	1	Unilateral transpedicular	-

VAS, visual analogue scale of pain; T, thoracic; L, lumbar.

compression fractures was osteoporosis (T score < -2.5 on bone densitometry) in all patients, and pain had not been successfully controlled with medication and bed rest. Ten patients had compression fractures in the lumbar spine, 9 in the thoracic spine and 2 in the thoracolumbar spine. All patients underwent plain radiography, CT, bone scan, and MRI before the procedure. Symptomatic lesions were decided upon by these imaging studies and by physical examination. Chest radiography, EKG, and blood examinations were also performed to evaluate co-morbidities. There were no special exclusion criteria for PVP, except coagulopathy and bursting fractures. The clinical outcome was evaluated by the visual analogue scale (VAS) of pain. The mean follow up period was 12.6 ± 5.2 weeks.

A prophylactic intravenous antibiotic agent (cephalosporin 1.0g) was given to all patients once just before the procedure. All patients underwent conscious sedation with neuroleptoanalgesia before the procedure. Each patient was placed on the CT table in the prone position. The cushion mat of the CT table was detached in advance to make a wider operational space between the patient's back and the CT gantry. CT was set to the conventional image acquisition mode. An aseptic dressing and draping for PVP were done in the usual manner, and then CT topography (120 kV, 130 mA, slice thickness 3 mm, scan for 512 mm length) of the regional spine, including the symptomatic lesion, was obtained. On this topographic image, the target vertebra was identified and the ideal course of needle advancement was determined. The angle of the CT gantry was reset parallel with the determined course of needle advancement. Axial CT scanning (120 kV, 200 mA, 8 slices with slice thickness 3 mm) was performed for target vertebra, and sectional images for needle advancement were selected. The imaging mode was switched to CTF, and the image size was magnified for focused monitoring of target vertebra. After local anesthesia with 2% lidocaine was administered at the needle puncture site, PVP was performed under real-time CTF monitoring. The PVP technique was the same as that adopted by most operators.[1,2,4,5] The needle approach to the vertebral body was via transpedicular or posterolateral access. CTF was acquired using CARE vision in a Somatom Plus 4 unit (Siemens Medical System, Forchheim, Germany) with 8 to 10 mm collimation at a low dose setting (80 kV, 75 mA). During the procedure, needle advancement from skin to vertebra, venous leakage of contrast media, the injecting process of PMMA, and its extravasation out of the vertebral body were carefully monitored. Sectional monitoring for contiguous higher and lower levels was also achieved during PMMA injection by moving the CT table in a transverse direction. After completion, the results were evaluated by CTF monitoring to see whether extraosseous leakage of PMMA had occurred and whether target vertebrae had been adequately filled with PMMA. The bone-setting mode was mainly used in CTF and was alternatively switched to a soft tissue setting during PMMA injection. The soft tissue setting was needed to evaluate the full amount of PMMA and was also necessary in the postprocedural evaluation of PMMA distribution and epidural hematoma. To evaluate the radiation dose, we performed dosimetric measurement in CTF and C-arm fluoroscopy (75 kV, 100 mA). A radiation dosimeter was placed in the field of the procedure at the C-arm and CT table, and then the cumulative radiation dose was measured for 5 minutes. In CTF, the radiation dose in topography and axial scanning was also measured. Measurements were repeated 3 times, and the average value was estimated. During the procedure, neurological function of the lower extremities was checked frequently.

RESULTS

Feasibility of PVP using CTF guidance

A total of 29 vertebral bodies, comprising 13 thoracic and 16 lumbar vertebral bodies, in 21 patients were treated, with a mean of 1.4 ± 0.6 (range of 1 to 3) vertebral bodies in each patient. Regarding the technical feasibility of PVP under CTF guidance alone, the technique was successful in all patients. Due to the ease in handling, needle placement to the target point of the vertebral body was readily achieved with both the transpedicular (n = 22) and posterolateral (n = 7) approaches. The

needle was advanced on displayed sectional images from the skin to the vertebra, and this process could be monitored in all patients (Fig. 1). A mean volume of 4.2 ± 0.6 mL (range of 2 to 6 mL) of PMMA was applied for each vertebra, with 86.2% (n = 25) of procedures performed using a unilateral approach.

Monitoring of the venogram and extraosseous leakage of PMMA

When contrast media was injected, we could monitor its leakage into the epidural and/or paravertebral venous plexus in all patients (Fig. 1). The degree of venous leakage varied among patients, and needle repositioning was done in 5 patients following the empirical decision that CT venography showed extensive leakage of contrast media into the epidural and/or paravertebral veins. PMMA injection could also be accurately monitored in all patients. In 5 patients, extraosseous leakage of PMMA was revealed as soon as it occurred, and further extravasation was prevented by ceasing injection (Fig. 2). Insufficient filling of PMMA or the presence of extravasation undetected during CTF-guided PVP was not demonstrated on postoperative CTF monitoring. The incidence of extraosseous PMMA leakage was 10.3% (n = 3) in epidural veins and 6.9% (n = 2) in paravertebral vessels.

Clinical outcomes and radiation dose during the procedure

Pain scales were significantly decreased following PVP (Fig. 3). Eight patients complained of severe local back pain during the injection of PMMA that was relieved spontaneously in 10 to 60 minutes. Although 1 patient changed his position during the procedure due to back pain, the procedure was performed and needle placement in the target vertebra was confirmed with CTF. One patient showed an additional compression fracture in an adjacent vertebra during the follow-up period. No neurological deficits occurred during or after the procedure, and there were no cases of symptomatic or radiographic pulmonary embolism due to paravertebral venous leakage of PMMA. At discharge, 9 patients (42.9%) were free of pain and 11 (52.4%) were significantly improved with a considerable reduction in the use of analgesic drugs. Only 1 patient complained of
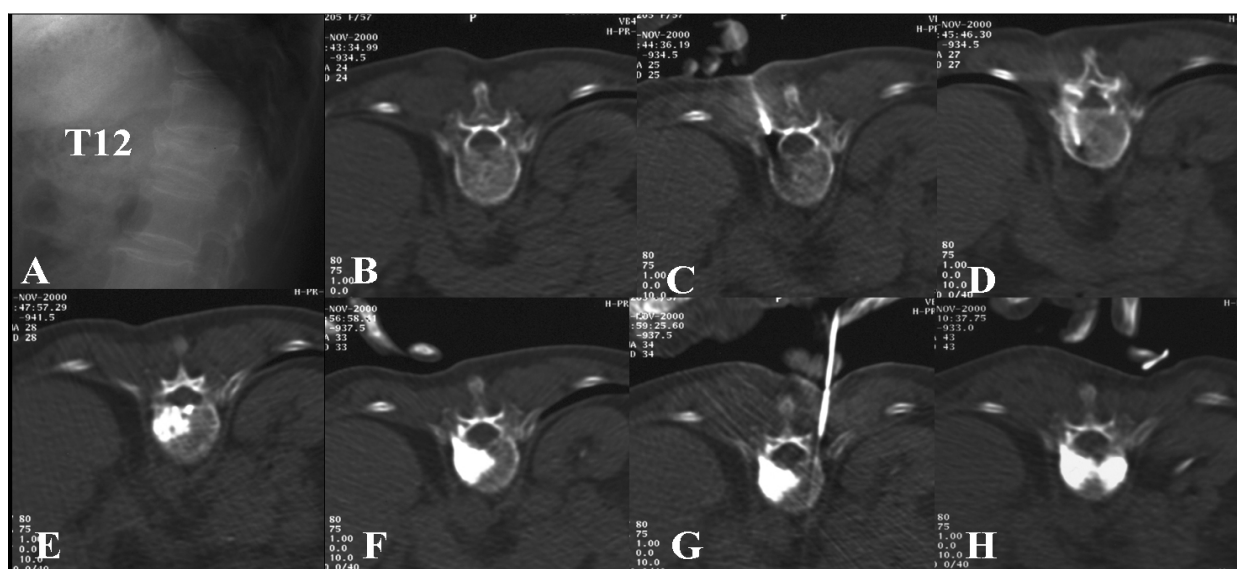

Fig. 1. Fifty-seven year-old female patient who complained of back pain that was unrelieved with medication. A. Thoracolumbar lateral radiograph shows a compression fracture of the T12 vertebra. C-D. Transpedicular needle placement was performed through the right pedicle. The needle tip was placed at the anterior one-third of the T12 vertebral body. E. CT venography shows contrast media leakage into the marrow space of the vertebral body and venous channel. F. PMMA was injected and mainly filled in the right portion of the vertebral body. G-H. Needle placement to the left portion of the vertebral body was subsequently performed through the left pedicle, and PMMA was injected.
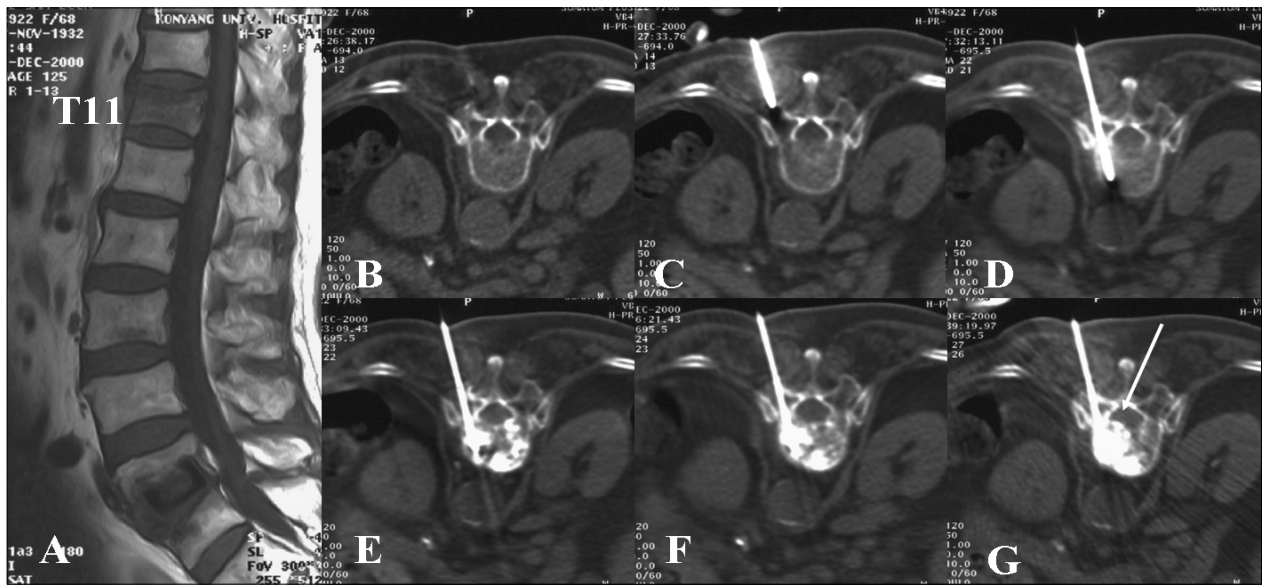
Fig. 2. Sixty-eight year-old female patient with osteoporosis. A. MRI shows compressive contour changes and marrow edema of the T11 vertebral body. C-D. The transpedicular approach for PVP was performed under guidance of CTF. F. PMMA injection began, and gradual filling of PMMA in the vertebral body was subsequently monitored on CTF. G. After filling in the right and anterior portion of the vertebral body, initiation of epidural PMMA leaking was monitored on CTF. PMMA injection was ceased immediately.
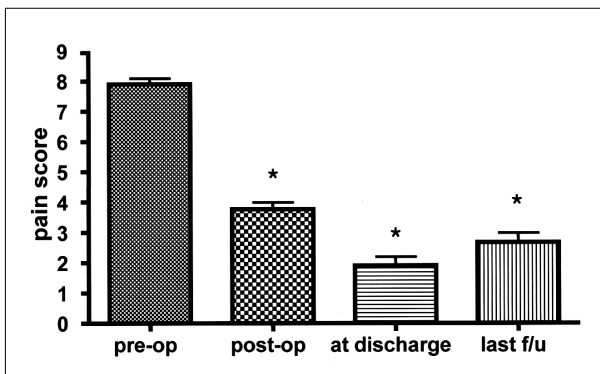
and 1.77 rad for axial CT scanning of the regional spine.

DISCUSSION

CT fluoroscopy is a recently developed imaging technique that allows real-time monitoring of sectional images through faster and continuous image updates.[9,13,14] Recent reports show that it is very useful in the field of interventional radiology.[10-12] We thought such capabilities of CTF might overcome the limitations of conventional CT imaging as a guiding tool for PVP, and the results of our study support this prediction. PVP under guidance of CTF alone was feasible, did not present significant difficulties, and provided additional benefits.

CTF is not a tool for diagnostic purposes as it was designed for use in interventional procedures.[9] Having a lower current image acquisition mode to reduce radiation dosage in patients, CTF produces an image quality that is inferior to CT images acquired in the conventional mode. However, CTF is sufficient to identify regions of interest, as well as the tip of the instrument used

Fig. 3. Change of VAS of pain at the pre-operative period, immediate post-operative period, discharge, and last follow-up period (12 weeks after procedure). VAS was decreased significantly after PVP. *$p < 0.05$ by paired t-test between pre-op (pre-operative state) and post-operative period, at discharge, and last follow-up period.

significant remaining pain and mild intercostal pain. The pain score (VAS) was significantly decreased during the post-operative and follow-up periods (Fig. 3). The average radiation dose measured in C-arm was 0.02 rad/min for fluoroscopy and 0.124 rad/min for spot image acquisition. The average radiation dose of CT was 3.64 rad/min in CTF, 0.03 rad for a single topography acquisition,

in procedures.[14] We did not experience any difficulties related to lower image quality during the procedure. Because CTF displays only sectional images, we had to move the CT table slowly from side to side to monitor contiguous upper and lower sections, especially during PMMA injection. The inability to monitor regional anteroposterior and lateral images of the spine and limitations in the monitoring range were inconveniences compared to C-arm fluoroscopy. However, we could monitor contrast media leakage into the venous plexus around vertebra, PMMA deposition in the vertebral body, and epidural leaking of PMMA in the monitoring range, at least on the target vertebra level. The most important purpose of image monitoring in PVP is to detect epidural leaking of PMMA which can be a cause of major neurologic deficits.[15] Although it is usually well-recognized in C-arm fluoroscopy, some epidural leakage in the early stage or paravertebral leakage may be missed by C-arm fluoroscopy. Because leakage of PMMA occurs at the level of target vertebra in almost all cases, it can be detected even by CTF. Moreover, very early stage PMMA leakage was detected in our study, suggesting an advantage of CTF as an imaging modality for PVP. On the other hand, detection of PMMA leakage into the adjacent discs may be missed on CTF due to limitations in the monitoring range; however, this is not clinically problematic, even if it does occur.[6]

One of the limitations of CTF guidance is its inability to monitor intraoperative venography. With C-arm fluoroscopy-guided PVP, we can obtain venographic imaging for the regional profile of the spine. It is difficult to take the whole venographic findings, because the image of CTF is confined to an axial two-dimensional view. Considering the clinical significance, however, the relationship between the needle tip and the venous channel is more important than the venogram itself. We could see venous leakage of contrast media at the level of the target vertebrae in all of our series. Recently, the necessity of venography in performing PVP has been questioned. A previous study demonstrating that PVP could be performed safely without a venographic evaluation was encouraging for our trial with CTF guidance16. However, it should be pointed out

that the study was limited to osteoporotic patients. We believe that full profile venography is required in the treatment of compression fractures with PVP due to hypervascular tumors, such as hemangiomas.

As other studies have reported, CT guidance is a safer method for needle placement than a conventional fluoroscopic guide.[7,8] This benefit is also present with CTF. We were able to monitor the full passage of needle advance from the skin to the vertebral body in sectional images, ensuring the procedure to be very safe. This may be especially advantageous in the posterolateral approach or in PVP for small targets - such as severely compressed vertebra, the upper thoracic spine, small tumors, and pediculoplasty.[17] In severely compressed vertebra, the far lateral approach is often required to reach residual bone marrow, instead of the standard transpedicular approach. We feel a safer procedure is guaranteed using CTF guidance in the far lateral approach. Percutaneous pediculoplasty is a procedure for lytic lesions in the pedicle.[17] It can be achieved under C-arm fluoroscopy guidance, but some lytic lesions may not be definitely seen on fluoroscopic images. CTF will be helpful in such cases, showing lytic lesions more clearly. Also, as mentioned in previous reports about the combined guidance of CT and C-arm fluoroscopy, CTF guidance is convenient in the cervical and upper thoracic spine.[7,8] Because the displayed image on CTF is a predetermined section showing the entire course of needle advancement, the procedure can be done not only more safely but also more quickly. The precise needle position can be achieved in the center of the vertebral body under CTF guidance. Therefore, an adequate volume of PMMA can be injected evenly via unilateral access. In this series, 86.2% of procedures were performed using a unilateral approach. The injected volume of PMMA varied according to the size of the vertebral body, but was similar to that of other reports.[1,5,7] Early detection of PMMA leakage can help in preventing serious complications (neurologic deficits, pulmonary embolism). There were no obvious complications in our series. We did not evaluate the time required with CTF- guided PVP, but we believe it is less than that that of C-arm-guided PVP. Regardless of the time required,

the duration of CTF-guided PVP is definite, in contrast to monoplane C-arm, in which frequent C-arm rotation is required during the procedure. Reduction in the time requirement has been mentioned in previous reports as an important benefit of CTF guidance.[18]

Another advantage of CTF-guided PVP lies in postoperative assessment. In almost all institutes, postoperative CT scans are routinely performed to evaluate PMMA filling and extravasation. Although such scans are necessary and useful, they result in additional charges and may annoy patients. With CTF-guided PVP, additional CT scans are not needed because an immediate postoperative evaluation of PMMA distribution is achieved by CTF monitoring. Therefore, CTF is believed to be advantageous from the standpoints of cost and patient care.

In spite of the feasibility and benefits, we are not adopting CTF as a routine monitoring modality in PVP. We think it is reasonable to consider CTF as an alternative for C-arm fluoroscopy in special situations. Many studies have discussed the advantages and convenience of C-arm guidance,[1,2,4,5] and we agree with such reports because C-arm guidance is very convenient, simple, cost-effective, and especially beneficial in terms of radiation dosage. Although the radiation dose associated with CTF is lower than that of conventional CT imaging modes,[14] it is much higher than that of C-arm fluoroscopy, as demonstrated in the results of our study. An additional concern is the radiation exposure of the operator's hands. In spite of careful handling, operators could not completely avoid radiation exposure during the procedure. Of course, exposure is usually limited to a very short time and the total dose is small; however, the use of thin lead gloves or other protective devices is advisable.[19] Another important advantage of C-arm guidance is that most operators are already familiar with its use. Except for a few special situations, skillful operators generally achieve PVP easily under C-arm guidance. Because the C-arm is open in one direction, there is no limitation in the operator's motion or limitations due to the patient's physique. In contrast, there are limitations in CTF because of the circumferential closed structure of the CT gantry. To make sufficient operating space, we detached the cushion mat of the CT table before placement of the patient and let down the CT table to the permitted level. Though there was no patient who failed in our series as a result of having a large physique or severe obesity, the limited space of the CT gantry may be an obstacle in this procedure. In addition, the risk of contamination is relatively high due to the small space, so surgeons should pay close attention to the possibility of postoperative infection.

CTF-guided PVP is feasible without the combined use of C-arm fluoroscopy and has its own unique benefits. The procedure can be safely performed under conscious sedation and local anesthesia. CTF provides an additional source of precise monitoring of the procedure and probably contributes to the safety of the procedure. Although it cannot substitute for C-arm guidance, CTF guidance can be used as an alternative method in some special situations, such as PVP of the cervical or upper thoracic spine, small focal lesions that are difficult to identify on C-arm fluoroscopy, and pediculoplasty. As hardware and software in CT scanners are continuously developing, a more advanced system for CTF is expected that will allow the more extensive use of CTF-guided PVP.

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