ORIGINAL RESEARCH ■ THORACIC IMAGING

Radiology

Pulmonary Cement Embolism after Percutaneous Vertebroplasty in Osteoporotic Vertebral Compression Fractures: Incidence, Characteristics, and Risk Factors[1]

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Purpose: To prospectively evaluate the incidence of, characteristics of, and risk factors for pulmonary cement embolism after percutaneous vertebroplasty (PVP) in osteoporotic vertebral compression fractures (VCFs).

Materials and Methods: Institutional review board approval and written informed consent were obtained. From June 2006 to September 2007, 75 patients (57 women, 18 men; mean age, 74.78 years; range, 48–93 years) who underwent 78 PVP sessions at 119 levels for osteoporotic VCFs were prospectively enrolled in this study. Computed tomographic (CT) scans of the chest and treated vertebrae were obtained after PVP. The presence, location, involved pulmonary arteries, number, and size of each pulmonary cement embolus were analyzed at CT. Possible risk factors were analyzed as follows: Age, injected cement volumes, and numbers of treated vertebrae were analyzed by using the Mann-Whitney *U* test; operators (radiologist or nonradiologist), level of treated vertebrae, guidance equipment, approach (uni- or bipedicular), presence of intravertebral vacuum clefts, and presence of paravertebral venous leakage were analyzed by using Pearson χ^2 and Fisher exact tests.

Results: Pulmonary cement emboli developed in 18 (23%) of 78 PVP sessions and were detected in the distal to third-order pulmonary arteries. Only cement leakage into the inferior vena cava showed a statistically significant relationship to pulmonary cement embolism ($P = .03$). A higher frequency of pulmonary cement embolism was noted for the absence of intravertebral vacuum clefts, for the bipedicular approach, and for a nonradiologist operator with C-arm fluoroscopy ($P > .05$).

Conclusion: In osteoporotic VCFs, pulmonary cement embolism was detected in 23% of PVP sessions, developed in the distal to third-order pulmonary arteries, and was related to leakage into the inferior vena cava.

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Percutaneous vertebroplasty (PVP) was first performed by Galibert and Deramond in 1984 (1). The procedure is now widely used for many painful vertebral compression fractures (VCFs) that are secondary to osteoporosis, multiple myeloma, metastatic tumors, and hemangioma (2–5). Complications are rare, and most are related to the leakage of bone cement (polymethylmethacrylate) into the spinal canal or the perivertebral venous system (3,4). Pulmonary cement embolism caused by polymethylmethacrylate migration during this procedure may be asymptomatic (3), but fatal cardiopulmonary complications such as pulmonary infarction, hypercapnia, and even cardiac arrest (6–9) have been reported. The devastating results of pulmonary cement embolism, however, have been reported less frequently than multiple myeloma and metastasis in osteoporotic VCFs (4–9). The available evidence regarding the complications of cement embolism is based on case reports and retrospective studies. Consequently, it seems clear that this issue must be studied prospectively. The purpose of our study was to prospectively evaluate the incidence of, characteristics of, and risk factors for pulmonary cement embolism after PVP in VCFs.

Advances in Knowledge

- The incidence of pulmonary cement embolism is about 23% (18 of 78 sessions) after percutaneous vertebroplasty in osteoporotic vertebral compression fractures.
- Cement leakage into the inferior vena cava is a significant risk factor for pulmonary cement embolism ($P = .03$).
- Although not statistically significant, our study reveals that the absence of intravertebral vacuum clefts, use of a bipedicular approach, and intraoperative C-arm fluoroscopy performed by a nonradiologist operator can be risk factors that decrease the order of risk ratio (relative risk ratio = 2.42, 1.8, and 1.69, respectively; odds ratio = 2.9, 2.16, and 2.01, respectively; $P > .05$).
- Pulmonary cement embolism shows slightly increased incidence in relation to paravertebral venous leakage but also develops without evidence of paravertebral leakage (relative risk ratio = 1.45; odds ratio = 1.64; $P > .05$).
- The treated vertebral level, the number of treated vertebrae (less than six per single session), and the total injected cement volume showed no statistically significant associations.

Materials and Methods

Patient Selection

Institutional review board approval and written informed consent were obtained for this study. From June 2006 to September 2007, a total of 130 patients underwent PVP for osteoporotic VCFs at our institution (Seoul National University Bundang Hospital). Indication for PVP was back pain caused by recent osteoporotic VCFs demonstrated at magnetic resonance (MR) imaging or newly developed on serial radiographs. Recent osteoporotic VCF was defined as a low-signal-intensity fracture line within the vertebral body or cortical breakage of endplate with adjacent bone marrow edema showing low signal intensity on T1-weighted sagittal MR images and high signal intensity on contrast material–enhanced fat-suppressed T1-weighted sagittal MR images, and a newly developed cortical breakage or decreased height of vertebral body on serial radiographs, corresponding with the region of acute back pain. Patients with metastatic disease, multiple myelomas, or back pain attributed to myelopathy or radiculopathy from stenosis of the vertebral canal or narrowing of the intervertebral foramen were excluded. We performed nonenhanced computed tomographic (CT) scanning of the lung and vertebrae immediately after PVP (hereafter, "post-PVP CT") to detect cement leakage and pulmonary cement embolism regardless of symptoms. Eighty-four patients agreed to undergo post-PVP CT and were enrolled in our prospective study. Among them, nine patients who had already been included in our previous study on the therapeutic effects of single-level PVP for VCFs with intravertebral vacuum clefts over 3 years (unpublished) were excluded. There were no other cases of exclusion. Eventually a total of 75 patients (mean age, 74.78 years; range, 48–93 years), 57 women (mean age, 73.8 years; range, 57–93 years) and 18 men (mean age, 77.4 years; range, 48–89

Implications for Patient Care

- Pulmonary cement embolism occurs more frequently than previously reported.
- Cement leakage into the inferior vena cava is closely related to pulmonary cement embolism, and pulmonary cement embolism can develop without evidence of paravertebral leakage at intraoperative fluoroscopy and postvertebroplasty CT.
- The absence of intravertebral vacuum clefts, the use of a bipedicular approach, and performance by a nonradiologist operator with intraoperative C-arm fluoroscopy may be risk factors for the development of pulmonary cement embolism (odds ratio = 2.9, 2.16, and 2.01, respectively; $P > .05$).

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Abbreviations:
CI = confidence interval
DSA = digital subtraction angiography
OR = odds ratio
PVP = percutaneous vertebroplasty
RR = relative risk ratio
VCF = vertebral compression fracture

Author contributions:
Guarantors of integrity of entire study, all authors; 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; literature research, all authors; clinical studies, all authors; statistical analysis, Y.J.K., J.W.L., H.S.J., J.M.P., H.S.K.; and manuscript editing, Y.J.K., J.W.L.

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years), were treated at 119 vertebral levels during 78 sessions of PVP and underwent post-PVP CT; there were 78 sessions total because three of the 75 patients each underwent an additional session of PVP for a new fracture after the initial PVP.

MR Protocol and Preoperative Analysis

MR was performed preoperatively for 75 of 78 sessions. One spinal radiology fellow (Y.J.K.) and a spinal radiologist (J.W.L.) analyzed the MR images together and determined the presence, level, and number of recent VCFs. The interval between MR imaging and PVP was also recorded. MR was performed at 1.5 T (Gyroscan Intera; Philips, Best, the Netherlands), according to the standard protocol at our institution. The T1-weighted, T2-weighted, and contrast material–enhanced fat-suppressed T1-weighted images were obtained in both sagittal and axial planes. The following imaging sequences were used: *(a)* a sagittal T1-weighted spin-echo sequence (repetition time msec/echo time msec, 488.7/9.6; section thickness of 4 mm; field of view of 320 × 320 mm), *(b)* a sagittal T2-weighted spin-echo sequence (3057/100, section thickness of 4 mm, field of view of 320 × 320 mm), *(c)* a sagittal fat-suppressed T1-weighted spin-echo sequence with contrast material enhancement (609.1/9.6, section thickness of 4 mm, field of view of 320 × 320 mm), *(d)* an axial T1-weighted spin-echo sequence (596.3/15, section thickness of 4 mm, field of view of 170 × 170 mm), *(e)* an axial T2-weighted spin-echo sequence (6203/120, section thickness of 4 mm, field of view of 170 × 170 mm), and *(f)* an axial fat-suppressed T1-weighted spin-echo sequence with contrast enhancement (596.3/15, section thickness of 4 mm, field of view of 170 × 170 mm).

PVP Technique and Intraoperative Findings

PVP procedures were performed according to the technique described by Jensen et al (3) and were undertaken in one of two departments: radiology or orthopedics. In the radiology department, PVP was performed by a spinal radiologist (J.W.L., with 4 years of experience in PVP) or one of two spinal radiology fellows (Y.J.K., H.S.J., each with 1 year of experience in PVP). The procedures performed by the spinal radiology fellows were strictly supervised by the spinal radiologist (J.W.L.). PVP was performed by using a biplanar (Intergris Allura 12/12; Philips) or uniplanar (Intergris Allura Xper FD 20; Philips) digital subtraction angiography (DSA) unit. Transpedicular (for lumbar) or parapedicular (for thoracic) approaches were adopted by using 11- or 13-guage bone biopsy needles (Osteo-site; Cook, Bloomington, Ind). A unipedicular approach was routinely used, but when cement filling of the fracture gap with one needle was not thought sufficient, a second needle was placed into the contralateral side of the pedicle after injecting cement through the first needle. After the needles were placed into the anterior third of the vertebral body with fluoroscopic control, liquid and powder polymethylmethacrylate (DePuy International, Blackpool, England) were mixed with 500 mg of cefazolin. Cement was injected carefully by using fluoroscopic control. The injection was stopped if the bone cement *(a)* filled the fracture gap, *(b)* reached the posterior quarter of the vertebral body, *(c)* leaked into epidural space, or *(d)* was leaking into the foraminal vein and inferior vena cava. After PVP, all patients had 2 hours of bed rest.

In the operating room, PVP was performed by one of two orthopedic surgeons (K.W.P. and J.S.Y., with 8 and 12 years of experience in PVP, respectively) with use of intraoperative mobile C-arm fluoroscopy (BV Libera; Philips). In contrast to the radiologists, the orthopedic surgeons preferred to use a bipedicular approach, whereby both needles were placed before cement injection and cement was injected through both needles alternately. The point at which cement ceased to be injected was the same as that for the radiologists. The orthopedic surgeons used neither bone cement mixed with antibiotics nor systemic intravenous antibiotic therapy.

Protocol of Post-PVP CT

Immediately after PVP, patients were transferred to the CT unit. Scanning was performed with a multidetector spiral CT scanner with 16 or 64 detector arrays (Mx 8000 IDT or Brilliant 64; Philips). Patients were scanned caudocranially within one breath hold. The entire thorax and treated vertebrae were included in the scan range. Contrast enhancement was not used because the intravascular contrast material could obscure a high-attenuation cement embolus, and the unenhanced CT scan was enough to identify a hyperattenuating cement embolus within the pulmonary vessels. The protocol and parameters are shown in Table 1.

Incidence and Distribution of Pulmonary Cement Embolism

Two radiologists (H.S.K. and J.M.P., each with >20 years of experience in radiology) who were unaware of the patients' clinical symptoms and surgical

Table 1

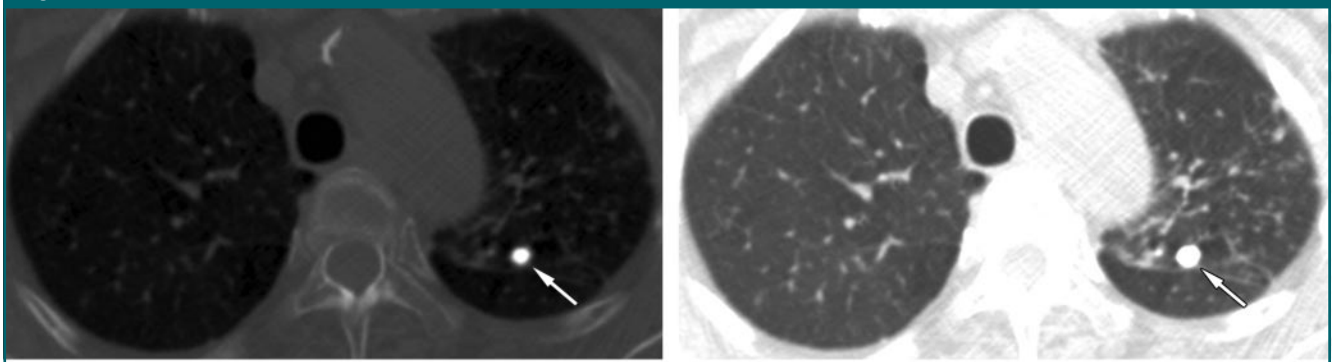
CT Protocol after PVP

Parameter	Spine	Chest
Scanning mode	Helix	Helix
Resolution	Standard	Standard
Detector collimation	40 × 0.625 mm	64 × 0.625 mm
Section thickness (mm)	2	0.67
Section increment (mm)	1	0.33
Pitch	1.026	1.173
Peak voltage/milliampere seconds (kVp/mAs)	140/290	120/200
Rotation time (sec)	0.75	0.5
Filter	Sharp	Sharp
Image matrix	512 × 512	512 × 512
Scan range	Thoracic and lumbar spine	Chest

findings reviewed the post-PVP CT scans together. A chest radiologist confirmed the locations of pulmonary cement embolism. On the post-PVP CT scans, the two radiologists tried to detect a cement embolus at the bone window (window width, 2400 HU; window level, 350 HU), lung window (window width, 1500 HU; window level, −700 HU), and wide window (window width, 1500 HU; window level, −400 HU) settings in both lung fields. Because distinguishing between a calcified granuloma and a pulmonary cement embolus was sometimes difficult, the following criteria for distinguishing a pulmonary cement embolus were used: *(a)* A branching high-attenuation area of more than 500 HU was located on the expected course of the pulmonary artery, *(b)* the high-attenuation area was no larger than the proximal luminal diameter of the pulmonary artery because of intraluminal lesions, and *(c)* it was a newly developed branching high-attenuation area, if a comparison with an old posteroanterior chest radiograph or a chest CT scan was possible.

For example, an opacity that was completely surrounded by pulmonary parenchyma, without the association of the pulmonary artery (Fig 1) and a well-circumscribed nodular opacity with adjacent fibrotic scars (Fig 2), should have been a calcified granuloma rather than a cement embolus. When cement embolism was detected on the CT scan, the location, involved pulmonary arterial level, and the number of cement emboli were recorded. Multiple opacities in the same pulmonary arterial distribution were considered the same cement embolus and were counted as one, but opacities in different pulmonary arterial distributions were counted separately. The size of the largest cement embolus was measured with ×12 magnification of images in the bone window setting.

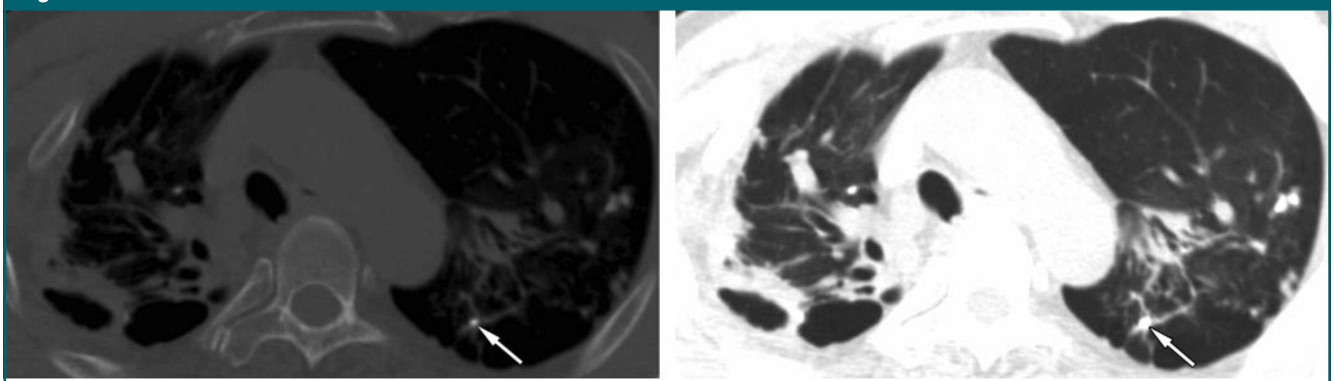
Figure 1



a. b.

Figure 1: Post-PVP CT scans in 63-year-old woman; PVP was performed at the T12 and L2 vertebral bodies. Axial images at **(a)** bone and **(b)** lung window settings show nodular opacity (arrow) completely surrounded by pulmonary parenchyma, suggesting a calcified granuloma rather than a cement embolus. There are no associations with the pulmonary artery on serial CT images that are not shown here.

Figure 2



a. b.

Figure 2: Post-PVP CT scans in 48-year-old man; PVP was performed at the T11 and T12 vertebral bodies. Axial images at **(a)** bone and **(b)** lung window settings show nodular opacity (arrow) with adjacent fibrotic scars, suggesting a calcified granuloma rather than a cement embolus.

Any abnormality associated with the cement embolism was also recorded. Especially, when a wedge-shaped and pleural-based area of consolidation was seen in the peripheral lung field, it was considered a pulmonary infarction.

Postoperative clinical assessment was performed by monitoring the partial pressure of oxygen in arterial blood (Pao_2) for 2 hours after PVP and checking vital signs and subjective pulmonary symptoms for 24 hours. Any change from the preoperative status was noted in this clinical assessment.

Evaluation of Risk Factors for Pulmonary Cement Embolism

A spinal radiology fellow (Y.J.K.) who was not aware of the post-PVP CT findings reviewed the medical and surgical records. The physicians performing PVP ("operators") and their departments (radiology or nonradiology) were noted. All levels of treated vertebrae were recorded and then divided into the following categories: T1 through T9, T10 through L2 (thoracolumbar junction), and L2 through L5. The patients' ages, number of treated vertebrae per single session, type of guidance equipment (intraoperative mobile C-arm fluoroscopy, uniplanar DSA, biplanar DSA), and type of approach (uni- or bipedicular) were documented. The total injected cement volume per session was documented by counting the numbers of syringes used to inject the cement. The spot radiographs obtained during PVP were reviewed to identify intravertebral vacuum clefts per each of the treated vertebrae. An intravertebral vacuum cleft was considered to be an air-filled cavity seen in the vertebral body on spot radiographs obtained during PVP (10).

Another radiologistAnother radiologist (H.S.J.) and one orthopedic surgeon (K.W.P.) who were unaware of the presence or absence of pulmonary cement embolism evaluated paravertebral venous leakage on post-PVP CT scans and intraoperative spot radiographs. When paravertebral venous leakage was observed on post-PVP CT scans, the extent was subcategorized as the limited anterior external venous plexus, azygos vein, and inferior vena cava.

Figure 3

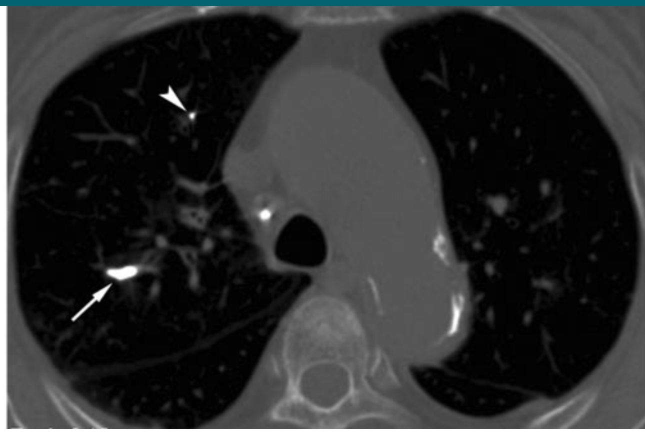


Figure 3: Post-PVP CT scan in 84-year-old woman; PVP was performed at the T12 vertebral body. Axial image shows a cement embolus in fourth-order (subsegmental branch) pulmonary artery in right upper lobe (arrow). It was the largest cement embolus in our study, approximately 4 mm in transverse maximal diameter. Another small cement embolus (arrowhead) is seen in the distal to fourth-order pulmonary artery.

Statistical Analysis

Pearson χ^2 test and Fisher exact test were used to analyze the relationship between pulmonary cement embolism and the following factors: the operators (radiologist vs nonradiologist), the levels of treated vertebrae, the type of guidance equipment, the approach, the presence of an intravertebral vacuum cleft at one level or more, and the presence and extent of paravertebral venous leakage on post-PVP CT scans. In addition, the unipedicular and bipedicular approaches were analyzed separately according to each type of guidance equipment (intraoperative mobile C-arm fluoroscopy, uniplanar DSA, biplanar DSA). The presence of an intravertebral vacuum cleft at one level or more was also separately analyzed according to each type of guidance equipment and each approach. The relative risk ratio (RR), the odds ratio (OR), and 95% confidence intervals (CI) were determined for the following risk factors: the operators' respective departments, the approach, the presence of an intravertebral vacuum cleft at one level or more, and the presence of paravertebral venous leakage. The Mann-Whitney *U* test was used to evaluate for the difference in age, cement volume, and the number of treated vertebrae per session between the two patients groups (presence vs absence of pulmonary cement embolism). Statistical analysis was performed by using statistical software (SPSS version 14.0; SPSS, Chicago, Ill). Differences were defined as statistically significant when $P < .05$.

Results

Incidence and Characteristics of Pulmonary Cement Embolism

On post-PVP CT scans, 61 cement emboli developed in 18 (23%) of 78 PVP sessions. Among the 18 patients with cement embolism, eight had a single cement embolus and the others had more than one embolus (two emboli in one session, three in five sessions, four in one session, five in one session, seven in one session, and 20 in one session). The largest cement embolus was seen in fourth-order (subsegmental) artery and measured approximately 4 mm (Fig 3). Other cement emboli were detected in the distal to fourth-order pulmonary arteries. The mean size of the cement emboli was 2 mm. Among a total of 61 cement emboli, 17 developed in the right upper lobe, five in the right middle lobe, 15 in the right lower lobe, 13 in the left upper lobe, and 11 in the left lower lobe. When there were multiple

cement emboli, they were scattered in peripheral portions of both lungs without specific lobar distribution. There was no relation between the location of pulmonary cement emboli and the side of the pedicle where the cement was injected. Similarly, there was no relation between the location of pulmonary cement emboli and the approach used (bipedicular or unipedicular approach). No patients showed immediate pulmonary parenchymal change associated with cement embolism. All patients showed no change in Pao_2 and vital signs compared with the preoperative state. Furthermore, no patients complained of subjective pulmonary symptoms 1 day after PVP.

Figure 4

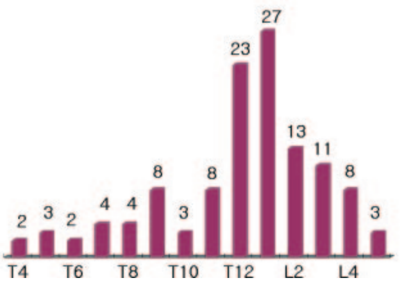


Figure 4: Graph shows number of treated vertebral levels.

Risk Factors for Pulmonary Cement Embolism

Among a total of 119 levels treated at 78 PVP sessions in 75 patients, preoperative MR imaging was conducted for 113 levels treated at 75 PVP sessions in 72 patients.

The mean interval between MR imaging and PVP was 5.45 days (range, 0–27 days). Levels of treated vertebrae are shown in Figure 4. Among a total of 78 sessions of PVP, orthopedic surgeons performed 19 (24%) sessions by using intraoperative mobile C-arm fluoroscopy, and 17 of these sessions were performed by one surgeon (K.W.P.). Radiologists performed 59 (76%) of 78 PVP sessions. Of these, 41 sessions were performed by a spinal radiologist (J.W.L.) and nine sessions were performed by each of two spinal radiology fellows (Y.J.K., H.S.J.) (ie, 18 sessions total) with the strict supervision of the spinal radiologist. In the radiology unit, uniplanar DSA was used in 33 sessions (42%) and biplanar DSA was used in 26 sessions (33%). A unipedicular approach was used in 46 sessions (59%) and a bipedicular approach was used in 32 (41%). The mean injected cement volume was 5.5 cm^3. The number of treated vertebrae per session was one in 48 sessions, two in 22 sessions, three in six sessions, four in one session, and five in one session. In a total of 119 levels treated in 78 sessions, intravertebral vacuum clefts were observed at 22 levels in 19 (24%) PVP sessions (three sessions each had two levels of intravertebral vacuum clefts). For sessions in which intravertebral vacuum clefts were present, seven PVP sessions were performed by using the bipedicular approach and 12 were performed by using the unipedicular approach. Six PVP sessions were performed by using C-arm fluoroscopy and 13 were performed by using DSA (nine sessions with uniplanar DSA and four with biplanar DSA) for intravertebral vacuum clefts.

The relationships between risk factors and pulmonary cement embolism are shown in Tables 2, 3, and 4. Only cement leakage into the inferior vena cava showed a statistically significant association with pulmonary cement embolism (P = .03). In all cases of cement leakage into the inferior vena cava, the patient developed pulmonary cement embolism (Fig 5). However, in one case of cement leakage into the azygos vein, the patient did not develop pulmonary cement embolism.

For 20 sessions, paravertebral venous cement leakage was detected on post-PVP CT scans. Among these, there was pulmonary cement embolism in six sessions (30%; RR = 1.45 [95% CI: 0.63, 3.35]; OR = 1.64 [95% CI: 0.52, 5.18]). However, on intraoperative spot radiographs, cement leakage into the

Table 2

Risk Factors and Development of Pulmonary Cement Embolism

Risk Factor	Cement Embolism: Present (n = 18)	Cement Embolism: Absent (n = 60)	P Value
Mean age (y)	74.5	74.9	.86
Operator			.1
Nonradiologist	7 (36.8)	12 (63.2)	
Radiologist	11 (18.6)	48 (81.4)	
Treated vertebral level*			.54
T1 through T9	7 (30.4)	16 (69.6)	
T10 through L2	15 (20.3)	59 (79.7)	
L3 through L5	6 (27.3)	16 (72.7)	
Mean number of treated vertebrae per session	1.56	1.52	.42
Guidance equipment			.23
Mobile C-arm fluoroscopy	7 (36.8)	12 (63.2)	
Uniplanar DSA	7 (21.2)	26 (78.8)	
Biplanar DSA	4 (15.4)	22 (84.6)	
Approach			.41
Unipedicular	8 (17.4)	38 (82.6)	
Bipedicular	10 (31.2)	22 (68.8)	
Mean injected cement volume (cm^3)	5.3	5.9	.50
Paravertebral venous leakage	6 (30)	14 (70)	.54
Anterior external venous plexus	4 (23.5)	13 (76.5)	
Azygos vein	0 (0)	1 (100)	
Inferior vena cava	2 (100)	0	.03†

Note.—Except where indicated, data are the numbers of PVP sessions. Numbers in parentheses are percentages.

* Data are numbers of vertebral levels.

† Statistically significant.

paravertebral vein was detected in only seven sessions, and all of these cases were confirmed at post-PVP CT. Among the 18 sessions of PVP in which pulmonary cement embolism developed, 12 (66.7%) did not show paravertebral venous leakage on both the post-PVP CT scans and intraoperative spot radiographs.

As shown in Table 3, VCFs without intravertebral vacuum clefts showed more frequent development of pulmonary cement embolism (15 of 59 [25.4%]; RR = 2.42 [95% CI: 0.6, 9.62], OR = 2.9 [95% CI: 0.6, 14]) than did VCFs with intravertebral vacuum clefts (three of 19 [15.8%]). This was true in all sessions and with each type of guidance equipment and approach. Notably, in only one session of PVP did a patient with an intravertebral vacuum cleft develop pulmonary cement embolism at DSA with the unipedicular approach. PVP sessions involving intravertebral vacuum clefts that were performed by using the bipedicular approach and C-arm fluoroscopy also showed a lower frequency of pulmonary cement embolism than did those sessions without intravertebral vacuum clefts performed with the same conditions. The differences, however, were smaller than for those sessions in which the unipedicular approach and DSA were used. However, there was no statistically significant association (P = .53).

The bipedicular approach showed an increased frequency of pulmonary cement embolism in general (10 [31.2%] of 32 sessions; RR = 1.8 [95% CI: 0.8, 4.1]; OR = 2.16 [95% CI: 0.74, 6.28]) and with the same guidance equipment. The only exception was mobile C-arm fluoroscopy, for which there was only one case of embolism by using the unipedicular approach (Table 4). These differences were not statistically significant ($P > .05$).

When the operator was a nonradiologist using C-arm fluoroscopy, pulmonary cement embolism developed more frequently (seven [36.8%] of 19 sessions; RR = 1.69 [95% CI: 0.72, 3.96]; OR = 2.01 [95% CI: 0.63, 6.45]) than when the operator was a radiologist using DSA (P = .10). PVP performed by a radiologist with biplanar DSA showed the lowest frequency of pulmonary cement embolism (four [15.4%] of 26 sessions; Table 2), but these differences were not statistically significant (P = .23).

Otherwise, mean age, mean number of treated vertebrae per session, and mean injected total cement volume per session showed no statistically significant association with pulmonary cement embolism, as shown in Table 2.

Table 3

Incidence of Pulmonary Cement Embolism with Intravertebral Clefts

Approach or Guidance Used	Intravertebral Cleft: Cement Embolism	Intravertebral Cleft: No Embolism	No Cleft: Cement Embolism	No Cleft: No Embolism
Total	3/19 (15.8)	16/19 (84.2)	15/59 (25.4)	44/59 (74.6)
Bipedicular	2/7 (28.6)	5/7 (71.4)	8/25 (32)	17/25 (68)
Unipedicular	1/12 (8.3)	11/12 (91.7)	7/34 (20.6)	27/34 (79.4)
C-arm fluoroscopy	2/6 (33.3)	4/6 (66.7)	5/13 (38.5)	8/13 (61.5)
DSA	1/13 (7.7)	12/13 (92.3)	10/46 (21.7)	36/46 (78.3)

Note.—Data are the numbers of PVP sessions, and numbers in parentheses are percentages. P = .53 for the association between intravertebral clefts and development of pulmonary cement embolism.

Table 4

Incidence of Pulmonary Cement Embolism by Approach Using Each Type of Imaging Guidance

Guidance and Approach Used	No. of Sessions with Cement Embolism	P Value
C-arm fluoroscopy		
Unipedicular (n = 1)	1 (100)	
Bipedicular (n = 18)	6 (33.3)	.37
Uniplanar DSA		
Unipedicular (n = 22)	4 (18.2)	
Bipedicular (n = 11)	3 (27.3)	.28
Biplanar DSA		
Unipedicular (n = 23)	3 (13.3)	
Bipedicular (n = 3)	1 (33.3)	.36

Note.—Data are the numbers of PVP sessions, and numbers in parentheses are percentages.

Discussion

Our study showed that the incidence of pulmonary cement embolism is 23% after PVP in VCFs, which means that this is not a rare complication. Pulmonary cement embolism after PVP was reported by Padovani et al (11) in 1999. In their case, a cement embolus caused pulmonary infarction, but they noticed no cement leakage during the procedure. Bernhard et al (12) reported a case of asymptomatic cement embolism that was detected on a chest radiograph. In 2002, Jang et al (13) described three cases of pulmonary cement embolism after PVP in 27 patients with malignant spinal tumors. One of the three patients was asymptomatic, but two had mild dyspnea and chest discomfort. The clinical importance of pulmonary cement embolism is controversial, as most cases seem to be asymptomatic. However, a growing number of reports list symptoms ranging from chest pain and dyspnea (6–9,11–13) to acute respiratory distress syndrome (14–16) and even death (7,16).

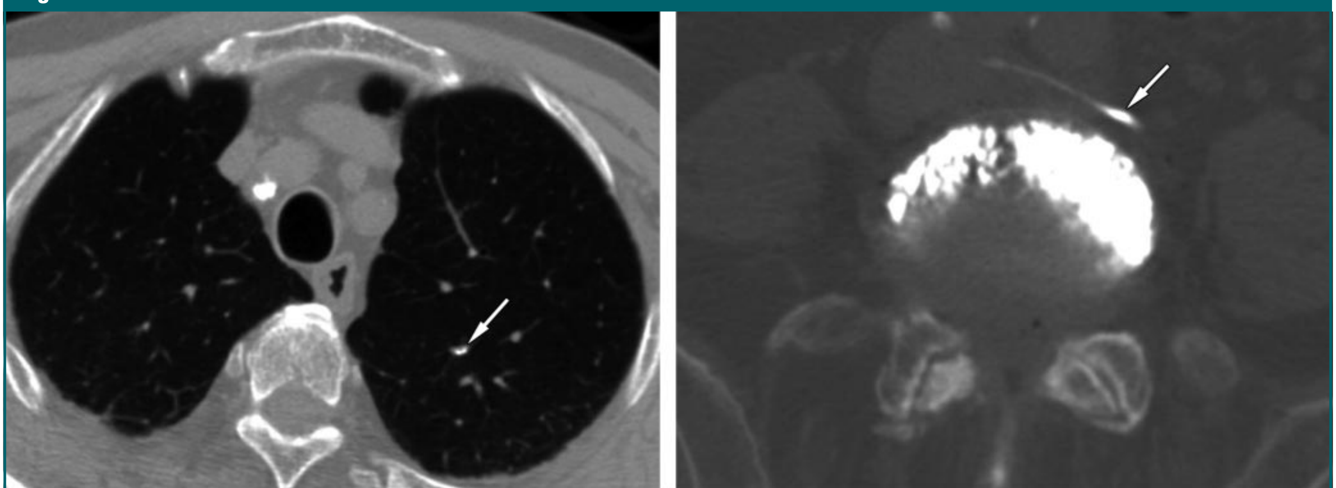
Previous studies described how pulmonary cement embolism could be seen as multiple dense opacities with a tubular and branching shape that are scattered sporadically or distributed diffusely throughout the lungs on a radio-

graph (17,18). We applied this finding to CT scans, and several criteria were added to confirm the cement embolism's intraluminal location and to distinguish other high-attenuation lesions such as calcified granulomas. Like previous studies, our study showed that pulmonary cement embolism developed sporadically or was scattered in peripheral portions of the lung without specific lobar distribution. There was no relationship between the location of the pulmonary cement embolism and the side of the pedicle injected with cement. Similarly, the kind of approach (bi- or unipedicular) used showed no relationship to the location of pulmonary cement embolism. The number of cement emboli varied from one to 20. All were seen in the distal to third-order pulmonary arteries and did not cause pulmonary infarction. In our study, vital signs for 24 hours and the Pao_2 for 2 hours after PVP did not change from the preoperative state. Generally, in a noncement pulmonary embolism, the clinical importance of small peripheral emboli in segmental (third-order) and subsegmental (forth-order) pulmonary arteries, in the absence of central emboli, is uncertain (19). In the overwhelming majority of cases, missing small peripheral emboli does not seem to adversely affect patient outcome (20). Parvizi et al (21) found that the incidence of diagnosed pulmonary embolism after joint arthroplasty increased markedly after introduction of multidetector CT, but no change was reported in mortality. However, a burden of small peripheral emboli may also have prognostic relevance in individuals with cardiopulmonary restriction. Furthermore, a burden of small peripheral emboli may be related to the development of chronic pulmonary hypertension in patients (20). According to Uemura et al (22), the Pao_2 decreases during PVP, and there is a correlation between the number of treated vertebral bodies and the Pao_2 decrease. Unfortunately, we did not record the Pao_2 intraoperatively and we performed minimal clinical assessments in the immediate postoperative state. In light of this, it is clear that a meticulous clinical assessment and a long-term clinical follow-up are needed with regard to small cement embolism.

To our knowledge, only two studies report the incidence of pulmonary cement embolism after PVP. Choe et al (17) reported an incidence of 4.6% after retrospectively reviewing postprocedural chest radiographs in 69 PVP sessions. In their report, all patients with cement emboli had multiple myeloma and remained asymptomatic (17). An association was found between pulmonary cement embolism and paravertebral venous cement leakage but not between pulmonary cement embolism and the number of vertebral bodies treated or whether kyphoplasty or vertebroplasty was performed (17). Duran et al (18) also retrospectively reviewed postprocedural chest radiographs, and when pulmonary cement embolism was detected, they confirmed it by means of CT. In their study, a total of five patients were found to have pulmonary cement embolism, estimated at 6.8% in a total of 73 patients. Four of their patients had osteoporotic compression fractures and one had multiple myeloma. In their study, venous leakage was not recognized during fluoroscopy in patients with pulmonary cement embolism (18). The association between pulmonary cement embolism and the number of treated vertebral bodies was also not statistically significant, as was the case in the study by Choe et al (17).

Compared with these previous studies, the incidence of pulmonary cement embolism in our study was much higher, although all patients in our study had benign osteoporotic VCFs. We think that this is related to the high sensitivity of multidetector CT for detecting

Figure 5



a. b.

Figure 5: Post-PVP CT scans in 84-year-old man; PVP was performed at the L3 and L5 vertebral bodies with pulmonary cement embolism. **(a)** A small cement embolus (arrow) is seen in the left upper lobe. **(b)** At the L5 vertebral level, cement leakage (arrow) is seen in the paravertebral vein extending into the inferior vena cava.

pulmonary embolism (19–21). Most of the cement emboli in our study were smaller than 4 mm and were in a peripheral vessel. Similar to the findings of Parvizi et al (21), we report that the clinical importance of diagnosing small pulmonary cement emboli at multidetector CT is still uncertain.

We evaluated the risk factors for pulmonary cement embolism. Only leakage into the inferior vena cava showed a statistically significant relationship to the development of pulmonary cement embolism, which corresponds with the study performed by Barragán-Campos et al (23), in which all patients with cement leakage into the inferior vena cava developed pulmonary cement embolism. In contrast to the study by Choe et al (17), there was no statistically significant association between the presence of paravertebral venous leakage and pulmonary cement embolism in our study. In a total of 18 sessions with pulmonary cement embolism, 12 did not show paravertebral venous leakage on the post-PVP CT scans. Like Duran et al (18) and Padovani et al (11), we report that most cement leakages were not detected at fluoroscopy during PVP. Thus, when the operator sees cement leakage into the inferior vena cava, careful observation of pulmonary symptoms is mandatory. Conversely, when a patient complains of pulmonary symptoms after PVP, pulmonary cement embolism should first be excluded, even though paravertebral venous leakage was not seen.

Although not statistically significant, our study reveals that the absence of intravertebral vacuum clefts, the use of a bipedicular approach, and a nonradiologist operator with intraoperative C-arm fluoroscopy can be risk factors that decrease the order of risk ratio.

VCFs with intravertebral vacuum clefts are known to have a low risk of cement leakage in PVP (24). In a study comparing kyphoplasty to vertebroplasty, Phillips et al (25) reported lower cement leakage risks in kyphoplasty owing to the presence of intravertebral cavitary spaces existing before cement injection.

Our study goes against the general concept that a bipedicular approach affords a larger margin of safety, with regard to cement leakage, than a unipedicular approach (26). According to Mathis (27), when a leak is seen during injection with the first needle, the operator can finish filling with the second needle and minimize the initial cement leak. However, with a unipedicular approach, a larger leak can occur because the operator will almost always try to finish a PVP session through the single existing needle rather than placing a second needle and remixing cement. O'Brien et al (28) noted that a bipedicular approach is safer than a unipedicular approach because it enables the placement of each needle tip in the lateral part of the vertebral body, avoiding the central part where venous leakage is more likely to occur. We hypothesize that, with regard to pulmonary cement embolism, placing the needle tip in the lateral part of the vertebral body may not be safe because it is close to the anterior external vertebral venous plexus, which is connected to the lumbar, azygos vein, and inferior vena cava (29). However, there is no evidence in the literature in relation to our hypothesis, so further evaluation is needed. Considering the fact that most unilateral approaches were performed by radiologists with the use of DSA, the association between the type of approach and pulmonary cement embolism is still uncertain. Moreover, our hypothesis is not acceptable for severe collapsed vertebrae in which vascular anatomy has to have been already altered.

A higher frequency of pulmonary cement embolism in relation to an operator who is not a radiologist is probably due to the guidance equipment and the different manner of cement injection. At our institution, radiologists tend to be more careful in filling the vertebral body, although this depends on the operator. There is no doubt that good-quality fluoroscopic control can be used to detect cement leakage more easily and prevent pulmonary cement embolism. Some authors insist that real-time detection of cement from lateral vertebral leakage remains difficult owing to the overlap of the intravertebral cement (30). Biplanar fluoroscopy or intermittent anteroposterior fluoroscopy could be used to overcome this problem (30), and this assertion appears to be supported by our study finding of the low incidence of pulmonary cement embolism with biplanar DSA.

Our study had several limitations. First, we could not perform post-PVP CT in some patients who did not want to participate in this study. Second, nine patients with intravertebral vacuum clefts were not included. Moreover, some cases of intravertebral vacuum clefts were possibly missed because some fracture clefts were filled only with fluid. Furthermore, other clefts may not be visible until the patient is placed prone with some extension and the obvious fracture cleft is filled by means of cement injection. However, in the case of intravertebral clefts filled with fluid, we could see air in the cavity immediately after the needle insertion into the cavity and withdrawal of the inner stylet during PVP. Because of the facts mentioned here, cases of missed intravertebral vacuum clefts may be negligible. Third, many variables were analyzed, but they were not controlled. Variables can affect each other, thereby reducing reliability. Some variables were compared under different conditions. For example, when unipedicular and bipedicular approaches were compared, the same conditions were not provided (ie, different operators and different levels of treated vertebrae). Fourth, although the operator variability and training may be the major determining factor with regard to the development of pulmonary cement embolism, we did not analyze each operator's performance and the effect of the learning curve. We thought that the operators who performed the majority of procedures—a spinal radiologist and an orthopedic surgeon—were very experienced, so it was expected that the effect of the learning curve would be minimal. The spinal radiology fellows performed with the strict supervision of a spinal radiologist, so the learning curve would not exactly reflect their experience. Moreover, the re-

maining three operators performed such a small number of PVP procedures that these procedures could not be analyzed in relation to the learning curve of the operators. Fifth, there are more levels and sessions than there are patients, so multiple observations from the same patients were made. However, a very small number of patients (three of 75, 4%) underwent PVP twice, and multiple observations were made only for age. Sixth, we counted the number of syringes that were used for the cement injection, but it is impossible to accurately gauge the volume that was actually injected. Last, despite the given relatively high frequency of patent foramen ovale, we could not perform brain CT because it was so difficult to get permission to perform brain CT in asymptomatic patients.

In conclusion, pulmonary cement embolism in osteoporotic VCFs *(a)* was detected in approximately one-quarter of patients, *(b)* developed in the distal to third-order pulmonary arteries, and *(c)* was significantly related to leakage into the inferior vena cava.

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