

High Rate of Pulmonary Cement Embolism after Cement-Augmented Pedicle Screw Fixation: A 12-Year Single-Center Study

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Abstract

Background The global trend toward increased life expectancy because of remarkable improvements in health care quality has drawn increased attention to osteoporotic fractures and degenerative spine diseases. Cement-augmented pedicle screw fixation has been established as the mainstay treatment for patients with poor bone quality. This study aimed to determine the number of patients with cement leakage and pulmonary cement embolism (PCE) as detected on thoracic computed tomography (CT), and to assess the potential risk factors for PCE.

Methods Patients undergoing cement-augmented pedicle screw placement in our institution between May 2008 and December 2020 were included. Data regarding baseline characteristics, complications, and cement leakage rates were collected. Indications for the performance of a postoperative thoracic CT due to the suspicion of PCE were intra- or postoperative complications, or postoperative oxygen supplementation. Moreover, PCE was accidentally diagnosed because the thoracic CT was performed for medical reasons other than the suspicion of PCE (tumor staging, severe pneumonia, or exacerbated chronic pulmonary obstructive disease).

Results A total of 104 patients with a mean age of 72.8 years (standard deviation of 6.7) were included. Of 802 screws, 573 were cement augmented. Of the 104 patients, 44 (42.3%) underwent thoracic CT scans to diagnose PCE; additionally, 67 (64.4%) demonstrated cement leakage, of whom 27 developed PCE and 4 were symptomatic. Cement-augmented thoracic screws were a risk factor for PCE (odds ratio: 1.5; 95% confidence interval: 1.2–2.1; $p = 0.004$).

Conclusions This study showed a high prevalence of cement leakage after cement-augmented pedicle screw insertion, with a relatively frequent incidence of PCE, as tracked by thoracic CT scans. Cement-augmented thoracic screw placement was a unique risk factor for PCE.

Keywords

- cement leakage
- cement-augmented pedicle screw placement
- pulmonary cement embolism
- osteoporotic fractures

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Introduction

Since a worldwide increase in the number of aged individuals is occurring, treatment strategies for spine degeneration and osteoporosis have become a focus of research.^{1,2} Increasing age is associated with a substantial loss of bone mineral density,³ thus conferring a higher risk of loosening of pedicle screws due to reduction of pullout strength in osteoporotic vertebrae.^{4–6} Cement-augmented pedicle screw fixation has been proposed as a critical pillar therapy for patients with poor bone quality because it increases the pedicle screw interface as well as the pullout force by up to 96 to 278%.⁷ Different techniques of cement application into the pedicle screws have been explored; however, all techniques can cause cement leakage into the neural structures⁸ or cardiovascular system, including the epidural veins, vena cava, pulmonary arteries, or right atrium. This phenomenon can contribute to the occurrence of pulmonary cement embolism (PCE), which can result in severe presentation and even death.^{2,9} Available data on PCE suggest that asymptomatic PCE is a less frequent phenomenon with an incidence rate of 3.5 to 23.0%; however, these numbers are predominantly based on chest radiographs.^{1,2,9} Hence, their accuracy and credibility are questionable since only computed tomography (CT) scans can provide high-resolution images to confirm the presence of PCE.¹⁰

As clinical evidence on the accuracy of pedicle screw fixation guided by spinal navigation accumulates, unsolicited events due to cement leakage can be avoided.^{10–12} Notwithstanding, to date, a few studies have systematically addressed the rates of potential complications and PCE verified by thoracic CT scan after insertion of cement-augmented pedicle screws by using spinal navigation.

The usage of thoracic CT for the detection of PCE has been previously described as an important tool with high sensitivity and specificity of over 83%.¹³

Therefore, we conducted this retrospective study (1) to assess the prevalence of PCE, (2) to define the number of patients undergoing a postoperative thoracic CT, and (3) to determine potential risk factors associated with the occurrence of PCE.

Material and Methods

Study Design and Patient Characteristics

All clinical and imaging data were retrospectively collected over a 12-year period from May 2008 to December 2020 from our institutional database. The present study was conducted in accordance with the Declaration of Helsinki and approved by the local ethics committee (S-723/2017). The requirement for informed consent was waived because of its retrospective nature. We consecutively enrolled patients aged ≥ 65 years who were diagnosed with osteoporosis and underwent cement-augmented pedicle screw fixation guided by intraoperative CT-based point-to-point navigation.¹⁴ Baseline characteristics, smoking status, history of arterial hypertension or diabetes mellitus type II, and the American Society of Anesthesiologists Physical Status Classification System (ASA) were collected from the patient's medical records. A CT of the

involved spine was performed in order to evaluate presence of osteoporosis as well as for preoperative planning, as previously described.^{15,16} Osteoporotic signs were the degree of vertebral reduction,¹⁷ cortical disruption, and impaction of trabeculae with increased density adjacent to the endplate. The final decision for augmentation was made by an experienced surgeon after screw placement based on the mechanical strength of the implanted pedicle screw. The number of screws applied in the patient being cement-augmented was similar across patients and varied between four and six cement-augmented pedicle screws.

Osteoporotic fractures (OF) were classified according to the classification developed by the Spine Section of the German Society for Orthopaedics and Trauma.^{18,19} According to this classification system, in cases of fractures classified as OF 3 and higher (OF 4 or OF 5), instrumented stabilization is recommended considering also the neurologic deficits and the clinical status of the patients. An experienced neuroradiologist (TS) and a neurosurgeon (BI) meticulously reviewed the imaging data and classified the fractures accordingly. In case of a degenerative spine, the decision-making for cement-augmented pedicle screws was conducted intraoperatively by the senior surgeon based on bone quality.

Operative Technique

All surgeries were performed by two experienced surgeons (KK and BI) under general anesthesia. The patients were placed in the prone position on a carbon table. First, a midline incision was made to expose the bony structures. Four to five navigation reference marker screws (4-mm self-drilling screws; Zimmer Biomet Holdings, Inc., Warsaw, Indiana, United States) were inserted into the laminae and spinous processes. Subsequently, a CT scan was performed under sterile conditions (Siemens, CT Emotion, Sliding Gantry, Siemens Company, Erlangen, Germany). The emerged data set (Stryker Navigation System II with SpineMap and NAV3i 3D-Navigation, Kalamazoo, Michigan, United States) was used to determine the insertion points, using marker screws as reference, and to identify the exact position, trajectory length, and diameter of the pedicle screws. The reference clamp was attached, and the marker screws were merged with the navigation; subsequently, pedicle insertion was performed. A calculated navigation accuracy of 0.3 to 0.5 mm was deemed appropriate and was met in all patients.

Screw placement was performed according to the technique described by Weinstein et al.²⁰ The screws were fully cannulated polyaxial titanium alloy screws. The radial holes were all within the distal third of the screw (Expedium, DepuySynthes and XIA, Stryker, Germany), varying in length and diameter according to each patient's individual anatomical characteristics. For thoracic levels, a total of 2 mL per vertebral body and 3 mL for lumbar levels were administered under intermittent X-ray fluoroscopy.

All procedures were performed following the guidelines of VERTECEM Bone Cement (DepuySynthes) and CORTOSS (Stryker). In case of cement leakage with X-ray fluoroscopy, a CT scan of the instrumented area was performed to detect the amount of cement leakage in the spinal canal or neural

foramina. Cement preparation and application was conducted according to the instructions provided by the company. In particular, the phase duration of mixing powder and liquid was 30 seconds, application device filling was also 30 seconds, and the waiting period of 300 seconds had to be maintained before use of the cement until its consistency was like toothpaste. Injection was interrupted if cement leakage was observed.

The findings of perivertebral cement leakage were categorized according to the classification of Yeom et al.²¹ An anteroposterior and lateral radiograph was performed postoperatively to evaluate the screw placements, as required by our institutional protocol.

Indications for the Performance of Chest CT on Suspicion of PCE

Patients who experienced intra- or postoperative complications, including difficulties in ventilation during the surgery, low oxygen saturation, or postoperative oxygen supplementation, underwent thoracic CT imaging as part of the standard diagnostic procedure for the detection of PCE in our institution. According to our institution standards, a low-dose CT pulmonary angiogram (CTPA) was performed to accurately localize the distribution of PCE within the pulmonary arteries.^{22,23}

Furthermore, PCE was accidentally diagnosed due to a thoracic CT performed for a medical reason other than the suspicion of PCE (tumor staging, severe pneumonia, or exacerbated chronic pulmonary obstructive disease). All radiologic reports were obtained by an experienced radiologist. Cement leakage was examined by independent experienced radiologists on postoperative radiographs and CT scans.

Statistical Analysis

Categorical variables are presented as absolute numbers and percentages. Continuous variables are presented as means if normally distributed. Potential risk factors were examined as independent variables in a binary logistic regression analysis model that used PCE as the dependent variable. Statistical significance was set at $p < 0.05$. All statistical analyses were performed using SPSS software version 24.0.0.0 (IBM Corp., Armonk, New York, United States).

Results

Baseline Characteristics

This analysis included 104 patients with cement-augmented pedicle screw insertion between May 2008 and December 2020. The overall mean age was 72.8 years (standard deviation of 6.7). There was a predominance of female patients (79/104, 76.0%). Of the examined comorbidities, arterial hypertension presented with the highest prevalence (77/104, 74.0%). ▶Table 1 shows the patients' baseline characteristics.

Among this cohort, a total of 802 screws were inserted into 403 vertebrae. Of these, 573 were cement-augmented screws. Osteoporosis was the main indication for placement

of cement-augmented screws (71/104, 68.3%). Among the 573 cement-augmented screws, 116 (20.2%) were inserted in the thoracic spine and 457 (79.8%) in the lumbar spine (▶Table 1).

Thirty-six patients presented with OF 4 fractures with loss of vertebral frame structures and vertebral body collapse, while 35 patients presented with OF 3 fractures, as indicated by deformation of the vertebral body with a distinct involvement of the posterior wall. On average, 2.1 (SD 0.4) levels were affected. Most of the osteoporotic fractures were detected from the T7 to the T9 level (55/71, 77.4%), 10 at T11 (10/71, 14.1%), and 6 at the L2 level (6/71, 8.5%). At the second stage of analysis, we compared patients with osteoporotic fractures in relation to leakage type. Twenty-five patients presented with cement leakage, 17 of whom presented with OF 4 fractures and 8 with OF 3 fractures. Univariate analysis revealed no significant differences between the groups, and the most prevalent type of leakage in both groups was perivertebral cement extrusion (OF 4: 12/17 [70.5%] vs. OF 3: 7/8 [87.5%]; $p > 0.05$), followed by inferior cava vein (OF 4: 3/17 [17.6%] vs. OF 3: 1/8 [12.5%]; $p > 0.05$) and epidural veins (OF 4: 2/17 [11.8%] vs. OF 3: 0/8 [0.0%]; $p > 0.05$).

Cement Leakage after Pedicle Screw Insertion

The localization and complications associated with cement leakage after cement-augmented screw placement are displayed in ▶Table 2. In 67 of 134 patients (64.4%), intraoperative cement leakage was indicated by X-ray fluoroscopy. To further diagnose this, according to our institutional standards, a supplementary CT scan of the instrumented area was performed. As shown on spinal CT, cement leakage was observed in 67/104 patients and was classified into four categories according to location: (1) perivertebral veins (62 patients, 92.5%); (2) inferior vena cava (15 patients [22.4%]; ▶Fig. 1); (3) azygos vein (8 patients [11.9%]); and (4) epidural vein (4 patients [6.0%]).

Occurrence and Incidence of PCE after Pedicle Screw Insertion

Among 104 patients, 44 (42.3%) underwent chest CT scans because of either significant cement extrusion demonstrated by radiograph or spinal CT scans, or intraoperative concerns for PCE. During hospitalization four patients (9.1%) underwent a thoracic CT scan because of medical indication (ventilation problems, significant decrease of oxygen saturation), thus strengthening the suspicion of postoperative occurrence of PCE. Three patients were already diagnosed with lung cancer and had undergone follow-up examination, while one patient had exacerbated chronic obstructive pulmonary disease (COPD). None of these patients presented with *clinical* signs of PCE. In total, 9.1% of the cases (4/44) undergoing chest CT presented with symptomatic PCE, while 61.4% (27/44) were asymptomatic. One patient suffered from anaphylactic shock. Twelve of 44 patients (27.3%) revealed no PCE according to chest CT, whereas a clinical suspicion was present.

Table 1 Baseline characteristics

	Overall	No cement leakage	Cement leakage
No. of patients	104	37	67
Age, y (mean, SD)	72.8 (6.7)	73.5 (7.9)	71.0 (5.9)
Sex, n (%)			
Male	25 (24.0)	10 (27.0)	17 (25.4)
Female	79 (76.0)	27 (73.0)	50 (74.6)
BMI (kg/m ²) (mean, SD)	27.4 (5.2)	27.2 (4.9)	27.6 (5.3)
Comorbidities, n (%)			
Arterial hypertension	77 (74.0)	23 (62.2)	54 (80.6)
Diabetes mellitus type II	18 (17.3)	8 (21.6)	10 (14.9)
Smoking	16 (15.4)	6 (16.2)	10 (14.9)
ASA score, n (%)			
1	3 (2.9)	2 (5.4)	1 (1.5)
2	47 (45.2)	14 (37.8)	33 (49.3)
3	51 (49.0)	19 (51.4)	32 (47.8)
4	3 (2.9)	2 (5.4)	1 (1.5)
Cement-augmented pedicle screws			
Total	573	273	300
Thoracic, n (%)	116 (20.2)	50 (18.3)	66 (22.0)
Lumbar, n (%)	457 (79.8)	223 (81.6)	234 (78.0)
Indications			
Degenerative spine disease, n (%)	33 (31.7)	10 (27.0)	23 (34.3)
Osteoporotic fractures, n (%)	71 (68.3)	27 (73.0)	44 (65.7)

Abbreviations: ASA, American Society of Anesthesiologists Physical Status Classification System; BMI, body mass index; SD, standard deviation.

Four patients with PCE were symptomatic. Three patients developed dyspnea, which was evident postoperatively with low oxygen saturation. In particular, in two of three cases, a thoracic CT scan showed PCE in the right and left pulmonary arteries. PCE was detected only in the right pulmonary artery in the third case. In the fourth case, a thoracic CT scan

revealed PCE in the inferior vena cava, azygos vein, and right pulmonary artery. ►**Fig. 2** shows a paradigm of PCE in pulmonary arteries as depicted on thoracic CT.

Association between PCE and Patient Characteristics

After performing logistic regression analysis and adjusting for relevant risk factors, we found that PCE was significantly associated only with the placement of cement-augmented thoracic screws (odds ratio: 1.5; 95% confidence interval: 1.2–2.1; $p = 0.004$; ►**Table 3**).

Table 2 Localization and complications in patients with cement leakage

No. of patients (%)	67/104 (64.4)
Localization, n (%)	
Perivertebral vein	62 (92.5)
Inferior vena cava	15 (22.4)
Azygos vein	8 (11.9)
Epidural veins	4 (6.0)
Complications, n (%)	
Pulmonary cement embolism	27/104 (26.0)
Symptomatic	4/67 (6.0)
Anaphylactic shock	1/104 (1.0)

Discussion

According to our data, the prevalence of cement leakage during pedicle screw insertion was substantially high at 64.4%, which is consistent with previously published data.^{2,9,24} However, to the best of our knowledge, this study provides instructive evidence on cement leakage and PCE after cement-augmented pedicle screw insertion as detected on 44 thoracic CTs. Among 104 patients who experienced cement leakage, 27 patients (26%) developed PCE, of whom 4 were symptomatic. Additionally, one patient died due to anaphylactic shock. Notably, the thoracic screw augmentation was a unique risk factor for PCE.



Fig. 1 Sagittal computed tomography showing cement leakage within the inferior vena cava (red arrow).

Cement Leakage during Pedicle Screw Insertion

The actual cement leakage rates and associated PCE after pedicle screw insertion remain unknown and are a matter of debate. Janssen et al,⁹ in their analysis of 165 patients with cement-augmented pedicle screw fixation, reported that 71% presented with cement leakage, although PCE occurred in only 13 patients, of whom 4 became symptomatic. Of note, only a few patients (9.1%) received a thoracic CT scan to confirm or exclude the occurrence of PCE. Their findings were primarily based on conventional radiographs, thus underpowering the significance of their results. Mueller et al observed cement leakage in 73.3% of the analyzed cases, noting that none of the cases presented with symptomatic

Table 3 Correlation between pulmonary cement embolism and patient characteristics

PCE	OR (95% CI)	<i>p</i> value
Age	1.2 (0.9–1.3)	0.275
Sex ^a	1.5 (0.9–5.4)	0.765
BMI	1.4 (1.1–1.5)	0.380
ASA	1.1 (0.3–3.6)	0.957
Arterial hypertension	0.4 (0.1–6.5)	0.431
Diabetes mellitus type II	1.4 (0.2–7.4)	0.916
Smoking	0.5 (0.1–3.7)	0.857
Amount of cement per vertebral body	3.5 (1.2–4.8)	0.087
Cement-augmented lumbar screws	1.4 (1.1–1.8)	0.279
Cement-augmented thoracic screws	1.7 (1.3–2.5)	0.004

Abbreviations: ASA, American Society of Anesthesiologists Physical Status Classification System; BMI, body mass index; CI, confidence interval; OR, odds ratio; PCE, pulmonary cement embolism.

^areference, male sex. The highlighted *p* values indicate statistically significant results.

PCE.² Notably, none of the patients received a thoracic CT scan. In the previous work of our study group, Ishak et al tracked three symptomatic patients with PCE, and one patient died due to suspected anaphylactic shock.²⁴ However, the number of patients who received thoracic CT in case of cement leakage or in case of various concerns for PCE development was unfortunately not determined.²⁴ In contrast, in the current analysis, 44 cases with cement leakage or with clinical suspicion of PCE received a chest CT scan; 27 of 104 patients (26.0%) developed PCE, of whom only 4 patients were symptomatic. CT examination plays a fundamental role in an all-day radiologic workup of patients in hospitals with modern health care equipment all around the world. A clinically justified CT examination and its benefit of an accurate diagnostic workup usually outweigh its associated individual risks, for example, stochastically induced risk of cancer.²⁵ However, in case of PCE, an enhanced thoracic CT is necessary in order to define the exact location of PCE within

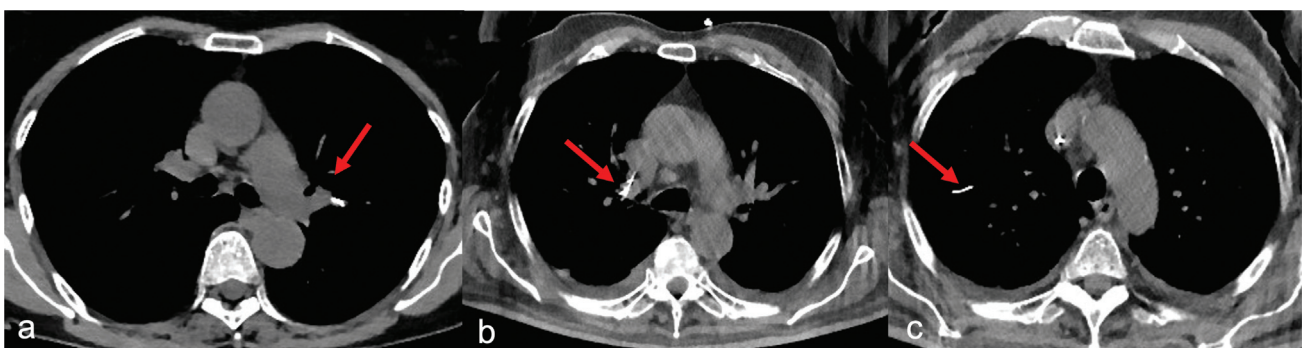


Fig. 2 Axial computed tomography depicting pulmonary cement embolism (a) in the main left upper lobe pulmonary artery, (b) in the main right upper lobe pulmonary artery, and (c) in the right segmental artery (red arrow).

the pulmonary arteries and rule out cases of right heart failure. Previous studies have already stated that low-dose CT (70 or 80 kV) is feasible and that its imaging quality is comparable to that of high-dose CT.²² Our institution, as a certified member of the EuroSafe Imaging Stars, seeks to reduce the radiation exposure of patients as much as possible.²³

The benefits of low-dose CT imaging have been gaining increasing attention in the last years. In our institution, as a member of EuroSafe Imaging Stars, low-dose CT scans are performed for the diagnosis of different pathologies, especially in cases of PCE. One might argue then that the imaging quality might be low, which may lead to misdiagnosis. In a recent review and metaanalysis, the authors stated that the imaging quality of low-dose CT scan is comparable to that of high-dose CT images.²² Interestingly, Sauter et al showed that dose reduction of even 75% for CTPA can still deliver results of full diagnostic confidence.²⁶ Furthermore, new techniques such as the use of ultra-high-pitch CTPA have been a focus of research in the emergent diagnosis of pulmonary embolism (PE) and have been shown to result in better depiction of cardiac structures, especially of the vessels.²⁷ The use of such systems for the diagnosis of acute PE even with reduced kilovoltage seems to produce promising results and most importantly lead to concurrent decrease radiation exposure.²⁸ McLaughlin et al, in their study on the merit of high-pitch low-voltage dual CTPA for the diagnosis of PE, advocated that deployment of such techniques with the additional application of an iterative reconstruction software is feasible in patients with acute PE and can produce acceptable image quality by also reducing the radiation exposure.²⁸ In line with the aforementioned studies, the Canadian Society of Thoracic Radiology also states the increasing importance of the use of dual-energy CT mainly in terms of decrease of radiation exposure.²⁹ Therefore, one might argue that these techniques might present the future direction of research and maybe should be established as part of the clinical routine for the diagnosis of PE. Our series on PCE could also be confirmed by low-dose CT, and the exact location of the embolus could be recognized. The identification of PCE is also of great importance due to the impact on the therapeutic strategies. Unreassuringly, there is still no consensus as to how to optimally treat patients with PCE. Nevertheless, current recommendations suggest the administration of anticoagulation with heparin followed by oral anticoagulation for 3 to 6 months, and thrombectomy in selected patients.³⁰

The rates of cement leakage and PCE after vertebroplasty or kyphoplasty have been well studied, which may be comparable to the current findings. The rates of PCE after kyphoplasty range between 3.5 and 23%, based on the type of imaging.¹ For example, Duran et al³¹ found the highest percentage of 23% of PCE after vertebroplasty in osteoporotic fractures, which is consistent with our results.²⁷ Herein, it should be emphasized that thoracic CT scans were performed in all patients. Therefore, these findings support the potential underestimation of the incidence of pulmonary cement extravasation on chest radiographs denoting that

thoracic CT scans should be implemented as a part of the medical imaging, specifically in critical cases.

We feel that the performance of thoracic CT in critical cases with suspicion of PCE can be helpful in detecting patients with PCE and can help initiate a therapeutic approach immediately.

Several morphologic and radiologic methods for detecting osteoporotic vertebral fractures have been proposed, but there is still no clear consensus regarding the definition. Genant et al accentuated the importance of the evaluation of the vertebral height and developed a classification system of three grades based on the reduction of the anterior, middle, and posterior vertebral height as identified on conventional radiographs. Such classification systems are, on the one hand, important to consider, but, on the other hand, they are mostly time-consuming, especially in the acute setting.¹⁷ Radiographic signs such as loss of self-similarity between adjacent vertebrae, loss of parallelism between adjacent endplates, endplate disruption as they are impacted into the vertebral body, fractures of the vertebral cortex or endplate characterized by cortical discontinuities, and buckling of the vertebral cortex, especially anteriorly,³² mainly guide decision-making in terms of kyphoplasty performance or even augmented posterior screw fixation after acute trauma in older patients.

Anatomical Considerations

In the present study, cement leakage was mostly present in the perivertebral veins (92.5%), followed by the inferior vena cava (22.4%), azygos vein (11.9%), and epidural veins (6.0%). Mueller et al² observed leakage in the perivertebral veins in 61.8% of cases. In addition, in the series by Janssen et al,⁹ the rate of cement leakage in the perivertebral veins was in agreement with those reported by Mueller et al at 57.0%.²

Clinicians are still confronted with considerable challenges to understand why the perivertebral veins are most affected by cement leakage. One reason for the higher prevalence of cement leakage across the perivertebral system might be, on the one hand, the reduced pressure of the venous system compared to the surrounding spongiosa and, on the other hand, the absence of venous valves in the internal and external anterior venous plexuses.³³ Of note, 15 cases with cement leakage in the inferior vena cava occurred after augmented screw fixation of the lumbar spine. This phenomenon might be explained by the venous connections between the lumbar venous plexus and abdominal veins, which primarily result in cement leakage into the inferior vena cava and not in the internal vertebral plexus, as proposed by Iwanaga et al.³⁴ Concerning treatment modalities, four symptomatic patients received heparin followed by oral anticoagulation for 3 to 6 months, and intensive care therapy was not needed. Asymptomatic patients were treated similarly. It is important to highlight that there is still no clear consensus on the most appropriate therapy for PCE; therefore, we implemented principles that have been well established for the therapy of venous PE.

It is well known that the pedicles of the thoracic spine are smaller and thinner than the ones of the lumbar spine; thus,

augmentation of these vertebrae is more challenging. Interestingly, the thoracic vertebrae are anatomically closer to the cardiopulmonary vessels like the superior vena cava, which is located at the T4 level. Hence, in case of cement leakage, it is easier for bone cement to enter the heart and consequently be transported to the pulmonary arteries, causing PCE. In contrast, cement from lumbar bone cement leakage needs to go through longer paravertebral veins or lumbar ascending veins to the inferior vena cava or the azygos vein; it can even be polymerized in the vertebral venous system before reaching the larger veins. Considering these points, surgeons should be aware of the anatomical landmarks when inserting cement-augmented screws in the thoracic spine since this subset of patients is touted to be at an increased risk of developing PCE.

Risk Factors

In line with previous studies, the potential risk factor for the occurrence of PCE was the augmentation of thoracic screws, whereas age, sex, body mass index, ASA, and underlying health conditions were not.^{24,35} In a study on risk factors for the occurrence of PCE after cement-augmented instrumentation, Guo et al found that the cement volume was not significantly associated with the occurrence of PCE, which is in line with the presented findings.³⁶ Another large study on cement leakage after cement-augmented pedicle screw instrumentation found that the amount of cement could be a significant risk factor for cement leakage; however, no analysis was performed concerning its impact on the occurrence of PCE.³⁷ We feel that the anatomical context should first be taken into consideration. Above the T10 vertebral levels, the azygos or hemiazygos veins directly drain into the pulmonary artery. Thus, cement leakage to the perivertebral segmental, hemiazygos, or azygos veins should be considered the main route to PCE. These two types of veins are relatively short and tend to connect directly to the main vessels. When a large volume of cement occupies a small cavity, the intracavitary pressure increases, causing extravasation of the cement into the segmental veins. The right segmental veins are closer to the inferior vena cava and shorter than the veins on the other side. Consequently, in the case of cement augmentation of thoracic screws, patients undergoing cement thoracic screw augmentation should receive close attention since they are at a higher risk of PCE.

Technical Considerations

The effect of surgical technique and factors, including screw length and screw and bone trajectory interface, on cement leakage rate remains controversial. Nevertheless, patients with osteoporotic bone should be studied meticulously since they are at a higher risk of cement leakage through the medial or lateral wall. Hecht et al advocated that compared to conventional fluoroscopy, intraoperative CT imaging allows reliable and more accurate screw assessment and placement, especially when inserting thoracic and cervical screws, which may potentially decrease cement leakage rate.³⁸ In contrast, Janssen et al⁹ found no serious screw displacement in patients with PCE who underwent cement

application using serial fluoroscopy, thus suggesting non-superiority of the intraoperative CT scan to intraoperative three-dimensional fluoroscopy. In our study, the use of CT-based point-to-point navigation for the placement of every pedicle screw led to accurate screw placement without pedicle wall penetration. Perivertebral cement leakage rate was relatively high; however, epidural space cement leakage was scarce (four patients). We believe that the adjunct of spinal navigation as a part of the surgical routine might be the key to decrease or even avoid epidural space leakage, hence diminishing symptomatic PCE and neurologic complications. Nonetheless, further studies are warranted to confirm our notion about the superiority of intraoperative CT-based navigation to fluoroscopic studies when performing cement pedicle screw insertion.

It is important to highlight that potential risk factors for the occurrence of PCE might be surgical details like the viscosity of bone cement, the injection pressure, and the amount of cement each time. Previous literature suggests that the amount of cement per pedicle screw ranges between 1.8 and 2.9 mL,^{39,40} which is in agreement with the amount applied in the present study. In particular, Frankel et al found no significant differences between low- and high-viscosity bone cement concerning the PCE rates; however, they hypothesized that using lower cement volumes in pedicle screw procedures might lead to a substantial decrease of cement toxicity.³⁹ Of note, the total volume of applied cement and higher injection speed are positively correlated with cement leakage. Therefore, it is recommended that cement volume not exceed the threshold of 2.8 mL per pedicle screw to diminish the rates of cement leakage.⁴⁰ Cement consistency should be in a toothpastelike state when applied, as previously described.^{1,41} Hence, application pressure, cement volume, and cement consistency should be carefully considered since they are conducive to higher cement leakage rates.

The main strength of this study is that to the best of our knowledge, we described systematically the actual rates of PCE after cement-augmented pedicle screw fixation mainly based on thoracic CT and to assess the potential risk factors for the occurrence of PCE. However, some limitations do exist. Due to the retrospective nature of the study, some selection bias might have been present. There was no matched analysis of cases with cement application after fluoroscopy-guided screw placement. Furthermore, PCE of 26% might be underestimated since PCE is mainly detected by low-sensitivity conventional radiographs. Nonetheless, it is important to highlight that most of our findings were based on the evaluation of thoracic CT scans (44%), thus empowering their significance. Since not all patients underwent chest CT to detect the occurrence of potential asymptomatic PCE, our findings might still underestimate its prevalence.

Conclusions

Our data suggest a high prevalence of cement leakage (64.4%) after cement-augmented pedicle screw insertion, as

previously described. Herein, it is paramount that every procedure be conducted by CT point-to-point navigation, which might lead to reduced PCE rate due to precise screw placement. However, further imaging studies are warranted to substantiate our notion. Thoracic CT was done in over 40% of the total cohort to track the occurrence of PCE. PCE seems to be a substantially frequent phenomenon (27/104 [26%]); however, it remains mostly clinically asymptomatic. The indication for cement augmentation, especially in patients with thoracic instrumentation, should be defined with increased awareness.

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Conflicts of Interest

None declared

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