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ORIGINAL ARTICLE

Analysis of adjacent vertebral fracture after percutaneous vertebroplasty: do radiological or surgical features matter?

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Abstract

Purpose To report the incidence and risk factors of adjacent vertebral fracture (AVF) after percutaneous vertebroplasty (PVP) in patients with osteoporotic vertebral compression fractures (OVCFs). We focused to investigate effect of radiological or surgical features on AVF.

Methods All patients with OVCFs who were treated with PVP between January 2016 and December 2019 were retrospectively reviewed. Patients were followed up at least 12 months after procedure according to treatment protocol. AVF was defined as postoperatively recurrent intractable back pain and subsequently presence of fracture on magnetic resonance imaging (MRI) in adjacent levels. Clinical, radiological, and surgical factors potentially affecting occurrence of AVF were recorded and analyzed using univariate and multivariate analysis.

Results Totally, 1077 patients with 1077 fractured vertebrae who underwent PVP were enrolled in the study, after inclusion and exclusion criteria were met. Mean follow-up time was 24.3 ± 11.9 months (range, 12–59 months). AVF was identified in 98 (9.1%) patients. Univariate analysis showed that seven significant factors related to AVF were older age, non-traumatic fracture, cortical disruption on anterior wall, cortical disruption on lateral wall, basivertebral foramen, type-B leakage and type-C leakage. In multivariate analysis, two clinical factors, older age ($P = 0.031$) and non-traumatic fracture ($P = 0.002$), were significantly associated with AVF. However, any radiological or surgical factor did not reach significance in final model analysis.

Conclusions Incidence of AVF after PVP in patients with OVCFs was 9.1% (98/1077). Older age and non-traumatic fracture were two clinical risk factors for AVF. Neither radiological nor surgical feature was significantly correlated with AVF.

Keywords Osteoporotic vertebral compression fractures · Percutaneous vertebroplasty · Adjacent vertebral fracture · Risk factors

Introduction

Percutaneous vertebral augmentation (PVA), including percutaneous vertebroplasty (PVP) and percutaneous kyphoplasty (PKP), has gained wide-spread acceptance as treatment option for osteoporotic vertebral compression fracture (OVCFs), as it is minimally invasive and highly effective in prompt pain relief and functional rehabilitation. Subsequent new vertebral fracture, especially adjacent vertebral fracture (AVF), was common at follow-up. Rates of AVF were variable from 7.3 to 29.0% in large series [1–11]. Risk factors of AVF had been reported in an increasing number of studies in recent two decades [1–11].

However, results of significant risk factors reported were misleading, as variation existed among series on term of procedure (PVP, PKP), definition of AVF (solely radiological, combined radiological and clinical), duration of follow-up, methodology (univariate analysis, multivariate analysis) [1–11]. Results reported in meta-analyzes were conflicting either [12, 13], as heterogeneity existed among pooled analysis due to literature updating. On the other hand, hypotheses on etiology of AVF were controversial among biomechanical studies [14–17]. Hence, it remains unclear whether AVF is

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related to clinical or radiological features, or if AVF is a consequence of augmentation with cement.

The aim of the study was to, with a largest sample and most parameters to date, reveal risk factors for AVF after PVP in patients with OVCFs. Identification of risk factors might provide an insight into whether clinical, radiological or surgical features matter in AVF.

Materials and methods

Patient population

All the patients with OVCFs who were treated with PVP between January 2016 and December 2019 were retrospectively reviewed. All patients provided informed consent, and the study protocol was approved by our institutional review board. The diagnosis of osteoporosis was made by a T-score < −2.5 of bone mineral density (BMD) according to dural-enegry X-ray absorptiometry (DEXA), or by clinical findings (subjects with a minor or no trauma history) and radiographic features [definitive decreased bone density on plain radiographs or computerized tomography (CT) scans of the spine]. The diagnosis of vertebral fracture was made by fracture signal on magnetic resonance imaging (MRI), which indicated low signal intensity of bone marrow within vertebral body on T1-weighted imaging and high signal intensity on fat-suppressed T2-weighted imaging. Inclusion criteria included single level OVCF, 5 or more scores of visual analog scale (VAS) of focal back pain, level of fracture of T5 or lower, aged 60 years or more, at least 12 months of follow-up. We excluded patients who had two or more levels OVCFs ($n = 179$), previous PVA or other spinal surgery ($n = 83$), unilateral vertebroplasty ($n = 59$), incomplete radiologic data ($n = 24$), malignant vertebral fracture ($n = 10$).

Surgical procedure and follow-up

All cases were performed by one of three senior surgeons. Under local anesthesia, a routine transpedicular approach was used bilaterally to perform PVP. Then, polymethylmethacrylate (PMMA) was carefully injected into fractured vertebra with fluoroscopic control. Procedure was terminated when intraoperative live fluoroscopy images demonstrated progressive symmetrical satisfactory filling of the vertebral body, or when cement leakage was noted.

Regular outpatient visits and radiographs were obtained postoperatively and at follow-up, that was at 3, 12 months and subsequently per year after procedure according to treatment protocol. When there was recurrent intractable back pain at any time point postoperatively, an additional MRI was performed to evaluate whether new vertebral fracture in adjacent or remote levels occurred.

Clinical, radiological and surgical evaluation

Clinical data were gathered retrospectively from case notes by one author (Y. D. L.). Clinical factors included sex, age, body mass index (BMI), fracture cause, fracture age. Fracture cause was categorized into: non-traumatic, when fracture occurred spontaneously during ordinary daily life activities, and traumatic, when fracture occurred due to specific traumatic episode, such as falls and low-energy vehicle accidents. Fracture age was classified according to duration of symptom as either acute (< 2 weeks), subacute (2–6 weeks), or chronic (> 6 weeks) [18].

Radiological factors included fracture location, fracture type, fracture severity, cortical disruption, intravertebral cleft, spinal canal compromise, basivertebral foramen, vertebral height, wedge angle, kyphotic angle. Fracture type was assessed on lateral radiographs and classified according to Genant et al. as either wedge, biconcave, or crush [19]. Fracture severity was classified according to percentage of vertebral body collapse as mild (20–25%), moderate (26–40%), and severe (> 40%) on lateral radiographs [19]. Cortical disruption was defined as evident diskontinuation at endplates, or anterior, posterior, lateral wall of vertebral body on MRI or CT [20]. An intravertebral cleft was defined as an intravertebral, abnormal, well-demarcated, linear or cystic hypointensity similar to air on radiographs or T1-weighted MRI sequences; an abnormal, well-demarcated, linear or cystic hyperintensity similar to cerebrospinal fluid on STIR sequences [21]. Spinal canal compromise was indicated abnormality of spinal canal area due to the intrusion of posterior wall on axial CT [22]. Basivertebral foramen was assessed as presence of triangle or trapezoid shaped foramen at posterior wall on middle-sagittal CT or MRI, or as presence of hemicycle shaped foramen on axial CT [23]. Vertebral height was measured according to Kim et al. at each anterior, middle, and posterior thirds, and then the smallest one was divided by a mean value of the corresponding cortical heights of the 2 nearest nonfractured vertebrae [24]. Wedge angle was defined as the angle by two lines passing along fractured vertebra's endplates [25]. Kyphotic angle was defined as the angle by two lines passing along the upper endplate of the upper vertebra and the lower endplate of the lower vertebra [25].

Surgical factors included morphology of cement, region of cement, cement leakage, cement volume, vertebral height restoration, wedge angle restoration, kyphotic angle restoration. Morphology of cement was assessed on lateral radiographs and classified according to Han et al. into two types: interdigitation, when cement was interspersed throughout trabeculae, and solid mass, when cement lumped without interspersion [26]. Inferior-to-superior

region of cement was assessed on lateral radiographs and classified according to a modification of Kim methods into three types: no-endoplate contact, one-endoplate contact, and two-endoplate contact [27]. Lateral-to-lateral region of cement was assessed on frontal radiographs and classified according to He et al. into two types: H-type, when cement was bilaterally diskontinuous or partly interdigitated, O-type, when cement was bilaterally continuous and completely interdigitated [28]. Anterior-to-posterior region of cement was assessed on lateral radiographs and classified according to maximal ratio of cement/vertebra anteroposterior-dimension as either $\geq 2/3$, or $< 2/3$. Any cement leakage was assessed on postoperative CT and classified into 4 types: through basivertebral vein (type B), through segmental vein (type S), through cortical defect (type-C), and intradiskal leakage (type D) [29, 30]. Vertebral height restoration, wedge angle restoration, kyphotic angle restoration was calculated as the difference between postoperative and preoperative vertebral height, wedge angle, kyphotic angle, respectively.

Radiological and surgical data were collected retrospectively from radiographs, CT or MRI, and evaluated independently by two authors (B. Q. T. and L. B. C.), with diskrepancies resolved by a third author (X. M. C.).

Definition of AVF

AVF was defined as postoperatively recurrent intractable back pain and subsequently presence of fracture signal on MRI in adjacent levels. Mostly, fracture signal was detected as low signal intensity of bone marrow within vertebral body on T1-weighted MR images.

Statistical analysis

Statistical analysis was performed using Statistical Package for the Social Sciences (SPSS), V 19.0 (Chicago, IL, USA). Univariate logistic regression model was used to explore effects of clinical, radiological and surgical parameters against occurrence of AVF. Significant correlates at *P* values of less than 0.05 were retained for final multivariate model. Multivariate binary logistic regression model was performed using a stepwise approach to identify significant risk factors for AVF. Statistical significance of potential predictors was assessed with the likelihood ratio test. In final model, a *P* value less than 0.05 was considered significant.

Table 1 Clinical features

No. of patients	N = 1077
Sex	
Male	267
Female	810
Mean age (range), yr	72.1 ± 8.3 (60–95)
BMI	24.3 ± 4.06
Fracture cause	
Traumatic	779
Non-traumatic	298
Fracture age	
Acute	805
Subacute	201
Chronic	71

BMI body mass index

Results

A total of 1077 patients with 1077 fractured vertebrae were finally included. Study population was made up of 267 males and 810 females with a mean age of 72.1 ± 8.3 years (range: 60–95 years) (Table 1). Mean follow-up time was 24.3 ± 11.9 months (range, 12–59 months). Clinical, radiological and surgical features were documented in Tables 1, 2 and 3.

Totally, 218 patients developed new vertebral fracture in untreated levels, of which 98 patients were diagnosed as AVF. Incidence of AVF was 9.1% (98/1077). AVF was detected at single superior or inferior level in 93 patients and at both superior and inferior level in 5 patients. On average, AVF occurred at 18.7 ± 16.0 months (range: 1–57 months) after PVP. 46.9% (46/98) of AVF developed within 12 months. The AVF-free rate at 12 months, which indicated the rate of non-AVF at 12 months, was 95.7% according to the Kaplan–Meier estimate (Fig. 1).

Univariate analysis showed that seven significant factors related to AVF were older age ($p = 0.001$), non-traumatic fracture ($p = 0.000$), cortical disruption on anterior wall ($p = 0.002$), cortical disruption on lateral wall ($p = 0.014$), basivertebral foramen ($p = 0.048$), type-B leakage ($p = 0.006$) and type-C leakage ($p = 0.004$). Type-D leakage as well as region of cement did not reach significance in univariate analysis (Table 4).

Multivariate analysis was performed to determine risk factors for AVF, as well as their effects. Older age ($p = 0.031$) and non-traumatic fracture ($p = 0.002$) were two significant risk factors for AVF. For every increase of per year in age, risk of AVF increased by 3.0%. Non-traumatic fracture exhibited 2.05-fold more at risk for AVF than traumatic fracture. However, any radiological and

Table 2 Radiological features

No. of fractured vertebrae	N = 1077
Fracture location	
Non-thoracolumbar	267
Thoracolumbar	810
Fracture type	
Wedge	662
Biconcave	94
Crush	321
Fracture severity	
Mild	797
Moderate	205
Severe	75
Cortical disruption	
No	448
Yes	629
Cortical disruption on anterior wall	
No	701
Yes	376
Cortical disruption on posterior wall	
No	1035
Yes	42
Cortical disruption on lateral wall	
No	824
Yes	253
Cortical disruption on endoplate	
No	629
Yes	448
Intravertebral cleft	
No	784
Yes	293
Spinal canal compromise	
No	719
Yes	358
Basivertebral foramen	
No	774
Yes	303
Vertebral height	0.77 ± 0.12
Wedge angle (°)	9.3 ± 4.3
Kyphotic angle (°)	15.2 ± 6.3

Table 3 Surgical features

No. of augmented vertebrae	N = 1077
Morphology of cement	
Interdigitation	794
Solid mass	283
Region of cement (Inferior-to-superior)	
No-endoplate contact	99
One-endoplate contact	408
Two-endoplate contact	570
Region of cement (Lateral-to-lateral)	
H-type	270
O-type	807
Region of cement (Anterior-to-posterior)	
< 2/3	44
≥ 2/3	1033
Cement leakage	
No	291
Yes	786
Type-B leakage	
No	739
Yes	338
Type-S leakage	
No	604
Yes	473
Type-C leakage	
No	917
Yes	160
Type-D leakage	
No	960
Yes	117
Cement volume, ml	5.5 ± 1.8
Vertebral height restoration	0.08 ± 0.05
Wedge angle restoration (°)	4.3 ± 3.7
Kyphotic angle restoration (°)	6.8 ± 3.2

surgical factors did not demonstrate their effectiveness to predict AVF in multivariate analysis (Table 5).

Discussion

New vertebral fracture in untreated levels were common and serious events after PVA in patients with OVCFs. In previous studies, 44.1–67.0% of new vertebral fracture occurred in adjacent levels [1–7], and 53.3–82.0% of AVF developed in the first 12 months after PVA [1, 31, 32]. In present study, 45.0% (98/218) of all new vertebral fracture was AVF and 46.9% (46/98) of all the AVF occurred within 12 months. The results were similar to that of previous studies [1–7, 31, 32].

Risk factors for AVF were widely evaluated in many series, however, results differed greatly [1–11]. Biomechanical etiology for AVF was highly investigated in several in vitro studies, but results were controversial [14–17]. Therefore, the current study, with a largest sample and most parameters to date, was carried out. Of note, any parameter was classified into three categories as either clinical, radiological or surgical, which might help to provide a good understanding in the effect of each aspect.

Older age and non-traumatic fracture were two clinical risk factors for AVF in present study. For every increase of per year in age, risk of AVF increased by 3.0%. Similarly,

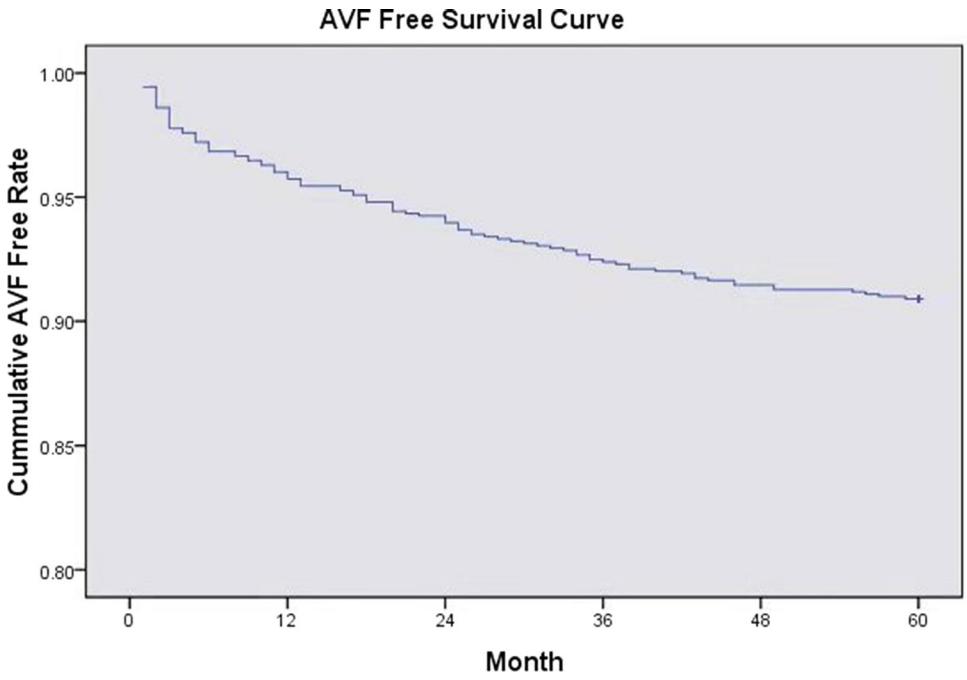

Fig. 1 A Kaplan–Meier survival curve the estimated AVF-free rate at 12 months after percutaneous vertebroplasty was 95.7%. Most (46.9%) AVF developed in the first 12 months, causing a rapid decline in the curve. *AVF* indicates adjacent vertebral fracture

in one study, age was significantly higher in AVF patient group compared with AVF-free patient group [2]. While, in more studies, older age was not significantly associated with AVF [3–5, 7, 8, 10, 31, 33]. It is possible that these studies did not find meaningful associations between older age and AVF because of relatively smaller sample size or due to the differences in patient selection. Fracture cause has not been investigated previously. The current study demonstrated that non-traumatic fracture exhibited 2.05-fold more at risk for AVF than traumatic fracture. It makes intuitive sense, a patient with non-traumatic fracture might have a more fragile spine, hence it was more vulnerable to a secondary fracture at any site, including adjacent levels. Of note, BMI was not significantly associated with AVF in present study. The result was in agreement with most recent series [1, 3, 5, 8, 32] and a meta-analysis [13].

With respect to radiological parameters, none was independent risk factor for AVF in our final analysis. However, several factors should be discussed. First, thoracolumbar region was reported as a risk factor for AVF in several studies [5, 8, 33, 34], and the given explanation stemmed from the fact thoracolumbar region is relatively mobile. However, the results were inconsistent with that of most other studies [1–4, 6, 7, 9] as well as ours. Thoracolumbar region might be a confounder factor, as it was indeed the most common site for not only initial fracture but also new fracture as either adjacent level or remote level.

Second, initial wedge angle was negatively [6], positively [8], or not [2] correlated with AVF in previous studies. Lee WS et al. thought that a lesser degree of wedge angle indicated more physiologic curvature of spine and subsequent more active in patients' daily life, hence increasing risk of new fracture [6]. On the contrary, Takahashi S et al. reported that a higher degree (> 25°) of wedge angle was risk factor for AVF [8]. However, more investigators demonstrated that wedge angle was not significantly associated with AVF [2, 13, 35], which was in line with our results. Similar to initial wedge angle, controversy exists in initial kyphotic angle, which had been reported to be a negative [32], positive [31], or no correlation [1–3, 5, 8, 10] with AVF in the literature available.

In contrast, fracture severity [1–3, 10], cortical disruption on endoplate [2, 7], intravertebral cleft [33, 36] were not significant factors in most studies as well as in ours.

Similar to radiological parameters, none of surgical ones reached significance in final model analysis. Biomechanically, Baroud et al. [14] and Nagaraja S et al. [15] addressed that rigid cement augmentation resulted in AVF, as shifts in stiffness, load or strains in adjacent level were clear or marked. On the contrary, Villarraga ML et al. [16] and Aquarius R et al. [17] thought cement in treated level did not result in AVF, as changes in stresses and strains in adjacent levels were minimal or not detrimental. Clinically, cement within treated vertebra were not risk factors or were the limited-evidence risk factors in several meta-analysis or systematic review [12, 13, 35]. When considering the results in our study, it might be presumed that cement itself, irrespective of morphology, region, and volume within vertebra, did not correlate with AVF.

Apart from cement within vertebra, cement extravertebral leakage, especially type-D leakage, should be discussed. Biomechanically, in contrast to fracture model

Table 4 Results of univariate analysis for adjacent vertebral fracture

Risk factors	AVF group (N = 98)	Non-AVF group (N = 979)	OR (95% CI)	*P*
Clinical factors				
Sex			1.106 (0.690–1.772)	0.676
Male	26 (26.5%)	241 (24.6%)		
Female	72 (73.5%)	738 (75.4%)		
Mean age (range), yr	74.6 ± 8.3	71.8 ± 8.2	1.041 (1.016–1.067)	0.001
BMI	23.6 ± 4.2	24.5 ± 4.0	0.945 (0.888–1.007)	0.082
Fracture cause			2.799 (1.837–4.266)	0.000
Traumatic	50 (51.0%)	729 (74.5%)		
Non-traumatic	48 (49.0%)	250 (25.5%)		
Fracture age			1.123 (0.803–1.572)	0.497
Acute	71 (72.4%)	734 (75.0%)		
Subacute	19 (19.4%)	182 (18.6%)		
Chronic	8 (8.2%)	63 (6.4%)		
Radiological factors				
Fracture location			1.083 (0.664–1.765)	0.751
Non-thoracolumbar	75 (76.5%)	735 (75.1%)		
Thoracolumbar	23 (23.5%)	244 (24.9%)		
Fracture type			1.159 (0.927–1.145)	0.196
Wedge	57 (58.2%)	605 (61.8%)		
Biconcave	4 (4.1%)	90 (9.2%)		
Crush	37 (37.8%)	284 (29.0%)		
Fracture severity			1.181 (0.853–1.634)	0.316
Mild	69 (70.4%)	728 (74.4%)		
Moderate	20 (20.4%)	185 (18.9%)		
Severe	9 (9.2%)	66 (6.7%)		
Cortical disruption			0.862 (0.568–1.310)	0.487
No	44 (44.9%)	404 (41.3%)		
Yes	54 (55.1%)	575 (58.7%)		
Cortical disruption on anterior wall			0.449 (0.270–0.746)	0.002
No	78 (79.6%)	623 (63.6%)		
Yes	20 (20.4%)	356 (36.4%)		
Cortical disruption on posterior wall			1.708 (0.701–4.162)	0.238
No	92 (93.9%)	943 (96.3%)		
Yes	6 (6.1%)	36 (3.7%)		
Cortical disruption on lateral wall			0.471 (0.258–0.859)	0.014
No	85 (86.7%)	739 (75.5%)		
Yes	13 (13.3%)	240 (24.5%)		
Cortical disruption on endoplate			1.270 (0.837–1.926)	0.261
No	52 (53.1%)	577 (58.9%)		
Yes	46 (46.9%)	402 (41.1%)		
Intravertebral cleft			1.201 (0.764–1.888)	0.427
No	68 (69.4%)	716 (73.1%)		
Yes	30 (30.6%)	263 (26.9%)		
Spinal canal compromise			0.767 (0.500–1.176)	0.224
No	60 (61.2%)	659 (67.3%)		
Yes	38 (38.8%)	320 (32.7%)		
Basivertebral foramen			1.548 (1.003–2.390)	0.048
No	62 (63.3%)	712 (72.7%)		
Yes	36 (36.7%)	267 (27.3%)		

Table 4 (continued)

Risk factors	AVF group (N = 98)	Non-AVF group (N = 979)	OR (95% CI)	*P*
Vertebral height	0.78 ± 0.14	0.77 ± 0.12	2.469 (0.400–15.222)	0.330
Wedge angle (°)	9.2 ± 4.8	9.9 ± 4.2	0.962 (0.916–1.011)	0.127
Kyphotic angle (°)	14.3 ± 6.3	15.3 ± 6.3	0.976 (0.943–1.010)	0.165
Surgical factors				
Morphology of cement			0.986 (0.616–1.578)	0.952
Interdigitation	72 (73.5%)	722 (73.7%)		
Solid mass	26 (26.5%)	257 (26.3%)		
Region of cement (Inferior-to-superior)			1.058 (0.768–1.458)	0.729
Non-endoplate contact	6 (6.1%)	93 (9.5%)		
One-endoplate contact	41 (41.8%)	367 (37.5%)		
Two-endoplate contact	51 (52.0%)	519 (53.0%)		
Region of cement (Lateral-to-lateral)			1.434 (0.851–2.414)	0.175
H-type	19 (19.4%)	251 (25.6%)		
O-type	79 (80.6%)	728 (74.4%)		
Region of cement (Anterior-to-posterior)			1.001 (0.351–2.859)	0.998
< 2/3	4 (4.1%)	40 (4.1%)		
≥ 2/3	94 (95.9%)	939 (95.9%)		
Cement leakage			1.089 (0.677–1.753)	0.724
No	25 (25.5%)	266 (27.2%)		
Yes	73 (74.5%)	713 (72.8%)		
Type-B leakage			1.813 (1.189–2.764)	0.006
No	55 (56.1%)	684 (69.9%)		
Yes	43 (43.9%)	295 (30.1%)		
Type-S leakage			1.498 (0.988–2.272)	0.057
No	46 (46.9%)	558 (57.0%)		
Yes	52 (53.1%)	421 (43.0%)		
Type-C leakage			0.224 (0.081–0.620)	0.004
No	94 (95.9%)	823 (84.1%)		
Yes	4 (4.1%)	156 (15.9%)		
Type-D leakage			1.041 (0.539–2.012)	0.904
No	87 (88.8%)	873 (89.2%)		
Yes	11 (11.2%)	106 (10.8%)		
Cement volume, ml	5.4 ± 1.6	5.5 ± 1.8	0.980 (0.872–1.103)	0.741
Vertebral height restoration	0.07 ± 0.05	0.08 ± 0.05	0.062 (0.001–3.298)	0.170
Wedge angle restoration (°)	4.2 ± 3.9	4.3 ± 3.7	0.993 (0.939–1.051)	0.811
Kyphotic angle restoration (°)	6.5 ± 3.2	6.9 ± 3.2	0.961 (0.897–1.028)	0.247

AVF adjacent vertebral fracture

OR odds ratio

CI confidence interval

and augmentation model, intervertebral disk leakage model was no available in published literature. Clinically, type-D leakage, when qualitatively defined as presence or absence, was one significant predictor for AVF in many studies [4, 9], but not in many others [1, 2, 5, 33, 36] as well as ours. Type-D leakage, when quantitatively documented furtherly as volume (ml) [3, 37], extent (%) [3, 38], severity (mild, moderate, severe) [11], and location (anterior, middle, posterior third of disk) [38], was correlated with AVF in subgroup analysis in several studies [3, 37, 38], but not in other one [11]. discrepancies would be due to variation among series. For example, in

Table 5 Results of multivariate analysis for adjacent vertebral fracture

Risk factors	OR (95% CI)	*P*
Clinical factors		
Older age	1.030 (1.003–1.057)	0.031
Non-traumatic fracture	2.048 (1.306–3.211)	0.002
Radiological factors		
Cortical disruption on anterior wall	0.662 (0.358–1.226)	0.190
Cortical disruption on lateral wall	1.008 (0.473–2.146)	0.984
Basivertebral foramen	1.322 (0.839–2.084)	0.228
Surgical factors		
Type-B leakage	1.333 (0.849–2.093)	0.211
Type-C leakage	0.361 (0.120–1.086)	0.070

OR odds ratio

CI confidence interval

our series, rate of type-D leakage, 10.9% (117/1077), was lower than that reported ranging from 12.1 to 43.5% [2–4, 9, 11, 33, 36–38], and type-D leakage was more homogeneous as minimal volume, low extent, mild severity, and middle location.

Additionally, vertebral height restoration [7, 34], vertebral angle restoration [7, 8], or kyphotic angle restoration [10, 36] were reported to be risk factors in several studies, in which hypothesis available was that increased restoration in height or angle results in increased stress on surrounding tissue, contributing to the risk of AVF [7, 34]. This hypothesis might be primitive as the fact that paradoxically, parameters usually reached significance alone when they were evaluated together [7, 36]. Hence, not surprisingly, they were not correlated with AVF in many other studies [2, 31, 33] as well as ours.

In general, our results implied that both radiological features and surgical procedure might play a negligible effect on occurrence of AVF and AVF might be due to natural course of osteoporosis.

Noticeably, new fracture was negatively correlated with distance between new facture and treated level (e.g.,, distance between L2 and L3 is one and that between T9 and L1 is four) [36, 37]. Hence, we cautiously hypothesize there might be additional hidden factors that induce different fracture etiology between adjacent and remote level, needing further studies to seek.

One strength of our study was a largest number of patients enrolled as well as the most parameters evaluated to date, making it sufficiently large and comprehensive to allow statistically valid conclusions to be drawn. Although the improvement over our efforts did not overcome the substantial limitations found in retrospective study design, the measurement of myriad radiologic and procedure-related variables might help to add valuable new information to the literature and guide future prospective studies on this issue.

Some other limitations must also be acknowledged. First, patients who had two or more level OVCFs were excluded, in order to simplify the statistical analysis in vertebra-specific level rather than patient level. Second, BMD was not quantitatively evaluated in analysis, as DEXA was not routinely obtained, especially in patients who had fragile fractures in hips or spine previously, who suffered vertebral fractures spontaneously, and who were aged 80 years or more. Third, other potential factors that were not directly assessed in our study included diabetes [10], use of osteoporosis drugs [33], sagittal index [1, 3], sagittal balance [5], spinopelvic balance [32].

Conclusion

Incidence of AVF was 9.1% (98/1077) within a mean follow-up time of 24.3 ± 11.9 months after PVP in patients with OVCFs. Most (46.9%, 46/98) AVF developed within 12 months after procedure. Older age and non-traumatic fracture were two clinical risk factors for AVF. However, neither radiological nor surgical factor was related with AVF in final model analysis.

Conflicts of interest

None.

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