

## Analysis of infection related factors and clinical characteristics after percutaneous vertebral augmentation procedures

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**Abstract: Objective** To analyze the infection-related factors and clinical characteristics to provide basis for preoperative prevention and diagnosis by the clinical study of patients infected after percutaneous vertebral augmentation procedures (PVAP). **Methods** A retrospective study was conducted to analyze the diagnosis and treatment process and prognosis of 5 patients with infection after PVAP in Shanghai Ninth People's Hospital from December 2017 to November 2023. **Results** There were 3 males and 2 females, with an average age of 74.8 years old. The time from operation to infection was 5 to 24 months. All patients presented with low back pain and visual analogue scale (VAS) score was 7 to 8. Physical examination of the patients showed that thoracolumbar movement was limited, local tenderness and percussion pain, and 4 patients had nerve symptoms such as decreased muscle strength in both lower limbs to varying degrees, 2 of which were accompanied by defecation disorder. In laboratory tests, white blood cell (WBC) count was  $(4.0-7.3) \times 10^9/L$ , C-reactive protein (CRP) was 1.51 to 66.00 mg/dL, erythrocyte sedimentation rate (ESR) was  $(2-94)$  mm/1h, and procalcitonin (PCT) was 0.10 to 0.40 ng/mL. X-ray, CT and MRI indicated the manifestations of infection, etiology and pathology confirmed 4 cases of *Mycobacterium tuberculosis*, of which 1 case was complicated with *Acinetobacter baumannii*, and the other case was diagnosed with *Staphylococcus epidermidis*. At the last follow-up, 2 patients died of complications, 3 patients were relieved of low back pain after surgery combined with drug treatment, body temperature was normal and inflammatory indicators were within the normal reference value range, and imaging examination showed no signs of infection. **Conclusion** Adequate preoperative assessment and symptomatic treatment of complications and standard operation during the operation can reduce the incidence of infection after PVAP. In case of infection, early diagnosis and systematic treatment can achieve good results.

**Keywords:** Percutaneous vertebral augmentation procedures; Postoperative infection; Pathogenic factors; Clinical characteristics

In the past three decades, percutaneous vertebral augmentation procedures (PVAP), including percutaneous vertebroplasty (PVP) and subsequent percutaneous kyphoplasty (PKP), have been widely used in the treatment of osteoporotic vertebral compression fractures (OVCF) among the elderly due to their advantages of minimally invasive surgery, rapid vertebral reinforcement, pain relief, and restoration of early functional activities of patients [1-2]. However, postoperative complications such as cement leakage, adjacent vertebral fractures, nerve injury, hematoma at the puncture site, rib fractures, and infection have also been the focus of attention among many scholars [3-4]. Some studies have reported that the incidence of post-PVAP infection ranges from 0.04% to 0.98%, and most cases occur in elderly patients [5-7]. Therefore, this study summarizes the case data of post-PVAP infection and analyzes the related factors and clinical characteristics of infection.

### 1 General data

This was a retrospective study. The study subjects were 5 patients with post-PVAP infection admitted to the Ninth

People's Hospital Affiliated to Shanghai Jiao Tong University School of Medicine from December 2017 to November 2023. Among them, there were 3 male patients and 2 female patients, with an age range of 68 to 81 years old, and an average age of 74.8 years old [Table 1].

### 2 Results

#### 2.1 Clinical manifestations

The time from PVAP surgery to confirmed infection was 5 to 24 months in the 5 patients. All patients presented with low back pain, and the VAS score was 7-8. There was limited thoracolumbar motion, local tenderness and percussion pain. Four patients had varying degrees of muscular weakness in both lower limbs and other neurological symptoms, including two patients with bowel and bladder dysfunction. [Table 1]. At admission, the body temperature of the 5 patients was within the normal range, with one patient having afternoon fever [Table 2]. Two patients presented with emaciated appearance and poor mental status, and one patient had extensive skin ulceration on the lumbar-sacral region and lower limbs.

Tab. 1 General data of patients infected after PVAP

No.	Gender	Age (years)	Involved Vertebral Body	VAS Score	Time from surgery to diagnosis of infection (months)	Are there any concomitant neurological symptoms
1	Male	71	T11	7	5	Yes <sup>a</sup>
2	Male	77	T11	8	6	Yes <sup>a</sup>
3	Female	81	T12, L1	8	10	Yes
4	Female	77	L3	7	24	Yes
5	Male	68	T12	8	5	No

Note:<sup>a</sup> Neurological symptoms complicated with dysfunction of urination and defecation.

Tab. 2 Temperature, laboratory examination, etiology, treatment and prognosis of patients with postoperative PVAP infection

No.	T (°C)	WBC( $\times 10^9/L$ )	CRP (mg/L)	ESR (mm/h)	PCT (ng/mL)	Pathogenic bacteria	Treatment	Prognosis
1	36.7	4.70	28.02	13	0.10	<i>Mycobacterium tuberculosis</i>	Antituberculosis	Death from complications
2	36.8	7.30	66.00	94	0.40	<i>Mycobacterium tuberculosis</i>	Surgery① + anti-tuberculosis	Cured
3	36.4	4.00	1.51	2	0.11	<i>Acinetobacter baumannii</i> + <i>Mycobacterium tuberculosis</i>	Antituberculosis	Death from complications
4	36.6	5.60	19.55	42	0.17	<i>Mycobacterium tuberculosis</i>	Surgery② + anti-tuberculosis	Cured
5	36.6	4.93	40.15	43	0.10	<i>Staphylococcus epidermidis</i>	Surgery③+Anti infection	Cured

Note: Surgery① was posterior T11 and T12 vertebral subtotal resection, iliac bone grafting, and T8-L2 internal fixation; Surgery② was posterior lesion clearance surgery; Surgery③ was posterior T12 vertebral subtotal resection, iliac bone grafting, and T10-L2 internal fixation.

### 2.2 Ancillary examinations

(1) Laboratory Examinations: The white blood cell (WBC) count was  $(4.00-7.30) \times 10^9/L$ , C-reactive protein (CRP) was 1.51-66.00 mg/dL, erythrocyte sedimentation rate (ESR) was 2-94 mm/h, and procalcitonin (PCT) was 0.10-0.40 ng/mL [Table 2]. Pathogen culture, next-generation sequencing (NGS) of pathogen metagenome, and pathological examination were performed on puncture fluid and tissue, including polymerase chain reaction (PCR) for acid-fast bacilli. Four patients were diagnosed with *Mycobacterium tuberculosis* infection, and their pathological examination showed granulomatous changes with caseous necrosis and Langhans giant cells, and Acid-fast bacilli PCR was positive. One patient with *Mycobacterium tuberculosis* infection had NGS suggesting concurrent infection with *Acinetobacter baumannii*. Another patient had a general bacterial culture and NGS examination suggesting *Staphylococcus epidermidis*. Postoperative pathology showed infiltration of a large number of acute and chronic inflammatory cells in the fibrous tissue, hyperplasia of granulation tissue, dilation and congestion of small blood vessels with hemorrhage.

(2) Imaging Examinations: X-ray after PVAP surgery showed compression changes of the involved vertebrae, and bone cement filling after surgery. X-ray of one patient showed soft tissue swelling around the involved vertebrae. All 5 patients underwent electronic computer tomography (CT) examination and showed vertebral bone destruction. Three patients showed spinal stenosis, and one showed a local slight patchy periosteal reaction. Magnetic resonance

imaging (MRI) showed a low signal on T1-weighted (T1WI) and a high signal on T2-weighted (T2WI), with uneven vertebral body signal. *Mycobacterium tuberculosis* infection was visible as soft tissue swelling around multiple adjacent vertebrae. MRI enhancement showed diffuse, marginal, or annular enhancement.

### 2.3 Treatment and prognosis

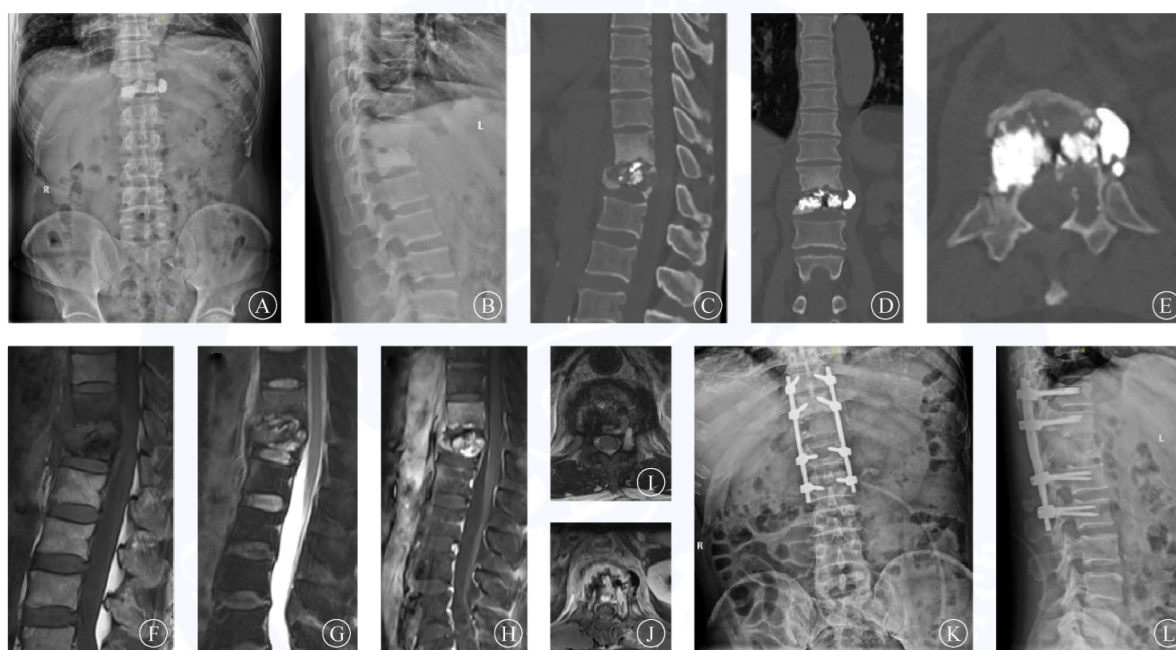
Antibiotics were given before surgery, and sensitive antibiotics were used for at least one week after identifying the pathogenic bacteria. If it is a tuberculosis bacilli infection, preoperative anti-tuberculosis treatment should be no less than 2 weeks. Two patients with *Mycobacterium tuberculosis* infection were unable to tolerate surgery due to poor general conditions and only received treatment with anti-tuberculosis drugs. They died of complications one month and three months after discharge, respectively. One patient underwent posterior lesion debridement. The last follow-up showed relief of low back pain, average temperature, inflammatory markers within the normal reference range, and no signs of infection on imaging examination. One patient was infected with tuberculosis bacilli involving T10, T11, and T12, with significant destruction of T11 and T12 vertebrae. The surgical plan was posterior T11 and T12 vertebral subtotal resection + iliac bone grafting + T8-L2 internal fixation. Postoperatively, anti-tuberculosis drugs were selected according to the advice of the tuberculosis hospital doctor, and the last follow-up showed good recovery. The patient was infected with *Staphylococcus epidermidis*, which mainly involved T12, and the surgical

plan was posterior T12 vertebral subtotal resection + iliac bone grafting + T10-L2 internal fixation. Sensitive antibiotic anti-infection treatment was continued after surgery (2 weeks of intravenous administration + 4 weeks of oral treatment). Regular follow-up inflammatory markers showed good recovery at the last follow-up.

### 2.4 Typical case

A 68-year-old male patient was admitted to the hospital due to "thoracic vertebral fracture 5 months after surgery, low back pain for 2 months". Physical examination upon admission showed tenderness and percussion pain at T12 spinous process, normal muscle strength and sensory function of both lower limbs, and

negative pathological signs. Laboratory tests showed WBC of  $4.93 \times 10^9/L$ , CRP of 40.15 mg/dL, ESR of 43 mm/h, and PCT of 0.10 ng/mL. Imaging examination suggested T<sub>12</sub> PVP postoperative vertebral infection. Puncture tissue culture and NGS suggested *Staphylococcus epidermidis*. Pathological diagnosis of puncture tissue: massive infiltration of acute and chronic inflammatory cells in fibrous tissue, hyperplasia of granulation tissue, dilation and congestion of small blood vessels with hemorrhage. After treatment with vancomycin anti-infection, posterior T12 vertebral subtotal resection + iliac bone grafting + T10-L2 internal fixation was performed. Postoperatively, anti-infection and thoracolumbar brace protection were continued. The last follow-up showed no significant pain in the low back and patients can walk normally [ Figure 1].



Note: A and B are the frontal and lateral X-ray films of the thoracolumbar segment during hospitalization, indicating cement leakage and kyphosis of the thoracolumbar segment after PVP operation; C, D and E are the sagittal, coronal and transverse two-dimensional reconstruction of lumbar CT, indicating bone destruction; F, G, H, I and J are the plain scan and enhanced MRI, indicating infection after PVP operation; K and L are the postoperative frontal and lateral X-ray films, showing that the bone graft and internal fixation are in good position.

**Fig. 1** Preoperative and postoperative images of typical cases of PVAP postoperative infection

### 3 Discussion

According to the literature report, the common pathogenic bacteria of postoperative infection after PVAP include *Mycobacterium tuberculosis* [8], methicillin-sensitive *Staphylococcus aureus* (MSSA), methicillin-resistant *Staphylococcus aureus* (MRSA), methicillin-resistant *Staphylococcus epidermidis* (MRSE), *Micrococcus microscopicus*, *Achromobacter xylosoxidans*, *Granulicatella adiacens* [5], *Staphylococcus epidermidis* [9], *Salmonella*, *Escherichia coli*, *Peptostreptococcus*, *Propionibacterium* [6], *Enterococcus faecalis*, and *Streptococcus hemolyticus*. In this study, four patients were diagnosed with *Mycobacterium tuberculosis* infection, of which one case was complicated with *Acinetobacter baumannii* infection; one case suggested *Staphylococcus*

*epidermidis* infection. Through a literature review and combined with clinical data, we find that there are many kinds of pathogenic bacteria causing postoperative infection after PVAP, among which *Mycobacterium tuberculosis* and *Staphylococcus aureus* are more common.

Postoperative *Mycobacterium tuberculosis* infection after PVAP is mostly seen in patients with a history of pulmonary tuberculosis [8] or contact history with active tuberculosis patients [10]. The possible mechanisms of vertebral infection include: (1) *Mycobacterium tuberculosis* spreads from the lungs to the vertebrae through the blood; (2) reactivation of *Mycobacterium tuberculosis* in the quiescent stage of the primary lesion [11]. Based on the theory of "locus minoris resistentiae" [12], OVCF may lead to the formation of intravertebral hematoma. Although PVAP is a minimally invasive

operation, it may still induce an inflammatory reaction, which may lead to the aggregation and release of macrophages carrying *Mycobacterium tuberculosis* at this site [13]. Park *et al.* [5] and Kang *et al.* [14] believed that some of these patients may have spinal tuberculosis misdiagnosed as OVCF or OVCF with concurrent vertebral infection and undergone PVAP surgery. In this study, two patients with *Mycobacterium tuberculosis* infection of the vertebral body had chest CT scans suggesting old pulmonary tuberculosis lesions. Although it was not clear whether there was any misdiagnosis in these two patients, OVCF patients with pulmonary tuberculosis changes should be carefully identified before surgery.

Some scholars believe that postoperative infection may be related to pre-existing infections in other parts of the body, among which urinary tract infection is the most common, followed by pulmonary infection, cholecystitis, meningitis, infectious bedsores, and acne vulgaris. Pathogenic bacteria flow through the artery or the vertebral venous plexus to the vertebral body, causing vertebral infection [15-17]. Although *Staphylococcus epidermidis* exists on human skin and mucosa, the incidence of postoperative *Staphylococcus epidermidis* infection after PVAP is relatively low, and there are currently few relevant literature reports. The cause of infection may be due to incomplete sterilization of the surgical area or non-standard operation, which leads to pathogenic bacteria entering the vertebral body through the puncture site, causing iatrogenic infection [11]. Other risk factors for infection include advanced age, smoking, malnutrition, immunosuppression, diabetes, renal insufficiency, rheumatic diseases, history of tumor, and cirrhosis [18].

A study found that the time from PVAP surgery to the diagnosis of tuberculous mycobacterial infection was  $(8.45 \pm 11.68)$  months, while in the non-tuberculous infection group, the time from surgery to infection diagnosis was  $(6.36 \pm 14.14)$  months [19]. This study found that the time interval from PVAP surgery to infection diagnosis ranged from 5 to 24 months. Vaccaro *et al.* [20] and Su *et al.* [21] believed that there were no obvious signs of infection before PVP surgery, but fever occurred after surgery. For patients with a time interval from surgery to infection diagnosis of less than 2 months, the cause of infection may be preoperative misdiagnosis or iatrogenic infection, and the cause of *Staphylococcus epidermidis* infection may be iatrogenic infection. For patients with fever after surgery and a time interval from surgery to infection diagnosis of more than 2 months, the cause of infection may be hematogenous infection. In this study, two patients had a time interval from surgery to confirmed infection exceeding 5 months. They were elderly and had poor general conditions, and ultimately died from complications. Therefore, some scholars suggest that for patients with preoperative urinary tract, pulmonary, and other infectious foci and/or abnormal elevations of WBC, CRP, ESR, as well as imaging suggesting a high possibility of infection, puncture biopsy should be performed when necessary to postpone PVAP surgery. It should be noted that PVAP surgery must be performed in a standardized manner to minimize the occurrence of iatrogenic infections.

In addition, for patients with Q fever-induced vertebral postoperative infection or *Brucella* vertebral infection who have a history of contact with animals and animal products in endemic areas, although the history of trauma is clear, differentiation is still needed to reduce misdiagnosis.

PVAP postoperative infection has no typical clinical manifestations and is similar to pyogenic spondylitis. Systemic symptoms can manifest as fever, nausea, vomiting, anorexia, fatigue, weight loss, etc. 25% to 55% of infected patients have normal body temperature [22]. In this study, there were two patients had a wasted appearance and poor mental status, but none of the five patients presented with high fever or chills. Only one patient had low-grade afternoon fever. Since the common sites of PVAP postoperative infection are T12 (20%) and L1 (19.09%) [11], local symptoms usually manifest as progressive or persistent low back pain. If there is nerve damage, it may manifest as rib, abdominal, hip, and lower limb radiating pain, decreased sensory level, decreased muscle strength, and even bowel and bladder dysfunction [5]. In this study, four patients had varying degrees of muscle strength reduction in both lower limbs and other neurological symptoms, including two patients with bowel and bladder dysfunction.

Park *et al.* [5] reported in the literature that 10 of 11 patients had one or more inflammatory markers (WBC, CRP, ESR) higher than the normal reference value. Acid-fast staining, tuberculous mycobacterial culture, T-spot, tuberculous mycobacterial/rifampicin (Xpert MTB/RIF) detection, and pathological examination are important reference bases for the diagnosis of tuberculous infection. X-ray imaging shows collapsed vertebrae and thickening of the paravertebral soft tissue. CT plain scan can show the degree of vertebral body destruction, bone fragments, and calcification. MRI imaging of the affected vertebra, adjacent vertebra, and surrounding soft tissue shows a slow signal on T1WI, a high signal on T2WI, and a high signal on STIR sequence [23]; enhanced MRI shows diffuse enhancement [4]. The characteristics of tuberculous mycobacterial infection are skipping lesions and paravertebral cold abscesses, and MRI suggesting paravertebral or epidural abscesses is helpful for diagnosis [24]. In this study, WBC count was  $(4.0-7.3) \times 10^9/L$ , CRP was 1.51-66 mg/dL, ESR was 2-94 mm/h, and PCT was 0.10-0.40 ng/mL. Therefore, inflammatory markers in PVAP postoperative infection patients are normal or mildly elevated. If imaging examination suggests signs of infection, puncture tissue pathogen culture, pathological examination, and NGS are helpful for further diagnosis.

In general, OVCF patients tend to be elderly and have many underlying diseases with low immunity. Post-PVAP infection affects patients' quality of life and may be fatal in severe cases. If there is a high suspicion of preoperative infection in OVCF patients, inflammatory indicators and imaging examinations should be actively improved, and infections in other parts of the body should be excluded. If necessary, a biopsy should be performed to postpone surgical treatment. When infection occurs after PVAP, biopsy should be used for histopathological examination, general bacterial culture, NCS, and *Mycobacterium*

tuberculosis detection to identify pathological fractures caused by infected vertebrae. After standardized and systematic treatment, the degree of vertebral defect and kyphosis should be evaluated to select appropriate surgical or revision surgical plans, so as to achieve satisfactory treatment results.

**Conflict of Interest:**None

## References

- [1] Boss S, Srivastava V, Anitescu M. Vertebroplasty and kyphoplasty[J]. Phys Med Rehabil Clin N Am, 2022, 33(2): 425-453.
- [2] Jang HD, Kim EH, Lee JC, et al. Management of osteoporotic vertebral fracture: review update 2022[J]. Asian Spine J, 2022, 16(6): 934-946.
- [3] Takahashi S, Inose H, Tamai K, et al. Risk of revision after vertebral augmentation for osteoporotic vertebral fracture: a narrative review[J]. Neurospine, 2023, 20(3): 852-862.
- [4] Cavka M, Delimar D, Rezan R, et al. Complications of percutaneous vertebroplasty: a pictorial review[J]. Medicina (Kaunas), 2023, 59(9): 1536.
- [5] Park JW, Park SM, Lee HJ, et al. Infection following percutaneous vertebral augmentation with polymethylmethacrylate[J]. Arch Osteoporos, 2018, 13(1): 47.
- [6] Liao JC, Lai PL, Chen LH, et al. Surgical outcomes of infectious spondylitis after vertebroplasty, and comparisons between pyogenic and tuberculosis[J]. BMC Infect Dis, 2018, 18(1): 555.
- [8] Mao KZ, Gao YZ, Mao KY, et al. Clinical manifestations and management of infectious spondylitis following vertebroplasty or kyphoplasty[J]. Chin J Orthop Trauma, 2021, 23(1): 33-38. [In Chinese]
- [8] Ivo R, Sobottke R, Seifert H, et al. Tuberculous spondylitis and paravertebral abscess formation after kyphoplasty: a case report[J]. Spine, 2010, 35(12): E559-E563.
- [9] Wang Z, Chen J, Hao J, et al. Pyogenic spondylitis of *Staphylococcus epidermidis* secondary to percutaneous vertebroplasty: a case report and literature review[J]. Orthop J China, 2021, 29(9): 826-829. [In Chinese]
- [10] Lai PJ, Liao JC, Chen LH, et al. Tuberculous spondylitis after percutaneous vertebroplasty: a case series of 9 cases[J]. Biomed J, 2019, 42(4): 285-292.
- [11] Ge CY, He LM, Zheng YH, et al. Tuberculous spondylitis following kyphoplasty: a case report and review of the literature[J]. Medicine, 2016, 95(11): e2940.
- [12] Agostoni G. Aneurysms of the thoracic aorta and traumatism; region of the aortic isthmus; locus minoris resistentiae[J]. Arch Mal Coeur Vaiss, 1953, 46(6): 550-558.
- [13] Bouvresse S, Chiras J, Bricaire F, et al. Pott's disease occurring after percutaneous vertebroplasty: an unusual illustration of the principle of locus minoris resistentiae[J]. J Infect, 2006, 53(6): e251-e253.
- [14] Kang JH, Kim HS, Kim SW. Tuberculous spondylitis after percutaneous vertebroplasty: misdiagnosis or complication?[J]. Korean J Spine, 2013, 10(2): 97-100.
- [15] Lee CB, Kim HS, Kim YJ. Pyogenic spondylitis after vertebroplasty - a report of two cases-[J]. Asian Spine J, 2007, 1(2): 106-109.
- [16] Syed MI, Avutu B, Shaikh A, et al. Vertebral osteomyelitis following vertebroplasty: is acne a potential contraindication and are prophylactic antibiotics mandatory prior to vertebroplasty?[J]. Pain Physician, 2009, 12(4): E285-E290.
- [17] Yu SW, Chen WJ, Lin WC, et al. Serious pyogenic spondylitis following vertebroplasty—a case report[J]. Spine, 2004, 29(10): E209-E211.
- [18] Buttermann GR, Mullin WJ. Percutaneous vertebral body cement augmentation for back pain related to occult osteomyelitis/diskitis[J]. Orthopedics, 2011, 34(11): e788-e792.
- [19] Zheng BW, Liu FS, Zheng BY, et al. Risk factors for tuberculous or nontuberculous spondylitis after percutaneous vertebroplasty or kyphoplasty in patients with osteoporotic vertebral compression fracture: a case-control study[J]. Front Surg, 2022, 9: 962425.
- [20] Vaccaro AR, Shah SH, Schweitzer ME, et al. MRI description of vertebral osteomyelitis, neoplasm, and compression fracture[J]. Orthopedics, 1999, 22(1): 67-73.
- [21] Su K, Jiang WT, Shao Z, et al. Surgical treatment for vertebral infection after percutaneous vertebroplasty[J]. Chin J Spine Spinal Cord, 2022, 32(12): 1139-1144. [In Chinese]
- [22] Schmid KE, Boszczyk BM, Bierschneider M, et al. Spondylitis following vertebroplasty: a case report[J]. Eur Spine J, 2005, 14(9): 895-899.
- [23] Hong JY, Li YW, Ouyang L. Trap of vertebroplasty: postoperative infection and preoperative misdiagnosis (report of 3 cases)[J]. Orthopaedics, 2022, 13(2): 176-180. [In Chinese]
- [24] Zou MX, Wang XB, Li J, et al. Spinal tuberculosis of the lumbar spine after percutaneous vertebral augmentation (vertebroplasty or kyphoplasty)[J]. Spine J, 2015, 15(6): e1-e6.

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· 论 著 ·

# 经皮椎体强化术后感染相关因素及临床特点分析

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**摘要:目的** 通过对经皮椎体强化术(PVAP)后感染患者的临床研究,分析感染相关因素及临床特点,为术前预防及诊断提供依据。**方法** 采用回顾性研究方法,对2017年12月至2023年11月上海交通大学医学院附属第九人民医院收治的5例PVAP术后感染患者诊疗经过及预后进行分析。**结果** 男3例,女2例,年龄68~81岁,平均74.8岁,从手术至明确感染的时间为5~24个月,所有患者均表现腰背部疼痛,视觉模拟量表(VAS)评分为7~8分,均有胸腰椎活动受限、局部压痛和叩击痛,4例患者有双下肢不同程度肌力下降等神经症状,其中2例伴二便障碍。实验室检查示白细胞(WBC)计数为 $(4.0\sim 7.3)\times 10^9/L$ ,C-反应蛋白(CRP)为1.51~66.00 mg/dL,红细胞沉降率(ESR)为2~94 mm/1 h,降钙素原(PCT)为0.10~0.40 ng/mL,X线、CT及MRI检查考虑感染表现,病原学及病理学明确4例结核分枝杆菌,其中1例合并鲍曼不动杆菌,另1例患者诊断为表皮葡萄球菌。末次随访时,2例患者死于并发症,3例患者经手术联合药物治疗后腰背部疼痛缓解,体温正常,炎性指标在正常参考值范围,影像学检查提示未见感染征象。**结论** 术前充分评估和合并症对症处理,术中规范操作,可减少PVAP后感染的发生,一旦发生感染,早期诊断与系统治疗可获得良好效果。

**关键词:** 经皮椎体强化术; 术后感染; 致病因素; 临床特点

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**Abstract: Objective** Based on the clinical study of patients infected after percutaneous vertebral augmentation procedures (PVAP), the infection related factors and clinical characteristics were analyzed to provide basis for early prevention and diagnosis. **Methods** A retrospective study was conducted to analyze the diagnosis and treatment process and prognosis of 5 patients with infection after PVAP in Shanghai Ninth People's Hospital from December 2017 to November 2023. **Results** There were 3 males and 2 females, aged 68-81 years, with an average age of 74.8 years. The time from operation to infection was 5 to 24 months. All patients presented with low back pain, the visual analogue scale (VAS) score was 7 to 8. All patients had limited thoracolumbar movement, local tenderness and percussion pain. Four patients had nerve symptoms such as decreased muscle strength in both lower limbs to varying degrees, 2 of which accompanied by defecation disorder. In laboratory tests, white blood cell (WBC) count was  $(4.0-7.3)\times 10^9/L$ , C-reactive protein (CRP) was 1.51-66.00 mg/dL, erythrocyte sedimentation rate (ESR) was 2-94 mm/1 h, and procalcitonin (PCT) was 0.10-0.40 ng/mL. X-ray, CT and MRI indicated the manifestations of infection, etiology and pathology confirmed 4 cases of *Mycobacterium tuberculosis*, of which 1 case was complicated with *Acinetobacter baumannii*, and the other case was diagnosed with *Staphylococcus epidermidis*. At the last follow-up, 2 patients died of complications, 3 patients were relieved of low back pain after surgery combined with drug treatment, body temperature

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was normal and inflammatory indicators were within the normal reference value range, and imaging examination showed no signs of infection. **Conclusion** Adequate preoperative assessment, symptomatic treatment of complications, and standard operation during the operation can reduce the incidence of infection after PVAP. If infection occurs, early diagnosis and systematic treatment can obtain good results.

**Keywords:** Percutaneous vertebral augmentation procedures; Postoperative infection; Pathogenic factors; Clinical characteristics

近三十年来,经皮椎体强化术(PVAP),包括经皮椎体成形术(PVP)以及随后的经皮椎体后凸成形术(PKP),凭借其微创、迅速强化椎体、缓解疼痛、恢复患者早期功能活动等优势,被广泛应用于老年骨质疏松性椎体压缩性骨折(OVCF)的治疗<sup>[1-2]</sup>。但是,术后并发症,比如骨水泥渗漏、邻近椎体骨折、神经损伤、穿刺部位血肿、肋骨骨折以及感染等,亦是诸多学者关注的焦点问题<sup>[3-4]</sup>。有文献报道,PVAP术后感染发生率为0.04%~0.98%,且以老年患者居多<sup>[5-7]</sup>,为此,本研究对PVAP术后感染病例资料加以总结,并分析感染的相关因素及临床特点。

## 1 一般资料

本研究为回顾性研究,研究对象为2017年12月至2023年11月上海交通大学医学院附属第九人民医院收治的5例腰椎压缩性骨折PVAP术后感染患者,其中男性3例,女性2例,年龄68~81岁,平均74.8岁。见表1。

## 2 结果

**2.1 临床表现** 5例患者从PVAP手术至明确感染的时间为5~24个月,所有患者均表现腰背部疼痛,视觉模拟量表(VAS)评分为7~8分。胸腰椎活动受限,局部压痛和叩击痛,4例患者有双下肢不同程度肌力下降等神经症状,其中2例伴有二便障碍。见表1。该5例患者入院时体温在正常范围内,其中1例患者午后低热。见表2。2例患者消瘦面容,精神欠佳,其中1例患者腰骶部及下肢大面积皮肤溃烂。

**2.2 辅助检查** (1) 实验室检查:白细胞(WBC)计

数为 $(4.00 \sim 7.30) \times 10^9/L$ , C-反应蛋白(CRP)为1.51~66.00 mg/dL,红细胞沉降率(ESR)为2~94 mm/1 h,降钙素原(PCT)为0.10~0.40 ng/mL。见表2。穿刺液及组织行病原菌培养、病原宏基因组二代测序(NGS)及病理学检查等,包括抗酸杆菌聚合酶链反应(PCR),其中4例患者诊断为结核分枝杆菌感染,病理学检查提示病灶组织可见肉芽肿性变伴凝固性坏死以及朗罕巨细胞,抗酸杆菌PCR(+). 1例结核分枝杆菌感染患者NGS提示合并感染鲍曼不动杆菌。另外1例患者经一般细菌培养及NGS检查提示表皮葡萄球菌,术后病理提示纤维组织内大量急慢性炎细胞浸润,肉芽组织增生,小血管扩张充血伴出血。(2) 影像学检查:PVAP术后X线可见受累椎体压缩改变,骨水泥填充术后,1例患者X线片显示受累椎体伴有椎旁软组织肿胀影。5例患者行电子计算机断层扫描(CT)检查均见椎体骨质破坏,3例可见椎管狭窄,1例见局部小片状骨膜反应。磁共振成像(MRI)可见T1加权(T1WI)呈等低信号,T2加权(T2WI)呈高信号,椎体信号欠均匀,结核分枝杆菌感染可见多个相邻椎体椎旁软组织肿胀。MRI增强呈弥散性、边缘性或环形强化表现。

表1 PVAP术后感染患者一般资料

Tab. 1 General data of patients infected after PVAP

序号	性别	年龄(岁)	受累椎体	VAS评分(分)	手术至感染确诊时间(月)	是否合并神经症状
1	男	71	T <sub>11</sub>	7	5	是 <sup>a</sup>
2	男	77	T <sub>11</sub>	8	6	是 <sup>a</sup>
3	女	81	T <sub>12</sub> 、L <sub>1</sub>	8	10	是
4	女	77	L <sub>3</sub>	7	24	是
5	男	68	T <sub>12</sub>	8	5	否

注:<sup>a</sup> 合并神经症状伴有二便障碍。

表2 PVAP术后感染患者入院时体温、实验室检查、病原学、治疗及预后

Tab. 2 Temperature, laboratory examination, etiology, treatment and prognosis of patients with postoperative PVAP infection

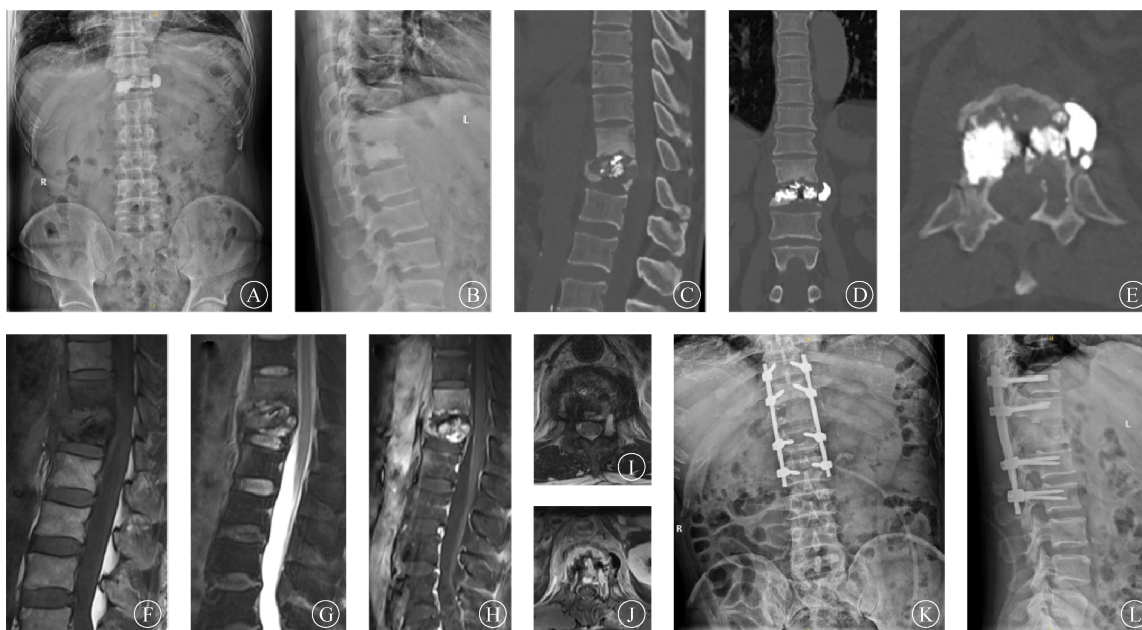
序号	体温(℃)	WBC( $\times 10^9/L$ )	CRP(mg/L)	ESR(mm/1 h)	PCT(ng/mL)	病原菌	治疗	预后
1	36.7	4.70	28.02	13	0.10	结核分枝杆菌	抗结核治疗	死于并发症
2	36.8	7.30	66.00	94	0.40	结核分枝杆菌	手术 <sup>①</sup> +抗结核治疗	治愈
3	36.4	4.00	1.51	2	0.11	鲍曼不动杆菌+结核分枝杆菌	抗结核治疗	死于并发症
4	36.6	5.60	19.55	42	0.17	结核分枝杆菌	手术 <sup>②</sup> +抗结核治疗	治愈
5	36.6	4.93	40.15	43	0.10	表皮葡萄球菌	手术 <sup>③</sup> +抗感染	治愈

注:手术<sup>①</sup>为后路T<sub>11</sub>、T<sub>12</sub>椎体次全切+髂骨植骨+T<sub>8</sub>~L<sub>2</sub>内固定;手术<sup>②</sup>为后路病灶清除术;手术<sup>③</sup>为后路T<sub>12</sub>椎体次全切+髂骨植骨+T<sub>10</sub>~L<sub>2</sub>内固定。

2.3 治疗及预后 术前抗感染治疗,明确致病菌后应用敏感抗生素不少于1周,如为结核分枝杆菌感染,术前抗结核治疗不少于2周。2例结核分枝杆菌感染患者因一般情况较差,无法耐受手术,仅抗结核药治疗,分别于出院后1个月和3个月死于合并症。1例患者行后路病灶清除术,末次随访腰背部疼痛缓解,体温正常、炎性指标在正常参考值范围,影像学检查提示未见感染征象。1例患者由于结核分枝杆菌感染累及T<sub>10</sub>、T<sub>11</sub>、T<sub>12</sub>,以T<sub>11</sub>、T<sub>12</sub>椎体破坏为著,选择后路T<sub>11</sub>、T<sub>12</sub>椎体次全切+髂骨植骨+T<sub>8</sub>~L<sub>2</sub>内固定方案,术后依据结核医院医师意见选择抗结核药物治疗,末次随访恢复良好。表皮葡萄球菌感染患者,累及范围主要在T<sub>12</sub>,手术方案采用后路T<sub>12</sub>椎体次全切+髂骨植骨+T<sub>10</sub>~L<sub>2</sub>内固定,术后继续敏感抗生素抗感染治疗

(2周静脉给药+4周口服治疗),定期随访炎性指标,末次随访时,患者恢复良好。

2.4 典型病例 患者男性,68岁,因“胸椎骨折术后5个月,腰背部酸痛2个月”入院,查体:T<sub>12</sub>棘突压痛、叩击痛,双下肢肌力、感觉功能正常,病理征阴性。实验室检查 WBC  $4.93 \times 10^9/L$ , CRP 40.15 mg/dL, ESR 43 mm/1 h, PCT 0.10 ng/mL。影像学检查考虑T<sub>12</sub> PVP术后椎体感染。穿刺组织培养及NGS提示表皮葡萄球菌。穿刺组织病理诊断:纤维组织内大量慢性炎细胞浸润,肉芽组织增生,小血管扩张充血伴出血。经万古霉素抗感染治疗后,行后路T<sub>12</sub>椎体次全切+髂骨植骨+T<sub>10</sub>~L<sub>2</sub>内固定,术后继续抗感染、胸腰椎支具保护,末次随访患者腰背部无明显疼痛,可正常行走。见图1。



注:A、B为入院时胸腰段正侧位X线片提示T<sub>12</sub> PVP术后,骨水泥渗漏,胸腰段后凸;C、D、E为腰椎CT矢状位、冠状位及横断面二维重建提示骨质破坏;F、G、H、I、J为MRI平扫及增强考虑T<sub>12</sub> PVP术后感染;K、L为术后正侧位X线片,X线片示植骨块及内固定位置良好。

图1 PVAP术后感染典型病例术前及术后影像

Fig. 1 Preoperative and postoperative images of typical cases of PVAP postoperative infection

### 3 讨论

据文献报道,PVAP术后感染的常见致病菌包括结核分枝杆菌<sup>[8]</sup>、甲氧西林敏感的金黄色葡萄球菌(MSSA)、耐甲氧西林金黄色葡萄球菌(MRSA)、耐甲氧西林表皮葡萄球菌(MRSE)、微小微单胞菌、木糖氧化无色杆菌、毗邻颗粒链球菌<sup>[5]</sup>、表皮葡萄球菌<sup>[9]</sup>、沙门菌、大肠埃希菌、消化链球菌属、丙酸杆菌<sup>[6]</sup>、粪肠球菌、溶血性链球菌等。在本研究中,4例

患者确诊结核分枝杆菌感染,其中1例合并鲍曼不动杆菌感染;1例提示表皮葡萄球菌感染。通过文献复习以及结合临床资料发现PVAP术后感染的致病菌种类较多,以结核分枝杆菌、金黄色葡萄球菌较为多见。

PVAP术后结核分枝杆菌感染,这类患者多有肺结核病史<sup>[8]</sup>或者活动性结核患者接触史<sup>[10]</sup>,椎体感染发生的可能机制包括:(1)结核分枝杆菌从肺部血行播散至椎体;(2)原发病灶静止期结核分枝杆菌复燃<sup>[11]</sup>。基于“最小抵抗部”理论<sup>[12]</sup>,OVCF可能导致



椎体内血肿形成, PVAP 虽然操作微创, 但仍可能诱发炎症反应, 进而导致携带结核分枝杆菌的巨噬细胞在该处聚集并释放<sup>[13]</sup>。Park 等<sup>[5]</sup>和 Kang 等<sup>[14]</sup>认为其中部分患者可能将脊柱结核误诊为 OVCF 或 OVCF 同时合并椎体感染而进行 PVAP 手术。在本研究中, 有 2 例椎体结核分枝杆菌感染的患者, 其胸部 CT 平扫提示陈旧性肺结核病变, 虽该 2 例患者尚无法明确是否存在误诊, 但是合并肺部结核改变的 OVCF 患者术前需谨慎鉴别。

一些学者认为术后感染可能与术前已存在的身体其他部位感染有关, 其中尿路感染最为常见, 还包括肺部感染、胆囊炎、脑膜炎、感染性褥疮及皮肤疮等, 病原菌通过动脉顺流或椎旁静脉丛逆流至椎体, 致椎体感染<sup>[15-17]</sup>。表皮葡萄球菌虽存在于人体皮肤和黏膜上, 但其导致 PVAP 术后表皮葡萄球菌感染的发生率较低, 目前相关文献报道较少, 感染发生原因可能是由于术区消毒不彻底或操作不规范, 导致病原菌经穿刺部位进入椎体, 造成医源性感染<sup>[11]</sup>。其他感染危险因素包括高龄、吸烟、营养不良、免疫抑制、糖尿病、肾功能不全、风湿疾病、肿瘤病史及肝硬化等<sup>[18]</sup>。

有研究发现, PVAP 手术至确诊结核分枝杆菌感染的时间为 $(8.45 \pm 11.68)$ 月, 非结核感染组从手术至感染确诊时间为 $(6.36 \pm 14.14)$ 月<sup>[19]</sup>。本研究发现, PVAP 术后至感染确诊时间间隔为 5~24 个月。Vaccaro 等<sup>[20]</sup>和苏锴等<sup>[21]</sup>认为 PVP 术前无明显感染迹象, 术后出现发热, 术后至感染确诊时间间隔小于 2 个月的患者, 感染的原因可能为术前误诊或医源性感染, 表皮葡萄球菌感染患者可能为医源性感染; 而对于术后出现发热, 手术至感染确诊时间间隔大于 2 个月的患者, 感染原因可能是血源性感染。本研究中 2 例患者, 从手术至确诊感染时间超过 5 个月, 高龄且一般情况较差, 最终死于合并症。因此, 有学者建议如术前存在尿路、肺部等感染病灶和/或 WBC、CRP、ESR 异常升高以及影像学提示感染可能性较大的患者, 必要时穿刺活检, 推迟 PVAP 手术。需要特别指出的是, PVAP 手术时务必规范操作, 尽可能避免医源性感染的发生。除此之外, Q 热所致椎体术后感染或布鲁菌性椎体感染的患者, 如存在疫区动物及动物制品接触史, 虽然外伤史明确, 仍需加以鉴别, 以减少误诊。

PVAP 术后感染无典型临床表现, 与化脓性脊柱炎相似, 全身症状可表现为发热、恶心、呕吐、厌食、乏力、体重下降等, 25%~55% 感染患者体温在正常范

围<sup>[22]</sup>。本研究发现, 2 例患者出现消瘦面容, 精神欠佳, 但是, 该 5 例患者均未出现高热、寒颤等表现, 仅 1 例患者出现午后低热。由于 PVAP 术后感染好发部位为 T<sub>12</sub> (20%) 和 L<sub>1</sub> (19.09%)<sup>[11]</sup>, 局部症状通常表现为腰背部疼痛, 呈渐进性加重或持续性疼痛, 如神经损害可能会表现为肋区、腹部、臀部以及下肢放射痛、感觉平面减退、肌力下降, 甚至二便障碍等<sup>[5]</sup>。在本研究中, 4 例患者存在双下肢不同程度肌力下降等神经症状, 其中 2 例伴有二便障碍。

Park 等<sup>[5]</sup>在文献中报道, 11 例患者中 10 例存在一项或多项炎症指标 (WBC、CRP、ESR) 高于正常参考值。抗酸染色、结核分枝杆菌培养、T-spot、结核分枝杆菌/利福平 (Xpert MTB/RIF) 检测以及病理学检查作为诊断结核感染的重要参考依据。X 线可见受累椎体塌陷及椎旁软组织增厚影。CT 平扫可见受累椎体破坏程度、碎骨片及钙化等。受累椎体、相邻椎体及周围软组织 MRI 影像 T1WI 呈低信号、T2WI 呈高信号, STIR 序列呈高信号<sup>[23]</sup>; 增强 MRI 表现弥散状增强<sup>[4]</sup>。结核分枝杆菌感染的特征为跳跃病变和椎旁冷脓肿, MRI 提示椎旁或硬膜外脓肿有助于诊断<sup>[24]</sup>。在本研究中, WBC 计数为 $(4.0 \sim 7.3) \times 10^9/L$ , CRP 为 1.51~66 mg/dL, ESR 为 2~94 mm/h, PCT 为 0.10~0.40 ng/mL, 因此, PVAP 术后感染患者, 炎症指标正常或轻度升高, 如影像学检查提示感染迹象, 穿刺组织致病菌培养、病理学检查及 NGS 有助于进一步明确诊断。

总之, OVCF 患者往往高龄, 且合并较多基础疾病, 免疫力较低, PVAP 术后感染影响患者的生活质量, 严重者危及生命。如高度怀疑 OVCF 患者术前存在感染, 积极完善炎症指标及影像学检查, 并排除身体其他部位感染, 必要时穿刺活检, 推迟手术治疗。PVAP 术后发生感染时, 穿刺活检进行组织病理学检查、一般细菌培养、NGS 和结核分枝杆菌检测, 鉴别受累椎体感染所致病理性骨折, 经规范系统治疗后, 评估椎体缺损情况及脊柱后凸程度, 选择合适手术或翻修手术方案, 可获得较为满意的治疗效果。

利益冲突 无

#### 参考文献

- [1] Boss S, Srivastava V, Anitescu M. Vertebroplasty and kyphoplasty [J]. Phys Med Rehabil Clin N Am, 2022, 33(2): 425-453.
- [2] Jang HD, Kim EH, Lee JC, et al. Management of osteoporotic vertebral fracture: review update 2022 [J]. Asian Spine J, 2022, 16(6): 934-946.
- [3] Takahashi S, Inose H, Tamai K, et al. Risk of revision after verte-

- bral augmentation for osteoporotic vertebral fracture: a narrative review[J]. *Neurospine*, 2023, 20(3): 852-862.
- [4] Cavka M, Delimar D, Rezan R, et al. Complications of percutaneous vertebroplasty: a pictorial review[J]. *Medicina (Kaunas)*, 2023, 59(9): 1536.
- [5] Park JW, Park SM, Lee HJ, et al. Infection following percutaneous vertebral augmentation with polymethylmethacrylate[J]. *Arch Osteoporos*, 2018, 13(1): 47.
- [6] Liao JC, Lai PL, Chen LH, et al. Surgical outcomes of infectious spondylitis after vertebroplasty, and comparisons between pyogenic and tuberculosis[J]. *BMC Infect Dis*, 2018, 18(1): 555.
- [7] 毛克政,高延征,毛克亚,等.椎体成形术后手术椎体感染的临床表现和疗效[J].*中华创伤骨科杂志*,2021,23(1):33-38.  
Mao KZ, Gao YZ, Mao KY, et al. Clinical manifestations and management of infectious spondylitis following vertebroplasty or kyphoplasty[J]. *Chin J Orthop Trauma*, 2021, 23(1): 33-38.
- [8] Ivo R, Sobottke R, Seifert H, et al. Tuberculous spondylitis and paravertebral abscess formation after kyphoplasty: a case report[J]. *Spine*, 2010, 35(12): E559-E563.
- [9] 王卓,陈俊,郝杰,等.经皮椎体成形术后表皮葡萄球菌性化脓性椎体炎:1例报道与综述[J].*中国矫形外科杂志*,2021,29(9): 826-829.  
Wang Z, Chen J, Hao J, et al. Pyogenic spondylitis of *Staphylococcus epidermidis* secondary to percutaneous vertebroplasty: a case report and literature review[J]. *Orthop J China*, 2021, 29(9): 826-829.
- [10] Lai PJ, Liao JC, Chen LH, et al. Tuberculous spondylitis after percutaneous vertebroplasty: a case series of 9 cases[J]. *Biomed J*, 2019, 42(4): 285-292.
- [11] Ge CY, He LM, Zheng YH, et al. Tuberculous spondylitis following kyphoplasty: a case report and review of the literature[J]. *Medicine*, 2016, 95(11): e2940.
- [12] Agostoni G. Aneurysms of the thoracic aorta and traumatism; region of the aortic isthmus; locus minoris resistentiae[J]. *Arch Mal Coeur Vaiss*, 1953, 46(6): 550-558.
- [13] Bouvresse S, Chiras J, Bricaire F, et al. Pott's disease occurring after percutaneous vertebroplasty: an unusual illustration of the principle of locus minoris resistentiae[J]. *J Infect*, 2006, 53(6): e251-e253.
- [14] Kang JH, Kim HS, Kim SW. Tuberculous spondylitis after percutaneous vertebroplasty: misdiagnosis or complication? [J]. *Korean J Spine*, 2013, 10(2): 97-100.
- [15] Lee CB, Kim HS, Kim YJ. Pyogenic spondylitis after vertebroplasty—a report of two cases—[J]. *Asian Spine J*, 2007, 1(2): 106-109.
- [16] Syed MI, Avutu B, Shaikh A, et al. Vertebral osteomyelitis following vertebroplasty: is acne a potential contraindication and are prophylactic antibiotics mandatory prior to vertebroplasty? [J]. *Pain Physician*, 2009, 12(4): E285-E290.
- [17] Yu SW, Chen WJ, Lin WC, et al. Serious pyogenic spondylitis following vertebroplasty: a case report [J]. *Spine*, 2004, 29(10): E209-E211.
- [18] Buttermann GR, Mullin WJ. Percutaneous vertebral body cement augmentation for back pain related to occult osteomyelitis/diskitis [J]. *Orthopedics*, 2011, 34(11): e788-e792.
- [19] Zheng BW, Liu FS, Zheng BY, et al. Risk factors for tuberculous or nontuberculous spondylitis after percutaneous vertebroplasty or kyphoplasty in patients with osteoporotic vertebral compression fracture: a case-control study[J]. *Front Surg*, 2022, 9: 962425.
- [20] Vaccaro AR, Shah SH, Schweitzer ME, et al. MRI description of vertebral osteomyelitis, neoplasm, and compression fracture[J]. *Orthopedics*, 1999, 22(1): 67-73.
- [21] 苏锴,姜文涛,邵哲,等.经皮椎体成形术后椎体感染的手术治疗[J].*中国脊柱脊髓杂志*,2022,32(12):1139-1144.  
Su K, Jiang WT, Shao Z, et al. Surgical treatment for vertebral infection after percutaneous vertebroplasty[J]. *Chin J Spine Spinal Cord*, 2022, 32(12): 1139-1144.
- [22] Schmid KE, Boszczyk BM, Bierschneider M, et al. Spondylitis following vertebroplasty: a case report [J]. *Eur Spine J*, 2005, 14(9): 895-899.
- [23] 洪加源,李延炜,欧阳林.椎体成形术之陷阱:术后感染与术前误诊(附3例报告)[J].*骨科*,2022,13(2):176-180.  
Hong JY, Li YW, Ouyang L. Trap of vertebroplasty: postoperative infection and preoperative misdiagnosis (report of 3 cases)[J]. *Orthopaedics*, 2022, 13(2): 176-180.
- [24] Zou MX, Wang XB, Li J, et al. Spinal tuberculosis of the lumbar spine after percutaneous vertebral augmentation (vertebroplasty or kyphoplasty)[J]. *Spine J*, 2015, 15(6): e1-e6.

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