Indolent Infection After Lumbar Interbody Fusion: An Under-recognized Cause of Pseudarthrosis, Which Can Be Successfully Treated With Anterior Revision Fusion

Andrew S Zhang, MD □
Ellis M. Berns, ScB □
Davis A. Hartnett, ScB □
Eren O. Kuris, MD
Alan H. Daniels, MD □

ABSTRACT

Introduction: Bacterial infection is a common etiology for pseudarthrosis after transforaminal lumbar interbody fusion, although it is often difficult to identify because of a delayed presentation and normal laboratory values. The primary goal of this study was to present a series of cases demonstrating patients with infection-related pseudarthrosis successfully managed with anterior revision.

Methods: We retrospectively reviewed patients presenting to a single academic spine center who were found to have evidence of Cutibacterium acnes or coagulase-negative Staphylococcus infection on routine culturing of lumbar interbody fusion revisions from July 2019 to January 2021. All patients underwent salvage of a transforaminal lumbar interbody fusion pseudarthrosis through an anterior lumbar approach.

Results: A total of six patients managed for pseudarthrosis secondary to suspected infection were eligible for this study (mean age 64.8 years, range 54-70 years; mean body mass index, range 24.5-39.1). Persistent radiculopathy was the primary presenting symptom in all patients with a mean time to revision of 17 months. Coagulase-negative Staphylococcus was the primary pathogen, identified from intraoperative samples in 50% of the cases. All patients demonstrated a resolution of symptoms after placement of an anterior lumbar interbody cage, without intraoperative complications, and a subsequent antibiotic regimen.

Discussion: Indolent infection is an under-recognized cause of pseudarthrosis of the lumbar spine. Revision surgery through an anterior lumbar approach, which promotes ease of cage removal and optimized alignment and surface area available for revision fusion, is sufficient to manage pseudarthrosis due to infection.
Transforaminal lumbar interbody fusion (TLIF) and posterior lumbar interbody fusion (PLIF) are common procedures done in the treatment of lumbar degenerative diseases. Pseudarthrosis, a failure of adequate fusion between adjacent vertebral bodies, is a complication seen in 2.6% to 15% of initial posterior fusion procedures, with reoccurrence reported in up to 51% of patients after revision surgery.

Patient-related risk factors for pseudarthrosis include diabetes, use of steroids or nonsteroidal anti-inflammatory drugs, and smoking. However, recent reports have described infection as a common etiology for pseudarthrosis, particularly Cutibacterium acnes (C. acnes) and coagulase-negative Staphylococcus (CoNS). C. acnes, formerly known as Propionibacterium acnes, is a gram-positive, anaerobic rod bacteria that is native to the hair follicles of the face, neck, and back. Pseudarthrosis secondary to C. acnes infection is often presumed to be aseptic because of its delayed presentation and often normal infectious laboratory values, including complete blood count, C-reactive protein, and erythrocyte sedimentation rate. Because of the low virulence and slow growth of C. acnes, prolonged incubation time, usually 2 weeks at minimum, is required for its identification as the source of fusion failure.

If pseudarthrosis secondary to infected lumbar interbody fusion is suspected, 1 proposed treatment strategy is revision anterior lumbar interbody fusion (ALIF). Advantages of ALIF include avoidance of posterior scar tissue, ease of cage removal, ample exposure for removal of the infected disk material, and full restoration of biomechanical alignment and stability.

Multiple recent case series have described successful salvage of TLIF pseudarthrosis with ALIF; however, to our knowledge, no patients described with pseudarthrosis secondary to C. acnes or CoNS infection resolved with ALIF have been reported. At our institution, routine culturing of lumbar interbody fusion revisions led to several cases of indolent infection as a cause of pseudarthrosis. We present a case series describing TLIF pseudarthrosis secondary to C. acnes and CoNS infection and salvage with anterior revision, débridement, and fusion.

### Methods and Results

This study was a retrospective case series of patients who underwent salvage of a TLIF pseudarthrosis through an anterior lumbar approach, with findings indicating C. acnes or CoNS infection at a single center between July 2019 and January 2021. A total of six patients managed for pseudarthrosis secondary to suspected infection were eligible for this study; five male and one female patient with a mean age of 64.8 years (range, 54-70) and a mean body mass index of 24.9 (range 24.5-39.1). Of the identified patients, 83% were smokers, 83% had a diagnosis of hypertension, and 50% had a history of abdominal surgery. Persistent radiculopathy was the primary presenting symptom in all patients with a mean time to revision of 17 months (range 6-45 months), and all patients underwent placement of a titanium anterior lumbar interbody cage without intraoperative complications. CoNS was identified from intraoperative samples in 50% of the cases and C. acnes in 33%, with one case finding gram-positive cocci, gram-positive rods, and gram-negative rods. All patients were placed on appropriate antibiotic regimens after bacterial identification.

### Table 1. Patient Demographic Data

| Patient | Age (y) | Sex | BMI | Smoking (Yes/No) | Diabetes (Yes/No) | HTN (Yes/No) | Prior Abdominal Surgery | Additional Relevant History |
|---------|---------|-----|-----|-----------------|------------------|-------------|------------------------|--------------------------|
| 1       | 68      | M   | 28.2| No              | No               | Yes         | None                   | Remote thyroid cancer     |
| 2       | 69      | M   | 26.1| Yes             | No               | Yes         | None                   | COPD                     |
| 3       | 54      | M   | 39.1| Yes             | No               | Yes         | None                   | Hemochromatosis and hypothyroidism |
| 4       | 65      | M   | 29.3| Yes             | No               | Yes         | Sigmoidectomy          |                          |
| 5       | 63      | F   | 24.5| Yes             | No               | No          | Total abdominal hysterectomy | Chronic bronchitis and hypothyroidism |
| 6       | 70      | M   | 29.3| Yes             | No               | Yes         | Inguinal hemia         | Prostate cancer treated with radiation |

BMI = body mass index, COPD = chronic obstructive pulmonary disease, HTN = hypertension
Case Illustrations

Case 1

A 54-year-old man (patient 3) presented with 1 month of persistent and progressive lower back pain and severe right lower extremity radicular symptoms. He previously underwent an L3-L5 decompression and fusion and a L5-S1 TLIF, and most recently underwent a revision L2-pelvis decompression and fusion for nonunion. No cultures were obtained at that time. He was doing well until the sudden onset of sharp back pain while walking, later radiating into his leg. Radiographs and a CT scan of the patient’s lumbosacral spine revealed evidence of L5-S1 pseudarthrosis, loss of foraminal height, and a broken rod (Figure 1). The patient had failed conservative management and elected to proceed with revision surgery.

Through a standard anterior approach to the lumbar spine, the L5-S1 disk space was accessed and the previous cage was easily identified, noted to be loose, readily removed, and sent for culture along with specimens of the intervertebral disk. After thorough débridement and end plate preparation, a new titanium ALIF cage packed with highly porous beta-tricalcium phosphate, allograft chips, recombinant human bone morphogenetic protein-2 (rhBMP-2), and vancomycin powder was inserted and secured with screws (Figure 2). Vancomycin powder was placed within the wound and then the incision was closed in multiple layers. The patient was transferred to the postanesthesia care unit before being admitted to the regular floor, where his pain management and mobility progressed appropriately, and he was discharged on oral pain medication on postoperative day 3. Of note, the patient completed 24 hours of cefazolin postoperatively and then transitioned to empiric Augmentin (amoxicillin-clavulanic acid) until cultures resulted. On postoperative day 5, the three intraoperative

| Patient | Previous Fusion Levels | Presenting Findings | Second Operation | Time to Revision (mo) | Op Time | Blood Loss (mL) | Cage | Surgical Complications | Radiographic Fusion After ALIF? |
|---------|------------------------|---------------------|----------------|----------------------|---------|----------------|------|------------------------|-----------------------------|
| 1       | L2-3; L5-S1            | Severe RLE radiculopathy | Revision L5-S1 ALIF and posterior instrumentation | 45       | 4:45    | 400            | Spine art secured lumbar anterior cage | None | Yes |
| 2       | L5-S1                  | Lower back pain and bilateral LE numbness/tingling | L5-S1 ALIF with revision posterior T12-S1 | 20       | 4:42    | 510            | Spineart secured lumbar anterior cage | None | TBD |
| 3       | L5-S1                  | Broken posterior rod with back pain and RLE radiculopathy | L5-S1 ALIF | 6        | 4:55    | 500            | Spineart secured lumbar anterior cage | None | TBD |
| 4       | L5-S1                  | Radiographic screw/cage loosening and LLE radiculopathy | L5-S1 ALIF with L2-pelvis revision instrumentation | 7        | 5:42    | 500            | Spineart secured lumbar anterior cage | None | TBD |
| 5       | L4-5                   | Continued lower back pain with bilateral LE numbness | L4-5 and L5-S1 ALIF and L4-pelvis | 8        | 7:38    | 700            | Spineart secured lumbar anterior cage | None | No |
| 6       | L3-4, L4-5, L5-1 TLIFs, L2-S1 fusion | Subsidence of L5-S1 and RLE radiculopathy | L5-S1 ALIF and L2-pelvis January 21, 2021 | 16       | 8:16    | 400            | Spineart secured lumbar anterior cage | None | TBD |

ALIF = anterior lumbar interbody fusion, LE = lower extremity, LLE = left lower extremity, RLE = right lower extremity, TBD = to be determined

Table 2. Patient Surgical Data
cultures unanimously grew *C. acnes*, and the patient was readmitted for antibiotic therapy and monitoring. Blood cultures were obtained, and the patient was started on intravenous (IV) ceftriaxone. Infectious disease services recommended ceftriaxone for 6 weeks, and he was discharged home again after the placement of a central catheter. The treatment was complicated by a *Clostridium difficile* infection managed with 14 days of oral vancomycin. After ceftriaxone therapy, the patient was transitioned to an oral doxycycline regimen for an additional 3 months, a regimen that was prolonged two additional months because of metatarsal surgery. At his 9-month follow-up, he had completed antibiotic therapy without recurrence of infection and reported markedly improved lower back pain and the absence of radicular symptoms with an increased ability to perform his activities of daily living.

### Case 2

A 68-year-old man (patient 1) with a history of two lumbar decompression and interbody fusion surgeries continued to experience back pain despite epidural injections. He reported severe disability from persistent

| Patient | Identified Bacteria                                | Length of Stay (d) | Antibiotic Regimen                          | Treatment Complications                      |
|---------|---------------------------------------------------|--------------------|--------------------------------------------|---------------------------------------------|
| 1       | Coagulase negative staphylococcus                | 5                  | 8 wk IV vancomycin and oral rifampin and then 6 mo of oral doxycycline and oral rifampin | Oral rifampin discontinued after 4 mo because of nausea |
| 2       | Gram-positive cocci, gram-positive rods, and gram-negative rods | 7                  | 6 wk IV vancomycin and IV cefepime and then oral minocycline for 6 mo | Cefepime discontinued after 5 wk because of AKI and diffuse rash |
| 3       | *Cutibacterium acnes*                            | 3, 2               | 6 wk IV ceftriaxone and then 5 mo oral doxycycline | *Clostridium difficile* infection           |
| 4       | *Cutibacterium acnes*                            | 4, 3               | 6 wk IV ceftriaxone and then 3 mo oral doxycycline | None                                        |
| 5       | Coagulase negative staphylococcus, *Corynebacterium* | 9                  | 1 wk IV vancomycin and then 1 mo oral doxycycline | Doxycycline briefly paused because of diarrhea |
| 6       | Coagulase negative staphylococcus                | 6                  | 8 wk IV ceftriaxone and IV vancomycin and oral rifampin and then 6-12 mo oral doxycycline | Oral rifampin discontinued because of a moderate allergic reaction |

AKI = acute kidney injury, IV = intravenous
lower back pain and right leg radiculopathy. His examination was notable for diminished sensation in the right L5 distribution. Radiographs revealed previous L2-S1 decompression and fusion with interbody support without instrumentation failure or fracture (Figure 3), but CT of the lumbar spine did show L5-S1 pseudarthrosis with interval increased L5-S1 spondylolisthesis and vacuum disk phenomenon and bilaterally loosened S1 pedicle screws. MRI of the lumbar spine also showed a large calcified L5-S1 disk herniation with impingement of the bilateral L5 and S1 nerve roots. Having failed conservative management, the patient underwent a revision L5-S1 ALIF with osteotomy, followed by posterior revision L2-S1 decompression and fusion almost 4 years after the index interbody surgery of L5-S1. Through the anterior approach, the previous L5-S1 TLIF cage was removed and sent for culture. The remainder of the L5-S1 disk space and end plates was prepared, and a titanium ALIF cage packed with highly porous beta-tricalcium phosphate, allograft chips, rhBMP-2, and vancomycin powder was implanted without issue. The patient was then turned prone and underwent revision posterior L2-pelvis instrumented fusion. Screws from L2-L5 were noted to be rigidly implanted in the bone, with a broken screw head at L2, and the decision was made to leave these screws in place. S1 screws were noted to be loose and were replaced, and sacral-2-alar-iliac screws were placed for pelvic fixation (Figure 4). Pseudarthrosis was confirmed at L5-S1, and revision decompression and instrumented fusion were done with substantial bone grafting. Vancomycin powder was placed deep into the posterior wound and a multilayer closure was done. After completing 24 hours of IV cefazolin postoperatively, the patient was then transitioned to empiric oral Augmentin until cultures would result. On postoperative day 3, two of three instrumentation cultures returned positive for CoNS. Infectious disease services were consulted, and he was started on IV vancomycin and oral rifampin for 8 weeks, after which he was transitioned to oral doxycycline for the next 6 months. At the 6-month follow-up, he demonstrated markedly improved lower back and right leg pain, with an increase in his activity and a drastically improved functional capacity, with no signs or symptoms of infection and radiographic evidence of fusion at L5-S1.

**Discussion**

Indolent infection is an under-recognized cause of pseudarthrosis of the lumbar spine. Pseudarthrosis can occur because of several reasons, including modifiable and nonmodifiable patient risk factors; however, spine surgeons should always have a suspicion that an infectious cause may be responsible even in the absence of overt signs of infection and normal inflammatory laboratory values. In such cases, low virulent bacteria, such as *C. acnes* and CoNS species, should remain high on the differential.

*C. acnes* has traditionally been associated with periprosthetic joint infections of the shoulder but can also cause spine infections. The presentation of patients with periprosthetic joint infection secondary to *C. acnes* is similar to those who develop spinal pseudarthrosis: often delayed with pain, decreased range of motion, and normal infectious laboratory values. It has recently gained attention as an increasingly prevalent pathogen in spinal surgical site infections, extended culture time for positive results, and nonstandard hospital methodologies for the aseptic workup. Steinhaus et al recently examined presumed aseptic revision spinal surgeries and found both male sex and a diagnosis of pseudarthrosis-predicted positive cultures, which were most commonly positive for *C. acnes*. Shifflet et al also examined presumed aseptic revision surgery and found that in cases with positive cultures, *C. acnes* grew in 48.9% and CoNS in 11.1%. The average time to positive culture for *C. acnes* was 6.1 days, reinforcing the need for extended incubation of cultures even in presumed aseptic cases. Burkhard et al found that 10.2% of cases were culture positive in revisions for presumed aseptic pseudarthrosis, with the results of *C. acnes* 46.2% and CoNS 38.5% of the time. In patients without clinical signs of infection, Hu and Lieberman found that *C. acnes* was the most frequently identified pathogen of all the implants removed, comprising 46.7% of these infected implants.

When revision is required, surgical approaches include posterior only, combined anterior and posterior, and anterior only. Albert et al recommended a combined anterior and posterior approach because of the ability to enhance the chance of fusion anteriorly and posteriorly. A recent meta-analysis of all TLIF procedures found a fusion rate of 93.3%. However, Safaei et al recently published their results of using an anterior approach to remove TLIF cages for pseudarthrosis, demonstrating that ALIF rescue was 96.6% successful with only a 2.4% chance of additional revision surgery in 84 patients who were able to simultaneously...
have the TLIF removed from this anterior-only approach. Similarly, Yun et al\textsuperscript{17} described a 9-patient case series with salvage ALIF after TLIF or PLIF, with all patients having successful fusion and improved clinical outcomes.

The anterior approach to the retroperitoneal space is the most powerful revision approach for a number of reasons. First, the epidural scar tissue from the posterior approach used to implant the TLIF during the index surgery can be avoided altogether, decreasing the chance of creating iatrogenic injury to the dura and neural elements during exposure and cage retrieval. The anterior access, if not previously operated on for unrelated abdominal pathologies, provides virgin tissue free of adhesions and obscured by scar, thereby creating a safer environment to operate and achieve the same objectives without the risk of causing neural damage from undue manipulation in a revision setting. A lateral approach can be considered above L5/S1 but may prove to be more challenging in retrieving a TLIF cage that was originally implanted in a perpendicular trajectory. The surgical window is much smaller and may preclude insertion of accessory instruments in helping to remove well-fixed cages. Additional end plate damage may also be incurred. Second, pseudarthrosis from infection still needs to be addressed, and an anterior approach can provide a larger working area to achieve both a more comprehensive débridement of the infected disk space and theoretically provide a larger scaffold for which a fusion can be achieved. In addition, fusion can be augmented through the anterior approach with an adjunctive use of rhBMP-2. The use of rhBMP-2 for lumbar fusion is only FDA approved for ALIF. Several studies have demonstrated equal or superior results with the use of rhBMP-2 over an iliac crest autograft.\textsuperscript{26,27} Therefore, in an attempt to overcome a previously failed fusion, the use of rhBMP-2 is a welcome adjunct to achieve this. However, there are certainly reservations in doing so in the setting of an active infection. Despite this, multiple studies have investigated this surgical dilemma. Allen et al\textsuperscript{28} reported a case series of patients in which 14 patients underwent circumferential fusion with the use of BMP. They were able to discern that rhBMP-2 use was safe and effective for solid fusion in their series with a two-year follow-up. Recently, Yaw Tee et al\textsuperscript{29} conducted a retrospective study examining reinfection rates and rates of revision surgery in cohorts with and without the use of BMP in the setting of active infection and found that there was no increased rate of either outcome in using BMP. Moreover, in a consensus statement by Walker et al,\textsuperscript{30} rhBMP-2 was deemed safe and efficacious for use in the setting of vertebral osteomyelitis/diskitis based on the current available literature. Given these reported trends in spine surgery, we elected to use BMP as a safe adjunct for fusion through an anterior lumbar approach.

In the illustrative cases in this study, both patients had cultures return positive shortly after surgery and appropriate antibiotics were started. At our institution, if patients are able to be discharged before final cultures have...
resulted, patients will complete 24 hours of perioperative antibiotics and then will be transitioned to empiric oral antibiotics, typically Augmentin. Once cultures were ensured to be negative, these empiric antibiotics could be safely discontinued. Typically, laboratories were asked to hold the cultures for at least 2 weeks, according to the most recent shoulder surgery literature recommendations, which are notoriously affected by *C. acnes* infections.31,32

There are several possible limitations to our study: The retrospective nature of the investigation has the potential to generate biases inherent to retrospective studies. The single-center design of the study and small patient sample size limit the ability to generate more generalized conclusions, as does lack of a long-term follow-up in the discussed patients. Regardless, this case series examines an under-investigated cause of pseudarthrosis and outlines an effective method of management for failed lumbar fusion due to indolent infection.

Pseudarthrosis after TLIF or PLIF in an otherwise asymptomatic patient should raise suspicion for indolent infection of the implant. Management should consist of revision surgery, optimally through an anterior lumbar approach to promote ease of cage removal, wide debridement, and to optimize alignment and the surface area available for revision fusion, all while circumventing a scarred posterior surgical field.

References

1. Lan T, Hu SY, Zhang YT, et al: Comparison between posterior lumbar interbody fusion and transforaminal lumbar interbody fusion for the treatment of lumbar degenerative diseases: A systematic review and meta-analysis. *World Neurosurg* 2018;112:86-93.

2. de Kunder SL, van Kuijk SMJ, Rijkers K, et al: Transforaminal lumbar interbody fusion (TLIF) versus posterior lumbar interbody fusion (PLIF) in lumbar spondylolisthesis: A systematic review and meta-analysis. *Spine J* 2017;17:1712-1721.

3. Derman PB, Singh K: Surgical strategies for the treatment of lumbar pseudarthrosis in degenerative spine surgery: A literature review and case study. *HSS J* 2020;16:183-187.

4. Berjano P, Langella F, Damilano M, et al: Fusion rate following extreme lateral lumbar interbody fusion. *Eur Spine J* 2015;24:369-371.

5. Ondra SL, Marzouk S: Revision strategies for lumbar pseudarthrosis. *Neurosurg Focus* 2003;15:E9.

6. Burkhard MD, Lorentz R, Uckay I, Bauer DE, Betz M, Farshad M: Occult infection in pseudarthrosis revision after spinal fusion. *Spine J* 2020;20:370-376.

7. Khalil JG, Gandhi SD, Park DK, Fischgrund JS: Cutibacterium acnes in spine pathology: Pathophysiology, diagnosis, and management. *J Am Acad Orthop Surg* 2019;27:e633-e640.

8. Kardile MP, Bains SS, Kuo CC, Lincoln TL, Bains RS: Is Propionibacterium acnes becoming the most common bacteria in delayed infections following adolescent idiopathic scoliosis surgery? *Spine Deform* 2021;9:757-767.

9. Birkenmaier C: Pseudarthrosis and construct failure after lumbar pedicle subtraction osteotomy: Influence of biomechanics, surgical technique, biology and avoidance strategies [in German]. *Orthopade* 2018;47:310-319.

10. Shiono Y, Watanabe K, Hosogane N, et al: Sterility of posterior elements of the spine in posterior correction surgery. *Spine (Phila Pa 1976)* 2012;37:523-526.

11. Leheste JR, Ruvolo KE, Christosofius JE, et al: *P. acnes*-driven disease pathology: Current knowledge and future directions. *Front Cell Infect Microbiol* 2017;7:81.

12. Haidar R, Najjar M, Der Boghossian A, Tabbahar Z, Haidar R: Scandinavian journal of infectious diseases Propionibacterium acnes causing delayed postoperative spine infection: Review. *Scand J Infect Dis* 2010;42:405-411.

13. Steinhaus ME, Salzmann SN, Lovecchio F, et al: Risk factors for positive cultures in presumed aseptic revision spine surgery. *Spine (Phila Pa 1976)* 2019;44:177-184.

14. Shifflett GD, Bjerke-Kroll BT, Nwachukwu BU, et al: Microbiologic profile of infections in presumed aseptic revision spine surgery. *Eur Spine J* 2016;25:3902-3907.

15. Chun DS, Baker KC, Hsu WK: Lumbar pseudarthrosis: A review of current diagnosis and treatment. *Neurosurg Focus* 2015;39:E10.

16. Ploumis A, Wu C, Mehboob A, et al: Revision of transforaminal lumbar interbody fusion using anterior lumbar interbody fusion: A biomechanical study in nonosteoporotic bone—Laboratory investigation. *J Neurosurg Spine* 2010;12:82-87.

17. Yun DJ, Yu JW, Jeon SH, Lee HC, Lee SH: Salvage anterior lumbar interbody fusion for pseudarthrosis after posterior or transforaminal lumbar interbody fusion: A review of 10 patients. *World Neurosurg* 2018;111:e746-e755.

18. Safaee MM, Tenorio A, Haddad AF, et al: Anterior lumbar interbody fusion with cage retrieval for the treatment of pseudarthrosis after transforaminal lumbar interbody fusion: A single-institution case series. *Oper Neurosurg* 2021;20:164-173.

19. Piggott DA, Higgins YM, Mella MT, et al: Characteristics and treatment outcomes of Propionibacterium acnes prosthetic shoulder infections in adults. *Open Forum Infect Dis* 2015;3:ofv191.

20. Koh CK, Marsh JP, Drinkovic D, Walker CG, Poon PC: Propionibacterium acnes in primary shoulder arthroplasty: Rates of colonization, patient risk factors, and efficacy of perioperative prophylaxis. *J Shoulder Elb Surg* 2016;25:846-852.

21. Gisler V, Benneker L, Sendi P: Late spinal implant infection caused by Cutibacterium acnes. *J Bone Jt Infect* 2019;4:163-166.

22. Hu X, Lieberman IH: Revision spine surgery in patients without clinical signs of infection: How often are there occult infections in removed hardware? *Eur Spine J* 2018;27:2491-2495.

23. Garcia D, Mayfield CK, Leong J, et al: Early adherence and biofilm formation of Cutibacterium acnes (formerly Propionibacterium acnes) on spinal implant materials. *Spine J* 2020;20:981-987.

24. Albert TJ, Pinto M, Denis F: Management of symptomatic lumbar pseudarthrosis with anteroposterior fusion: A functional and radiographic outcome study. *Spine (Phila Pa 1976)* 2000;25:125-130.

25. Makanji H, Schoenfeld AJ, Bhalla A, Christopher M, Bonomo M: Critical analysis of trends in lumbar fusion for degenerative disorders revisited: Influence of technique on fusion rate and clinical outcomes. *Eur Spine J* 2018;27:1868-1876.

26. Burkus JK, Sandhu HS, Gornet MF: Influence of rhBMP-2 on the healing patterns associated with allograft interbody constructs in comparison with autograft. *Spine (Phila Pa 1976)* 2006;31:775-781.
27. Burkus JK, Gornet MF, Schuler TC, Kleeman TJ, Zdeblick TA: Six-year outcomes of anterior lumbar interbody arthrodesis with use of interbody fusion cages and recombinant human bone morphogenetic protein-2. J Bone Joint Surg Am 2009;91:1181-1189.

28. Allen RT, Lee YP, Stimson E, Garfin SR: Bone morphogenetic protein-2 (BMP-2) in the treatment of pyogenic vertebral osteomyelitis. Spine (Phila Pa 1976) 2007;32:2906-2906.

29. Yaw Tee LY, Hunter S, Baker JF: BMP use in the surgical treatment of pyogenic spondylodiscitis: Is it safe? J Clin Neurosci 2022;95:94-98.

30. Walker B, Koerner J, Sankaranarayanan S, Radcliff K: A consensus statement regarding the utilization of BMP in spine surgery. Curr Rev Musculoskelet Med 2014;7:208-219.

31. Dodson CC, Craig EV, Cordasco FA, et al: Propionibacterium acnes infection after shoulder arthroplasty: A diagnostic challenge. J Shoulder Elbow Surg 2010;19:303-307.

32. Shields MV, Abdullah L, Namdari S: The challenge of Propionibacterium acnes and revision shoulder arthroplasty: A review of current diagnostic options. J Shoulder Elbow Surg 2016;25:1034-1040.