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Spinal Infections

Surgical strategies for spinal infections: A narrative review

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ABSTRACT

The successful operative management of spinal infections necessitates a thoughtful approach. Ideal treatment combines the universal goals of any spine operation, which are decompression of the neural elements and stabilization of instability, with source control and eradication of infection. Techniques to treat infection have evolved independently and alongside advances in implant technology and surgical techniques. This review will seek to outline current thinking on approaches to both primary and secondary spinal infections.

Introduction

Spinal infections encompass a wide variety of pathology and clinical presentations ranging from primary infections of the spine, such as spondylodiscitis, to early and late postoperative infections. They can be as dangerous as they are ubiquitous, and spinal infections can potentially lead to catastrophic patient outcomes. A low index of suspicion is often necessary for prompt and accurate diagnosis. The landscape of surgical management of spinal infections continues to evolve. This narrative review delves into the different surgical strategies to safely and effectively treat spinal infections.

Ideal treatment combines the universal goals of any spine operation, which are decompression of the neural elements and stabilization, with source control and eradication of the infection. Techniques to treat infection have evolved independently and alongside advances in implant technology and surgical techniques. This review outlines surgical techniques for managing spinal infections. Both primary pyogenic spondylodiscitis and secondary postoperative infections are covered in detail. The heterogeneity of the presentation of spinal infections remains a barrier to performing large-scale, prospective, randomized studies. It is critical to develop a meticulous plan for each patient tailored to their specific pathology.

Primary spinal infections: cervical spine

Though the overall incidence of cervical osteomyelitis and epidural abscess is less than that of the thoracolumbar spine, the severity of infections is often quite high. Compression within the limited epidural space can rapidly lead to significant neurologic deficits [1]. Early recognition, diagnosis, and treatment is paramount. Progression of hematogenous spondylodiscitis by direct extension into the ventral epidural space is thought to be the most common etiology [2]. Infection secondary to spread of adjacent soft tissue infection, such as retropharyngeal abscess, is also known to occur. Patients with prior neck surgery, immunosuppression, and irradiation are at higher risk [3]. Consultation with otolaryngology colleagues is highly recommended in such cases, and co-surgery is frequently employed. Careful evaluation of the imaging must be noted, as the abscess may propagate cephalad, caudal, and circumferentially from the primary site of spondylodiscitis.

Indications for an anterior approach to cervical spondylodiscitis include ventrally compressive abscess, retropharyngeal infection requiring debridement, and structural compromise with instability necessitating anterior column reconstruction. One and 2 level involvement can often be treated successfully through an anterior approach alone [4]. Infection involving only a single intervertebral level is frequently treated

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with debridement followed by anterior cervical discectomy and fusion. However, infection at 2 contiguous levels often implicates an intervening vertebral body and possibly a retrovertebral abscess. In such cases, corpectomy is often needed for adequate debridement, and titanium cages are frequently useful in addition to stabilization with plate-screw constructs. For multilevel corpectomy, consideration should be given for circumferential stabilization to reduce the risk of pseudarthrosis [5]. Over time, there has been a shift from external devices such as a halo vest toward posterior instrumentation, as patients undergoing combined fixation have not shown an increased rate of complications compared to anterior-only procedures [6].

The posterior approach is recommended in cases of dorsal cervical abscess formation and is also frequently performed in combination with an anterior operation. Isolated dorsal epidural infections can occur from hematogenous seeding, but also from external inoculation such as epidural steroid injection, implanted devices such as spinal cord stimulators, and postoperative infection [7,8]. The decision to perform isolated multilevel cervical laminectomy is controversial, and studies in the literature focusing on cases of infection are limited. In the degenerative spine literature, laminectomy for decompression of cervical stenosis may be complicated by postlaminectomy kyphosis, which ranges from 6% to 47%. It is also important to note that resection of more than 30% to 50% of a facet joint necessitates fusion [9]. Though more limited approaches such as a laminotomy for catheter-based irrigation and evacuation may have a selective indication for isolated decompression, there is a low threshold for performing a thorough debridement and instrumented fusion in many cases.

Posterior cervical techniques for ventral abscess decompression have also been described. The approach involves a laminectomy, foraminotomy for identification of the exiting nerve root, and medial transpedicular drilling of the inferior pedicle for access, irrigation, and suction of the ventral space. Following decompression, the involved levels are stabilized with posterior instrumented fixation and fusion [10]. Though not a commonly employed technique, it represents a useful alternative in cases where the anterior approach is contraindicated.

Infection of the upper cervical spine is exceedingly rare. Owing to the unique anatomy of the region, debridement of abscesses within the periodontoid space is challenging. The posterior approach affords multiple options for rigid fixation and extension to the occiput when necessary, but comprehensive debridement is typically not possible [11]. While a single-stage posterior approach can be successful, persistent infection may require direct debridement via transoral or transnasal approaches [12]. An odontoid-sparing approach utilizing simultaneous transnasal, transoral endoscopic access has been described, though larger series would be needed to determine if avoiding resection of the C1 arch and dens obviates the need for posterior stabilization [13].

While most cervical epidural abscesses are predominantly ventral or dorsal, in rare cases the spread of purulence can span circumferentially to form a contiguous holocord abscess. Both epidural and intramedullary cases have been published, and the extent of infection frequently spans multiple levels and regions. In combination with the principles outlined for anterior and posterior debridement, partial laminectomy and decompression provides access to the epidural space for passage of a small-lumen flexible tube or catheter [14,15]. Apical laminectomies, remote from the site of primary posterior debridement, allow for irrigation of the intervening space and provide an endpoint for the catheter. This technique is very helpful in limiting the extent of laminectomy, particularly in cases of cervicothoracic and thoracolumbar multilevel infection [16].

Primary spinal infections: thoracic spine

The thoracic spine presents unique challenges for anterior access. Upper thoracic segments may require partial resection of the manubrium or sternotomy. Many of the remaining segments may be accessed via thoracotomy [17]. Coordination with an approach specialist is advised, and the risk of pulmonary complications should be weighed. Lateral, retropleural access is also feasible, though this necessitates posterior rib resection [18]. The all-posterior approach is perhaps the most common. More extensive debridement is enabled by costotransversectomy if indicated, and the shorter surgical time may be especially favorable in patients with more medical comorbidities [19].

Motion-sparing and minimally invasive options have been explored and utilized even in extensive disease. Thoracic laminoplasty has been reported as a feasible solution for multilevel thoracic abscess [20]. Endoscopic transforaminal access has also been reported to be successful in irrigation and drainage of multilevel ventral abscesses in the thoracic spine [3]. In the lumbar spine, endoscopic debridement via a posterolateral approach has also been described [21].

Primary spinal infections: lumbar spine

The lumbar spine lends itself to a variety of approaches. Over the years, there has been an evolution in anterior, oblique, and lateral techniques that afford excellent access for anterior column debridement and reconstruction. Oblique and lateral approaches to the mid and upper lumbar spine afford the potential for minimally invasive exposure without the need for an access surgeon. However, the advent of more robust posterior hardware systems has also expanded the utility of the all-posterior approach to accomplish the goals of the operation without repositioning the patient [22]. Complete anterior debridement is made possible by extended posterior approaches involving facetectomy and transpedicular work.

While several studies have sought to compare anterior and lateral to posterior-only approaches, it is unclear which approach yields the best clinical result. Rather, the optimal strategy is determined on a case-by-case basis. Approach selection involves what is feasible for the patient, what is accessible at the treating institution, and an exposure the surgeon is confident in performing a thorough evacuation of infected tissue through. Modern implants offer excellent fixation and robust interbody cage options from all approaches, and for this reason no relevant differences persist in terms of achieving high rates of fusion and construct stability. However, anterior-based approaches allow for better lordotic correction and improved sagittal alignment, and thus may be preferred in cases of clinically significant segmental kyphosis and infection at lower lumbar segments. Older studies initially reported better clinical outcomes with anterior reconstruction and posterior fixation, but the relevance of the findings are difficult to interpret in light of more modern implant choices [23,24]. Newer studies have shown that posterior-only strategies with interbody support and long-segment constructs are as effective as a combined approach, but only when the sagittal malalignment is limited. Choi et al. [25] reported that their decision to pivot from a posterior-only strategy to the inclusion of an anterior or lateral approach is when the local kyphosis of the collapsed vertebra exceeds 8.2°. With regard to the anterior approach, the use of percutaneous posterior instrumentation has been shown to be feasible with similar clinical outcomes and control of infection compared to the open posterior fixation group [26]. This affords the benefit of shorter operative time, less blood loss, and potentially less pain.

The oblique corridor has been used as a minimally invasive option to successfully treat single-level infections of the middle and upper lumbar segments [27,28]. Lateral transpsoas approaches have similarly shown success [29]. The authors note that limitations arise with accessing multiple levels when multisegmental disease is present, and the inability to access infection in the posterior elements. The minimally invasive posterior approach with tubular access and minimally invasive transforaminal interbody lumbar fusion (MIS-TLIF) has also been used successfully, even in cases with epidural abscess formation. The authors noted improved postoperative pain scores at discharge compared to the open group [30].

With regard to interbody choice, modern titanium and polyetheretherketone (PEEK) cages are successful options for anterior column support that do not increase the risk of reinfection [31]. While no differences have been definitively shown between these 2 options, iliac strut autograft has been shown to have a higher subsidence rate [32]. In terms of graft choice, smaller studies have shown that both allograft and autograft may be used successfully in the postinfectious spine [33].

In some cases, a high comorbidity burden dictates the consideration of a less thorough operation. Posterior transpedicular curettage, drainage, and stabilization has been reported to be successful in patients too sick to undergo an anterior debridement, which the authors considered a more definitive operation [10].

Postoperative spinal infections: superficial versus deep infections

Postoperative spinal infections often present unique challenges. Infections affecting the skin and subcutaneous tissues superficial to the fascia may resolve with nonoperative treatments such as wound care and antibiotic treatment, though abscess formation may require percutaneous drainage or open debridement. Deep infections are typically operative. Antibiotic treatment alone is rarely indicated, and a meticulous surgical plan with a thorough workup is mandatory to maximize the odds of success. Advanced infections may result in new instability, and debridement itself may result in destabilization. Hardware retention, exchange, and removal must be carefully weighed both prior to and during surgery.

Postoperative spinal infections: early versus late infections

For early and acute infections, particularly those occurring within the first postoperative month, the general recommendation is to retain prior hardware and remove loose graft material [34]. The effectiveness of single debridement with hardware retention likely decreases after this period, and most surgeons consider infections after 3 months to be late-presenting [35]. Infections at these later points often require more nuanced decision making. In all cases, loose hardware should be removed. If necessary to maintain stability, it should be replaced. Preoperative imaging should be examined carefully to guide the surgical plan, and hardware with associated vertebral osteomyelitis should be removed regardless of the time point.

Interbody implants are typically retained, but should be removed if signs of adjacent osteomyelitis, osteolysis, or abscess are present. If interbody removal is indicated, the size and location of the cage may dictate the best approach. However, anterior-based approaches have the most favorable access in general and have the unique advantage of avoiding epidural fibrosis and scar tissue when removing posterior interbody implants. Regrafting the interbody space with a new cage versus autogenous iliac crest bone graft have both been described with overall good results [36,37].

In areas where fusion has not yet occurred or pseudarthrosis is present, removal of hardware may result in instability. In long-standing infection, biofilm formation on the surface of prior instrumentation may result in chronic infection despite repeat attempts at surgical and antibiotic treatment. In such cases, hardware removal or exchange is necessary for source control [38]. Intraoperatively, sonication of removed implants to break down biofilms may yield improved culture results for direction of antibiotic treatment, particularly for low-virulence organisms [39]. Progressive deformity has been reported in cases of hardware removal both in the setting of pseudarthrosis and apparently solid fusion, highlighting the potentially protective effect of one-stage exchange [40]. For known pseudarthrosis, delayed instrumented fusion may also be considered after the infection is cleared. In patients who are too unwell to undergo repeat surgery, hardware removal or even surgery itself may confer unacceptable risk. Chronic antibiotic suppression should be considered for such cases. In terms of recurrence, the majority of studies have reported better long-term control of infection through complete removal of hardware, though the heterogeneity of prior data makes these conclusions somewhat uncertain. While a definitive answer is not available, complete removal of hardware for late-presenting infection is recommended when possible [41,42].

Debridement should be thorough and include removal of all grossly infected and necrotic tissue as well as foreign objects such as sutures. Most cases can be treated successfully with a single-stage operation, but more virulent infections in sicker patients are not cleared as easily. Specific factors that raise the risk for needing serial debridement include diabetes, methicillin-resistant staph aureus infection, polymicrobial infection, posterior lumbar infection, and nonautograft bone graft material [43,44]. During the debridement, prior areas of bony fusion may be left intact. Similar to primary infection, areas of significant neural compression secondary to abscess or phlegmon formation should be decompressed if possible. Irrigation is useful for both diluting bacterial burden and aiding in removal of loosened infected tissue. High-quality literature is lacking, but some small studies on infection prevention indicate that pulse lavage may be more effective in the posterior muscular layer, while bulb irrigation is sufficient for the intervertebral space [45]. Dilute betadine soak and irrigation may also help reduce bacterial load [46]. Devascularized wound beds, of particular concern in infected revisions, also limit the ability of systemic antibiotic treatment to reach the site of infection. Local high-dose delivery through adjuvants such as antibiotic-impregnated beads may be employed as an alternative to standard intrawound antibiotic powder. Vacuum-assisted closure may also be employed to facilitate wound healing. Involvement of plastic surgery should be considered, particularly with debridement of long-segment constructs, multiple operated surgical sites, and when there is notable dead space secondary to necrotic muscle defects [47].

Conclusions

The surgical management of spinal infections is challenging. The heterogeneity of presentation is a barrier to performing large-scale, prospective, randomized studies. Fortunately, a variety of techniques have emerged for successful management that allow the surgeon to develop a meticulous plan for each patient tailored to the specific pathology.

Declarations of competing interests

One or more of the authors declare financial or professional relationships on ICMJE-NASSJ disclosure forms.

References

[1] Reihsaus E, Waldbaur H, Seeling W. Spinal epidural abscess: a meta-analysis of 915 patients. Neurosurg Rev 2000;23(4):175–204 discussion 205.
[2] Tay BKB, Deckey J, Hu SS. Spinal infections. J Am Acad Orthop Surg 2002;10(3):188–97.
[3] Shin KE. Epidural abscess formation after chemoradiation therapy for esophageal cancer. Medicine (Baltimore) 2022;101(21):e29426.
[4] Zarghooni K, Röllinghoff M, Sobottke R, Eysel P. Treatment of spondylodiscitis. Int Orthop (SICOT) 2012;36(2):405–11.
[5] Oni P, Schultheiß R, Scheufler KM, Roberg J, Harati A. Radiological and clinical outcome after multilevel anterior cervical discectomy and/or corpectomy and fixation. J Clin Med 2018;7(12):469.
[6] Ghobrial GM, Viereck MJ, Margiotta PJ, et al. Surgical management in 40 consecutive patients with cervical spinal epidural abscesses: shifting toward circumferential treatment. Spine (Phila Pa 1976) 2015;40(17):E949–53.
[7] Huang RC, Shapiro GS, Lim M, Sandhu HS, Lutz GE, Herzog RJ. Cervical epidural abscess after epidural steroid injection. Spine (Phila Pa 1976) 2004;29(1):E7–9.
[8] Bara GA, Thissen J. Cervical epidural abscess due to implantation of a spinal cord stimulation lead. Clin Case Rep 2022;10(6):e05931.
[9] McAllister BD, Rebholz BJ, Wang JC. Is posterior fusion necessary with laminectomy in the cervical spine? Surg Neurol Int 2012;3(Suppl 3):S225–31.
[10] Lara-Reyna J, Yaeger KA, Margetis K. Transpedicular approach for ventral epidural abscess evacuation in the cervical spine. World Neurosurg 2021;145:127–33.
[11] Suchomel P, Buchvald P, Barsa P, Lukas R, Soukup T. Pyogenic osteomyelitis of the odontoid process: single stage decompression and fusion. Spine (Phila Pa 1976) 2003;28(12):E239–44.
[12] Wiedau-Pazos M, Curio G, Grüsser C. Epidural abscess of the cervical spine with osteomyelitis of the odontoid process. Spine (Phila Pa 1976) 1999;24(2):133–6.

[13] Shawky Abdelgawaad A, Kellner G, Elnady B, Ezzati A. Odontoid-sparing transnasal approach for drainage of craniocervical epidural abscess; a novel technique and review of the literature. Spine J 2018;18(3):540–6.
[14] Ahuja K, Das L, Jain A, Meena PK, Arora SS, Kandwal P. Spinal holocord epidural abscess evacuated with double thoracic interval laminectomy: a rare case report with literature review. Spinal Cord Ser Cases 2019;5:62.
[15] Desai KI, Muzumdar DP, Goel A. Holocord intramedullary abscess: an unusual case with review of literature. Spinal Cord 1999;37(12):866–70.
[16] Abd-El-Barr MM, Bi WL, Bahluyen B, Rodriguez ST, Groff MW, Chi JH. Extensive spinal epidural abscess treated with "apical laminectomies" and irrigation of the epidural space: report of 2 cases. J Neurosurg Spine 2015;22(3):318–23.
[17] Amini A, Beisse R, Schmidt MH. Thoracoscopic debridement and stabilization of pyogenic vertebral osteomyelitis. Surg Laparosc Endosc Percutan Tech 2007;17(4):354–7.
[18] Ahmadian A, Uribe JS. Mini-open lateral retro-pleural thoracic corpectomy for osteomyelitis. Neurosurg Focus 2013;35(2 Suppl) Video 17.
[19] Kao FC, Tsai TT, Niu CC, Lai PL, Chen LH, Chen WJ. One-stage posterior approaches for treatment of thoracic spinal infection: transforaminal and costotransversectomy, compared with anterior approach with posterior instrumentation. Medicine (Baltimore) 2017;96(42):e8352.
[20] Lehman RA, Lenke LG. Extensive epidural abscess treated with a thoracic laminoplasty. Spine J 2011;11(8):798–9.
[21] Ito M, Abumi K, Kotani Y, Kadoya K, Minami A. Clinical outcome of posterolateral endoscopic surgery for pyogenic spondylodiscitis: results of 15 patients with serious comorbid conditions. Spine (Phila Pa 1976) 2007;32(2):200–6.
[22] Zhang HQ, Wang YX, Wu JH, Chen J. Debridement and interbody graft using titanium mesh cage, posterior monosegmental instrumentation, and fusion in the surgical treatment of monosegmental lumbar or lumbosacral pyogenic vertebral osteomyelitis via a posterior-only approach. World Neurosurg 2020;135:e116–25.
[23] Včelák J, Chomiak J, Toth L. Surgical treatment of lumbar spondylodiscitis: a comparison of two methods. Int Orthop 2014;38(7):1425–34.
[24] Linhardt O, Matussek J, Refior HJ, Krödel A. Long-term results of ventro-dorsal versus ventral instrumentation fusion in the treatment of spondylitis. Int Orthop 2007;31(1):113–19.
[25] Choi SH, Koo JW, Hur JM, Kang CN. A new surgical strategy for infective spondylodiscitis: comparison between the combined antero-posterior and posterior-only approaches. Spine 2020;45(19):E1239.
[26] Lin TY, Tsai TT, Lu ML, et al. Comparison of two-stage open versus percutaneous pedicle screw fixation in treating pyogenic spondylodiscitis. BMC Musculoskelet Disord 2014;15:443.
[27] Wang B, Chen C, Hua W, et al. Minimally invasive surgery oblique lumbar interbody debridement and fusion for the treatment of lumbar spondylodiscitis. Orthop Surg 2020;12(4):1120–30.
[28] Tong YJ, Liu JH, Fan SW, Zhao FD. One-stage debridement via oblique lateral interbody fusion corridor combined with posterior pedicle screw fixation in treating spontaneous lumbar infectious spondylodiscitis: a case series. Orthop Surg 2019;11(6):1109–19.
[29] He L, Xie P, Shu T, et al. Clinical and radiographic results of a minimally invasive lateral transpsoas approach for treatment of septic spondylodiscitis of the thoracolumbar and lumbar spine. World Neurosurg 2018;116:e48–56.
[30] Tschugg A, Hartmann S, Lener S, Rietzler A, Sabrina N, Thomé C. Minimally invasive spine surgery in lumbar spondylodiscitis: a retrospective single-center analysis of 67 cases. Eur Spine J 2017;26(12):3141–6.
[31] Schomacher M, Finger T, Koeppen D, et al. Application of titanium and polyetheretherketone cages in the treatment of pyogenic spondylodiscitis. Clin Neurol Neurosurg 2014;127:65–70.
[32] Pee YH, Park JD, Choi YG, Lee SH. Anterior debridement and fusion followed by posterior pedicle screw fixation in pyogenic spondylodiscitis: autologous iliac bone strut versus cage. J Neurosurg Spine 2008;8(5):405–12.
[33] Dobran M, Iacoangeli M, Nasi D, et al. Posterior titanium screw fixation without debridement of infected tissue for the treatment of thoracolumbar spontaneous pyogenic spondylodiscitis. Asian Spine J 2016;10(3):465–71.
[34] Dowdell J, Brochin R, Kim J, et al. Postoperative spine infection: diagnosis and management. Global Spine J 2018;8(4 Suppl) 37S–43S.
[35] Divi SN, Kepler CK, Boody BS, et al. Consensus on implants in infections after spine surgery. Clin Spine Surg 2020;33(4):163–71.
[36] Zhang AS, Berns EM, Hartnett DA, Kuris EO, Daniels AH. Indolent infection after lumbarinterbody fusion: an under-recognized cause of pseudarthrosis, which can be successfully treated with anterior revision fusion. J Am Acad Orthop Surg Glob Res Rev 2022;6(3):e21.00259.
[37] Ha KY, Kim YH. Postoperative spondylitis after posterior lumbar interbody fusion using cages. Eur Spine J 2004;13(5):419–24.
[38] Prinz V, Vajkoczy P. Surgical revision strategies for postoperative spinal implant infections (PSII). J Spine Surg 2020;6(4):777–84.
[39] Prinz V, Bayerl S, Renz N, et al. High frequency of low-virulent microorganisms detected by sonication of pedicle screws: a potential cause for implant failure. J Neurosurg Spine 2019;31(3):424–9.
[40] Lall RR, Wong AP, Lall RR, Lawton CD, Smith ZA, Dahdaleh NS. Evidence-based management of deep wound infection after spinal instrumentation. J Clin Neurosci 2015;22(2):238–42.
[41] Hersh A, Young R, Pennington Z, et al. Removal of instrumentation for postoperative spine infection: systematic review. J Neurosurg Spine 2021;35:376–88.
[42] Hedequist D, Haugen A, Hresko T, Emans J. Failure of attempted implant retention in spinal deformity delayed surgical site infections. Spine (Phila Pa 1976) 2009;34(1):60–4.
[43] Dipaola CP, Saravanja DD, Boriani L, et al. Postoperative infection treatment score for the spine (PITSS): construction and validation of a predictive model to define need for single versus multiple irrigation and debridement for spinal surgical site infection. Spine J 2012;12(3):218–30.
[44] Karamian BA, Lambrechts MJ, Sirch F, et al. Does postoperative spine infection bacterial gram type affect surgical debridement or antibiotic duration? Spine (Phila Pa 1976) 2022;47(21):1497–504.
[45] Ahn DK, Lee S, Moon SH, Kim DG, Hong SW, Shin WS. Bulb syringe and pulsed irrigation: which is more effective to remove bacteria in spine surgeries? Clin Spine Surg 2016;29(1):34–7.
[46] Fei J, Gu J. Comparison of lavage techniques for preventing incision infection following posterior lumbar interbody fusion. Med Sci Monit 2017;23:3010–18.
[47] Dumanian GA, Ondra SL, Liu J, Schafer MF, Chao JD. Muscle flap salvage of spine wounds with soft tissue defects or infection. Spine (Phila Pa 1976) 2003;28(11):1203–11.