PURULENT COMPLICATIONS IN SPINE SURGERY WITH METAL IMPLANTS: LITERATURE REVIEW*

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Currently, the use of implants has become an integral part of surgery for various pathologies of the spine. The incidence of infection after spinal instrumentation varies from 0.7 to 20.0 %. The development of this complication may adversely affect the remote results and increase the cost of treatment. The paper presents a review of the literature devoted to surgical site infection after spine surgery with metal implants and related to the factors influencing emergence and progression of the infection, its diagnosis and treatment.
Key Words: biofilm, infection, implant, scoliosis, spine surgery.

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Before the mid-19th century, surgical patients commonly developed postoperative "irritative fever" followed by purulent drainage from their incisions, overwhelming sepsis, and often death. It was not until the late 1860s, after Joseph Lister introduced the principles of antisepsis that postoperative infectious morbidity decreased substantially. Lister's work radically changed surgery from an activity associated with infection and death to a discipline that could eliminate suffering and prolong life.

Infectious complications have extremely negative effect on outcomes of surgical correction of idiopathic scoliosis often leading to the need of implant removal and consequently to loss of achieved correction of instrumented spine. Early-onset and late-onset surgical site infection (SSI) rates following spinal instrumentation for idiopathic scoliosis vary from 1.4 to 6.9 % [8, 53, 54].

We present the literature review of surgical site infections after spinal instrumentation, as the number of papers devoted to SSI in idiopathic scoliosis correction is small.

The incidence of SSI after spinal instrumentation varies from 0.7 to 20.0 % [7, 9–12, 16-19, 29, 34, 39, 47, 50, 56, 57, 60, 62, 71, 84, 88].

Emergence of SSI results in increased hospital stay and health care costs.

Advances in infection control practices include improved operating room ventilation, sterilization methods, barriers, surgical technique, and availability of antimicrobial prophylaxis. Despite these activities, SSI remains a substantial cause of morbidity among hospitalized patients [1].

Definitions

The «Guideline for Prevention of Surgical Site Infection» is the fundamental document in the United States that presents the Centers for Disease Control and Prevention's recommendations for the prevention of surgical site infections [1, 54]. Criteria for defining a surgical site infection include the following.

Superficial incisional SSI

Infection occurs within 30 days after the operation. Infection involves only skin or subcutaneous tissue of the incision and the patient has at least one of the following:

1) purulent drainage, with or without laboratory confirmation, from the superficial incision;

2) organisms isolated from an aseptically obtained culture of fluid or tissue from the superficial incision;

3) at least one of the following signs or symptoms of infection: pain or tenderness, localized edema, redness, or heat and superficial incision is deliberately opened by surgeon, unless incision is culture-negative;

4) diagnosis of superficial incisional SSI by the surgeon or attending physician.

Deep incisional SSI

Infection occurs within 30 days after the operation and infection involves deep soft tissues (for example, fascial and muscle layers) of the incision and the patient has at least one of the following:

1) purulent drainage from the deep incision;

2) a deep incision spontaneously dehisces or is deliberately opened by a surgeon when the patient has at least one of the following signs or symptoms: fever (>38 C), localized pain, or tenderness, unless site is culture-negative;

3) an abscess or other evidence of infection involving the deep incision is found on direct examination, during reoperation, or by histopathologic or radiologic examination;

4) diagnosis of a deep incisional SSI by a surgeon or attending physician.

Factors influencing the emergence and development of SSIs

Based on the Russian National Guidelines [2], the risk factors for SSI include five main categories (groups): the patient's characteristics, preoperative, intraoperative and postoperative characteristics, and operating room environment.

The patient's characteristics include the underlying disease (greater severity of the patient's clinical condition is associated with more significant development of infection), comorbid disease or conditions which reduce tolerance to infection and/or delay wound healing (diabetes mellitus, multiple trauma, obesity, cachexia, skin diseases, especially infectious skin diseases, immunosuppression, malignancies), and extremes of age (infants, elderly).

Preoperative factors include prolonged preoperative hospital stay, which is frequently suggested as a patient characteristic associated with increased SSI risk caused by multi-resistant nosocomial flora. Other risk preoperative factors include preoperative shaving, inadequate antibiotic prophylaxis, and inadequate preoperative preparation of skin at the incision site with antiseptic agents.

Operative characteristics include the degree of cleanliness (intraoperative microbial contamination) of the incision site (risk of SSI in the clean procedures is lower than at clean-contaminated, contaminated or dirty-infected operations); excellent surgical technique that includes adherence to the principles of aseptics and the condition of the incision up to the completion of the operation; duration of the operation, which depends on many factors, including the skills of the surgeon, the complexity of the operation, maintaining effective hemostasis, degree of traumatic tissue dissection, condition of the incision site after the operation (poor vascularization, hematomas, removing necrotic or devitalized tissues or foreign bodies); any foreign body, for example, use of drains, may promote migration of microorganisms from the skin at the surgical site; excessive diathermy.

Factors of operating room environment include overcrowding and a large number of observers (students) in the operating room, methicillin-resistant S. aureus (MRSA) nasopharyngeal carriage by operating room personnel, non-minimized personnel traffic, inadequate surgical suits and attire, poor ventilation in the operating room, open containers with disinfectants, inadequate sterilization of surgical instruments and surgical materials, disinfection of equipment and environmental surfaces and other items, and violation of the aseptics during the operation.

Postoperative factors are post-operative incision care procedures, as well as arrangement and technique of dressings, adherence to aseptics during dressings of the surgical sites, disinfection of equipment and other items in the dressing room, inadequate suits and attire of the personnel, the order of the dressings in the same room, colonized personnel with MRSA strains.

Since the hands of the members of the surgical team is the main route of SSI causative agents transmission, inadequate preoperative hand/forearm antisepsis and improper wearing of gloves are leading factors for SSIs.

Epstein [26] believes that the use of posterior approach, use of allografts, the duration of the operation of more than 5 hours, and blood transfusions increase the risk of infection. The use of intraoperative instruments (for example, surgical microscopes, radiographic examination, intraoperative computed tomography imaging) also increases the risk of SSI. Additional strict adherence to proper postoperative wound care is also important in minimizing the risk of postoperative wound infections.

Closed wound suction drainage is believed to reduce the risk of SSI as even small postoperative hematomas may provide a medium for bacterial overgrowth. Nevertheless, the use of post-operative wound drains unevenly reduces the incidence of early postoperative infections. It is found that failure of prevention of postoperative hematomas correlated with a significantly higher risk of SSI [12, 13, 42, 48, 61].

Resistance to infection may depend on the type of implant, which influences the susceptibility to bacterial biofilm development [5, 74, 83, 86]. There is the possibility of bacterial adhesion to biomaterial with the formation of a biofilm. A biofilm is a structured consortium of bacteria embedded in a self-produced matrix [36–38]. The microorganisms in a biofilm are strongly attached to a surface or to each other. The cells within these communities are protected from antibiotics and the host defense (phagocytic, cellular and humoral immune responses) [20, 22]. Furthermore, the bacteria within the biofilm often exhibit an altered phenotype in terms of growth rate and gene transcription which may affect the diagnosis and treatment tactics [22-34, 36, 38, 43].

Preoperative time of antibiotics administration strongly correlates with an increased risk of postoperative infection. Most surgeons consider it appropriate to deliver preoperative prophylactic antibiotics within one hour before surgery, but some argue that antibiotic prophylactic therapy 15 minutes before the incision can be even more effective [9, 11].

Vitale et al. [81] developed 14 SSI prevention strategies during spinal surgery in pediatric patients:

1) patients should have a chlorhexidine skin wash the night before surgery;

2) patients should have preoperative urine cultures obtained;

3) patients should receive a preoperative patient sanitation education sheet;

4) patients should have a preoperative nutritional assessment;

5) if removing hair, clipping is preferred to shaving;

6) patients should receive perioperative intravenous cefazolin;

7) patients should receive perioperative intravenous prophylaxis for gram-negative bacilli;

8) adherence to perioperative antimicrobial regimens should be monitored;

9) operating room access should be limited;

10) UV lights need not be used in the operating room;

11) patients should have intraoperative wound irrigation;

12) vancomycin powder should be used in the bone graft and/or the surgical site;

13) impervious dressings are preferred postoperatively;

14) postoperative dressing changes should be minimized before discharge to the extent possible.

Treatment

There is a variety of mays of operative therapy of postoperative infection with no consensus on which to use: only irrigation and/or debridement, vacuum-assisted wound closure, continuous irrigation, antibiotic impregnated beads, if revising of the instrumentation (for example, for the instrumentation instability) or implant removal/retention are necessary, which antibiotic to use in the treatment protocol [6, 35, 49, 55, 70, 76]. Due to the concern for the pathogenetic role of biofilms on implants, many medical specialists recommend removal of the implanted spinal instrumentation [3, 4, 68]. This provides successful eradication of infection because the bacterial biofilm is removed. Nevertheless, this decision must be weighed with risks of losing deformity correction and spine stability. Biofilms are the key factor in deciding whether or not to remove the spinal instrumentation. Laboratory studies have documented that biofilms can develop within 5–6 hours after bacterial contamination, and the age of a biofilm is associated with the stability of the biofilm and greater resistance to antibiotics resulting in serious clinical consequences [23]. Early surgical intervention for acute SSI with wound irrigation and/or debridement can easily disrupt biofilm formation and facilitate the penetration of systemic antimicrobial agents for the resolution of infection, while preserving instrumentation/stability. This concept is supported by clinical experience, which demonstrates that appropriate treatment of early postoperative infections leads to a higher level of infection resolution, retention of implant and better clinical outcomes [4, 27, 35, 58, 66, 72].

In contrast to early-onset infections, late-onset wound infections often require implant removal or replacement [7, 14, 49, 67, 69, 77, 85].

Ho et al. [41] reported that there is a nearly 50 % chance that the infection will remain if all spinal implants are not removed. They found that patients at time of the first irrigation and debridement with implant retained required a second irrigation and debridement procedure.

Some authors advocate prophylactic removal of spinal instrumentation for minimization of infection recurrence [19, 59]. Implant removal is associated with better clearing of the surgical site and, thus, reduces the risk of infection relapse [18, 40, 49, 59]. Concerns about loss of spinal correction at late infections are less significant than in early postoperative infections, as spine fusion has already been formed in most cases, or at least, tough fibrous joining has developed. Nevertheless, one cannot exclude that radiographic data after removal of spinal instrumentation may indicate pseudarthrosis or loss of correction. As a consequence, these patients require careful monitoring [21, 40, 59, 64].

Debridement and irrigation procedures enabled early postoperative infection care after spinal instrumentation [4, 27, 63]. Serial debridements may be required for successful eradication of infection. Poorly vascularized tissues or complex spine wound defects require the use of flaps [25, 82]. In addition to debridement and postoperative antibiotic therapy, wound infections may be treated using suction/irrigation systems, antimicrobial beads or VAC-devices (vacuum-assisted closure). The VAC technique is a negative-pressure wound therapy, which may improve treatment results of infection following spinal instrumentation in some patients. VAC-systems may prevent multiple surgery for closure of the wound. Excellent results have been obtained when using these devices as reflected in many references [35, 45, 52, 70, 75, 78, 87].

The VAC system is a useful adjunct, which promotes wound healing and eliminates complex postoperative bacterial infections of the spine [14, 15, 44, 46, 51, 55, 77, 79, 80, 89, 90]. This new technique involves the controlled application of subatmospheric pressure to the local wound environment to draw out fluid from the wound and remove edema, leading to increased localized blood flow. The technique reduces the level of microbial contamination of wounds and the applied forces result in the enhanced formation of granulation tissue [6, 79].

Glassman et al. [35] have described the successful treatment of surgical wound infection after instrumented lumbar fusions using antibiotic impregnated beads and irrigation procedures. The treatment by this technique takes from 5 days to 2 weeks.

The duration of antibiotic treatment is another aspect of postoperative infection after spinal instrumentation to be resolved. It is based on optimal antimicrobial agent selection from bacteria culture data and sensitivity of the bacteria to antibiotics. Although 6–8 weeks of antibiotic administration is recommended, there is no consensus on requirement and duration of oral antimicrobial suppression therapy [65, 73].

Conclusion

Spine surgery has been developing rapidly in recent decades that resulted in an increase in the number of surgical interventions using metal implants and advanced constructions of metal implants. The Russian specialists have started to perform spinal instrumentation using metal implants, though with some delay, but their involvement has increased substantially.

Purulent complications in vertebral surgery, despite the significant advances in their prophylaxis, still develop being an urgent medical concern. The increase in the number of the operations inevitably leads to an increase in the absolute number of cases of SSI. This issue has been addressed in many papers which are primarily aimed at identification of significant risk factors for complications. In our country, related studies have not been performed based on the literature. Based on extensive clinical material, we would like to fill this gap and offer the first review in the Russian literature of the purulent complications in spine surgery to our colleagues.

We believe that consistency in the diagnosis and treatment of the symptoms of superficial and deep purulent complications and maximum consideration of the risk factors of their development are necessary in the daily practice of any vertebral surgeon.

This paper is devoted to the problem as a whole, later we plan to focus on purulent complications in surgery for scoliosis.

References

1. **Mangram A.Dzh., Khran T.C., Pearson M.L., Sil'ver L.C., Dzharvis W.R.** Guideline for prevention of surgical site infection. Clinical Microbiology and Antimicrobial Chemotherapy. 2003;5(1):74–101. In Russian.
2. Surgical Infections of Skin and Soft Tissues. Russian National Guidelines. Ed. by V.S. Savel'ev. Moscow, 2009:53–54. In Russian.
3. **Abbey DM, Turner DM, Warson JS, Wirt TC, Scalley RD.** Treatment of postoperative wound infections following spinal fusion with instrumentation. J Spinal Disord. 1995;8:278–283.
4. **Ahmed R, Greenlee JD, Traynelis VC.** Preservation of spinal instrumentation after development of postoperative bacterial infections in patients undergoing spinal arthrodesis. J Spinal Disord Tech. 2012;25:299–302. DOI: 10.1097/BSD.0b013e31821fbf72.
5. **Arens S, Schlegel U, Printzen G, Ziegler WJ, Perren SM, Hansis M.** Influence of materials for fixation implants on local infection. An experimental study of steel versus titanium DCP in rabbits. J Bone Joint Surg Br. 1996; 78: 647–651.
6. **Argenta LC, Morykwas MJ.** Vacuum-assisted closure: a new method for wound control and treatment: clinical experience. Ann Plast Surg. 1997; 38: 563–577. DOI: 10.1097/00000637-199706000-00002.
7. **Aydinli U, Karaeminogullari O, Tiskaya K.** Postoperative deep wound infection in instrumented spinal surgery. Acta Orthop Belg. 1999;65:182–187.
8. **Bachy M, Bouyer B, Vialle R.** Infections after spinal correction and fusion for spinal deformities in childhood and adolescence. Int Orthop. 2012;36:465–469. DOI: 10.1007/s00264-011-1439-8.
9. **Barker FG, 2nd.** Efficacy of prophylactic antibiotic therapy in spinal surgery: a meta-analysis. Neurosurgery. 2002;51:391–400. DOI: 10.1227/01.NEU.0000072304.16102.2F.
10. **Beiner JM, Grauer J, Kwon BK, Vaccaro AR.** Postoperative wound infections of the spine. Neurosurg Focus. 2003;15:E14.
11. **Blam OG, Vaccaro AR, Vanichkachorn JS, Albert TJ, Hilibrand AS, Minnich JM, Murphey SA.** Risk factors for surgical site infection in the patient with spinal injury. Spine. 2003;28:1475–1480.
12. **Brown EM, Pople IK, de Louvois J, Hedges A, Bayston R, Eisenstein SM, Lees P.** British Society for Antimicrobial Chemotherapy Working Party on Neurosurgical Infections. Spine update: prevention of postoperative infection in patients undergoing spinal surgery. Spine. 2004;29: 938–945.
13. **Brown MD, Brookfield KF.** A randomized study of closed wound suction drainage for extensive lumbar spine surgery. Spine. 2004; 29: 1066–1068. DOI: 10.1097/00007632-200405150-00003.
14. **Canavese F, Gupta S, Krajbich JI, Emara KM.** Vacuum-assisted closure for deep infection after spinal instrumentation for scoliosis. J Bone Joint Surg Br. 2008; 90:377–381. DOI: 10.1302/0301-620X.90B3.19890.
15. **Canavese F, Krajbich JI.** Use of vacuum assisted closure in instrumented spinal deformities for children with postoperative deep infections. Indian J Orthop. 2010;44:177–183. DOI: 10.4103/0019-5413.62067.
16. **Capen DA, Calderone RR, Green A**. Perioperative risk factors for wound infections after lower back fusions. Orthop Clin North Am. 1996;27:83–86.
17. **Christodoulou AG, Givissis P, Symeonidis PD, Karataglis D, Pournaras J.** Reduction of postoperative spinal infections based on an etiologic protocol. Clin Orthop Relat Res. 2006;444:107–113.
18. **Clark CE, Shufflebarger HL.** Late-developing infection in instrumented idiopathic scoliosis. Spine. 1999; 24: 1909–1912. DOI: 10.1097/00007632-199909150-00008.
19. **Collins I, Wilson-MacDonald J, Chami G, Burgoyne W, Vineyakam P, Berendt T, Fairbank J.** The diagnosis and management of infection following instrumented spinal fusion. Eur Spine J. 2008; 17:445–450. DOI: 10.1007/s00586-007-0559-8.
20. **Costerton JW.** Biofilm theory can guide the treatment of device-related orthopaedic infections. Clin Orthop Relat Res. 2005; 437: 7–11. DOI: 10.1097/00003086-200508000-00003.
21. **Deckey JE, Court C, Bradford DS.** Loss of sagittal plane correction after removal of spinal implants. Spine. 2000; 25: 2453–2460. DOI: 10.1097/00007632-200010010-00006.
22. **Donlan RM.** Biofilm formation: a clinically relevant microbiological process. Clin Infect Dis. 2001; 33:1387–1392. DOI: 10.1086/322972.
23. **Donlan RM, Costerton JW.** Biofilms: survival mechanisms of clinically relevant microorganisms. Clin Microbiol Rev. 2002; 15: 167–193. DOI: 10.1128/CMR.15.2.167-193.2002.
24. **Donlan RM, Forster T, Murga R, Brown E, Lucas C, Carpenter J, Fields B.** Legionella pneumophila associated with the protozoan Hartmannella vermiformis in a model multi-species biofilm has reduced susceptibility to disinfectants. Biofouling. 2005; 21: 1–7.
25. **Dumanian GA, Ondra SL, Liu J, Schafer MF, Chao JD.** Muscle flap salvage of spine wounds with soft tissue defects or infection. Spine. 2003; 28: 1203–1211. DOI: 10.1097/01.BRS.0000067260.22943.48.
26. **Epstein NE.** Do silver-impregnated dressings limit infections after lumbar laminectomy with instrumented fusion? Surg Neurol. 2007; 68: 483–485.
27. **Falavigna A, Righesso Neto O, Fonseca GP, Nervo M.** [Management of deep wound infections in spinal lumbar fusions]. Arq Neuropsiquiatr. 2006; 64:1001–1004. In Portuguese.
28. **Falavigna A, Righesso O, Traynelis VC, Teles AR, da Silva PG.** Effect of deep wound infection following lumbar arthrodesis for degenerative disc disease on long-term outcome: a prospective study: clinical article. J Neurosurg Spine. 2011; 15: 399–403. DOI: 10.3171/2011.5.SPINE10825.
29. **Fang A, Hu SS, Endres N, Bradford DS.** Risk factors for infection after spinal surgery. Spine. 2005; 30:1460–1465.
30. **Fletcher M, Loeb GI.** Influence of substratum characteristics on the attachment of a marine pseudomonad to solid surfaces. Appl Environ Microbiol. 1979; 37:67–72.
31. **Foglar C, Lindsey RW.** C-reactive protein in orthopedics. Orthopedics. 1998; 21: 87–691.
32. **Friedman ND, Sexton DJ, Connelly SM, Kaye KS.** Risk factors for surgical site infection complicating laminectomy. Infect Control Hosp Epidemiol. 2007; 28:1060–1065.
33. **Gaine WJ, Andrew SM, Chadwick P, Cooke E, Williamson JB.** Late operative site pain with isola posterior instrumentation requiring implant removal: infection or metal reaction? Spine. 2001; 26: 583–587. DOI: 10.1097/00007632-200103010-00027.
34. Gaynes RP, Culver DH, Horan TC, Edwards JR, Richards C, Tolson JS. Surgical site infection (SSI) rates in the United States, 1992-1998: the National Nosocomial Infections Surveillance System basic SSI risk index. Clin Infect Dis. 2001; 33(Suppl 2): S69–77.

35. **Glassman SD, Dimar JR, Puno RM, Johnson JR. Sa**lvage of instrumental lumbar fusions complicated by surgical wound infection. Spine. 1996;21: 2163–2169. DOI: 10.1097/00007632-199609150-00021.
36. **Gristina AG.** Biomaterial-centered infection: microbial adhesion versus tissue integration. Science. 1987; 237: 1588–1595. DOI: 10.1126/science.3629258.
37. **Gristina AG, Costerton JW.** Bacterial adherence to biomaterials and tissue. The significance of its role in clinical sepsis. J Bone Joint Surg Am. 1985; 67:264–273.
38. **Gristina AG, Jennings RA, Naylor PT, Myrvik QN, Webb LX.** Comparative in vitro antibiotic resistance of surface-colonizing coagulase-negative staphylococci. Antimicrob Agents Chemother. 1989; 33: 813–816. DOI: 10.1128/AAC.33.6.813.
39. **Hahn F, Zbinden R, Min K.** Late implant infections caused by Propionibacterium acnes in scoliosis surgery. Eur Spine J. 2005; 14: 783–788. DOI: 10.1007/s00586-004-0854-6.
40. **Hedequist D, Haugen A, Hresko T, Emans J.** Failure of attempted implant retention in spinal deformity delayed surgical site infections. Spine. 2009;34:60–64. DOI: 10.1097/BRS.0b013e31818ed75e.
41. **Ho C, Skaggs DL, Weiss JM, Tolo VT.** Management of infection after instrumented posterior spine fusion in pediatric scoliosis. Spine. 2007;32:2739–2744. DOI: 10.1097/BRS.0b013e31815a5a86.
42. **Ho C, Sucato DJ, Richards BS.** Risk factors for the development of delayed infections following posterior spinal fusion and instrumentation in adolescent idiopathic scoliosis patients. Spine. 2007; 32: 2272–2277. DOI: 10.1097/BRS.0b013e31814b1c0b.
43. **Hoiby N, Bjarnsholt T, Givskov M, Molin S, Ciofu O.** Antibiotic resistance of bacterial biofilms. Int J Antimicrob Agents. 2010; 35: 322–332. DOI: 10.1016/j.ijantimicag.2009.12.011
44. **Horn PL, Ruth B, Kean JR.** Use of wound V.A.C. therapy in pediatric patients with infected spinal wounds: a retrospective review. Orthop Nurs. 2007;26:317–322. DOI: 10.1097/01.NOR.0000295960.94450.69.
45. **Ido K, Shimizu K, Nakayama Y, Shikata J, Matsushita M, Nakamura T.** Suction/irrigation for deep wound infection after spinal instrumentation: a case study. Eur Spine J. 1996;5:345–349. DOI: 10.1007/BF00304351.
46. **Jones GA, Butler J, Lieberman I, Schlenk R.** Negative-pressure wound therapy in the treatment of complex postoperative spinal wound infections: complications and lessons learned using vacuum-assisted closure. J Neurosurg Spine. 2007; 6: 407–411. DOI: 10.3171/spi.2007.6.5.407.
47. **Kanafani ZA, Dakdouki GK, El-Dbouni O, Bawwab T, Kanj SS.** Surgical site infections following spinal surgery at a tertiary care center in Lebanon: incidence, microbiology, and risk factors. Scand J Infect Dis. 2006; 38: 589–592.
48. **Kanayama M, Oha F, Togawa D, Shigenobu K, Hashimoto T.** Is closed-suction drainage necessary for single-level lumbar decompression? Review of 560 cases. Clin Orthop Relat Res. 2010; 468: 2690–2694. DOI: 10.1007/s11999-010-1235-6.
49. **Kowalski TJ, Berbari EF, Huddleston PM, Steckelberg JM, Mandrekar JN, Osmon DR.** The management and outcome of spinal implant infections: contemporary retrospective cohort study. Clin Infect Dis. 2007; 44: 913–920. DOI: 10.1086/512194.
50. **Labbe AC, Demers AM, Rodrigues R, Arlet V, Tanguay K, Moore DL.** Surgical-site infection following spinal fusion: a case-control study in a children's hospital. Infect Control Hosp Epidemiol. 2003; 24:591–595.
51. **Labler L, Keel M, Trentz O, Heinzelmann M.** Wound conditioning by vacuum assisted closure (V.A.C.) in postoperative infections after dorsal spine surgery. Eur Spine J. 2006; 15: 1388–1396. DOI: 10.1007/s00586-006-0164-2.
52. **Levi AD, Dickman CA, Sonntag VK.** Management of postoperative infections after spinal instrumentation. J Neurosurg. 1997; 86: 975–980.
53. **Mackenzie WG, Matsumoto H, Williams BA, Corona J, Lee C, Cody SR, Covington L, Saiman L, Flynn JM, Skaggs DL, Roye DP Jr, Vitale MG.** Surgical site infection following spinal instrumentation for scoliosis: a multicenter analysis of rates, risk factors, and pathogens. J Bone Joint Surg Am. 2013; 95:800–806. DOI: 10.2106/JBJS.L.00010.
54. **Marks MC, Newton PO, Bastrom TP, Betz PP, Sponseller PD, Lonner B, Shah SA, Samdani A, Petcharaporn M, Shufflebarger H, Asghar J.** Harms Study Group. Surgical site infection in adolescent idiopathic scoliosis surgery. Spine Deform. 2013;1:352–358. DOI: 10.1016/j.jspd.2013.07.004.
55. **Mehbod AA, Ogilvie JW, Pinto MR, Schwender JD, Transfeldt EE, Wood KB, Le Huec JC, Dressel T.** Postoperative deep wound infections in adults after spinal fusion: management with vacuum-assisted wound closure. J Spinal Disord Tech. 2005; 18: 14–17. DOI: 10.1097/01.bsd.0000133493.32503.d3.
56. **Milstone AM, Maragakis LL, Townsend T, Speck K, Sponseller P, Song X, Perl TM.** Timing of preoperative antibiotic prophylaxis: a modifiable risk factor for deep surgical site infections after pediatric spinal fusion. Pediatr Infect Dis J. 2008; 27: 704–708. DOI: 10.1097/INF.0b013e31816fca72.
57. **Mirovsky Y, Floman Y, Smorgick Y, Ashkenazi E, Anekstein Y, Millgram MA, Giladi M.** Management of deep wound infection after posterior lumbar interbody fusion with cages. J Spinal Disord Tech. 2007; 20:127–131. http://dx.doi.org/10.4184/jkss.2010.17.4.184.
58. **Mok JM, Guillaume TJ, Talu U, Berven SH, Deviren V, Kroeber M, Bradford DS, Hu SS.** Clinical outcome of deep wound infection after instrumented posterior spinal fusion: A matched cohort analysis. Spine. 2009; 34: 578–583. DOI: 10.1097/BRS.0b013e31819a827c.
59. **Muschik M, Luck W, Schlenzka D.** Implant removal for late-developing infection after instrumented posterior spinal fusion for scoliosis: reinstrumentation reduces loss of correction. A retrospective analysis of 45 cases. Eur Spine J. 2004; 13: 645–651. DOI: 10.1007/s00586-004-0694-4.
60. **O'Toole JE, Eichholz KM, Fessler RG.** Surgical site infection rates after minimally invasive spinal surgery. J Neurosurg Spine. 2009; 11: 471–476. DOI: 10.3171/2009.5.SPINE08633.
61. **Payne DH, Fischgrund JS, Herkowitz HN, Barry RL, Kurz LT, Montgomery DM.** Efficacy of closed wound suction drainage after single-level lumbar laminectomy. J Spinal Disord. 1996; 9: 401–403. DOI: 10.1097/00002517-199610000-00006.
62. **Perry JW, Montgomerie JZ, Swank S, Gilmore DS, Maeder K.** Wound infections following spinal fusion with posterior segmental spinal instrumentation. Clin Infect Dis. 1997;24:558–561.
63. **Picada R, Winter RB, Lonstein JE, Denis F, Pinto MR, Smith MD, Perra JH.** Postoperative deep wound infection in adults after posterior lumbosacral spine fusion with instrumentation: incidence and management. J Spinal Disord. 2000; 13: 42–45. DOI: 10.1097/00002517-200002000-00009.
64. **Potter BK, Kirk KL, Shah SA, Kuklo TR.** Loss of coronal correction following instrumentation removal in adolescent idiopathic scoliosis. Spine. 2006; 31:67–72.
65. **Quinones-Hinojosa A, Jun P, Jacobs R, Rosenberg WS, Weinstein PR.** General principles in the medical and surgical management of spinal infections: a multidisciplinary approach. Neurosurg Focus. 2004; 17: E1.
66. **Rayes M, Colen CB, Bahgat DA, Higashida T, Guthikonda M, Rengachary S, Eltahawy HA.** Safety of instrumentation in patients with spinal infection. J Neurosurg Spine. 2010; 12: 647–659. DOI: 10.3171/2009.12.SPINE09428.
67. **Richards BR, Emara KM.** Delayed infections after posterior TSRH spinal instrumentation for idiopathic scoliosis: revisited. Spine. 2001; 26: 1990–1996.
68. **Richards BS.** Delayed infections following posterior spinal instrumentation for the treatment of idiopathic scoliosis. J Bone Joint Surg Am. 1995; 77: 524–529.
69. **Robertson PA, Taylor TK.** Late presentation of infection as a complication of Dwyer anterior spinal instrumentation. J Spinal Disord. 1993; 6: 256–259. DOI: 10.1097/00002517-199306030-00013.

70. **Rohmiller MT, Akbarnia BA, Raiszadeh K, Raiszadeh K, Canale S.** Closed suction irrigation for the treatment of postoperative wound infections following posterior spinal fusion and instrumentation. Spine. 2010; 35: 642–646. DOI: 10.1097/BRS.0b013e3181b616eb.
71. **Sasso RC, Garrido BJ.** Postoperative spinal wound infections. J Am Acad Orthop Surg. 2008; 16: 330–337.
72. **Sheehan E, McKenna J, Mulhall KJ, Marks P, McCormack D.** Adhesion of Staphylococcus to orthopaedic metals, an in vivo study. J Orthop Res. 2004; 22: 39–43.
73. **Sierra-Hoffman M, Jinadatha C, Carpenter JL, Rahm M.** Postoperative instrumented spine infections: a retrospective review. South Med J. 2010; 103:25–30. DOI: 10.1097/SMJ.0b013e3181c4e00b.
74. **Soultanis KC, Pyrovolou N, Zahos KA, Karaliotas GI, Lenti A, Liveris I, Babis GC, Soucacos PN.** Late postoperative infection following spinal instrumentation: stainless steel versus titanium implants. J Surg Orthop Adv. 2008; 17: 193–199.
75. **Thalgott JS, Cotler HB, Sasso RC, LaRocca H, Gardner V.** Postoperative infections in spinal implants. Classification and analysis – a multicenter study. Spine. 1991; 16: 981–984.
76. **Tibbs PA.** Closed irrigation-suction technic in lumbar laminectomy infections. Neurosurgery. 1980; 6: 120. DOI: 10.1097/00006123-198001000-00020.
77. **Van Rhee MA, de Klerk LW, Verhaar JA.** Vacuum-assisted wound closure of deep infections after instrumented spinal fusion in six children with neuromuscular scoliosis. Spine J. 2007; 7: 596–600. DOI: 10.1016/j.spinee.2006.09.002.
78. **Vender JR, Hester S, Houle PJ, Choudhri HF, Rekito A, McDonnell DE.** The use of closed-suction irrigation systems to manage spinal infections. J Neurosurg Spine. 2005; 3: 276–282. DOI: 10.3171/spi.2005.3.4.0276.
79. **Venturi ML, Attinger CE, Mesbahi AN, Hess CL, Graw K**S. Mechanisms and clinical applications of the vacuum-assisted closure (VAC) Device: a review. Am J Clin Dermatol. 2005; 6: 185–194. DOI: 10.2165/00128071-200506030-00005.
80. **Vicario C, de Juan J, Esclarin A, Alcobendas M.** Treatment of deep wound infections after spinal fusion with a vacuum-assisted device in patients with spinal cord injury. Acta Orthop Belg. 2007; 73: 102–106.
81. **Vitale MG, Reidel MD, Glotzbecker MP, Matsumoto H, Roye DP, Akbarnia BA, Anderson RC, Brockmeyer DL, Emans JB, Erickson M, Flynn JM, Lenke LG, Lewis SJ, Luhmann SJ, McLeod LM, Newton PO, Nyquist AC, Richards BS 3rd, Shah SA, Skaggs DL, Smith JT, Sponseller PD, Sucato DJ, Zeller RD, Saiman L.** Building consensus: development of a Best Practice Guideline (BPG) for surgical site infection (SSI) prevention in high risk pediatric spine surgery. J Pediatr Orthop 2013; 33: 471–478. DOI: 10.1097/BPO.0b013e3182840de2.
82. **Vitaz TW, Oishi M, Welch WC, Gerszten PC, Disa JJ, Bilsky MH.** Rotational and transpositional flaps for the treatment of spinal wound dehiscence and infections in patient populations with degenerative and oncological disease. J Neurosurg. 2004;100(1 Suppl Spine): 46–51.
83. **Webster TJ, Patel AA, Rahaman MN, Sonny Bal B.** Anti-infective and osteointegration properties of silicon nitride, poly(ether ether ketone), and titanium implants. Acta Biomater. 2012; 8: 4447–4454. DOI: 10.1016/j.actbio.2012.07.038.
84. **Weinstein MA, McCabe JP, Cammisa FP Jr.** Postoperative spinal wound infection: a review of 2,391 consecutive index procedures. J Spinal Disord. 2000; 13: 422–426. DOI: 10.1097/00002517-200010000-00009.
85. **Widmer AF.** New developments in diagnosis and treatment of infection in orthopedic implants. Clin Infect Dis. 2001; 33(Suppl 2): S94–106. DOI: 10.1086/321863.
86. **Williams DL, Woodbury KL, Haymond BS, Parker AE, Bloebaum RD.** A modified CDC biofilm reactor to produce mature biofilms on the surface of peek membranes for an in vivo animal model application. Curr Microbiol. 2011; 62: 1657–1663. DOI: 10.1007/s00284-011-9908-2.
87. **Wimmer C, Gluch H.** Management of postoperative wound infection in posterior spinal fusion with instrumentation. J Spinal Disord. 1996; 9: 505–508. DOI: 10.1097/00002517-199612000-00008.
88. **Wimmer C, Gluch H, Franzreb M, Ogon M.** Predisposing factors for infection in spine surgery: a survey of 850 spinal procedures. J Spinal Disord. 1998; 11:124–128. DOI: 10.1097/00002517-199804000-00006.
89. **Yuan-Innes MJ, Temple CL, Lacey MS.** Vacuumassisted wound closure: a new approach to spinal wounds with exposed hardware. Spine. 2001; 26:E30–33.
90. **Zehnder SW, Place HM.** Vacuum-assisted wound closure in postoperative spinal wound infection. Orthopedics. 2007; 30: 267–272.

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