Review Article

AO SPINE

Global Spine Journal
2020, Vol. 10(5) 640-646

DOI: 10.1177/2192568219869330
journals.sagepub.com/home/gsj
SAGE

Implant Retention or Removal for Management of Surgical Site Infection After Spinal Surgery

Aakash Agarwal, PhD[1], Amey Kelkar, MS[1], Ashish G. Agarwal, MBBS[2], Daksh Jayaswal, MS[1], Christian Schultz, MD[1], Arvind Jayaswal, MD[2], Vijay K. Goel, PhD[1], Anand K. Agarwal, MD[1], and Sandeep Gidvani, MD[3]

Abstract

Study Design: A literature review.

Objective: To summarize the implant removal rate, common bacterial organisms found, time of onset, ratio of superficial to deep infection, and regurgitating the prevalence among all the retrospective and prospective studies on management and characterization of surgical site infections (SSIs).

Methods: PubMed was searched for articles published between 2000 and 2018 on the management or characterization of SSIs after spinal surgery. Only prospective and retrospective studies were included.

Results: A total of 49 articles were found relevant to the objective. These studies highlighted the importance of implant removal to avoid recurrence of SSI. The common organisms detected were methicillin-resistant *Staphylococcus aureus*, methicillin-resistant *Staphylococcus epidermis*, *Staphylococcus epidermis*, *Staphylococcus aureus*, and *Propionibacterium acnes*, with prevalence of 1% to 15%. A major proportion of all were deep SSI, with minority reporting on late-onset SSI.

Conclusion: Long-term antibiotics administration, and continuous irrigation and debridement were common suggestion among the authors; however, the key measure undertaken or implied by most authors to avoid risk of recurrence was removal or replacement of implants for late-onset SSI.

Keywords

surgical site infection, biofilm, revision surgery, readmission, implant removal, implant retention, contamination

Introduction

Surgical site infections (SSIs) are extremely burdensome to the patients, a leading cause of morbidity, and a major cause of readmission with longer lengths of stay after spinal surgery.[1] Although meticulous prophylactic surgical practice is crucial to avoid such incidences, there is always some incidence of infection in or around the area that has been instrumented in surgery.[1,2] Many authors have summarized the key prevention and postsurgical management techniques for SSI in spine surgery; however, because of the varied nature of surgical practices and the numerous factors involved, the focus has been on overall preventative and management measures.[2-4] In addition, SSIs in medical care are deemed as "never events" and their occurrence is considered to be influenced by the hospital policies and procedures. Such an outlook toward infection leads many practitioners and hospital system to bundle as many potential measures and/or increase the intensity (dosage in some cases) of individual measures, some to the point of redundancy.[5,6] The result of such practices is no less than controversial as can be exemplified simply by the previously cited ranges in prevalence of SSI.[7] Therefore, it is very useful to consistently

[1] University of Toledo, Toledo, OH, USA
[2] Primus Super Speciality Hospital, New Delhi, India
[3] OrthoNorCal, Inc, Los Gatos, CA, USA

Corresponding Author:
Aakash Agarwal, Department of Bioengineering and Orthopaedics Surgery, University of Toledo, 5051 Nitschke Hall, MS 303, 2801 West Bancroft Street, Toledo, OH 43606, USA.
Email: aakash.agarwal@rockets.utoledo.edu

Table 1. Medline Search Strategy Using PubMed.

http://www.ncbi.nlm.nih.gov/pubmed/advanced
MeSh terms:
1. Surgical Wound Infection/surgery [mh]
[mh] denotes a Medical Subject Heading (MeSH) term ("exploded");
AND (Boolean operator)
Terms for area of interest:
1. Spine [tw]
2. Spinal [tw]
[tw] denotes text word;
NOT (Boolean operator)
Terms for exclusion:
1. Cord [ti]
2. Case Reports [ptyp]
[ti] denotes title;
[ptyp] denotes publication type;
AND (Boolean operator)
Terms for date range:
1. "2000/01/01"[PDat]: "2018/12/31"[PDat]
[PDat] denotes publication date;

evaluate the results of all recently published clinical practice, in an attempt to corroborate or nullify isolated variables into being effective or not. Few such variables during management of SSI are implant removal rate, common bacterial organisms found, time of onset, ratio of superficial to deep infection, and so on. Thus, the objective of this literature review is to summarize the findings on implant removal rate, common bacterial organisms found, time of onset, ratio of superficial to deep infection, and regurgitating the prevalence among all the retrospective and prospective studies on management and/or characterization of SSI.

Methods

The general method utilized for the literature review was adopted from Cochrane collaboration. Table 1 shows the search strategy that was developed for the PubMed database, for the period 2000-2018. Title and abstracts were reviewed to shortlist articles for full length review. The shortlisting was followed by full-text review of all references that appeared to retrospectively or prospectively address the key SSI management techniques at an event of surgical site infection.

Results

A total of 79 full-text articles were retrieved after screening through titles and abstracts. Of these, only 49 articles were found relevant, and were used for the synthesis below.[8-56] Below is the summary of their findings. Relevancy was determined purely based on if the articles answered any one of the following: (1) implant removal rate, (2) common bacterial organisms found following infection, (3) time of onset, and (4) ratio of superficial to deep infection. Furthermore, only prospective or retrospective studies were included.

Implant Removal/Retention Rate

In a study by Maruo et al,[16] 154 of 197 (78%) of SSIs were eradicated within 90 days, of which 76% were also able to retain the implants. Forty-three of 197 (22%), which were not managed within 90 days, were considered failure in management of SSI.[16] However, 93% of these 78% aforementioned were superficial infections.[16] A few studies had close to 0% to 10% implant removal.[17-20] Yin et al[21,22] in their 2010-2014 series were able to retain implant in 40 of 41 cases of late onset SSI. In contrast, many other studies required implant removal on all or majority of cases, for example, 13 of 13, 26 of 26, 20 of 20, 10 of 10 (100%), and so on.[23-27] Di Silvestre et al,[28] in a long-interval SSI detection period (3 years), found the need for 100% removal of implants in all 15 SSI cases among the 540 cases operated upon. Nevertheless, other authors such as Kanayama et al,[29] even at short-interval SSI detection period, observed 8 of 8 (100%) in need of hardware removal. Another study looking at a specific bacterial species reported 31 of 68 (46%) had need for complete removal of implant, and additional 13 of 68 (19%) has partial implant removal.[30] Among few studies with significant yet not majority implant removal proportion, one identified 61 of 84 cases (73%) had implant retention with deep SSI, and 48 of 48 (100%) with superficial SSI.[31] Similarly, other cohorts showed at least 21 of 83 (25%), 26 of 44 (58%), 22 of 42 (52%) needing implant removal.[32-34]

Bacterial Genus/Species

The common type of bacterial infection was methicillin-resistant *Staphylococcus aureus* (MRSA): 10 of 14 (71%), 11 of 18 (61%), 7 of 20 (35%), 5 of 10 (50%); methicillin-resistant *Staphylococcus epidermidis* (MRSE): 9 of 21 (43%); coagulase-negative staphylococci (possibly *Staphylococcus epidermidis*): 12 of 27 (45%), 3 of 9 (33%); *Staphylococcus aureus*: 31 of 51 (61%), 7 of 17 (41%), 6 of 20 (30%), 3 of 10 (30%); polymicrobial: 7 of 17 (41%); methicillin-resistant coagulase-negative staphylococci (MRCNS): 1 of 10 (10%); *Aspergillus fumigatus* (a. fumigatus): 1 of 10 (10%); gram negative, anaerobic such as *Propionibacterium acnes*, antibiotic-resistant strains: 5 of 9 (83%).[17,18,20,23-24,29,35-38]

SSI Onset Time

Studies that specified the onset interval of SSI, early onset (<30 days) constituted 162 of 225 (72%), 7 of 14 (50%), 13 of 20 (65%), 33 of 41 (80.5% skewed proportion; because authors didn't report late onset SSI), 42 of 51 (82% skewed).[16,19,24,37,39] Delayed onset (30 days to 1 year) constituted 57 of 225 (25%), 5 of 14 (35%), 3 of 20 (15%), 8 of 41 (19.5% skewed), and 9 of 51 (17.6 skewed), whereas late onset (>1 year) constituted 6 of 225 (3%), 2 of 14 (15%), and 4 of 20 (20%).[16,19,24,37,39]

Table 2. Prevalence of Surgical Site Infections (SSI) Among Various Studies.

SSI (%)	No. of SSIs	No. of Patients	Start Year	End Year	Country	Type
1.9	16	824	1997	2002	USA	Posterior spinal fusion (n = 7) 360-degree fusion (n = 9)
2.9	22	854	1986	2001	USA	Posterior spinal fusion (n = 22)
4	63	1532	2003	2005	USA	Posterior spinal fusion (n = 36)
9.8	11	112	2003	2011	USA	Posterior spinal fusion of cervical spine (n = 11)
5.8	78	1347	2006	2008	USA	Scoliosis with posterior instrumentation (n = 78)
11.1	42	379	1996	2010	USA	Growth rod surgeries (n = 42)
3.9	5	127	2001	2013	USA	Posterior spinal fusion of cervical spine (n = 5)
3.8	216	5761	2003	2013	USA	Posterior spinal fusion (n = 184)
10.3	44	428	1980	2010	USA	Scoliosis with posterior instrumentation (n = 44)
5.2	29	551	2008	2012	USA	Posterior spinal fusion of cervical spine (n = 29)
1.4	26	1771	1995	2006	USA	Scoliosis with posterior instrumentation (n = 26)
4.2	132	3174	1996	2005	USA	Posterior spinal fusion (n = 105)
1.9	17	854	NA	NA	USA	Posterior spinal fusion (n = 17)
12.7	40	314	2008	2011	USA	Posterior spinal fusion (n = 40)
1.22	45	3673	2007	2009	USA	Posterior spinal fusion (n = 45)
3.4	272	7991	2005	2009	USA	Posterior spinal fusion (n = 272)
12.15	41	334	NA	NA	USA	Scoliosis with posterior instrumentation (n = 41)
3.2	45	1400	2008	2010	USA	Posterior spinal fusion (n = 45)
6.1	53	874	2006	2008	USA	Scoliosis with posterior instrumentation (n = 53)
3.5	176	5023	2005	2009	USA	Posterior spinal fusion (n = 176)
1.5	67	4464	2011	2014	USA	Posterior spinal fusion (n = 67)
5.6	290	5170	2003	2009	USA	Posterior spinal fusion (n = 290)
13	7	54	NA	NA	USA	Posterior spinal fusion (n = 7)
1.9	999	52567	2005	2012	USA	Posterior spinal fusion (n = 999)
4.12	40	971	2012	2013	USA	Posterior spinal fusion (n = 40)
2	16	799	2013	2014	USA	Posterior spinal fusion (n = 16)
0.7	586	83658	2013	2014	USA	Posterior spinal fusion (n = 586)
0.2	39	19706	2008	2009	USA	Posterior spinal fusion (n = 39)
6	6	100	2013	2014	UK	Posterior spinal fusion (n = 6)
1.4	11	786	2004	2006	Taiwan	Posterior spinal fusion (n = 9)
11.6	54	466	2008	2011	Spain	Posterior spinal fusion (n = 54)
0.9	32	3457	2000	2009	Korea	Posterior spinal fusion (n = 3) Posterior lumbar interbody fusion with pedicle screws (n = 29)
0.6	11	1597	1997	2004	Japan	Posterior decompression (n = 3) Posterior spinal fusion (n = 8)
6.3	14	223	2005	2006	Japan	Posterior spinal fusion (n = 11)
4.6	16	345	2005	2011	Japan	Posterior spinal fusion (n = 16)
4.4	18	409	2007	2013	Japan	Posterior spinal fusion (n = 18)
3.15	21	665	2007	2014	Japan	Posterior spinal fusion (n = 21)
2.8	16	564	2010	2011	Japan	Posterior spinal fusion (n = 16)
7.5	3	40	2011	2012	Greece	Posterior spinal fusion (n = 20)
2.04	1	49	2013	2014	France	Posterior spinal fusion (n = 1)
9.70	68	698	2002	2006	France	Scoliosis with posterior instrumentation (n = 58)
10.3	51	496	2007	2012	France	Scoliosis with posterior instrumentation (n = 51)
5.2	14	270	1994	1998	Canada	Posterior spinal fusion (n = 10) 360-degree fusion (n = 4)
2.77	15	540	1993	2005	Brazil	Posterior spinal fusion (n = 15)

Deep Versus Superficial SSI

Another variable that existed was identification of deep versus superficial infection. Some recorded the distribution, whereas others focused on deep SSI (via exclusion of superficial SSI). Deep SSI constituted 2 of 4 (50%), 11 of 22 (50%), 22 of 29 (76%), 10 of 17 (58%), 29 of 54 (53%), 64 of 78 (82%), 53 of 104 (51%), 1409 of 2344 (60%), 12 of 27 (45%), 7 of 9 (77%), 2 of 2 (100%), 84 of 132 (64%), 69 of 79 (87%) among various studies, whereas superficial SSI constituted 2 of 4 (50%), 11 of 22 (50%), 7 of 29 (24%), 7 of 17 (42%), 24 of 54 (47%), 13 of 78 (16.7%), 41 of 104 (39%), 867 of 2344 (37%), 15 of 27 (55%), 2 of 9 (23%), 48 of 132 (36%), 10 of 79 (13%).[25,26,29,31,36,40-45]

SSI Incidence Rate

The SSI incidence rate itself varied and is presented in Table 2.

Discussion

In majority of the studies, patients who presented with SSI had to be readmitted for irrigation and debridement and implant removal/replacement. However, there were also fewer studies where revision surgery for SSI was not necessary in all the patients, for example, 9 of 14 (64%) with mean hospital stay of 43 days.[39] Key steps for management included irrigation and debridement, vacuum-assisted wound closure (VAC) in 25% and more cases, and variable term antibiotics administration (both intravenous and oral).[17-20,24,28,31,36,39,44,46-53]

Many authors concluded that eradication of deep SSIs was not possible without complete removal of spinal implants. In addition, repeated site debridement could not eradicate SSI either while the implants (pedicular and/or interbody constructs) were retained, and therefore removal in most or all patients was later necessary.[23,27] Furthermore, one of this study also disclosed that the average number of surgeries required for infection treatment to be 4 (range 1-16), leading up to an average cost of SSI treatment range from quarter of a million to just shy of a million dollars per patient.[27] A smaller proportion of such recovering patients still presented with residual back pain and reduced activity.[23] To reconcile differences in practices (complete versus partial removal of implants), recently Khanna et al[54] presented a thorough retrospective analysis on implant retention and its association with antibiotic administration and onset interval. They associated delayed onset or late onset SSI patient with higher risk of SSI recurrence in absence of hardware removal. Most of their cases with early or delayed SSI were able to retain implants with early aggressive debridement.[54] When comparing the type of SSI (deep vs superficial, and late vs delayed vs early onset SSI) among these studies, eradicating deep SSI with delayed and late onset infections were most difficult, with majority needing repeated debridement and drainage.[16,29] A common problem was that of late onset SSI with low virulent p. acnes. Being low virulent bacteria, it remained undetected in the early intervals leading to widespread biofilm formation on the implants, later leading to a resilient onset of SSI.[30] For instance, because of repeated detection of *P acnes*, 8 of 68 (11.7%) patients underwent multiple revision surgeries in one series.[31] An exception to this trend was the study by Yin et al,[21] where they retained implants in most cases with late-onset SSI (*S aureus* was the common organism). It should be noted that they also noticed negative culture results in seven patients with late onset SSI (hence the underlying risk of undetected growth of organism) and one with hardware loosening due to recurrence of infection.[21]

Most common organism detected were MRSA, MRSE, *S epidermis*, *S aureus*, and *P acnes*; nonetheless there were also others like polymicrobial and gram negative cited in the studies.[17,18,20,23,24,29,35-38] Authors noted that gram negative infection was common in early infections, whereas later ones presented with *S aureus*, *P acnes*, and so on.[39] In many studies, the interval of infection onset was limited to early, that is, <30 days, <90 days, between 30 and 90 days, or <6 months for detection of SSI, or was not mentioned.[24,27,55,56] In few, the authors specifically looked at late onset infection with average occurrence about 70 months with 15 of 540 index cases (2.77%).[28] Longer term studies, extending over 6 years also concluded 56 to 80 months as average SSI detection length with total incidence of 68 *P acnes* cases of 698 index cases (9.7%).[30] There were higher proportion of deep SSI over superficial SSI in most studies. Higher incidence of failure in management of SSI (recurrence) were seen with iliac fixation, polymicrobial infections, *P acnes* infections (of which many often were delayed or late onset), and >6-level fixation.[16]

As shown in Table 2, the SSI incidence rate could be argued to be a result of varied spinal surgical practices and reporting methods, including differences in prophylactic measures, quality of hospital facilities, duration of follow-up, and the country of practice at the minimum.[7,57-61]

Besides physical examination, common diagnostic tools used to detect infection are imaging (computed tomography and magnetic resonance imaging), blood culture, C-reactive protein, erythrocyte sedimentation rate, white blood cell count, and other inflammatory biomarkers. Many of these methods provide high positive predictive value but relatively lower negative predictive value. Lower negative predictive value implies that there still exist possibilities of hidden contamination, which presents itself as full-blown infection at a later interval, as delayed or late onset SSI. Furthermore, unlike superficial infection (localized to the skin and subcutaneous tissue), most deep infections lack superficial presentations making their diagnosis solely presumptive. Thus, a more cautious pathway in management of late-onset SSI may be complete removal or replacement of implants in such cases. Some authors of these studies concluded that attempts made to retain implants only lead to multiple reoperations, higher costs, and patient burden.[27] Recent studies on identification of occult infection led hardware loosening, and propensity of bacterial infestation and growth on implant surfaces outside and inside the theatre provides further evidences of levels of higher uncertainty (of subsequent infection) involved in the management of SSI and its preventive measures.[62-68]

Conclusion

Based on the data presented in myriads of prospective and retrospective studies, it is perhaps prudent to replace or remove the existing implants for management of late onset deep SSI. Additionally, although a wide range of SSI incidence rates have been observed, there exists uniformity in the type of bacterial organisms being reported.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article. AA reports royalties from Paradigm Spine, Joimax, consultancy from Spinal Balance, editorial board membership from *Clinical Spine Surgery* and *Spine*, outside the submitted work. AKA and VKG reports royalties from Paradigm Spine, Joimax, investment/options from Osteonovus and Spinal Balance, outside the submitted work.

SG reports consultancy for Spinal Balance and Si Bone, resident and fellow education committee, CME committee, website and digital platform committee, Chair for NASS, and international committee member for AAOS, outside the submitted work. Rest of the authors have nothing to disclose.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iD

Aakash Agarwal, PhD https://orcid.org/0000-0002-6183-3765

References

1. Anderson PA, Savage JW, Vaccaro AR, et al. Prevention of surgical site infection in spine surgery. *Neurosurgery*. 2017;80(3 suppl):S114-S123.
2. Meredith DS, Kepler CK, Huang RC, Brause BD, Boachie-Adjei O. Postoperative infections of the lumbar spine: presentation and management. *Int Orthop*. 2012;36:439-444.
3. Lazennec JY, Fourniols E, Lenoir T, et al Infections in the operated spine: update on risk management and therapeutic strategies. *Orthop Traumatol Surg Res*. 2011;97(6 suppl):S107-S116.
4. Vitale MG, Riedel MD, Glotzbecker MP, et al. 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.
5. Featherall J, Miller JA, Bennett EE, et al. Implementation of an infection prevention bundle to reduce surgical site infections and cost following spine surgery. *JAMA Surg*. 2016;151:988-990.
6. Van Hal M, Lee J, Laudermilch D, Nwasike C, Kang J. Vancomycin powder regimen for prevention of surgical site infection in complex spine surgeries. *Clin Spine Surg*. 2017;30:E1062-E1065.
7. McClelland S, Takemoto RC, Lonner BS, et al. Analysis of postoperative thoracolumbar spine infections in a prospective randomized controlled trial using the centers for disease control surgical site infection criteria. *Int J Spine Surg*. 2016;10:14.
8. Chikawa T, Sakai T, Bhatia NN, et al. Retrospective study of deep surgical site infections following spinal surgery and the effectiveness of continuous irrigation. *Br J Neurosurg*. 2011;25:621-624.
9. Rathjen K, Wood M, McClung A, Vest Z. Clinical and radiographic results after implant removal in idiopathic scoliosis. *Spine (Phila Pa 1976)*. 2007;32:2184-2188.
10. Gelalis ID, Arnaoutoglou CM, Politis AN, Batzaleksis NA, Katonis PG, Xenakis TA. Bacterial wound contamination during simple and complex spinal procedures. A prospective clinical study. *Spine J*. 2011;11:1042-1048.
11. Ahn DK, Park HS, Choi DJ, et al. The difference of surgical site infection according to the methods of lumbar fusion surgery. *Clin Spine Surg*. 2012;25:E230-E234.
12. Ishii M, Iwasaki M, Ohwada T, et al. Postoperative deep surgical-site infection after instrumented spinal surgery: a multicenter study. *Global Spine J*. 2013;3:95-102.
13. Lee MJ, Cizik AM, Hamilton D, Chapman JR. Predicting surgical site infection after spine surgery: a validated model using a prospective surgical registry. *Spine J*. 2014;14:2112-2127.
14. Mazur MD, Sivakumar W, Riva-Cambrin J, Jones J, Brockmeyer DL. Avoiding early complications and reoperation during occipitocervical fusion in pediatric patients. *J Neurosurg Pediatr*. 2014;14:465-475.
15. Nota SP, Braun Y, Ring D, Schwab JH. Incidence of surgical site infection after spine surgery: what is the impact of the definition of infection? *Clin Orthop Relat Res*. 2015;473:1612-1619.
16. Maruo K, Berven SH. Outcome and treatment of postoperative spine surgical site infections: predictors of treatment success and failure. *J Orthop Sci*. 2014;19:398-404.
17. Takizawa T, Tsutsumimoto T, Yui M, Misawa H. Surgical site infections caused by methicillin-resistant *Staphylococcus* epidermidis after spinal instrumentation surgery. *Spine (Phila Pa 1976)*. 2017;42:525-530.
18. Miyazaki S, Kakutani K, Maeno K, et al. Surgical debridement with retention of spinal instrumentation and long-term antimicrobial therapy for multidrug-resistant surgical site infections after spinal surgery: a case series. *Int Orthop*. 2016;40:1171-1177.
19. Fang XT, Wood KB. Management of postoperative instrumented spinal wound infection. *Chin Med J (Engl)*. 2013;126:3817-3821.
20. 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.
21. Yin D, Liu B, Chang Y, Gu H, Zheng X. Management of late-onset deep surgical site infection after instrumented spinal surgery. *BMC Surg*. 2018;18:121.
22. Cáceres AG, Jiménez JL, Martín ÁR, Durán JM, Diaz BS, de Quevedo Puerta DG. Prognosis of deep infection in spinal surgery using implants, treated by retention, removal of bone graft and lengthy antibiotherapy. *Rev Esp Cir Ortop Traumatol*. 2019;63:7-11.
23. Ha KY, Kim YH. Postoperative spondylitis after posterior lumbar interbody fusion using cages. *Eur Spine J*. 2004;13:419-424.
24. Kim JI, Suh KT, Kim SJ, Lee JS. Implant removal for the management of infection after instrumented spinal fusion. *J Spinal Disord Tech*. 2010;23:258-265.
25. Croft LD, Pottinger JM, Chiang HY, Ziebold CS, Weinstein SL, Herwaldt LA. Risk factors for surgical site infections after pediatric spine operations. *Spine (Phila Pa 1976)*. 2015;40:E112-E119.
26. Kuhns BD, Lubelski D, Alvin MD, et al. Cost and quality of life outcome analysis of postoperative infections after subaxial dorsal cervical fusions. *J Neurosurg Spine*. 2015;22:381-386.
27. 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;34:60-64.
28. Di Silvestre M, Bakaloudis G, Lolli F, Giacomini S. Late-developing infection following posterior fusion for adolescent idiopathic scoliosis. *Eur Spine J*. 2011;20(suppl 1):S121-S127.
29. Kanayama M, Hashimoto T, Shigenobu K, Oha F, Togawa D. Effective prevention of surgical site infection using a Centers for Disease Control and Prevention guideline-based antimicrobial prophylaxis in lumbar spine surgery. *J Neurosurg Spine*. 2007;6:327-329.

30. Bémer P, Corvec S, Tariel S, et al. Significance of Propionibacterium acnes-positive samples in spinal instrumentation. *Spine (Phila Pa 1976)*. 2008;33:E971-E976.
31. ter Gunne AF, Mohamed AS, Skolasky RL, van Laarhoven CJ, Cohen DB. The presentation, incidence, etiology, and treatment of surgical site infections after spinal surgery. *Spine (Phila Pa 1976)*. 2010;35:1323-1328.
32. Tempel Z, Grandhi R, Maserati M, et al. Prealbumin as a serum biomarker of impaired perioperative nutritional status and risk for surgical site infection after spine surgery. *J Neurol Surg A Cent Eur Neurosurg*. 2015;76:139-143.
33. Ramo BA, Roberts DW, Tuason D, et al. Surgical site infections after posterior spinal fusion for neuromuscular scoliosis: a thirty-year experience at a single institution. *J Bone Joint Surg Am*. 2014;96:2038-2048.
34. Kabirian N, Akbarnia BA, Pawelek JB, et al. Deep surgical site infection following 2344 growing-rod procedures for early-onset scoliosis: risk factors and clinical consequences. *J Bone Joint Surg Am*. 2014;96:e128.
35. Watanabe M, Sakai D, Matsuyama D, Yamamoto Y, Sato M, Mochida J. Risk factors for surgical site infection following spine surgery: efficacy of intraoperative saline irrigation. *J Neurosurg Spine*. 2010;12:540-546.
36. 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.
37. Maesani M, Doit C, Lorrot M, et al. Surgical site infections in pediatric spine surgery: comparative microbiology of patients with idiopathic and nonidiopathic etiologies of spine deformity. *Pediatr Infect Dis J*. 2016;35:66-70.
38. Núnez-Pereira S, Pellisé F, Rodríguez-Pardo D, et al. Individualized antibiotic prophylaxis reduces surgical site infections by gram-negative bacteria in instrumented spinal surgery. *Eur Spine J*. 2011;20(suppl 3):397.
39. 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.
40. Boetto J, Chan-Seng E, Lonjon G, Pech J, Lotthé A, Lonjon N. Is hospital information system relevant to detect surgical site infection? Findings from a prospective surveillance study in posterior instrumented spinal surgery. *Orthop Traumatol Surg Res*. 2015;101:845-849.
41. Smith JS, Shaffrey CI, Sansur CA, et al. Rates of infection after spine surgery based on 108 419 procedures: a report from the Scoliosis Research Society Morbidity and Mortality Committee. *Spine (Phila Pa 1976)*. 2011;36:556-563.
42. Maragakis LL, Cosgrove SE, Martinez EA, Tucker MG, Cohen DB, Perl TM. Intraoperative fraction of inspired oxygen is a modifiable risk factor for surgical site infection after spinal surgery. *Anesthesiology*. 2009;110:556-562.
43. Satake K, Kanemura T, Matsumoto A, Yamaguchi H, Ishikawa Y. Predisposing factors for surgical site infection of spinal instrumentation surgery for diabetes patients. *Eur Spine J*. 2013;22:1854-1858.
44. Mackenzie WS, Matsumoto H, Williams BA, et al. 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,S1-S2.
45. Núñez-Pereira S, Rodríguez-Pardo D, Pellisé F, et al. Postoperative urinary tract infection and surgical site infection in instrumented spinal surgery: is there a link? *Clin Microbiol Infect*. 2014;20:768-773.
46. Manet R, Ferry T, Castelain JE, et al. Relevance of modified debridement-irrigation, antibiotic therapy and implant retention protocol for the management of surgical site infections: a series of 1694 instrumented spinal surgery. *J Bone Jt Infect*. 2018;3:266-272.
47. Ploumis A, Mehbod AA, Dressel TD, Dykes DC, Transfeldt EE, Lonstein JE. Therapy of spinal wound infections using vacuum-assisted wound closure: risk factors leading to resistance to treatment. *J Spinal Disord Tech*. 2008;21:320-323.
48. Hong HS, Chang MC, Liu CL, Chen TH. Is aggressive surgery necessary for acute postoperative deep spinal wound infection? *Spine (Phila Pa 1976)*. 2008;33:2473-2478.
49. 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. *J Neurosurg Spine*. 2011;15:399-403.
50. Mok JM, Guillaume TJ, Talu U, et al. Clinical outcome of deep wound infection after instrumented posterior spinal fusion: a matched cohort analysis. *Spine (Phila Pa 1976)*. 2009;34:578-583.
51. Caroom C, Tullar JM, Benton EG Jr, Jones JR, Chaput CD. Intrawound vancomycin powder reduces surgical site infections in posterior cervical fusion. *Spine (Phila Pa 1976)*. 2013;38:1183-1187.
52. Hikata T, Iwanami A, Hosogane N, et al. High preoperative hemoglobin A1c is a risk factor for surgical site infection after posterior thoracic and lumbar spinal instrumentation surgery. *J Orthop Sci*. 2014;19:223-228.
53. Ando M, Tamaki T, Yoshida M, et al. Surgical site infection in spinal surgery: a comparative study between 2-octyl-cyanoacrylate and staples for wound closure. *Eur Spine J*. 2014;23:854-862.
54. Khanna K, Janghala A, Sing D, et al. An analysis of implant retention and antibiotic suppression in instrumented spine infections: a preliminary data set of 67 patients. *Int J Spine Surg*. 2018;12:490-497.
55. Whitmore RG, Stephen J, Stein SC, et al. Patient comorbidities and complications after spinal surgery: a societal-based cost analysis. *Spine (Phila Pa 1976)*. 2012;37:1065-1071.
56. Cizik AM, Lee MJ, Martin BI, et al. Using the spine surgical invasiveness index to identify risk of surgical site infection: a multivariate analysis. *J Bone Joint Surg Am*. 2012;94:335-342.
57. Dalstrom DJ, Venkatarayappa I, Manternach AL, Palcic MS, Heyse BA, Prayson MJ. Time-dependent contamination of opened sterile operating-room trays. *J Bone Joint Surg Am*. 2008;90:1022-1025.

58. Agarwal A, MacMillan A, Goel V, Agarwal AK, Karas C. A paradigm shift toward terminally sterilized devices. *Clin Spine Surg*. 2018;31:308-311.
59. Agarwal A, Schultz C, Goel VK, et al. Implant prophylaxis: the next best practice toward asepsis in spine surgery. *Global Spine J*. 2018;8:761-765.
60. Rehman A, Rehman AU, Rehman TU, Freeman C. Removing outer gloves as a method to reduce spinal surgery infection. *J Spinal Disord Tech*. 2015;28:E343-E346.
61. Radcliff KE, Rasouli MR, Neusner A, et al. Preoperative delay of more than 1 hour increases the risk of surgical site infection. *Spine (Phila Pa 1976)*. 2013;38:1318-1323.
62. 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.
63. Agarwal A, Lin B, Wang JC, et al. Efficacy of intraoperative implant prophylaxis in reducing intraoperative microbial contamination. *Global Spine J*. 2019;9:62-66.
64. Agarwal A, Schultz C, Agarwal AK, Wang JC, Garfin SR, Anand N. Harboring contaminants in repeatedly reprocessed pedicle screws. *Global Spine J*. 2019;9:173-178.
65. Leitner L, Malaj I, Sadoghi P, et al. Pedicle screw loosening is correlated to chronic subclinical deep implant infection: a retrospective database analysis. *Eur Spine J*. 2018;27:2529-2535.
66. Eren B, Güzey FK, Kitiş S, Özkan N, Korkut C. The effectiveness of pedicle screw immersion in vancomycin and ceftriaxone solution for the prevention of postoperative spinal infection: a prospective comparative study. *Acta Orthop Traumatol Turc*. 2018;52:289-293.
67. Agarwal A, Lin B, Elgafy H, et al. Updates on evidence-based practices to reduce preoperative and intraoperative contamination of implants in spine surgery: a narrative review [published online June 21, 2019]. *Spine Surg Relat Res*. doi:10.22603/ssrr.2019-0038
68. 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 [published online May 28, 2019]. *J Neurosurg Spine*. doi:10.3171/2019.1.SPINE18102