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ORIGINAL ARTICLE

Risk factors for implant removal after spinal surgical site infection

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Abstract
Purpose Few studies have investigated the risk factors for implant removal after treatment for spinal surgical site infection (SSI). Therefore, there is no firmly established consensus for the management of implants. We aimed to investigate the incidence and risk factors for implant removal after SSI managed with instrumentation, and to examine potential strategies for avoiding implant removal.
Methods Following a survey of seven spine centers, we retrospectively reviewed the records of 55 patients who developed SSI and were treated with reoperation, out of 3967 patients who had spinal instrumentation between 2003 and 2012. We examined implant survival rate and applied logistic regression analysis to assess the potential risk factors for implant removal.
Results The overall rate of implant retention was 60% (33/55). A higher implant retention rate was observed for posterior cervical surgery than for posterior-thoracic/lumbar surgery (100 vs. 49%, $P < 0.001$). On univariate analysis, significant risk factors for implant removal included greater blood loss, delay of reoperation, and delay of intervention with effective antibiotics. Multivariate analysis revealed that a delay in administering effective antibiotics was an independent and significant risk factor for implant removal in posterior-thoracic/lumbar surgery (odds ratio 1.17; 95% confidence interval 1.02–1.35, $P = 0.028$).
Conclusions Patients with SSI who underwent posterior cervical surgery are likely to retain the implants. Immediate administration of effective antibiotics improves implant survival in SSI treatment. Our findings can be applied to identify SSI patients at higher risk for implant removal.

Keywords Spinal instrumentation · Surgical site infection · Posterior thoracic surgery · Posterior cervical surgery · Implant removal

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Introduction

Surgical site infection (SSI) after spinal surgery with instrumentation is an undesired and troublesome complication. In particular, there is a lack of consensus regarding implant management, and the issue remains controversial. Some surgeons recommend removing the implant if the infection is uncontrolled, because the presence of a foreign material could preclude eradication of the infection, whereas other surgeons advocate serial wound debridement with retention of a stable implant [1–5].

To date, few large-scale studies have focused on evaluating implant survival and determining the risk factors for implant removal in the treatment of spinal SSI. Implant salvage was previously evaluated in two large-scale studies, which included 51 patients with posterolateral thoracolumbar spinal fusion [6] and 43 patients who had undergone posterior spinal fusion with instrumentation [7]. Such studies indicated late infection, delayed treatment, systemic sepsis, and number of fused segments as risk factors associated with implant removal, but these previous conclusions had limited statistical power because of the relatively small number of patients with implant removal (10 and 9 patients, respectively), the single-center design, and limited coverage of anatomical sites (e.g., no patients with cervical surgery were included). Other potential risk factors, such as those related to different surgical sites or postoperative treatment strategies, have not been explored to date.

Therefore, in the present study, we investigated the risk factors for implant removal after spinal SSI in a relatively large sample including various patient populations, indications for surgery, types of surgical procedures, and surgical sites. We aimed to achieve a better understanding of implant-related risk factors to facilitate development of optimal SSI treatment strategies for improving patient outcomes.

Materials and methods

We performed a retrospective multi-center survey in seven hospitals affiliated with Kyoto University Hospital. The study was conducted with the approval of the Institutional Ethics Committee of each participating hospital. Using the surgical databases and medical records maintained by the participating hospitals, we identified all patients who had undergone various types of spinal surgeries between April 2003 and March 2012. Consequently, 6685 patients (3967 with spinal instrumentation and 2718 without instrumentation surgery) were enrolled in the current study. Among the 3967 patients with spinal instrumentation, we identified all patients who developed SSI, excluding those with an infection that was managed successfully with nonsurgical treatment and those followed-up for less than 1 year. Finally, we performed a detailed evaluation of the records of 55 patients (1.4%) with SSI managed via reoperation.

We collected information regarding preoperative, intraoperative, and postoperative parameters for each of the 55 patients, and calculated the rate of implant retention in consideration of these parameters. In addition, we analyzed the contribution of these parameters as potential risk factors for implant removal during surgical treatment of SSI eradication.

Definitions

The primary outcome was implant removal on reoperation to eradicate SSI. Our definition of SSI was based on the Centers for Disease Control and Prevention criteria; that is, a condition with an abscess or other evidence of infection in the soft tissues [8]. "Reoperation" was defined as surgery performed at the same anatomic location as the initial surgery, aimed at eradicating SSI. "Implants" included any interbody devices, posterior spinal rods, cross connecters, screws, and anterior plates. "Implant removal" was defined as partial or complete removal of implants (including re-instrumentation) during reoperation for SSI eradication, and did not refer to removal required because of pull out (even if infection-related). "Time to SSI" was defined as the time from initial surgery to SSI diagnosis, which was ultimately at the discretion of the attending surgeon; this information was determined based on the medical records. "Time from SSI to reoperation" was defined as the time from SSI diagnosis to reoperation for SSI eradication; only the time until the first reoperation was considered in patients who required further procedures. "Time from SSI to effective antibiotics" was defined as the time from SSI diagnosis to the administration of antibiotics with sensitivity against SSI pathogens. For negative cultures, effective antibiotics were defined as broad-spectrum antibiotics such as aminoglycosides or carbapenems. Surgical sites were classified according to approach (anterior or posterior) and spine region (cervical or thoracic/lumbar). Patients who underwent surgery via both the anterior and posterior approach were categorized according to the approach used to eradicate SSI. The isolated culture results were classified according to the presence of methicillin-resistant *Staphylococcus* (MRS) as follows: MRS infection for cultures that included at least one methicillin-resistant organism, and non-MRS infection for cultures that included all organisms except MRS. Polymicrobial infection, characterized by cultures that grew at least one type of MRS, was considered MRS infection. "Cure" from infection was defined as achieving both a dry healed wound and normalized levels of inflammatory markers such as C-reactive protein at the 1-year follow-up.

Statistical analysis

We used Fisher's exact test to compare categorical variables and the Mann–Whitney *U* test to compare continuous variables. Continuous variables were expressed as mean ± standard deviation, median (interquartile range), or average (range), while categorical variables were expressed as number of observations. Univariate analysis was performed to identify the factors associated with an increased risk of implant removal. Multiple logistic

regression analysis using the forced-entry method was performed to identify independent risk factors for implant removal. The model included all variables showing a significant univariate association ($P < 0.05$) with implant removal. The results of the regression analyses were expressed as odds ratios (ORs) with 95% confidence intervals (CIs). The threshold for significance was $P < 0.05$. We used SPSS version 22.0 for Windows (IBM Japan, Ltd., Tokyo, Japan) for all analyses.

Results

Demographics of patients

We identified 55 patients with SSI that underwent at least one reoperation aimed at eradicating SSI. Of these, 39 patients had posterior-thoracic/lumbar (PTL) surgery, 14 had posterior cervical (PC) surgery, and two had anterior cervical (AC) surgery. No patients with SSI received anterior thoracic or anterior lumbar surgery. Table 1 shows the demographics of all 55 patients, as well as those of the PTL and PC groups. Only two variables (time to SSI and time from SSI to reoperation) were significantly different between the PTL and PC groups, being greater in patients with PTL. There were no statistically significant differences in other parameters between the PTL and PC groups.

The pathology at the initial surgery included: degenerative etiology (36 cases), trauma (2 cases), and other (1 case) in the PTL group; atlantoaxial disorder (6 cases), trauma (3 cases), metastatic tumor (2 cases), rheumatoid disorder (2 cases), and degenerative etiology (1 case) in the PC group; and degenerative etiology (2 cases) in the AC group. The initial surgical procedure included: transforaminal/posterior interbody fusion (23 cases), posterior lateral fusion (12 cases), anterior spinal fusion with posterior lateral fusion (2 cases), vertebroplasty with posterior lateral fusion (1 case), and pedicle subtraction osteotomy (1 case) in the PTL group; posterior cervical fusion (9 cases) and occipito-cervical fusion (5 cases) in the PC group.

Treatment outcome and procedures of patients with SSI

At first reoperation for SSI eradication, the implant was retained in 48 of 55 patients, and removed in the remaining 7 patients. Cure from infection was noted in 30 of 48 patients with implant retention and in 6 of 7 patients with implant removal at first reoperation. However, 18 of 48 patients with implant retention were not cured and required a second reoperation. Of these 18 patients, only 3 were cured with implant retention, while the remaining 15 underwent implant removal, which resulted in cure from infection in 13 patients; one patient required a third reoperation and another patient died as an indirect result of persistent infection after the second reoperation. One of the seven patients with implant removal at the first reoperation also died as an indirect result of infection (Fig. 1).

First reoperation included irrigation and debridement only (I and D) (40 patients), combined antibiotic-impregnated cement (CE) (14 patients), or combined irrigation–suction systems (CISS) (1 patient). Of the 48 patients with implant retention at the first reoperation, 30 patients were cured from infection (22 with I and D, 7 with CE, and 1 with CISS), while 18 patients (13 with I and D and 5 with CE) were not cured and required a second reoperation (Fig. 1). All patients were cured from infection at 1 year after the index surgery, except for the two patients who had died during follow-up. The main causes of implant removal were implant loosening (9 patients) or persistence of infection (13 patients).

Rate of implant retention

The overall rate of implant retention was 60% (33/55). The implant retention rates according to pre-, intra-, and postoperative parameters are described in Table 2. Implant retention rates differed significantly with the time to SSI (i.e., within or beyond the first 90 days after index surgery; 64.7 vs. 0%, respectively; $P = 0.021$), time from SSI to reoperation (fewer or more than 5 days; 73.5 vs. 42.1%, respectively; $P = 0.010$), time from SSI to effective antibiotics (fewer or more than 5 days; 81.3 vs. 31.8%, respectively; $P < 0.001$), and surgical site (100% or 14/14 for PC surgery, 49% or 19/39 for PTL surgery, and 0% or 0/2 in AC surgery; $P < 0.001$). Implant retention rate did not differ significantly with parameters such as initial surgical procedure or first reoperation procedure.

Risk factors for implant removal

On univariate analysis, implant removal was significantly associated with higher estimated blood loss (OR 1.003; 95% CI 1.001–1.005; $P = 0.005$), time from SSI to effective antibiotics (OR 1.175; 95% CI 1.054–1.304; $P = 0.002$), and time from SSI to reoperation (OR 1.091; 95% CI 1.008–1.180; $P = 0.003$). On multivariate analysis, only one factor—estimated blood loss—was found to be significantly associated with implant removal (OR 1.002; 95% CI 1.000–1.004; $P = 0.037$) in the entire sample of patients with surgically managed SSI (Table 3).

On univariate analysis involving only the 39 patients with PTL surgery, implant removal was significantly associated with higher estimated blood loss (OR 1.002; 95% CI 1.000–1.004; $P = 0.029$) and time from SSI to effective antibiotics (OR 1.208; 95% CI 1.047–1.393;

Table 1 Characteristics of 55 patients with surgical site infection (SSI)

Characteristic	All patients ($n = 55$)	PTL group ($n = 39$)	PC group ($n = 14$)	P value
Preoperative data				
Male:female, *n*	37:18	26:13	10:4	1.000
Age, years, median [IQR] (mean, range)	72 [60–77] (66, 8–87)	73 [64–78] (67, 8–85)	60 [56–74] (60, 19–87)	0.072
BMI, kg/m^2, mean ± SD	23.0 ± 4.0	23.5 ± 4.1	23.5 ± 3.2	0.402
Previous spine surgery				
Yes:no, *n* (%)	9:46 (16%)	5:34 (13%)	3:11 (21%)	0.353
Pathology of initial surgery				
Degenerative, *n*	46	36	9	
Trauma, *n*	5	2	3	
Tumors, *n*	2	0	2	
Others, *n*	2	1	0	
Intraoperative data				
Estimated blood loss, ml, median [IQR], (mean, range)	290 [141–574] (418, 30–1440)	326 [174–765] (495, 30–1440)	203 [134–304] (228, 43–535)	0.065
Allogeneic transfusion				
Yes:no, *n* (%)	16:36 (31%)	14:24 (37%)	2:11 (15%)	0.136
Operative time, min, median [IQR], (mean, range)	210 [152–275] (231, 81–526)	204 [130–269] (221, 81–512)	210 [184–257] (247, 142–526)	0.522
Fused segments, n, median [IQR], (mean, range)	3.0 [2.0–5.0] (3.5, 1–10)	3.0 [1.5–4.0] (3.1, 1–8)	3.5 [2.0–5.0] (3.8, 1–10)	0.499
Postoperative data				
Time to SSI, days,				0.025
Median [IQR], (mean, range)	16 [11.0–26.5] (35, 3–350)	17 [13.0–28.0] (42, 6–350)	11 [7.5–14.5] (16, 3–56)	
Time from SSI to reoperation, days, median [IQR], (mean, range)	3.0 [1.0–7.5] (9, 0–175)	4.0 [1.0–11.0] (11, 0–175)	1.0 [0.3–3.0] (3.8, 0–19)	0.103
Time from SSI to effective antibiotics, days, median [IQR], (mean, range)	3.0 [1.0–7.0] (7, 0–66)	4.0 [1.0–12.0] (8.6, 0–66)	1.0 [0.0–3.8] (3.1, 0–19)	0.032
Isolated culture				0.111
MRS:non-MRS, *n* (%)	25:24 (51%)	19:14 (58%)	4:10 (29%)	
Total number of times reoperation				
Single:multiple, *n*	37:18	25:14	12:2	0.183
First reoperation procedure				
Debridement:antibiotic cement, *n*	35:12	22:9	11:3	0.442

P values were computed for the comparison between the PTL and PC groups, and were obtained using Fisher's exact test or the Mann–Whitney *U* test

PTL posterior thoracic/lumbar surgery, *PC* posterior cervical surgery, *BMI* body mass index, *IQR* interquartile range, *SD* standard deviation, *MRS* methicillin-resistant *Staphylococcus*

$P = 0.009$). On multivariate analysis, only time from SSI to effective antibiotics (OR 1.172; 95% CI 1.017–1.350; $P = 0.028$) remained an independent risk factor for implant removal in patients with PTL (Table 4).

Discussion

We found that implant retention rates until SSI eradication were 100% (14/14) for PC surgery and 49% (19/39) for PTL surgery. In addition, we determined delays in treatment (reoperation or administration of effective antibiotics) and increased blood loss as new potential risk factors for implant removal.

Implant retention rates

Previous large-scale studies have reported various rates of implant retention: 49% in 61 cases of pediatric deformity [2], 77% in 43 deep infections [7], and 81% in 53 cases of pediatric scoliosis [9]. We found an overall implant retention rate of 60% in 55 cases of SSI, which is consistent

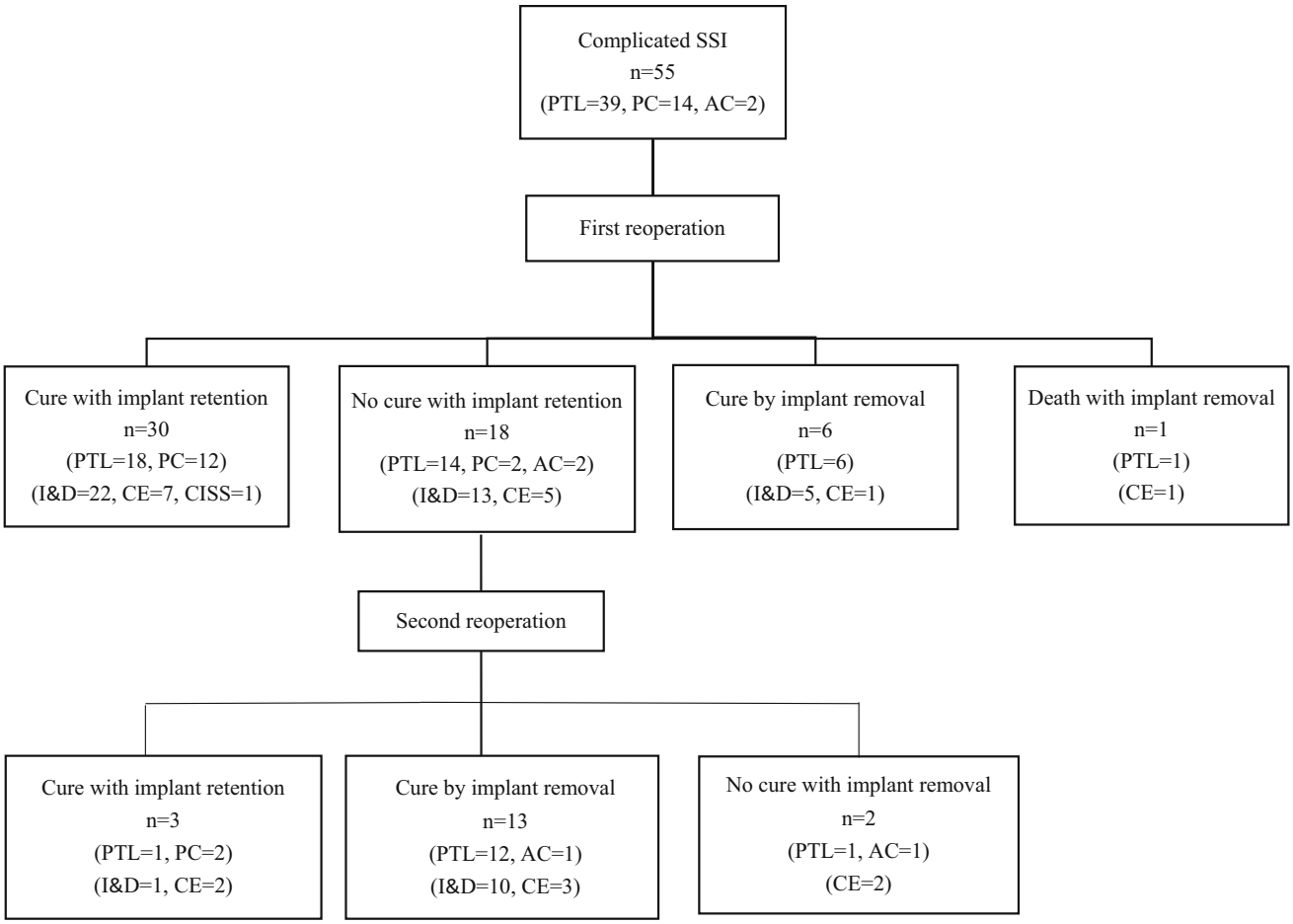

Fig. 1 Flowchart of treatment outcomes and procedures in 55 patients with surgical site infection (SSI). *PTL* posterior thoracic/lumbar, *PC* posterior cervical, *AC* anterior cervical, *I* and *D* irrigation and debridement, *CE* antibiotic-impregnated cement, *CISS* combined irrigation–suction systems

with these earlier observations. However, direct comparisons are difficult, because implant retention rates likely vary with patient population, ethnicity, depth of invasion (superficial vs. deep infection), time of occurrence (acute vs. late infection), SSI management strategy, and surgical site.

The association between different surgical sites and implant retention rates has been unclear and few studies have described implant survival in posterior cervical surgery. Ishii et al. reported implant retention rates of 100% (4/4) among patients with cervical surgery, compared to 40% (6/15) in patients with degenerative thoracolumbar disease, although the difference did not reach statistical significance [10]. A similar result was obtained in our study. Specifically, we found significantly higher rates of implant retention for PC surgery than for PTL surgery, correlating with significantly longer time to SSI and time from SSI to effective antibiotics in the PTL group, which suggests that PC surgery may allow for earlier diagnosis of infection and administration of effective antibiotics. This finding might be related to the fact that the subcutaneous tissue of the posterior neck is relatively thinner, causing the wound and infection-related manifestations (swelling, redness, discharge, and dehiscence) to be exposed relatively sooner, which allowed for earlier and more facile detection of SSI in patients with PC surgery than in those with PTL surgery. Moreover, almost half of patients with PTL surgery had loosening of the pedicle screw and, therefore, required implant removal at reoperation, whereas screw loosening was not observed in patients with PC surgery. We speculate that the absence of screw loosening is the main reason why our surgeons could retain the implant in PC surgery. Finally, SSI eradication required more reoperations in PTL surgery than in PC surgery (rate of multiple reoperations, 36 vs. 14%), which is similar to previous observations that, compared to posterior cervical or thoracic surgery, posterior surgery in the lumbar spine was likely to result in the need for multiple I and D procedures for treating SSI [11]. Taken together, these findings suggest that eradicating SSI is more difficult for PTL surgery than for PC surgery, decreasing implant survival rates in PTL.

Table 2 Implant retention rate in patients with surgical site infection (SSI)

Parameter	Retention rate (%)	*P* value
Surgical location		<0.001
Posterior thoracic/lumbar	19/39 (49.0)	
Posterior cervical	14/14 (100.0)	
Anterior cervical	0/2 (0.0)	
Time to SSI (cutoff 30 days)		0.037
<30 days	29/43 (67.4)	
≥30 days	4/12 (33.3)	
Time to SSI (cutoff 90 days)		0.021
<90 days	33/51 (64.7)	
≥90 days	0/4 (0.0)	
Time from SSI to reoperation (cutoff 5 days)		0.010
0–4 days	25/34 (73.5)	
≥5 days	8/19 (42.1)	
Time from SSI to effective antibiotics (cutoff 5 days)		<0.001
0–4 days	26/32 (81.3)	
≥5 days	7/22 (31.8)	
Initial surgical procedure in PTL surgery		0.397
PLF	6/12 (50.0)	
TLIF/PLIF	9/23 (39.1)	
First reoperation procedure		0.521
Debridement only	22/35 (62.9)	
Antibiotic cement combined	7/12 (58.3)	

Stratification was performed according to various SSI parameters

P values were computed for within-category comparisons, and were obtained using Fisher's exact test

PTL posterior thoracic/lumbar, *PLF* posterior lateral fusion, *TLIF* transforaminal interbody fusion, *PLIF* posterior interbody fusion

For patients with unstable segments, especially in the cervical region, implant removal may be detrimental as it may introduce higher instability. Therefore, it is possible that surgeons are biased toward avoiding implant removal in patients with unstable segments. Our study population included patients with unstable segments in both the PC group (e.g., atlantoaxial disorder and trauma cases) and the PTL group (e.g., patients who underwent pedicle subtraction osteotomy or anterior spinal fusion with posterior lateral fusion). Fortunately, implant loosening did not occur in any of the patients with unstable segments, and all could retain their implant. Therefore, we infer that such bias related to the surgeon's fear of increasing instability by implant removal was unlikely to be significant.

Implant retention rates were previously shown to differ between early and late SSI, varying between 0 and 29% in late infection, and between 75 and 100% in early infection [1, 2, 6, 12–16]. Cahill et al. found a strong relationship between implant retention rate and the time from index surgery to SSI diagnosis [2]. In agreement with these previous observations, we found that implant retention rates of early and late infections were, respectively, 64.7 vs. 0% (when using the 90-day cutoff) and 67.4 vs. 33.3% (when using the 30-day cutoff). However, sample size was inadequate to provide a clear conclusion regarding retention rates in the late infection. In terms of reoperation procedure, I and D and CE provided similar retention rates (62.9 and 58.3%, respectively). However, recent studies indicated retention rates of nearly 100% when using vacuum-assisted closure for treating early infection [13, 17]. Unfortunately, this technique was not used to manage SSI in our series. Moreover, the outcomes of late infections could not be analyzed in this study. Therefore, further studies with larger sample size are needed to assess implant survival associated with late infections treated by vacuum-assisted closure.

Risk factors for implant removal

To date, only a few risk factors for implant removal have been described [6, 7, 18]. Núñez-Pereira et al. reported the number of fused segments as an independent predictor of treatment failure (implant removal or death) [7]. Unexpectedly, we found that the number of fused segments had no significant association with implant removal rate. However, we newly demonstrated that increased blood loss is a possible risk factor for implant removal. Greater blood loss is a known risk factor for SSI [19] because of its association with extensive surgical invasion, large hematoma formation, decreased hemoglobin levels, and need for transfusion. Pronounced dissection of the soft tissue as a result of extensive surgical invasion, together with localized tissue hypoxia due to decreased hemoglobin levels, creates poor conditions for wound healing, which increases the risk of SSI and development of persistent SSI that would eventually require implant removal. Moreover, allogeneic blood transfusion was suggested to induce relative immune suppression in the recipient, resulting in an increased risk of infections [20, 21]. We speculate that, although we did not determine allogeneic transfusion as a significant risk factor, immune suppression due to allogeneic transfusion did contribute to delaying wound healing, which increased the difficulty in treating SSI and, therefore, the risk of implant removal. Since patients with significant blood loss and extensive surgical invasion at the initial surgery are likely to have poor wound healing, they should be carefully monitored for development of persistent SSI with possible implant removal.

A new key finding of our analysis was that delay of reoperation and delay of intervention with effective antibiotics were potential risk factors for implant removal, especially among patients with PTL surgery, indicating that

Table 3 Risk factors for implant removal in patients with surgical site infection (SSI)

Variable	Univariate analysis		Multivariate analysis	
	OR (95% CI)	*P* value	OR (95% CI)	*P* value
Preoperative data				
Male (vs. female)	0.760 (0.228–2.528)	0.654	–	
Age (per year)	1.014 (0.980–1.049)	0.435	–	
BMI (per 1 kg/m^2)	0.991 (0.865–1.135)	0.890	–	
Previous spine surgery	2.132 (0.503–9.042)	0.304	–	
Intraoperative data				
Estimated blood loss (per ml)	1.003 (1.001–1.005)	0.005	1.002 (1.000–1.004)	0.037
Allogeneic transfusions	2.922 (0.866–9.857)	0.084		
Operative time (per min)	1.002 (0.997–1.007)	0.474	–	
Fused segments (per number)	1.095 (0.862–1.391)	0.458	–	
Postoperative data				
Time to SSI (per day)	1.029 (0.994–1.060)	0.057	–	
Time from SSI to reoperation (per day)	1.091 (1.008–1.180)	0.031	1.056 (0.958–1.165)	0.272
Time from SSI to effective antibiotics (per day)	1.175 (1.059–1.304)	0.002	1.097 (0.972–1.238)	0.133
MRS (vs. non-MRS)	1.629 (0.549–4.828)	0.379	–	

Data obtained via logistic regression analysis of the entire study sample ($n = 55$)

OR odds ratio, *CI* confidence interval, *BMI* body mass index, *SSI* surgical site infection, *MRS* methicillin-resistant *Staphylococcus*

Table 4 Risk factors for implant removal in patients with surgical site infection (SSI) after posterior thoracic/lumbar surgery

Variable	Univariate analysis		Multivariate analysis	
	OR (95% CI)	*P* value	OR (95% CI)	*P* value
Preoperative data				
Male (vs. female)	0.538 (0.138–2.082)	0.654	–	
Age (per year)	1.001 (0.964–1.038)	0.980	–	
BMI (per 1 kg/m^2)	1.006 (0.861–1.175)	0.939	–	
Previous spine surgery	4.500 (0.455–44.546)	0.199	–	
Intraoperative data				
Estimated blood loss (per ml)	1.002 (1.000–1.004)	0.029	1.002 (0.999–1.003)	0.183
Allogeneic transfusions	2.520 (0.649–9.833)	0.183		
Operative time (per min)	1.003 (0.997–1.009)	0.336	–	
Fused segments (per number)	1.179 (0.825–1.684)	0.366	–	
Postoperative data				
Time to SSI (per day)	1.024 (0.991–1.057)	0.154	–	
Time from SSI to reoperation (per day)	1.110 (0.999–1.231)	0.050	–	
Time from SSI to effective antibiotics (per day)	1.208 (1.047–1.393)	0.009	1.172 (1.017–1.351)	0.028
MRS (vs. non-MRS)	0.617 (0.145–2.545)	0.504	–	

Data obtained via logistic regression analysis of the subgroup of patients with posterior thoracic/lumbar surgery ($n = 39$)

OR odds ratio, *CI* confidence interval, *BMI* body mass index, *SSI* surgical site infection, *MRS* methicillin-resistant *Staphylococcus*

immediate reoperation and administration of effective antibiotics may help improve implant survival. In our series, the main reason why reoperation and intervention with effective antibiotics were delayed was that surgeons could not detect SSI because of poor initial clinical manifestations or that surgeons misdiagnosed SSI for other

nosocomial infections such as those of the urinary or upper respiratory tract. Therefore, if the treating surgeon was not able to identify the infecting pathogens, the patients continued to receive non- or low-sensitivity antibiotics until SSI was detected, reoperation was performed, and cultures were obtained. Wang et al. described a case of occult late infection, where the implant could be retained, because infection was successfully detected early using positron emission tomography/computed tomography [22], suggesting that such imaging modalities might represent a useful alternative approach for early diagnosis of occult SSI in patients with no apparent clinical manifestations or no findings on needle aspiration. Once SSI is diagnosed, we recommend immediate reoperation with surgical debridement in the absence of antibiotics, to obtain cultures. Administration of antibiotics with broad-spectrum empiric coverage should be initiated promptly, based on Gram-staining results, until the pathogens can be identified [23]. After the culture sensitivities are determined, the treatment can be deescalated to narrow-spectrum antibiotics. Ahmed et al. reported that spinal instrumentation was successfully retained in all 17 patients with SSI by means of aggressive surgical debridement and initial administration of empiric broad-spectrum antimicrobial agents [24]. Therefore, we believe that this strategy provides the fastest approach to effective antibiotic treatment and the key to decreasing the risk of implant removal.

Regarding the duration of antimicrobial therapy, Meredith et al. recommended at least 6 weeks of intravenous antibiotic therapy postoperatively, followed by oral suppressive antibiotics for treating instrumented SSI [25]. Furthermore, Keller et al. showed that 3–6 months of therapy with oral suppressive antibiotics was highly effective for the management of orthopedic infections with retention of hardware components [26]. In the present study, various durations of antibiotic therapy were equally successful in eradicating infection, although the treatment duration did prove insufficient in a few patients, who had recurrence of infection and underwent implant removal. Therefore, we infer that, in itself, the heterogeneity of antibiotic treatment duration had little influence on implant removal rates.

Dipaola et al. found that a positive methicillin-resistant *Staphylococcus aureus* (MRSA) culture was a strong predictor of the need for multiple I and D in SSI treatment [11], which indicated that MRSA was more difficult to eradicate. Nevertheless, in the present study, MRS infection was not a significant risk factor for implant removal (entire sample, $P = 0.379$; PTL group, $P = 0.504$). Miyazaki et al. also reported that all 11 consecutive patients with multi-drug-resistant SSI were successfully treated by surgical debridement with implant retention and long-term antimicrobial therapy including oral antimicrobials such as rifampicin with sulfamethoxazole/trimethoprim or minomycin [27]. In the present study, MRS-positive patients with implant retention received 2–10 weeks of intravenous anti-MRS agents, usually followed by oral combination antibiotics (sulfamethoxazole/trimethoprim, sulfamethoxazole/trimethoprim with rifampicin, or minomycin) for over 4 weeks. Taken together, these findings suggest that implant retention is feasible even in MRS-positive patients provided that appropriate intravenous antibiotics are used immediately and for a sufficient period of time, followed by oral suppressive antibiotics.

Limitations

There are several limitations to the present study. First, this was a retrospective study based on data entered into the electronic or paper medical records, and the possibility of patient selection bias could not be excluded. Second, this was a multi-center study, leading to potential heterogeneity in terms of the characteristics of the patient population, antibiotic prophylaxis regimen, and treatment strategies (e.g., indications and timing of implant removal) among the seven participating institutions or among the attending surgeons. In particular, there were no clear criteria regarding the decision to remove the implants, and the possibility of surgeon-specific biases could not be excluded completely, although the decision for implant removal was typically taken in patients with loosening implants or persistent infection not responsive to the first reoperation. Kanayama et al. demonstrated that magnetic resonance imaging findings of vertebral osteomyelitis and/or intervertebral abscess were useful for decision making regarding implant removal [28]. Therefore, ideally, it is desirable that the decision for implant removal or retention should be made not at the surgeon's subjective discretion but by objective assessment, as described by Kanayama et al. [28]. Third, the sample size was relatively small, and insufficient for drawing conclusions regarding anterior approach surgery because of the extremely low incidence of SSI in such patients. With regard to PC and PTL surgery, we performed a post hoc analysis and concluded that the sample size used in our study (i.e., 14 patients with PC surgery and 39 patients with PTL surgery) provided a statistical power of 98.1%, indicating sufficient statistical support to our conclusion that implant survival differs significantly between PC and PTL surgery. Fourth, since we could not collect accurate information regarding infection relapse beyond the first postoperative year, it was not possible to determine whether a longer observation period would have affected the implant removal rate. Finally, not all known risk factors for implant removal were included in the present analysis. The role of currently unidentified or other

known confounding risk factors (e.g., presence of sepsis or distant site infection, comorbidities, and nutritional status) should be investigated in the future.

Conclusions

We demonstrated that, on surgical management of SSI after spinal instrumentation, PC rather than PTL surgery was more likely to result in implant retention. In addition, we found that significant blood loss at the initial surgery, delay of reoperation, and delay of intervention with effective antibiotics is possible risk factors for implant removal. These findings suggest that: (1) retaining the implant is easy to achieve in PC surgery, but tends to fail in PTL surgery, especially when surgery is very invasive, with significant blood loss and (2) immediate administration of effective antibiotics significantly improves implant retention in SSI that underwent PTL surgery. Our findings are helpful in developing strategies to reduce the risk of implant removal.

Compliance with ethical standards

Conflict of interest The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper. This manuscript does not contain information about medical devices/drugs.

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