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ORIGINAL ARTICLE

Risk factors for deep surgical site infections after spinal fusion

J. J. P. Schimmel · P. P. Horsting · M. de Kleuver · G. Wonders · J. van Limbeek

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Abstract Surgical site infections (SSI) are undesired and troublesome complications after spinal surgery. The reported infection rates range from 0.7 to 11.9%, depending on the diagnosis and the complexity of the procedure. Besides operative factors, patient characteristics could also account for increased infection rates. Because the medical, economic and social costs of SSI are enormous, any significant reduction in risks will pay dividends. The purpose of this study is to compare patients who developed deep SSI following lumbar or thoracolumbar spinal fusion with a randomly selected group of patients who did not develop this complication in order to identify changeable risk factors. With a case–control analysis nested in a historical cohort of patients who had had a spinal fusion between January 1999 and December 2008, we identified 36 cases with deep SSI (CDC criteria). Information regarding patient-level and surgical-level risk factors was derived from standardized but routinely recorded data and compared with those acquired in a random selection of 135 uninfected patients. Univariate analyses and a multivariate logistic regression were performed. The overall rate of infection in 1,615 procedures (1,568 patients) was 2.2%. A positive history of spinal surgery was associated with an almost four times higher infection rate (OR = 3.7, 95% BI = 1.6–8.6). The risk of SSI increased with the number of levels fused, patients with diabetes had an almost six times higher risk and smokers had more than a two times higher risk for deep SSI. The most common organism cultured was *Staphylococcus aureus*. All infected patients underwent at least one reoperation, including an open débridement and received appropriate antibiotics to treat the organism. Patients who had had a previous spinal surgery are a high-risk group for infection compared with those that never had surgery. Total costs associated with preventive measures are substantial and should be compensated by health care insurance companies by means of separate clinical pathways. High-risk patients should be informed about the increased risk of complications.

Keywords Surgical site infection · Risk factors · Preventive measures · Spinal fusion

J. J. P. Schimmel (✉) · G. Wonders · J. van Limbeek
Department of Research Development and Education, Sint Maartenskliniek, PO Box 9011, 6500 GM Nijmegen, The Netherlands
e-mail: j.schimmel@maartenskliniek.nl

P. P. Horsting · M. de Kleuver
Department of Orthopaedics, Sint Maartenskliniek, PO Box 9011, 6500 GM Nijmegen, The Netherlands

Introduction

Surgical site infections (SSI) are undesired and troublesome complications after spinal procedures. Spinal surgeries report a higher infection rate compared with other orthopaedic surgeries such as primary total hip arthroplasty, the most performed orthopaedic procedure [11]. For example, the Dutch PREZIES network (PREventie (prevention) van (of) ZIEkenhuisinfecties (hospital infections) door (through) Surveillance, The Netherlands) reported mean incidences of 1.9% for superficial SSI and 0.9% for deep SSI after primary total hip arthroplasty in the period 1996–2003 [12]. In contrast, the infection rate of spinal surgeries reported in the literature ranges from 0.7 to 11.9% depending on the diagnosis and the complexity of the procedure [5, 9, 21].

SSI accounts for enormous medical, social and economical costs for the patient, as well as the hospital and the

health insurance companies. The total costs are mainly influenced by the depth of the infection [18]. Direct costs include a longer hospital stay, frequent re-operation and additional radiological procedures and laboratory tests. Indirect costs of SSI include a loss of productivity of the patient and his/her family [18]. A postoperative infection may also have a large emotional impact on a patient's overall outcome, despite a generally successful treatment of the infected area [16]. As a result of the growing awareness of the consequences of a postoperative infection, the Center of Disease Control (CDC) developed a guideline with several measures regarding the prevention of SSI (CDC Guidelines 1999). For example, improved operating room ventilation, sterilization methods, washing of hands and forearms with antiseptic agents and the availability and increased use of antimicrobial prophylaxis are recommended in order to reduce the risk of SSI after a (spinal) orthopaedic procedure (CDC Guidelines [3]).

Spinal surgeries are at higher risk for infection compared with other orthopaedic procedures probably as a result of their continuous expanding complexity and the increasing number of invasive procedures instead of conservative treatments. Improvements in the instrumentation and the surgical and anaesthetical techniques have also made spinal procedures available to a growing variety of different and/or complicated diagnoses. Unfortunately, more complicated procedures result in higher infection rates since the nature of the procedure accounts for the variability of the infection risk [5, 9, 21]. The rate of infection after simple discectomy or laminectomy is approximately 1%, whereas a spinal fusion has rates of 2–5%. The addition of an implant to a spinal fusion increases the infection risk further, ranging from 2.4 to 8.5%. The most frequently infected spinal fusion is a combined anterior/posterior procedure [5]. Another drawback of the increasing complexity in spinal surgery is that these procedures mostly result in increased procedure time, which is in itself a well-known intra-operative risk factor for SSI [5, 9, 13, 14]. Besides surgical factors, the patient's preoperative characteristics could also account for an increase in the amount of postoperative complications, including SSI. For example, increased age, smoking, diabetes, increased body mass index, steroid use, malnutrition and previous surgical infection have all been identified as risk factors for SSI (CDC Guidelines [5, 7, 14]).

Given the complexity of many spinal procedures, preventive interventions have the potential to improve a patient's overall outcome. Furthermore, they may translate into decreased hospital stay and postoperative recovery time and thus lower costs for the patient, hospital and health insurance companies. In conclusion, any significant reduction in infection risks will pay dividends.

The literature about risk factors for SSI after spinal surgery principally considered all types of procedures, whether a discectomy or fusion, and all types of infection, whether superficial, organ-space or deep. Moreover, no consensus about the identification and/or strength of the most important risk factor(s) for SSI could be obtained. Numerous spinal fusions have been performed in our specialized clinic. The purpose of this study is, therefore, to compare patients who developed deep SSI following spinal fusion with a randomly selected group of patients who did not develop this complication in order to identify changeable risk factors for the occurrence of deep SSI after spinal fusion. The ultimate goal is to improve a patient's outcome by reducing these risk factors.

Materials and methods

Study design

After approval by the hospitals' investigational review board, we performed a review of all lumbar spinal fusions performed at the orthopaedic department of the Sint Maartenskliniek Nijmegen, to identify patients who developed a deep surgical site infection. The clinic is a specialized musculoskeletal, tertiary referral centre. Due to the absence of level-I ICU facilities in our hospital and to a regional agreement, trauma cases are treated in a general or university hospital in Nijmegen. All surgeries were performed by experienced orthopaedic surgeons. Patients who underwent a spinal fusion between January 1999 and December 2008 were found by querying the hospital medical database for surgeries coded for a dorsal spinal fusion (code 455). During this period 1,615 lumbar fusions in 1,568 patients were performed. All types of diagnoses were considered in the analysis.

Identification of surgical site infection

Surgical site infections (SSI) as classified according to the CDC criteria (Centres for Disease Control and prevention) were studied. An infection was considered to be a surgical site infection when it occured at the site of the surgery within 30 days after the operation or within 1 year if the operation included placement of a foreign body, e.g. an implant. A deep surgical site infection was defined as an infection involving the deep soft-tissue muscle and fascia, in contrast to a superficial infection with only infected skin and subcutaneous tissue. Additional criteria for deep SSI were assessed according to the Dutch national PREZIES guidelines. These guidelines supplement the CDC criteria in which solely the diagnosis by an orthopaedic surgeon is sufficient to establish SSI. According to the PREZIES

guidelines, SSI should present with at least one of the classical signs of inflammation (pain, swelling, redness, increased local temperature) and drainage of purulent fluid from the operating incision, spontaneous wound dehiscention or an abces or other signs of infection at observation, re-operation, histo-pathological or radiological investigation. Patients with a persistent drainage of the surgical wound on the 5th day after surgery were treated according to the protocol for "open débridement". An open débridement was also performed when the patient presented clinically with a suspicion for an infection after discharge. During an open débridement microbiological cultures were taken in order to confirm the presence of SSI and to determine further treatment. Our hospital has a special infection & hygiene committee, which includes a microbiologist and a hospital hygienist. All suspected infections and all cultures, including negative cultures, are always reported to this committee.

Thirty-six cases with deep SSI were identified and confirmed through microbiological cultures. With the use of a random number generator, 135 control patients without SSI were selected from the cohort of patients who underwent a spinal fusion in the specified period. In this way a ratio of approximately 1:4 (infection to no infection) was obtained.

Data collection

Demographic and preoperative variables were collected from the medical records using a standardized data collection form by one investigator who was not involved in the initial treatment. Information regarding preoperative risk factors was derived from standardized, routinely recorded data as reported in the patient charts. Surgical-level risk factors that could be considered as possible risk factors for infection were derived from operative reports in the orthopaedic surgeons' database. When the data collection was finished, all data were checked by a second investigator in order to identify illogical or impossible data. If those were present the second investigator reviewed the medical and/or database records to resolve the conflicting results.

Preoperative patient-level risk factors reviewed included age at time of surgery, gender, height, weight and diagnosis. Additionally, smoking habits, comorbidity and previous lumbar surgeries were recorded and the Body Mass Index (BMI) was calculated. Surgical-level risk factors included use of pre-operative antibiotics, duration of surgery (and >75th percentile), level of operative procedure, type of procedure, number of levels fused, type of bone graft and the use of implanted instrumentation.

The registered types of comorbidity included diabetes mellitus type I and II, rheumatoid arthritis, cardiovascular diseases and pulmonary diseases. The type of operative procedure was classified as having one posterior procedure, a combined posterior/anterior procedure with the patient under the same anaesthesia or a two-stages posterior/anterior procedure performed on separate days. In all patients who underwent a two-staged procedure on separate days, only the first (posterior) procedure was selected for the subsequent analyses. The second (anterior) procedure was performed 7 days after the first surgery, and if possible, patients were mobilized and discharged between the two surgeries. The use of bone graft was scored as autograft or allograft. If both autograft and allograft were used, we scored this as allograft. We scored autograft if bone was used in combination with chronOS^{TM} (β-tricalcium phosphate bone graft substitute, Synthes). Further categorizations were based on frequency charts and a thorough review of the literature.

Data analysis

Two-tailed independent t tests, Chi-square tests or appropriate non-parametric alternatives are used to identify differences between the groups of infected and non-infected patients. Moreover, correlations between all continuous variables were viewed in order to detect possible colinearity, for example duration of surgery and number of levels fused. Eligible variables for inclusion in a multivariate model were those reported in the literature and those with clinical and biological plausibility; in addition, those with p values of <0.20 in univariate analyses were included.

A multivariate logistic regression was performed to identify independent risk factors for SSI, using the EGRET® statistical package for Windows (Version 2.0.31, Cytel Software Corporation). The model was built manually using stepwise extension. Possible risk factors were grouped into two blocks, first the operative factors and then the patient factors. In both blocks the variable with the lowest p value was manually added to the logistic model first. The deviance of the predictive value of the new model was checked and tested with the likelihood ratio test. If the likelihood test was <0.05, the added variable was retained; otherwise, the variable was removed. This procedure was repeated until the most parsimonious model was built, which meant that the least number of variables were retained all with a p value <0.05 and a 95% confidence interval of the odds ratio not including 1. Odds ratios > 1 indicate increased risk, while odds ratios <1 indicate decreased risk. The final model was checked with a backward procedure to ensure it was well specified. After identification of the main effects, all clinical meaningful interactions of this model were tested.

Table 1 Overview of the different diagnoses in the infected and the control group

Diagnosis	Infected group ($n = 36$) (%)	Control group ($n = 135$) (%)
Spondylolisthesis	7 (19)	48 (36)
Spinal stenosis[a]	6 (17)	17 (13)
Scoliosis (idiopathic and degenerative)	4 (11)	12 (9)
Kyphosis	4 (11)	0 (0)
Degenerative disc disease/discopathy	6 (17)	28 (20)
Failed Back Surgery Syndrome (FBSS)[b]	4 (11)	19 (14)
Spondylolysis	1 (3)	5 (4)
Tumour/radiation	0 (0)	2 (1)
Other	4 (11)	4 (3)

[a] In combination with in situ fusion

[b] Including postlaminectomy syndrome and pseudarthrosis

Results

During the 10-year period studied, the overall rate of a deep postoperative infection in a total of 1,615 procedures (in 1,568 patients) was 2.2% (36 cases). During the study period the yearly infection rate varied from 0.0 to 4.9%. A lumbar spinal fusion was most frequently performed to correct a spondylolisthesis: 19% in the infection group and 36% in the control group, respectively. Table 1 provides a summary of the different diagnoses in both groups. Tumour and radiation cases were usually treated in a university hospital in Nijmegen for reasons of logistics and expertise. In two cases included in this study, the surgeon was asked to perform these operations because for his specific orthopaedic expertise. The category "other diagnoses" included a diagnosis of collapsing spine or spinal instability, for example.

The most common micro-organism isolated from the cultures obtained from the surgical wounds was *Staphylococcus aureus* (*S. aureus*), which was found in 90% of the cases. Other cultured micro-organisms were *Escherichia coli* (*E. coli*), *Enterococcus*, *Enterobacter*, *Proteus mirabilis*, *Streptococcus* and *CNSA* (co-agulase negative *S. aureus*). The majority of the cases were monomicrobial, but in three cases a mixed infection was found. Table 2 provides a summary of the micro organisms reported in the infections.

The median time from the operation to the diagnosis of the infection was 13.5 days (25–75 percentiles 10–21 days), with a minimum of 6 days for an infection with *E. coli* and a maximum of 169 days for a *S. aureus* infection. Four infections could be classified as late infections because they occurred >90 days after the primary surgery; three of them were monomicrobial with *S. aureus*, and one infection was a mixed infection with *CNSA* and *S. aureus*. All patients underwent at least one reoperation to treat the infection. During the first reoperation, débridement of the infected tissue was performed. All devitalized tissues, and if necessary loose fragments of the bone graft, were removed. At least six cultures were obtained from all kinds of tissue in the absence of antibiotics, and a pulsed lavage irrigation was performed. It is important to note that if the patient already had received antibiotic therapy from the general practitioner or family doctor at the time of the first reoperation, the results of the cultures were assessed with caution. These cultures could have been biased as a result of previous antibiotic medication and hence might have formed resistant colonies and thus give negative results. In 28 of the 33 cases with spinal implants (85%) it was possible to leave the implants in situ and obtain healing of the infection. In 28 of the 36 infected cases (78%) (all with implanted instrumentation) gentamycin beads were placed and left in situ for at least 2 weeks, in order to create a high concentration of antibiotics locally and making it possible to leave the implants in situ. Patients were treated with intravenous antibiotics (cefazoline, Kefzol®) in the hospital until the results of the cultures were available. Results of the cultured micro-organisms determined further treatment, and if necessary antibiotic therapy was changed. In 19 cases the gentamycin beads were removed during a second

Table 2 Overview of the different micro-organisms in the reported infections

Micro-organism(s)	Number of cases
S. aureus[a]	27
E. coli[b]	1
Proteus mirabilis	1
CNSA[c]	2
Streptococcus	1
Enterococcus	1
CNSA[c] + *S. aureus*[a]	1
Enterobacter + *S. aureus*[a]	1
Enterococcus + *S. aureus*[a]	1

[a] *Staphylococcus aureus*

[b] *Escherichia coli*

[c] Co-agulase Negative *Staphylococcus aureus*

operation, of which in seven cases gentamycin beads were replaced based on the results of the cultures and ESR/CRP blood levels. In four cases a drain after pulsed lavage of the infected area was placed instead of using gentamycin beads, according to the surgeon's preference. In those cases it was also possible to leave the spinal implants in situ. Antibiotic therapy was continued for at least 6 weeks following a negative culture taken during surgery in combination with a normalization of the ESR/CRP blood levels. ESR reference values ranged from 0–15 mm/h depending on age and sex; CRP levels should be between 0 and 5 mg/L.

No patient died as a result of the infection. A total of 74 extra operative procedures were performed to treat the infections, resulting in a mean of 2.1 additional surgeries per case. The patient (30 years at surgery) infected with *E. coli* was treated for degenerative disc disease at the level of L4-5 and had a total of seven repeated surgeries in a period of 18 months. The initial surgery consisted of a combined posterior/anterior procedure on the same day, with the use of autograft and implanted instrumentation. In the 4-month period after the initial operation four surgeries with débridements and gentamycin beads were performed. Three months later the gentamycin beads were removed and the translaminar screws were tightened. Seventeen months after the initial surgery a solid fusion was achieved, and the two translaminar screws were removed, but two chains of gentamycin beads were placed to treat a dorsal fistula. After a week, a final surgery was necessary to remove those gentamycin beads.

There were a total of 1,121 extra hospital days for additional treatments, with a median of 28.5 days (Inter-Quartile Range (IQR) 16 days, range 7–106). One patient treated for FBSS (level T12-L5) who had had a previous surgery in the same area, was known to have diabetes mellitus type 2 and a BMI of 31, stayed an additional 60 days in the intensive care unit of a university hospital because a sepsis occurred as a result of an infection with *S. aureus*. Afterwards, the patient was transferred back to our hospital for further mobilization and rehabilitation.

In the infected group, six patients (19%) underwent an additional operation in the follow-up period investigated after treatment of the infection. In the control group six patients (4%) needed an additional surgery, which was significantly lower ($p = 0.004$). In the infected group, two repeat fusions were performed because of pseudarthroses. The first case was treated with two additional pedicle screws on the proximal end without grafts; the second was treated with spinal implants and autograft. In three cases the instrumentation was removed because the implanted screws caused irritation on the skin and/or back muscles as a result of friction between these structures and the screw head prominence, producing soft tissue irritation and/or local pain. These indications warrant implant removal only after solid fusion was achieved; in these cases 8, 10 and 12 months after the initial surgery. In one case translaminar transfacet screws had been placed to provide additional stabilization to an interspinous process spacer (Diam implant); 10 months later, a repeat fusion with pedicle screws, rods and allograft was performed. In the control group two pseudarthroses were diagnosed in which repeat fusions were performed. One case was treated with a spinal implant and allograft; in the other case additional pedicle screws were placed. In addition, a radiculopathy and a spinal stenosis at a lower level were diagnosed. The two other surgeries contained an exploration at a lower level and a removal of the instrumentation after solid fusion 14 months after the initial surgery.

Table 3 provides the factors at the patient level for the infected and non-infected patients. The analyses showed that the two groups were comparable in terms of gender, age at surgery, length, weight, mean BMI and having any type of comorbidity. Previous surgery and smoking showed a significant difference between the groups, with p values <0.05. A nearly significant difference was found in the categorized BMI ($p = 0.054$), in which the infected group reported a higher portion of patients with a BMI ≥ 30 (25 vs. 10%). Remarkably, more than 50% of the operated patients suffered from overweight (BMI > 25), since the median BMI was 25.5 (IQR 4.9) in the control group and 25.9 (IQR 9.0) in the infected group. Not surprisingly, there was significant colinearity between length, weight and BMI. Therefore, we used only the categorized BMI in the multivariate regression model. Furthermore, no significant difference was found in having any type of comorbidity; thus, a differentiation into the most common types was made, in which a patient could suffer from more than one type of comorbidity (Table 3). The infected patients reported significantly more diabetes mellitus (DM) compared with the control group (11% compared with 3%, respectively: $p = 0.040$). All patients with rheumatoid arthritis (RA) also presented with other comorbidities (cardiovascular or pulmonary). Most frequently reported in the non-infected patients were pulmonary diseases (14%). Examples of other comorbidities were carcinomas, epilepsy and Ménière's disease. Since only DM had a p value <0.20, only this comorbidity was used in the multivariate regression model.

Factors at the surgical-level between the infected and non-infected patients are listed in Table 4. The level of surgery, number of levels, type of bone graft and surgical approach showed significant differences between the infected patients and the non-infected patients. In the infected group most surgeries were performed in the thoracolumbar area (50%), in contrast to the control group in which 50% of the surgeries were performed in the lumbar

Table 3 Patient-level characteristics between groups with and without a surgical site infection

Patient factor	Infected group ($n = 36$)	Control group ($n = 135$)	p Value[e]
Sex (M:F)	17:19 (M = 47%)	56:79 (M = 41%)	0.708
Age at time of surgery (years)[a]	51 (16.8)	48 (14.7)	0.260
Length (cm)[a]	173 (9.0)	174 (9.7)	0.713
Weight (kg)[a]	77 (16.6)	77 (12.9)	0.919
BMI (kg/m^2)[a]	25.7 (4.7)	25.5 (3.7)	0.779
BMI (kg/m^2)			0.054
≤ 25	16 (44%)	61 (45%)	
>25 and <30	11 (31%)	60 (45%)	
≥ 30	9 (25%)	14 (10%)	
Smoking (yes)	20 (56%)	47 (35%)	0.024
Previous surgery (yes)[b]	20 (56%)	36 (27%)	0.001
Comorbidity (yes)[c]	10 (28%)	47 (35%)	0.426
Comorbidity[d]			
Diabetes mellitus (type I/II)	4 (11%)	4 (3%)	0.040
Cardiovascular diseases	3 (8%)	15 (11%)	0.629
Pulmonary diseases	3 (8%)	19 (14%)	0.361
Rheumatoid arthritis (RA)	1 (3%)	5 (4%)	0.788
Other	2 (6%)	15 (11%)	0.322

[a] Values are mean ± standard deviations

[b] Previous spinal surgery in the same area (new incision made in existing scar)

[c] Having any type of comorbidity

[d] Patient can suffer from more than one type of comorbidity

[e] p Values of two-tailed independent t tests, Chi-square tests or appropriate non-parametric tests

area. In both groups most surgeries involved 1–2 levels, but in the infected group a larger portion of surgeries involved four or more levels (42%), in contrast to only 18% in the control group. The median duration of the operation was somewhat longer for the patients with an infection (91 compared with 77 min), nearly statistically significant. The 75th percentile of the operating time has been used by other researchers and in the PREZIES system [12, 14]. Therefore, we calculated this for the total group, resulting in a surgery time of 115 min. The median number of vertebrae involved in operations longer than 115 min was 4–6 vertebrae compared with a median number of 1–2 vertebras for operations lasting less than the 75th percentile. Surgeries with >7 levels were mostly performed because of a correction for (degenerative) scoliosis and had a duration of more than the 75th percentile (115 min). Nevertheless, we found only a small but significant correlation between duration of surgery and the number of levels fused ($r_s = 0.505$, $p < 0.001$). A significantly higher percentage of the infected patients (47%) received an allograft compared with 21% in the control group. The surgeries with more levels (i.e. scoliosis) used allograft and were mainly performed at the thoracolumbar level ($p < 0.001$), whereas surgeries with fewer vertebrae used autograft and were mainly performed at the lumbosacral junction (i.e. spondylolisthesis). The most common type of surgical approach to become infected was the one-stage posterior procedure. During the investigated period the type of the surgical procedures was significantly different ($p < 0.001$). A trend during the study period towards more one-staged posterior procedures and fewer two-staged posterior/anterior procedures under the same anaesthesia was seen.

The results of the multivariate logistic regression model to identify independent risk factors for SSI are listed in Table 5. In the final model diabetes had the strongest association with SSI, with an odds ratio of 5.92. In addition, a positive history of previous spinal surgery had a strong association with the occurrence of an infection, with an odds ratio of 3.70. Other variables that remained independently associated with an increased risk were the number of levels and smoking habits (Table 5). The model was statistically significant compared with the initial model with only a constant term (deviance drop = 26.69 with 7 degrees of freedom (df), $p < 0.001$).

Discussion

The purpose of this study was to identify risk factors for the occurrence of deep SSI following lumbar spinal fusion at a

Table 4 Surgical-level characteristics between groups with and without a surgical site infection

Surgical factor	Infected group ($n = 36$)	Control group ($n = 135$)	p Value[e]
Level			0.005
Thoracolumbar	18 (50%)	55 (41%)	
Lumbar	9 (25%)	68 (50%)	
Lumbosacral	9 (25%)	12 (9%)	
Number of levels			0.036
1–2	14 (39%)	74 (55%)	
3	7 (19%)	36 (27%)	
4–6	11 (31%)	19 (14%)	
≥7	4 (11%)	6 (4%)	
Duration of surgery (min)[a]	91 (50)	77 (56)	0.054
Duration of surgery >75th percentile[b]	11 (31%)	30 (22%)	0.298
Bone grafts			0.002
None[c]	2 (6%)	2 (1%)	
Autograft	17 (47%)	104 (77%)	
Allograft	17 (47%)	29 (21%)	
Approach[d]			0.005
One stage posterior	29 (81%)	68 (50%)	
Combined posterior/anterior	3 (8%)	29 (22%)	
Two staged	4 (11%)	38 (28%)	
Implanted instrumentation (yes)	33 (92%)	128 (95%)	0.474

[a] Value is median number of minutes with interquartile range

[b] The 75th percentile of surgery time was 115 min

[c] No bone grafts used in scoliosis surgery

[d] Surgery with a combined posterior/anterior approach was under the same anaesthesia; a two staged approach is a posterior procedure followed by an anterior procedure on a separate day (generally 1 week apart)

[e] p Values of two-tailed independent t tests, Chi-square tests or appropriate non-parametric tests

single institution during a 10-year period. During the study period 36 patients who developed deep SSI were compared with 135 randomly selected patients from the same institution who did not develop this complication. Our most important finding was that a positive history of previous spinal surgery was associated with an almost four times higher risk of deep SSI. Furthermore, the risk of a postoperative infection increased with the number of levels fused; patients with diabetes had an almost six times higher risk; smokers had more than a two times higher risk for the development of deep SSI.

Several factors increasing the risk of a deep surgical site infection have been identified, and could be classified as related to either patient characteristics or the surgical procedure [5, 14, 21]. However, odds ratios reported in literature are scarce, inconsistent, considered risk factors for all types of spinal procedures and were not stratified as to type of infection, making a quantitative comparison with our results difficult.

We found that patients with a history of previous spinal surgery have an increased risk for infection compared with those that never had surgery. This was in contrast to Fang and Olsen [5, 14], who both reported a non-significant odds ratio for previous surgery, but it is unclear whether Fang [5] reported only previous spinal surgeries or previous surgeries regardless of area or diagnosis. Furthermore, our results confirmed the finding that patients with diabetes and smoking habits had an increased risk for SSI [4, 5, 13]. Finally, the number of levels fused was independently associated with the development of deep SSI. The risk increased with the number of levels fused, but was only significant for surgeries involving ≥7 vertebrae. This finding was in line with that of Olsen [14] who reported that a cervical procedure, with a limited number of vertebrae, decreased the infection risk. However, it is questionable whether this finding was due to the limited number of vertebrae or to the cervical procedure. The cervical spinal area itself is less susceptible for SSI than the lumbar spine in the abdominal region.

It is not surprising that the duration of surgery, the area of surgery and the type of bone graft were not independently associated with the occurrence of an infection.

Rheumatoid Arthritis (RA) is surprisingly not a factor of influence in our study. This might be due to the small sample size of six RA cases (one infection, five control). However, upon review, we found that for these cases two had had a previous surgery in the same area (one infection and one control), two cases were smokers (one infection and one control), which are all factors independently associated with increased risk. For this reason, we assume that in our study population RA is not independently associated with an increased risk for infection.

We reported an infection rate of 2.2% for deep SSI, which is comparable to the overall infection rate in some previous studies [13, 14, 21] and in the lower range of other reported rates [9, 16]. This percentage is remarkably low, because in contrast to other studies we studied only fusion surgeries with ≥92% instrumented fusions. It is known that infection risk depends on the nature of the procedure and increases with the use of implanted instrumentation [9, 21]. One could expect a higher infection rate in our centre since this is a specialized clinic for spine surgery, making it likely that more complex procedures would be performed than in a community or general hospital. Although the 2.2% infection rate reported in our study is slightly higher than the 1.1% for all orthopaedic procedures reported by the Dutch PREZIES network, the infection rate is still much lower than the higher rates reported for spinal fusion which up to 11.9% [5, 9, 21]. Our centre has strict protocols and routines in the operating rooms and nursing departments in order to prevent infections.

The most common organism cultured from the primarily monomicrobial, infected wounds, was *Staphylococcus aureus*; the median time from the primary surgery to the diagnosis of infection was 13.5 days. Infected patients were treated according to the guidelines of the National Institute for Health and Clinical Excellence (NICE, www.nice.org.uk), and no patient died as a result of the infection or had a recurrent or chronic infection during the period investigated. The absence of recurrent infections and the low rate of pseudarthroses (5.6%) may indicate an appropriate surgical and medical treatment for infections. Despite the fact that we did not investigate patient outcomes after an infection, it is likely that these are similar to outcomes of the non-infected group because Mok [10] concluded that patients with a deep wound infection after instrumented posterior spinal fusion had similar clinical outcomes to matched controls.

We have shown that deep SSI had large impact on hospital costs. A mean of 2.1 surgeries per case were necessary to treat the infection resulting in a total of 1,121 extra hospital days. Since the mean number of planned hospital days for a lumbar fusion is 6 days in our hospital, a total of 36 deep infections account for a loss of productivity of almost 190 comparable surgeries (1,121/6 = 187). Our purpose was not to quantify the total costs of deep SSI, but it is obvious that these are extremely high, especially because Urban showed that costs also increase with the depth of the infection [18].

A weakness of this study is the relatively small sample size of infected patients ($n = 36$). This could be due to the focus on only one type of infection (deep SSI) in a specific type of spinal surgery (spinal fusion) in contrast to previous research on SSI which generally focused on all spinal procedures and all types of infection. This is its strength also, paradoxically. The homogeneous study group and procedure made it possible to study the risk factors of spinal infections more in-depth by using a manually guided, stepwise multivariate logistic regression to determine independent risk factors for SSI. The strength of this study is also the study period of 10 years, which to our knowledge, is the longest period investigated.

Several preventive (medical) measures should be taken for the groups of patients that turned out to be at high risk for the development of SSI, probably being more cost-effective than repeated operations. Patients with a history of spinal surgery should have an extended prophylactic antibiotic therapy to at least 72 h post-operatively (1 g cefazolin IV every 8 h); however, initially this seems to be in contrast with the NASS evidence-based guidelines [20]. Hellbusch [6] reported that an extended postoperative antibiotic protocol compared with a preoperative single dose reduced the infection rate in instrumented lumbar fusion from 4.3 to 1.7%. Despite this large difference, no statistical significance was reached probably due to the relatively small sample size ($n = 269$) and the large drop-out rate of >13%. Because they did not include high-risk patients and studied only procedures for degenerative disease diagnoses, it seems reasonable to assume that high-risk patients with a positive history of spinal surgery do have the potential to benefit from a postoperative multiple-dose antibiotic regime. Hellbusch [6] findings are thus in contradiction with the NASS evidence-based guidelines [20]. However, these guidelines are rather conservative and not convincing, since only one time a level II evidence could be found, although they used the best available literature. For now, surgeon preference probably seems to be most important in the policy of prophylactic therapy. Further, microbiological cultures ought to be taken regularly during revision (fusion) surgery, in order to determine if a low-grade infection is already present, and if necessary, extend or change antibiotic therapy.

Despite the fact that diabetes is a well-known, high risk factor, as supported by our results, there is insufficient evidence to support strict glycaemic control versus conventional management (maintenance of glucose <200 mg/dL) for the prevention of SSI [8]. Nevertheless, treatment for diabetic patients should be given with appropriate extra

Table 5 Multivariate logistic regression model for the development of a deep surgical site infection

Risk factor	Odds ratio (95% confidence interval)	*p* Value
Previous surgery	3.70 (1.59–8.62)	0.003
Number of levels		0.027[a]
1–2	1.0	
3	0.75 (0.26–2.19)	0.599
4–6	2.44 (0.89–6.76)	0.084
≥7	6.21 (1.37–28.2)	0.018
Diabetes mellitus	5.92 (1.23–28.5)	0.026
Smoking	2.33 (1.02–5.32)	0.045

Final model: Deviance 149.32 ($df = 164$), LR test 87.74 ($df = 7$), p value <0.001; Initial model with only constant: Deviance 176.01 ($df = 170$), LR test 61.04 ($df = 1$), p value <0.001

[a] p value from Termwise Wald test (Wald statistic 9.16 (degrees of freedom (df) = 3))

attention because the risk for infection is almost six times greater than patients not suffering from diabetes. Furthermore, patients have to stop smoking before surgery. Despite the fact that we did not differentiate between past-smokers, 'small' smokers or 'heavy' smokers and used any smoking history in our analyses, our odds ratio might even be an underestimation, since Ahn [1] already concluded that the risk increased for heavy smokers. Thomsen [17] showed that surgical patients may benefit from intensive preoperative smoking cessation interventions which had to be initiated at least 4 weeks before surgery and included Nicotine Replacement Therapy (NRT). Finally, mupirocin (bactroban®) can routinely be used in orthopaedic surgeries with a relatively high risk, such as spinal surgeries [12]. Mupirocin appeared to be effective in people who are nasal carriers of *S. aureus* [15, 19]. Theoretically, the possibility of surgical site infection decreases approximately by a quarter, since the prevalence of nasal carriage of *S. aureus* is approximately 20–30% in the general population [2].

All these preventive measures will increase the hospital costs, and therefore it seems reasonable to establish a separate clinical pathway for high-risk patients; this could be accompanied by an appropriate financial compensation from health care insurance companies. We emphasize the need for properly designed studies to evaluate risk factors for the development of SSI after spinal surgery. Future studies should focus on one type of infection in different types of surgeries and/or diagnoses, for example deep SSI in spondylolisthesis, in order to clarify preventive measures for specific patient groups. Finally, it is advisable to inform patients about the increased risks of complications, in order to adjust the patient's expectation and to prevent disappointment.

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