Evaluation of the surveillance of surgical site infections within the Dutch PREZIES network

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Evaluation of the surveillance of surgical site infections within the Dutch PREZIES network

Evaluatie van de surveillance van postoperatieve wondinfecties binnen het Nederlandse PREZIES netwerk

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Introduction

INTRODUCTION

Healthcare-associated infections continue to represent a significant public health problem. Even though some infections are unavoidable due to the inherent risks of underlying disease and medical interventions, infection rates can and should be decreased.
In the Netherlands, about 3% of surgical patients develop a surgical site infection (SSI), which leads to a longer duration of hospitalization, an increase in morbidity and mortality rates, and an increase in costs.[1-3] SSI rates, especially in clean surgery in which no bacteria-colonized tract of the body is opened, are considered an indicator of the quality of surgical and postoperative care in hospitals.
Surveillance is the ongoing systematic collection, analysis, interpretation, and feedback of data, followed if necessary by implementation of interventions. It is characterized by the Plan-Do-Study-Act cycle, developed by the American Institute for Healthcare Improvement.[4] Surveillance has been widely accepted throughout the world as a primary step toward prevention of healthcare-associated infections. In order to be successful and to generate accurate and reliable data, the surveillance system should comply with several criteria.
In the Netherlands, a national network for the surveillance of nosocomial infections was set up in 1996. The first module concerned SSIs, and so far 90% of all acute care hospitals in the Netherlands have participated for a period between 3 months and 11 years.
The underlying question of this thesis is to assess the quality of the Dutch SSI surveillance and whether it could be optimized. Therefore, the methods and applications of the surveillance were critically evaluated and the trend in SSI incidence studied.

Background of surgical site infections
Healthcare-associated infections are infections that develop as a result of the patient's stay in a healthcare facility like a hospital, nursing home or rehabilitation centre. 'Nosocomial infections' is a subgroup, which encompasses infections related to procedures, treatments, or other events that occur during hospitalization. Such infections reveal not necessarily during hospitalization; often they manifest later. The incidence of nosocomial infections can reflect the quality of care in the hospital.

Modern surgery can be said to have its roots in the 19th century with the development of asepsis and narcosis.[5] As a result, reconstructive, tissue-preserving operations began to replace amputations.[6] After a surgical procedure, the patient may develop a SSI. The development of a SSI can be multicausal, but the necessary cause is damage to host barrier mechanisms induced by the trauma of a surgical incision. For most SSIs, the source of pathogens is the endogenous flora of the patient's skin, mucous membranes, or hollow viscera.[7 8] However, contamination may also occur from an exogenous source such as surgical personnel, the operating environment, and all tools, instruments, and materials brought to the sterile field during an operation. Excellent surgical technique is widely believed to reduce the risk of SSI. Such technique includes maintaining effective hemostasis while

preserving adequate blood supply, preventing hypothermia, gently handling tissues, avoiding unintentional entries into a hollow internal organ, removing devitalized (e.g., necrotic) tissues, using drains and suture material appropriately, eradicating dead space, and appropriately taking care of the postoperative incision.[3] The surgical technique has improved over the last decades, and more often minimally invasive (laparoscopic or endoscopic) surgical procedures are performed, which causes fewer SSI.[9 10]

SSIs are divided into (Figure 1):

- superficial incisional SSIs: involving only skin or subcutaneous tissue of the incision,
- deep incisional SSIs: involving deep soft tissues (fascial and muscle layers) of the incision;
- organ/space SSIs: involving any part of the anatomy other than the incision (e.g. organs or spaces), opened or manipulated during the operative procedure).

The surgical site is the second or third most-common site of all nosocomial infections, with infections of the urinary tract being the most-common. Among surgical patients, SSIs account for 38% of all nosocomial infections. Currently, about 3% of surgical patients in Dutch hospitals develop a SSI.[11] SSIs have adverse consequences like a longer duration of hospitalization of on average a week, an increase in morbidity and mortality rates, and an increase in antibiotic use. Consequently, SSIs lead to an increase in healthcare costs, varying from €1,000 per superficial SSI to €20,000 per severe deep SSI. These costs refer to direct hospital costs, e.g., extra bed days, diagnostics, medication and revision surgery.[12 13]

Determinants for the development of SSI

Knowledge of patient and operation characteristics that may influence the risk of SSI development (directly or indirectly) is useful in two ways. First, they allow stratification of operations, making

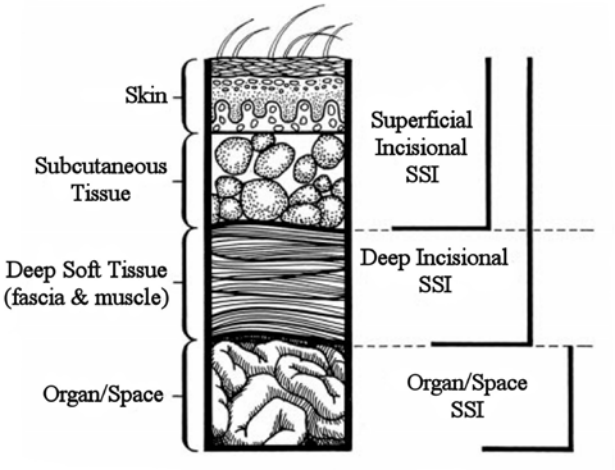

Figure 1. The anatomy of surgical site infections and their appropriate classification.[62]

surveillance data more comprehensible. Second, knowledge of risk factors beforehand, may allow for targeted prevention measures.

Four key factors, which interact in a complex way, affect the risk of surgical site infection:

- the degree of bacterial contamination;
- the virulence of the microorganism;
- the resistance of the host, i.e., the patient's ability to control the microbial contamination;
- the physiologic condition of the surgical site at the end of the operation. A surgical site that is poorly vascularized or that contains damaged or necrotic tissue or foreign material is at higher risk of infection given the same degree of microbial contamination. The condition of the surgical site is also determined by the underlying disease process that necessitated surgery (e.g., the severity of trauma) and by operative technique (i.e., the skill of the surgeon).

Studies have identified other risk factors, but they may be viewed as secondary in that they are likely to act through interaction with the key factors; e.g., by affecting the resistance of the host or the condition of the surgical site. Age as a risk factor is linked to co-morbidities like thinning of the dermis which is more susceptible to ischemia, diminished host immune responses, increased exposure to long-term care facilities, and malnutrition.[14] Smoking delays the primary wound healing secondary to decreased oxygen tension in the tissue. Obesity is associated with a poor tissue oxygenation in adipose tissue and a higher incidence of diabetes.[15] Diabetes itself is associated with hyperglycemia, in case of unsatisfactory glucose control. Hyperglycemia during the immediate postoperative period is an independent risk factor for development of SSI, because of a direct effect of elevated glucose on immune mechanisms.[16]

As mentioned above, the risk of developing an SSI is influenced by the degree of microbial

Table 1. Surgical wound classification.[3]

Class	Surgical wound contamination
1 Clean	An uninfected operative wound in which no inflammation is encountered and the respiratory, alimentary, genital, or uninfected urinary tract is not entered. In addition, clean wounds are primarily closed and, if necessary, drained with closed drainage. Operative incisional wounds that follow nonpenetrating (blunt) trauma should be included in this category if they meet the criteria.
2 Clean-contaminated	An operative wound in which the respiratory, alimentary, genital, or urinary tracts are entered under controlled conditions and without unusual contamination. Specifically, operations involving the biliary tract, appendix, vagina, and oropharynx are included in this category, provided no evidence of infection or major break in technique is encountered.
3 Contaminated	Open, fresh, accidental wounds. In addition, operations with major breaks in sterile technique (e.g., open cardiac massage) or gross spillage from the gastrointestinal tract, and incisions in which acute, nonpurulent inflammation is encountered are included in this category.
4 Dirty/infected	Old traumatic wounds with retained devitalized tissue and those that involve existing clinical infection or perforated viscera. This definition suggests that the organisms causing postoperative infection were present in the operative field before the operation.

contamination of the operative site. A widely accepted system of classifying operative site contamination was developed by the National Research Council in 1964 and modified in 1982 by the American Centers for Disease Control (CDC) for use in SSI surveillance (Table 1).[3] The incidence of infection increases as the wound classification changes from clean to dirty.

Table 2. Physical status classification, American Society of Anesthesiologists.[17]

ASA Class	Patient's preoperative physical status
1	Normally healthy patient
2	Patient with mild systemic disease
3	Patient with severe systemic disease that is not incapacitating
4	Patient with an incapacitating systemic disease that is a constant threat to life
5	Moribund patient who is not expected to survive for 24 hours with or without operation

The American Society of Anesthesiologists (ASA) physical status classification is widely used as a measure for intrinsic host susceptibility, with a higher score indicating an increased infection risk (Table 2).[17] An advantage of the ASA classification is that it is already available before the start of surgery. A drawback is that it represents a subjective parameter, which might result in inter-physician variations.[18 19]

The length of operation has long been established as an important risk factor for SSIs.[20] In the 1980s, surgery lasting more than 2 hours was found to be an important risk factor for SSIs.[21] Later, the 75th percentile of the distributions of duration of surgery for each procedure seemed to be a better predictor of infection.[22] Exactly how prolonged surgery increases the risk for SSI remains speculative, but it might be influenced by the experience of a surgeon, the complexity of the surgery, or by complications during surgery.[23]

In 1991, the NNIS risk index was developed in America, which combines three risk factors.[22] One point is scored for each of the following when present:
1) American Society of Anesthesiologists (ASA) physical status classification of >2;
2) Either contaminated or dirty/infected wound classification;
3) Length of operation > 75th percentile of the specific operation.
For calculation of the NNIS risk index, PREZIES uses the 75th percentile of duration of surgery in minutes per surgical procedure, which is computed from the PREZIES data.

Infection control

In the Netherlands in 1980, the Working Party on Infection Prevention (WIP) was founded to stimulate infection prevention in the Netherlands. Professionals from three Dutch societies are participating in the WIP: the Infectious Disease Society of the Netherlands, the Dutch Society of Medical Microbiology, and the Society for Hygiene and Infection Prevention in Healthcare. The WIP develops and publishes up-to-date, scientifically based guidelines for prevention of healthcare-associated infections. The guidelines are meant to be a helping hand in the preparation

of local guidelines. Regarding SSIs, a relevant guideline is 'Prevention of postoperative wound infections', which includes recommendations regarding:

- preoperative factors: preparation of the patient, hand/forearm antisepsis for surgical team members, management of infected or colonized surgical personnel, administration of antimicrobial prophylaxis;
- intraoperative factors: ventilation of the operating room, cleaning and disinfection of environmental surfaces, microbiologic sampling, sterilization of surgical instruments, using surgical attire and drapes, surgical technique;
- postoperative factor: incision care.

Surveillance of SSI

The first large nosocomial infection surveillance network was set up in America by the CDC in 1970, known as the National Nosocomial Infections Surveillance (NNIS) system.[24] Currently, many countries worldwide have a nosocomial infection surveillance system with methods and infection definitions adopted from the American NNIS system. Nowadays, surveillance has been generally accepted as a primary step toward prevention of nosocomial infections and thereby improvement of patient safety.[25]

The American Institute for Healthcare Improvement developed a tool for testing changes in healthcare.[4] The *Plan – Do – Study - Act* cycle is shorthand for testing a change by developing a plan to test the change (Plan), carrying out the test (Do), observing and learning from the consequences (Study), and determining what modifications should be made to the test (Act) (Figure 2). This tool can also be used for surveillance of nosocomial infections.

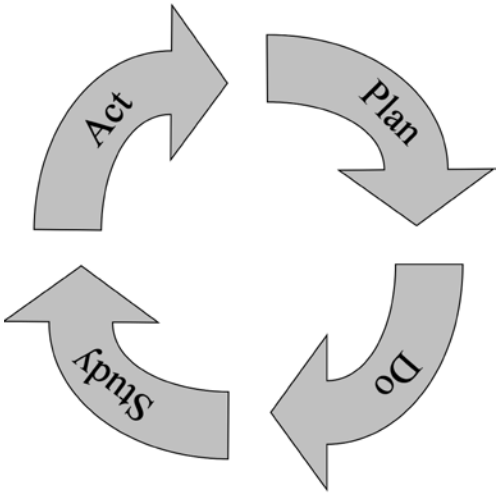

Figure 2. The *Plan – Do – Study - Act* cycle.

For SSI surveillance within a national network, the steps might include the following aspects:

- Plan: determine the included surgical procedures, the registration period, the goal regarding the SSI incidence (e.g., below the national 25th percentile), and the data needed to be collected by whom.
- Do: carry out the surveillance according to the protocol and send the data to the national nosocomial infection surveillance network.
- Study: use the received feedback report to compare the data with your predictions, and summarize and reflect what you learned. Feed back the results to involved personnel.
- Act: determine what modifications should be made and prepare a new plan.

Critical components for a high-quality and successful nosocomial infection surveillance system, both on national and on hospital level, are[26-30]:

- Voluntary and confidential participation.
- A written plan with goals and objectives.
- Efficient use of limited resources.
- Standardized surveillance protocols and methods: using the same exact, concise, and nonambiguous definitions and apply them consistently is essential for accurate infection rates and reliable inter-hospital comparison.
- Risk-adjustment of infection rates: control for variation in case mix, underlying disease and severity of illness at participating hospitals.
- Feed back of surveillance results: feed back of risk-adjusted and reliable infection rates to the involved healthcare professionals may substantially affect their behavior and enable them to take appropriate action, and may be the catalyst for organizational improvements.

Promoting factors are:

- Close collaboration among all healthcare workers within the hospitals.
- Close collaboration and dedication of infection control professionals and of the network team.
- Infection control professionals should be trained professionals that understand epidemiology and surveillance.
- Computer support, information and technology services, and administrative support.
- Regular evaluation of the surveillance.

In summary, surveillance is the ongoing systematic collection, analysis, interpretation, and feedback of data. After determination of baseline rates of nosocomial infections, changes in the rates can be detected, e.g., to determine whether interventions were effective.

The structure of this thesis follows the steps of the *Plan – Do – Study - Act* cycle, with the methods of the Dutch PREZIES network described in the 'Plan-step'. In the 'Do-step', aspects regarding the execution of surveillance are evaluated, namely validation and postdischarge surveillance. Risk-adjustment, comparison of the Dutch and the German surveillance data, and the change in SSI rate over time are discussed in the 'Study-step'. The 'Act-step' is used to describe the effect of implementing the national guideline for antibiotic prophylaxis on the SSI rate.

PLAN

Methods of the Dutch PREZIES network

In 1996, the national nosocomial surveillance network PREZIES ('PREventie van ZIEkenhuisinfecties door Surveillance') was set up in the Netherlands. It is a cooperation between the National Institute for Public Health and the Environment (RIVM), the Dutch Institute for Healthcare Improvement (CBO) and the participating Dutch hospitals. General goals of the PREZIES network are:

- Implement and maintain standardized surveillance of nosocomial infections to gain insight into the national (change in) incidence of nosocomial infections, risk factors and pathogens causing the infections. Furthermore, the surveillance data can support national policies.
- Generate comparable and accurate infection data so that hospitals can compare their infection rates with the national data, which may support optimization of the infection prevention policies in the hospitals.
- Create a basic infrastructure for intervention studies, which may support improvement in the quality of care and patient safety.

In 1996, the PREZIES network started with an incidence module on SSIs.[2] Other modules were developed later: incidence modules on SSIs after cardiac surgery, ventilator-associated pneumonia, and central venous catheter-related sepsis, and a prevalence module on all nosocomial infections. Participation in PREZIES is voluntary and confidential, and currently 90% of the 98 hospitals in the Netherlands participate. The person in the hospital responsible for the execution of the surveillance usually is the infection control professional. The participating hospitals should follow the protocols, and use the definitions of the PREZIES network for all variables and infections. The hospitals that participate in the SSI module, may choose the specific surgical procedures they want to include in the surveillance. Each healthcare organization must tailor its surveillance system to use limited resources optimally by taking into account population characteristics, outcome priorities, and organizational objectives.

The SSI definition of PREZIES is based on the one developed by the American Centers for Disease Control and Prevention, which was translated by the Dutch WIP. PREZIES made some specifications to this definition, i.e., that clinical symptoms must always be present and that the diagnosis of the surgeon or physician alone is not decisive. Acceptance of such a subjective diagnosis of a surgeon/physician, without any clarification or diagnostics, jeopardizes the comparability of the data. The diagnosis 'SSI' by the surgeon/physician will not be ignored, but a foundation of arguments needs to be inquired and should be reported. Furthermore, in PREZIES deep incisional SSIs and organ-space SSIs are evaluated under the umbrella term 'deep SSI', because in practice it is often difficult to distinguish deep SSIs from organ-space SSIs. Figure 3 shows a decision tree for assigning a SSI as published in a PREZIES brochure.

Participating hospitals collect data on putative determinants, based on international studies: age (date of birth), sex, type of surgical procedure, wound contamination class, ASA classification, duration of surgery, elective or acute procedure, administration of antimicrobial prophylaxis

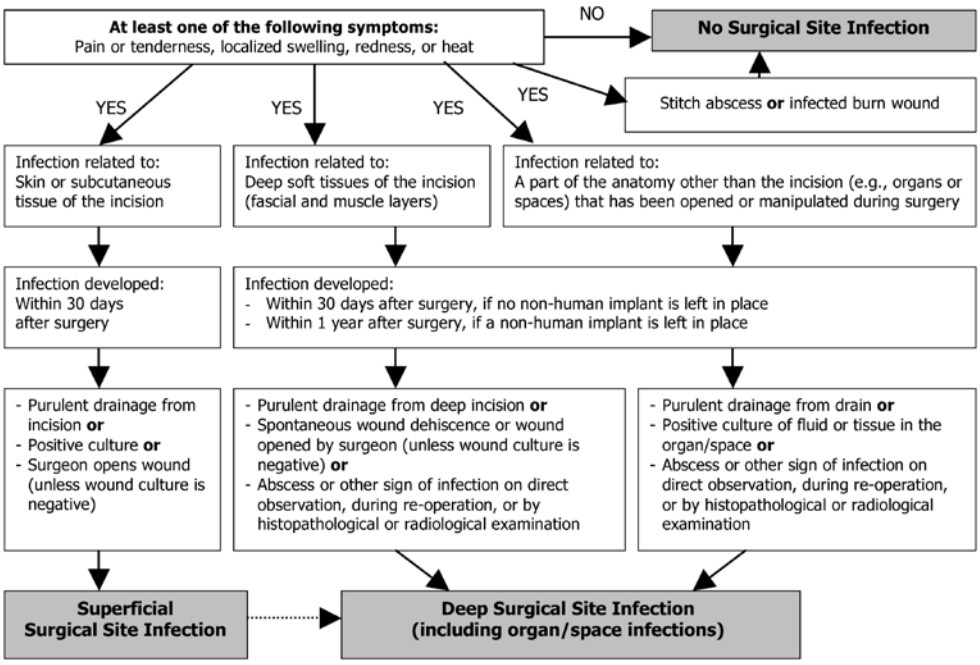

Figure 3. Decision tree for assigning the diagnosis of a surgical site infection (Source: PREZIES brochure).

(yes/no), multiple procedures performed through same incision, whether a non-human implant was left in place, and duration of hospitalization (date of admission, date of surgery, date of discharge). In case of an SSI, the date and type of infection are registered. The recording of cultured microorganisms is optional. Other optional variables that can be registered are obesity, method of pre-operative hair removal, and whether a re-operation occurred at the same body side.
For each surveillance module, workshops are organized yearly by PREZIES to give information, discuss positive and negative experiences, talk about possible infection prevention strategies, and practice cases studies.

DO

Postdischarge surveillance and validation
Important aspects of SSI surveillance within the PREZIES network are the performance of postdischarge surveillance and the ongoing validation of the surveillance.
According to the CDC definition, a SSI can develop until 30 days or 1 year (in case of a non-human implant) after surgery. Because the duration of hospitalization of surgical patients is generally shorter than 30 days, SSIs may develop after hospital discharge. The follow-up of patients after discharge ('postdischarge surveillance') will result in more-accurate SSI rates.
In 1998, PREZIES developed a method for postdischarge surveillance (PDS)[31]. PDS is voluntary, and for each hospital is recorded if and how PDS is carried out. However, the number of SSIs found

after discharge if hospitals performed PDS according to this method has not been investigated yet. In ***Chapter 2*** of this thesis, the method for PDS that is recommended by PREZIES is described. Furthermore, the value of postdischarge surveillance is evaluated by showing the number of SSIs that developed after discharge. This might give an indication of the surgical procedures with the most SSIs recorded after hospital discharge, and thus with a high need for PDS.

To ensure the accurateness and reliability of the infection rates, the data and process of surveillance should undergo periodic evaluation and validation. In PREZIES, voluntary on-site validation was implemented in 1999, and validation has been mandatory for each participating hospital every three years since 2002. As validation is very time-consuming, it is important to evaluate its usefulness. Therefore, the method and value of the validation visits are studied in ***Chapter 3*** of this thesis.

Procedure: femoropopliteal or femorotibial bypass (CTG code 33675 + 33676)
Number of hospitals: 37
Registration period: January 1, 2004 – December 31, 2005

	Procedures No.	**Superficial SSI % (No.)**	**Deep SSI % (No.)**	**Total SSI rate % (95% CI)**	**Expected* total SSI rate % (95% CI)**	**Procedures with antimicrobial prophylaxis %**
Your hospital this period	106	5.7 (6)	3.8 (4)	9.4 (5.2-16.5)	5.2 (2.3-11.2)	93
Your hospital since 1996, standard method PDS	388	5.4 (21)	4.6 (18)	10.1 (7.4-13.4)	5.1 (3.3-7.8)	90
National since 1996, standard method PDS	2280	2.9 (65)	2.2 (50)	5.0 (4.2-6.0)	5.0 (4.2-6.0)	80
Your hospital since 1996, no (standard method) PDS	-	-	-	-	-	-
National since 1996, no (standard method) PDS	1346	1.8 (24)	1.6 (21)	3.3 (2.5-4.4)	3.3 (2.5-4.4)	83

PDS: postdischarge surveillance
* Expected SSI rate is adjusted for NNIS risk index

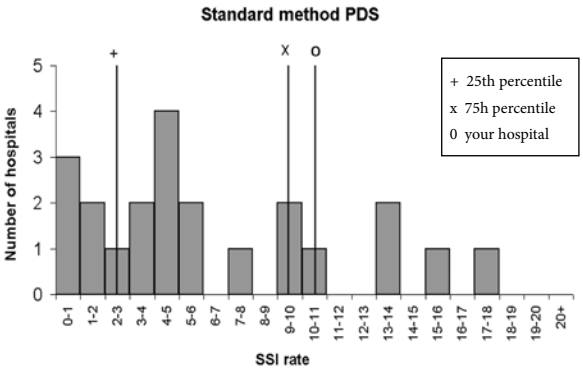

Figure 4. Example of a feedback report from PREZIES to the participating hospitals.

STUDY

Risk adjustment of SSI surveillance results in feedback reports

Every time a hospital sends data to the PREZIES network, it receives a procedure-specific feedback report, with its infection rates compared with the national rates. An example of a feedback report for the SSI module is shown in Figure 4.

For comparison of SSI rates between hospitals or within a hospital over time, it is important to correct for risk factors related to the patient, surgery or hospital. Nowadays, the NNIS risk index is used for risk-adjustment of SSI surveillance data by many countries. However, recent studies have shown that the NNIS index might not be the optimal risk score for all surgical procedures.[18 32 33]
In PREZIES, hospitals can compare their observed SSI rate with a predicted SSI rate, which is calculated by using the NNIS index. In ***Chapter 4*** of this thesis, we evaluate the accurateness of the predicted SSI rates and assess whether the risk adjustment can be improved. For many surgical procedures, we compare the predictive power of the NNIS index to new models including other determinants.

Comparison of SSI surveillance between the Netherlands and Germany

There is an increasing interest in comparing SSI data, not only between hospitals within a country, but also between countries. We as well wondered how patient safety in the Netherlands is related to other countries. However, comparing countries is more difficult than hospitals within a country, because the healthcare system and practices, type of hospitals, patient-mix, and reason for participation in a national surveillance system are likely to vary between countries. A previous study showed that the practice of the surveillance in the Netherlands (PREZIES) and Germany (KISS) are comparable: their protocols are based on the American NNIS protocol using the definitions developed by the CDC, participation is voluntary and confidential, the project is funded by the Ministry of Health, and the networks are coordinated centrally by a multidisciplinary team.[34]
Therefore, in ***Chapter 5*** of this thesis the SSI surveillance data of KISS and PREZIES are compared regarding the patient and hospital characteristics and SSI rates for several surgical procedures

The time-trend in SSI rate

Already in 1985, Haley showed that SSI control programs could reduce hospitals' infection rates by 32% if the programs included organized surveillance and control activities, a trained infection control physician, one infection control nurse per 250 beds, and a system for reporting infection rates to practicing surgeons.[21] Since then, the effect of surveillance in reducing SSI rates has been demonstrated by others.[35-38]
Also for the Dutch PREZIES surveillance data, a reduction in SSI rate with longer participation was shown by Geubbels.[39] She used SSI surveillance data from the period 1996-2000, and analyzed the trend in SSI rates over seven pooled procedures as to increase power. The number of records in the PREZIES database has more than doubled since. Therefore, in ***Chapter 6*** of this thesis, we

evaluate the time-trend in SSI rate in relation to the duration of surveillance, separately for five frequently-performed surgical procedures, using data from 1996 to 2006.

ACT

Interventions that change infection control in the hospital can lead to improvements in the quality of care and with that may reduce the number of nosocomial infections. A national network for surveillance of nosocomial infections can serve as an infrastructure for intervention studies on the quality of care. The PREZIES surveillance network contributed to a multi-center intervention project to improve the quality of surgical prophylaxis. PREZIES provided the 'patient outcome' parameter, namely the occurrence of SSIs.
The goal of prophylactic antibiotics is to eradicate or inhibit the growth of contaminating microorganisms such that SSIs can be avoided. An adequate concentration of antibiotic within the serum and tissues during the period between incision and closure of the wound is necessary. The efficacy of antimicrobial prophylaxis for preventing SSIs was established in the 1960s and has since been demonstrated repeatedly.[40-43] Proper administration of antimicrobial prophylaxis might prevent 40% to 60% of SSIs.[3] The timing of the first administration is critically important and the most common problem in antibiotic prophylaxis for SSIs.[41 43 44] Consensus guidelines state that prophylactic antibiotics should be given within 60 minutes before incision to achieve therapeutic levels,[3 45 46] and both early and late administration increase SSI rates.[43]

In 2000, the Dutch Working Party on Antibiotic Policy (SWAB) developed a guideline for perioperative prophylaxis in Dutch hospitals.[47] This guideline focuses on procedures that are performed relatively often, those with a relatively high SSI risk, those for which the consequences of a SSI would be severe and those for which the benefit of prophylaxis has been studied extensively. The guideline recommends intravenous prophylaxis of an inexpensive non-toxic antibiotic with a limited spectrum, which is not used extensively in therapy, administered within 30 minutes before the first incision. For reasons of cost-effectiveness and prevention of induction of resistance, single-dose prophylaxis is recommended, which has been proven as effective as multiple-dose prophylaxis for most procedures[48-53].

In 2000-2002, the Surgical Prophylaxis and Surveillance project (CHIPS) took place, in which the adherence to local hospital guidelines for surgical prophylaxis was assessed, and the national guideline issued by the SWAB was implemented. The aim of the CHIPS project was to improve the quality of prophylaxis in Dutch hospitals and to promote prudent use while maintaining or improving the efficacy of prophylaxis in reducing SSIs. This prospective multi-center intervention study had a before-and-after design without a control group. Thirteen hospitals throughout the Netherlands participated, which is 13% of all hospitals in the Netherlands. All hospitals participated in the component "Surgical site infections" of the Dutch PREZIES network. The CHIPS study was limited to frequently performed procedures for which antimicrobial prophylaxis is generally

recommended[47 54]: grafting of the aorta, femoropopliteal or femorotibial bypass, various colorectal procedures, abdominal and vaginal hysterectomy with or without vaginal repair, total hip arthroplasty and replacement of the head of the femur.

During the pre-intervention period, the antibiotic choice, duration, dose, dosing interval and timing of the first dose were concordant with the hospital guideline in 92%, 82%, 89%, 43% and 50%, respectively. Adherence to all aspects of the guideline simultaneously, however, was achieved in only 28%.[55] After the pre-intervention period, every hospital received feedback of its own results on the administration of antibiotic prophylaxis. Depending on the results, the intervention focused on modification of local guidelines, guideline adherence or both.

Prophylaxis was completely administered according to the recommendations of the national guideline in only 0.4% of the patients before the intervention, and in 25% after the intervention. After the intervention, the antimicrobial use decreased from 121 to 79 defined daily doses per 100 procedures, costs were reduced by 25% per procedure, and antibiotic choice and duration improved.[56] However, the reduction in antibiotic use was not supposed to lead to a decreased efficacy of prophylaxis, as measured by a higher SSI incidence. Therefore, in ***Chapter 7*** of this thesis the patient outcome of the optimized and restrictive antimicrobial prophylaxis policy is assessed by comparing the SSI rate before and after the intervention.

SSIs after total hip arthroplasty are rare but severe, often leading to revision surgery and impairment of short-term functional outcome, and resulting in a slight increase in mortality risk.[57] It is the most-often registered type of surgical procedure within PREZIES. Most studies that have analyzed risk factors for SSIs following total hip arthroplasty have mainly focused on patient, procedure, or hospital characteristics.[58-61] However, prospective studies of the contribution of the qualitative aspects of surgical prophylaxis to the prevention of SSIs following this procedure are scarce. In ***Chapter 8***, the contribution of prophylaxis process parameters to the incidence of SSI for the population undergoing total hip arthroplasty is explored, with emphasis on the timing of administration of prophylaxis.

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2

Impact of postdischarge surveillance on surgical site infection rates for several surgical procedures: results from the nosocomial surveillance network in the Netherlands

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ABSTRACT

Objective: To compare the number of surgical site infections (SSIs) registered after hospital discharge with respect to various surgical procedures and to identify the procedures for which postdischarge surveillance (PDS) is most important.

Design: Prospective SSI surveillance with voluntary PDS. Recommended methods for PDS in the Dutch national nosocomial surveillance network are addition of a special registration card to the outpatient medical record, on which the surgeon notes clinical symptoms and whether a patient developed an SSI according to the definitions; an alternative method is examination of the outpatient medical record.

Setting: Hospitals participating in the Dutch national nosocomial surveillance network between 1996 and 2004.

Results: We collected data on 131,798 surgical procedures performed in 64 of the 98 Dutch hospitals. PDS was performed according to one of the recommended methods for 31,134 operations (24%) and according to another active method for 32,589 operations (25%), and passive PDS was performed for 68,075 operations (52%). Relatively more SSIs were recorded after discharge for cases in which PDS was performed according to a recommended method (43%), compared with cases in which another active PDS method was used (30%) and cases in which passive PDS was used (25%). The highest rate of SSI after discharge was found for appendectomy (79% of operations), followed by knee prosthesis surgery (64%), mastectomy (61%), femoropopliteal or femorotibial bypass (53%), and abdominal hysterectomy (53%).

Conclusions: For certain surgical procedures, most SSIs develop after discharge. SSI rates will be underestimated if no PDS is performed. We believe we have found a feasible and sensitive method for PDS that, if patients routinely return to the hospital for a postdischarge follow-up visit, might be suitable for use internationally.

INTRODUCTION

Surgical site infections (SSIs) are the second most common type of nosocomial infection, after urinary tract infection, and account for approximately 17% of all nosocomial infections.[1] SSIs lead to increased morbidity and costs, because patients who develop SSIs have a longer hospital stay, are more likely to be readmitted, and are more likely to die.[2-10] SSI rates, especially in clean surgery in which no bacteria-colonized tract of the body is opened, are considered an indicator of the quality of surgical and postoperative care given in hospitals.

Over the past decade, there has been an increasing trend toward shorter length of hospital stay and use of ambulatory day surgery. Thus, an increasing proportion of SSIs occur after the patient has left the hospital, which makes postdischarge surveillance (PDS) increasingly important. If no PDS is performed, SSIs will be missed, and the recorded infection rates will be underestimations of the real infection rates. Furthermore, inter-hospital comparison may not be valid if the sensitivity and specificity of the PDS methods used are not similar.

Unlike for inpatient SSI surveillance, there is no international consensus on the optimal method for PDS.[3,11,12] Two challenges for a good method of PDS are to follow up all patients and to accurately diagnose the presence or absence of an SSI. Direct examination of the wounds of all patients by a trained professional is often used as the "gold standard" for detection of SSIs. For PDS this method is, however, labor-intensive, difficult to perform routinely, and very expensive.[12] Therefore, the third challenge is feasibility, with limited time investment.

In the Netherlands in 1998, a literature review was conducted to assess whether there was a method for PDS that would be feasible for all hospitals, in terms of a high sensitivity and a low time investment.[13] As a result of that study, in the Dutch national nosocomial surveillance network PREZIES ("PREventie van ZIEkenhuisinfecties door Surveillance") 2 methods for PDS are recommended. The first method is addition of a special registration card to the outpatient medical record, on which the surgeon notes clinical symptoms and whether a patient developed an SSI according to the definitions. This is recommended as a feasible and reliable method for PDS in the Netherlands, because almost every patient is seen again by the surgeon after hospital discharge. A crucial point is that the surgeon returns the registration cards of *all* patients who visited the outpatient clinic. If the feedback and collaboration of the surgeon are suspected to be unsatisfactory, the method needs to be validated internally. If unsatisfactory validity is observed, (additional) examination of all outpatient medical records is the alternative recommended method for PDS. A condition of this method is that the medical reporting in the outpatient record is sufficient.

Examples of other - not recommended - active PDS methods that can be used are questionnaires sent to patients, questionnaires sent to surgeons, and telephone interviews with patients. If no active PDS is performed, SSIs can still be detected accidentally (for instance, when patients are hospitalized for this type of infection). This is called "passive" PDS.

Studies that examine the value added by PDS to SSI surveillance often focus on only one or a few surgical procedures and usually involve a single hospital.[3,6,8,14,15] With this approach, it is impossible

to discover the procedures for which PDS is most essential, which may be important for efficient allocation of resources.
In the present study, we analyzed PREZIES data on several surgical procedures from 62 hospitals. The purpose was to compare the number of SSIs registered after discharge with respect to various surgical procedures and to identify the procedures for which PDS is most important. In addition, we compared SSI rates obtained with recommended PDS methods and those obtained with other active PDS methods and with passive PDS.

METHODS

The PREZIES network in the Netherlands started in 1996 with surveillance of SSIs. Participation in PREZIES is voluntarily. Hospitals are free to make a selection of procedures they want to include in the surveillance. They can also choose how long they want to participate, but a minimum of 3 months is recommended, to obtain enough data for reliable results. According to the PREZIES protocol, patients younger than 1 year are excluded as well as patients with an infection at hospital admission. For the current study, patients were also excluded if the method for PDS was unknown or if the date of infection was unknown.
The definition of an SSI used is based on the definition of the Centers for Disease Control and Prevention,[11,16] which was translated by the Dutch Working Party on Infection Prevention.[17] We have chosen to evaluate both deep incisional and organ-space SSIs under the umbrella term "deep SSI".
According to the CDC definition of nosocomial infection, an SSI is an infection that occurs within 30 days after the operation if no implant is left in place or within 1 year after the operation (only deep SSIs) if an implant is left in place and the infection appears to be related to the operation. An implant is understood to mean a non-human-derived implantable foreign body (eg, a prosthetic heart valve, a non-human vascular graft, a mechanical heart, or a hip prosthesis) that is permanently placed in a patient during surgery. To ensure that PDS was completed for all records in the database, we excluded data from the year 2004 for specialties in which implants are often used; this was done for bone surgery and vascular surgery.
The person responsible for the surveillance (predominantly the infection control professional) ensures that everybody involved collects data according to the surveillance protocol and uses the right definitions. To monitor the quality and reliability of the surveillance data in PREZIES, the surveillance at each participating hospital is validated at least once every 3 years. The following information is collected on the patients, procedures, hospitals, and infections: the patient's sex and date of birth; the dates of admission, surgery, and discharge; the type and duration of the procedure; the American Society of Anesthesiologists physical status score[18] for the severity of any underlying disease; the wound contamination class;[11] whether antibiotic prophylaxis was given (yes or no); the type of procedure (elective or emergency); the type of hospital (university or peripheral); the date of infection; and the type of infection (superficial incisional, deep incisional, or organ-space).
Hospitals in the PREZIES network are allowed to change the method used for PDS over time and

to perform different methods for different surgical procedures. Every time a hospital sends in registered data, the infection control professional states which method for PDS is used for which procedures. A distinction is made between recommended PDS, other active PDS, and passive (no active) PDS.

SSI rates were determined according to PDS method and according to type of procedure. The percentage of SSIs diagnosed after discharge was compared between PDS methods and between procedures. Changes over time were examined.

Comparative analysis of categorical variables was performed using a $\chi 2$ test with the Yates correction. Continuous variables were analyzed using the Students *t* test for normally distributed variables and the Mann-Whitney *U* test for non-normally distributed variables. The nonparametric Kruskal-Wallis test was used to compare the values of a non-normally distributed variable between multiple independent groups. The *P* values of all tests of significance were 2-tailed, and a *P* value of .05 or less was considered to indicate statistical significance. All statistical analyses were performed using SAS software, version 8.2 (SAS Institute).

RESULTS

The PREZIES network has collected SSI data on 143,321 procedures from 1996 to 2004. These data were collected at 73 hospital sites in 64 hospitals of the total of 98 hospitals in the Netherlands. One record was excluded because the infection date was unknown, and 8,122 records were excluded because the method for PDS was unknown. We also excluded vascular surgery and bone surgery data from 2004 (records on 3,400 procedures), because the 1-year postdischarge follow-up period for implant surgery had not passed yet. Therefore, the results we describe are based on data for 131,798 records from 73 hospital sites (hereafter referred to as "hospitals"). The number of hospitals participating yearly varied between 29 and 50 during the period 1996-2003 and was 11 in 2004. This low number of participating hospitals in 2004 occurred partly because not all hospitals had sent in their data yet at time the analyses were performed and partly because the records for vascular and bone surgery were excluded.

PDS was performed according to one of the recommended methods for 31,134 operations (24%) and according to another active method in 32,589 operations (25%), and passive PDS was performed in 68,075 operations (52%) (Table 1). Relatively more postdischarge SSIs were recorded

Table 1. Comparison of the number of surgical site infections (SSIs) identified by various postdischarge surveillance (PDS) methods.

PDS method used	No. of operations	No. of SSIs	SSI rate, (%)[a]	No. (%) of SSIs that developed after hospital discharge
Recommended PDS	31,134	1154	3.7	492 (43)
Other active PDS	32,589	1036	3.2	306 (30)
Passive PDS	68,075	2,086	3.1	514 (25)
Total	131,798	4,276	3.2	1,312 (31)

[a] Percentage of operations after which an SSI developed.

Table 2. Comparison of the types of surgical site infection (SSI) identified by various postdischarge surveillance (PDS) methods during and after hospitalization.

	SSI during hospitalization			SSI after discharge		
PDS method used	**No. of SSIs**	**Deep, %**	**Superficial, %**	**No. of SSIs**	**Deep, %**	**Superficial, %**
Recommended PDS	646	40	60	492	45	55
Other active PDS	715	45	55	304	49	51
Passive PDS	1,558	43	57	512	61	39
Total	2,919	43	57	1,308	52	48

for cases in which PDS was performed according to one of the recommended methods (43% of operations), compared with cases in which other active PDS was used (30%) or passive PDS was used (25%).

In Table 2, the type of SSI detected -superficial or deep- is compared for SSIs that developed during and after hospitalization, stratified by PDS method. For 49 operations, information on the type of SSI was missing, and therefore these operations are excluded from the analysis. Relatively more superficial SSIs were recorded when PDS was performed according to one of the recommended PDS methods. A relatively smaller proportion of superficial SSIs were recorded after discharge (48% of SSIs) than before discharge (57%), but the proportion of superficial SSIs identified after discharge was higher with use of a recommended PDS method than with use of other active and passive PDS methods. The differences between PDS methods in the types of SSI identified were larger for postdischarge SSIs ($P < .001$) than for in-hospital SSIs ($P = .17$).

Figure 1 shows that the percentage of hospitals that predominantly performed PDS according to one of the recommended methods increased from 24% in 1996 to 50% in 2003. Both a shorter length of stay and use of a recommended PDS method result in a higher proportion of infections being

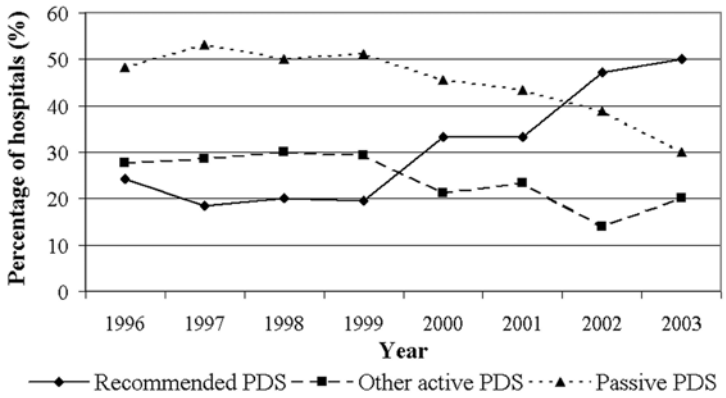

Figure 1. Predominant postdischarge surveillance (PDS) methods used by hospitals in the Netherlands, by year, 1996-2003. Data from 2004 were excluded from this figure because of the relatively small number of hospitals that reported in that year.

detected after discharge. Only for total hip prosthesis surgery, a frequently performed procedure, was there a clear decrease in the median length of stay for patients without an SSI observed, from 13 days during 1996-1999 to 10 days during 2000-2003 ($P < .001$, data not shown). Simultaneously, there was an increase in the percentage of SSIs that developed after discharge for this procedure, from 23% to 44% ($P < .001$, data not shown). This increase was similar for all PDS methods ($P = .83$). Thus, the relatively high proportion of postdischarge SSIs detected by the recommended PDS method, compared with other methods, truly is the result of using this PDS method and cannot be explained by shorter hospital stays. However, the mean proportion of SSIs associated with total hip surgery that were detected after discharge during the period 1996-2003 gives an underestimation of the proportion of SSIs detected after discharge in recent years.

Table 3. Comparison of the number of surgical site infections (SSIs) identified by recommended postdischarge surveillance (PDS) and by passive PDS during and after hospitalization, according to surgical procedure.

	Recommended PDS used				Passive PDS used			
	All SSIs		Postdischarge SSIs		All SSIs		Postdischarge SSIs	
Procedure[a]	No. of SSIs	SSI rate, %[b]	No. of SSIs	% of all SSIs[c]	No. of SSIs	SSI rate, %[b]	No. of SSIs	% of all SSIs[c]
Appendectomy	49	6.6	37	76	65	4.1	23	35
Knee prosthesis surgery	108	2.7	69	64	73	1.5	37	51
Mastectomy	62	6.2	38	61	141	4.2	59	42
Femoropopliteal or -tibial bypass	55	18.6	29	53	74	8.4	21	28
Abdominal hysterectomy	30	2.3	16	53	16	1.3	1	6
Total hip prosthesis surgery	277	2.7	118	43	303	2.7	74	24
Repair of osteopertrochanteric collum fracture	16	7.6	5	31	21	3.0	2	10
Replacement of head of femur	89	5.7	23	26	139	5.3	18	13
Colon resection	92	11.3	23	25	218	11.8	6	3
Reconstruction of aorta	23	5.4	5	22	38	3.5	5	13
Revision of total hip prosthesis	34	6.3	7	21	82	6.6	10	12
Anterior resection of rectosigmoid	42	13.0	7	17	98	11.1	6	6
Osteosynthesis of collum fracture	26	3.4	3	12	52	4.2	4	8
Removal of infected hip	15	10.4	0	0	11	4.4	2	18

[a] Procedures in which at least 10 SSIs were identified by both PDS methods.
[b] Percentage of operations after which an SSI developed.
[c] Postdischarge SSIs as a percentage of all SSIs.

Table 3 shows the number of SSIs identified, overall and after discharge, by recommended PDS and passive PDS, according to the type of surgical procedure. For 10 procedures, a higher total SSI rate was recorded with use of recommended PDS than with use of passive PDS; the opposite was the case for 4 procedures. Relatively fewer SSIs were recorded after discharge with use of passive PDS, compared with recommended PDS, for 13 of 14 procedures. The highest percentage of postdischarge SSIs (ie, postdischarge SSI as a percentage of all SSIs) identified by recommended PDS was found for appendectomy (76%), followed by knee prosthesis surgery (64%), mastectomy (61%), femoropopliteal or femorotibial bypass (53%), and abdominal

Table 4. Comparison of the number of deep surgical site infections (SSIs) identified by recommended postdischarge surveillance (PDS) and by passive PDS during and after hospitalization, according to surgical procedure.

Procedure[a]	Recommended PDS		Passive PDS	
	No. of deep SSIs that occurred in the hospital	No. (%) of deep SSIs that occurred after discharge	No. of deep SSIs that occurred in the hospital	No. (%) of deep SSIs that occurred after discharge
Knee prosthesis surgery	11	41 (79)	8	26 (76)
Appendectomy	7	23 (77)	34	14 (29)
Revision of total hip prosthesis	9	5 (63)	18	8 (31)
Total hip prosthesis surgery	34	56 (62)	48	57 (54)
Femoropopliteal or -tibial bypass	12	12 (50)	18	11 (38)
Replacement of head of femur	33	14 (30)	32	15 (32)
Reconstruction of aorta	8	3 (27)	15	4 (21)
Anterior resection of rectosigmoid	20	5 (20)	50	6 (11)
Colon resection	35	9 (20)	133	2 (1)

[a] Procedures in which at least 10 deep SSIs were identified by both PDS methods.

hysterectomy (53%).

Table 4 shows the number of deep SSIs identified by recommended PDS and by passive PDS during and after hospitalization, according to surgical procedure (procedures for which at least 10 deep SSIs were identified by both PDS methods). For 8 of the 9 procedures, recommended PDS identified relatively more deep SSIs after discharge than did passive PDS. The percentage of postdischarge deep SSIs identified ranged from 1% for colon resection with passive PDS to 79% for knee prosthesis with recommended PDS.

In addition, we investigated differences in the duration of hospital stay for patients with and patients without SSIs, considering only procedures where one of the recommended PDS methods was used and at least 100 operations and 10 SSIs were registered. The median hospital stay for patients without an SSI varied from 3 days for hernia inguinalis surgery to 17 days for removal of an infected hip prosthesis. For all types of procedures together, patients with an SSI detected during hospitalization had a longer median hospital stay (23 days) than did patients without an SSI (10 days) and patients with a postdischarge SSI (9 days). Thus, an SSI that developed before discharge resulted, on average, in 14 extra hospital days, ranging from 5 extra bed days for a caesarean section to 42 extra bed days for a femoropopliteal or femorotibial bypass (values not corrected for risk factors).

Figure 2 shows the percentage of all SSIs (both superficial and deep together) according to postoperative day, that developed during the hospital stay and after discharge. The peak for SSIs recorded during the patient's hospital stay was during postoperative week 1, and the peak for SSIs recorded after discharge was during postoperative week 2. Of the infections detected during the hospital stay, 90% of the superficial SSIs was detected at day 16, and 90% of the deep SSIs were detected at day 20. Of the infections detected after discharge, 90% of the superficial SSIs was detected at day 25, and 90% of the deep SSIs was detected at day 122.

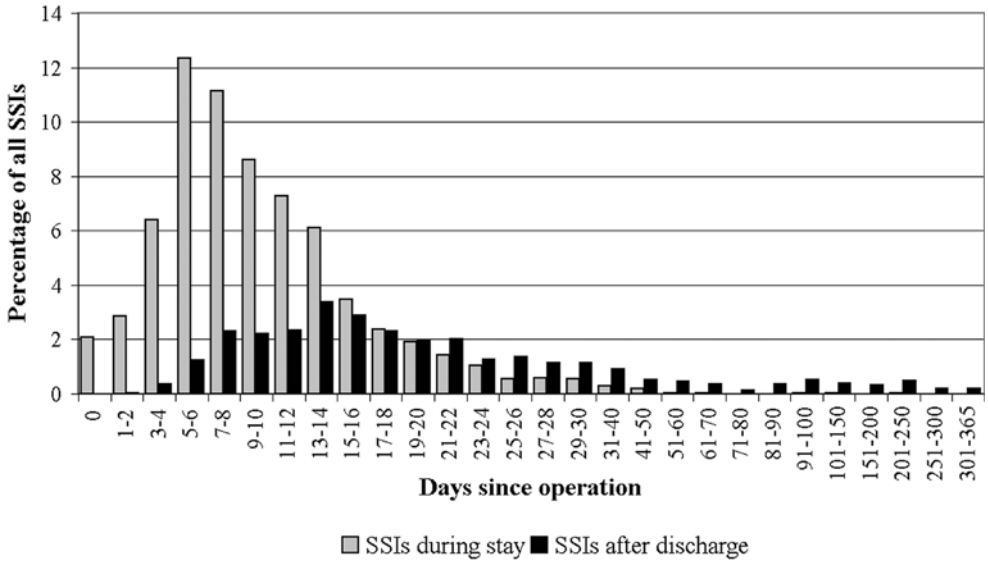

Figure 2. Time curve showing the percentage of all SSIs (both superficial and deep, with data from all procedures and all postdischarge surveillance methods together) that developed during hospitalization and after discharge, by postoperative day.

We also examined whether there was a relationship between the time to infection and the wound contamination class. For procedures in contamination class 1, the median time to infection was 12 days; for contamination class 2, it was 9 days; for contamination class 3, it was 9 days; and for contamination class 4, it was 7 days. For procedures in contamination class 1, 37% of SSIs were found after discharge; for contamination class 2, 22%; for contamination class 3, 17%; and for contamination class 4, 15%. The distribution of the time to infection was significantly different between wound contamination classes ($P < .001$).

DISCUSSION

The increasing trend towards more outpatient surgery and a shorter postoperative hospital stay makes it more difficult for infection control professionals to detect all SSIs. Therefore, PDS becomes increasingly important to obtain correct and complete -and thus useful- infection frequency data. According to our national surveillance data, up to 79% of SSIs (for appendectomy) occurred after the patient's discharge from the hospital.

The methods for PDS recommended by the Dutch national surveillance network, PREZIES, are addition of a special registration card to the outpatient medical record, on which the surgeon notes clinical symptoms and whether a patient developed an SSI according to the definitions; an alternative is examination of the outpatient medical record. These methods are considered to be achievable and reliable for most Dutch hospitals, because almost every patient is seen by their

surgeon after discharge. Besides the recommended methods, other PDS methods could be used, such as telephone interviews or questionnaires filled in by the surgeon or patient. The disadvantage of questionnaires is that by no means all of them will be returned. Moreover, self-assessments by patients are not very reliable. Telephone interviews by the infection control professional can result in more reliable information but are very time-consuming. Questionnaires filled in retrospectively by surgeons sometimes have a low sensitivity. Direct observation of the wound by a surgeon or infection control professional (one who is familiar with the definition of an SSI) has seemed more reliable, but is also more expensive and time-consuming.[3,12,19-22]

Another issue, besides the costs and time consumption, is the follow-up rate. Rates of follow-up can be influenced by socioeconomic conditions, levels of education, population density, availability of transport and population mobility. When follow-up is inadequate, the follow-up "responders" may no longer be representative of the original population. A potential bias is introduced (attrition bias).[23] The follow-up rates in Dutch hospitals are high, as (almost) every patient returns to the hospital or outpatient clinic after discharge. However, our surveillance data cannot provide sensitivity estimates for our recommended PDS methods because we could not compare it with a "gold standard".

If one of the two methods for PDS recommended by PREZIES was used, a higher proportion of SSIs were found after discharge (43%) than if another active method (30%) or passive surveillance (25%) was used. No distinction between the two recommended PDS methods could be made, as it was not separately recorded which of the two methods was used. It is favorable that, since 1999, the relative number of Dutch hospitals participating in PREZIES that used a recommended PDS method has increased, up to 50% in 2003. This increase since 1999 might be explained by the fact that the importance of using the recommended methods has been brought to the attention of healthcare professionals multiple times since 2000; for example, during the yearly workshops organized by the PREZIES network and during validation visits.

It is remarkable that for some surgical specialties (peripheral blood vessel surgery and mammary surgery), PDS is rarely performed according to one of the recommended methods (for 14% and 14% of operations respectively), whereas many SSIs occur after discharge (51% and 63% of SSIs, respectively). We should focus on these specialties and try to convince the surgeons and infection control professionals of the importance of performing PDS for these specialties.

The reported percentage of SSIs found after discharge differs greatly between countries. This depends on the type of procedures for which surveillance is performed but might also be influenced by differences in PDS methods and differences in length of hospital stay. For example, for knee prosthesis surgery, Friedman et al.[24] found 72% of the SSIs after discharge, whereas we found 64% after discharge. For cesarean section, 2 studies recorded 83% of the SSIs after discharge,[20,25] whereas we found 68% after discharge (data not shown). Hardly any study examined and reported the number of SSIs discovered through passive surveillance. Medina-Cuadros et al.[26] found 14% after discharge by passive surveillance. In our study, 25% of the SSIs were detected by passive surveillance after discharge. Differences in the performance of PDS methods makes it hard to compare SSI rates between hospitals or between countries, especially when information on PDS is not registered, which for example is the case for the National Nosocomial Infections Surveillance System data.

In our study, the number of SSIs recorded after discharge depended on the wound contamination class. This is partly because patients with a higher wound contamination class have a longer hospital stay.[26,27] However, the time to infection was also shorter with increasing wound contamination class. A likely explanation is that contamination during surgery contributes to wound infection, so that infection following procedures classified as "dirty" is likely to develop quickly, but infection following a procedure classified as "clean" is likely to present later, usually after hospital discharge.

We found relatively fewer superficial SSIs after discharge than before discharge from the hospital. This is partly caused by the difference in definition; superficial SSIs may occur until 30 days after surgery, and deep SSIs may occur until 1 year after surgery, for a synthetic (non-human-derived) implant. Another explanation might be that superficial infections are less severe than deep SSIs. Therefore, patients with superficial SSIs will less often return to the hospital, which results in an underestimation of the number of superficial SSIs that occur after hospital discharge. However, even with passive PDS, 38% of the postdischarge SSIs were superficial. Apparently, SSIs are noticed and registered even though no active PDS method is used.

The way passive PDS is performed will differ between hospitals. Some might not register postdischarge SSIs at all, whereas others might watch carefully for readmitted patients with an SSI. However, this detailed information on the performance of passive PDS by hospital is not available.

With use of a recommended method for PDS was used, the percentage of all deep SSIs that developed after discharge was highest for knee prosthesis surgery, appendectomy, revision of total hip prosthesis, and total hip prosthesis surgery. In particular, PDS should be performed for surveillance of such procedures, because deep SSIs are more severe than superficial SSIs and have more negative consequences for patients and higher costs.

Because of the more severe side effects, a patient with a deep SSI is more likely to return to the hospital after discharge, at which time a deep SSI can be found by passive surveillance. However, this assumption is not confirmed by the PREZIES data, because the ratio of deep SSIs identified after discharge to deep SSIs identified in the hospital was lower for nearly all surgical procedures with use of passive PDS, compared with use of a recommended method for PDS. Thus, it seems that not all patients with a deep SSI return to the hospital where the surgery was performed. In addition, passive PDS might have a lower sensitivity.

Some studies have shown that there are important epidemiologic differences between in-hospital SSIs and postdischarge SSIs.[15,26,28,29] Although inpatients with SSIs were characterized by known risk factors, patients with a postdischarge SSIs were not. For most of the classic risk factors, patients with postdischarge SSI were more similar to non-infected patients than to patients with an in-hospital SSI. If postdischarge SSIs are taken into account in the analysis of risk factors for SSI, it would decrease the degree of association between classic risk factors and SSI risk to an extent related to the proportion of postdischarge SSIs among all SSIs.[26]

Data in the present study also demonstrated differences in risk factors between patients with in-hospital SSIs and patients with postdischarge SSIs according to the type of surgical procedure. However, there were no obvious risk factors for in-hospital or postdischarge SSI that were similar for several surgical procedures (data not shown).

In summary, it appears that for comparison of SSI rates, it is extremely important to know whether and how PDS was performed. In each report, publication or communication, the PDS method used and the proportion of patients seen after discharge should be given routinely. In the Dutch SSI surveillance system, recording the PDS method used is compulsory; however, it is not mandatory to record whether each patient is seen again by the surgeon after discharge. But we do regularly emphasize the importance of registering the latter information.

Because surveillance that includes PDS yields the most correct infection rates (ie, those with the smallest underestimations), it is best to perform PDS, especially if conducting surveillance for procedures that usually have a short length of stay and/or many infections that occur after discharge.

In the current study, performance of active PDS appeared to be extremely important for most surgical procedures. Because of the significance of PDS, the yearly Dutch national reference SSI rates for each type of surgical procedure are given separately for (1) operations in which PDS was performed according to one of the two recommended methods (in-hospital and postdischarge SSIs are reported together) and for (2) all operations with or without PDS performed, in which only the in-hospital SSIs were reported. Therefore, each hospital can compare their own infection rates with appropriate national reference numbers. Ideally, all hospitals would perform PDS in the same way. We believe we have found a feasible and sensitive method for PDS that may be suitable for use internationally, in circumstances in which patients routinely return to the hospital for postdischarge checkup and healthcare workers can be convinced of the importance and value of PDS.

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3

Validation of surgical site infection surveillance in the Netherlands

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ABSTRACT

Objective: To describe how continuous validation of data on surgical site infection (SSI) is being performed in the Dutch National Nosocomial Infection Surveillance System (Preventie Ziekenhuisinfecties door Surveillance [PREZIES]), to assess the quality and accuracy of the PREZIES data, and to present the corresponding outcomes of the assessment.

Design: Mandatory, 1-day validation visit to participating hospitals every 3 years. The process of surveillance, including the quality of the method of data collection, is validated by means of a structured interview. The use of SSI criteria is validated by review of medical records, with the judgment of the validation team as the criterion standard.

Setting: Hospitals participating in PREZIES.

Results: During 1999-2004, the validation team visited 40 hospitals and reviewed 859 medical charts. There was no deviation between reports of SSI by infection control professionals and findings by the PREZIES validation team at 30 hospitals and 1 deviation in each of 10 hospitals; the positive predictive value was 0.97, and the negative predictive value was 0.99. The validation team often gave advice to the hospital, aimed at perfecting the process of surveillance. On 2 occasions, data were removed from the PREZIES database after the validation visit revealed deviations from the SSI surveillance protocol that could have resulted in nonrepresentative SSI rate data.

Conclusions: PREZIES is confident that the assembled Dutch SSI surveillance data are reliable and robust and are sufficiently accurate to be used as a reference for interhospital comparison. PREZIES will continue performing on-site validation visits, to improve the process of surveillance and ensure the reliability of the surveillance data.

INTRODUCTION

Surgical site infection (SSI) is a common nosocomial infection that leads to increased morbidity and mortality, causes a longer hospital stay, and increases cost.[1-3] In the 1970s, the Study on the Efficacy of Nosocomial Infection Control showed that infection surveillance with feedback of the results to the staff reduces infection rates.[4] In a nosocomial infection surveillance system, infection rates are compared within and between hospitals. To ensure the quality and reliability of surveillance data, surveillance methods should be standardized, and a clear statement of the criteria used to analyze the patients, procedures and infection variables must be included.[5] Validation is the only independent means to determine the accuracy for surveillance data, and thus it is essential for determining the reliability of a SSI surveillance network in which data are aggregated from multiple data collectors and used for comparisons between hospitals.

In recent decades, national surveillance systems for detection of nosocomial infections have been set up in many countries. Data are being collected from several institutions and gathered in one national reference database in these multi-hospital surveillance systems, and ensuring the quality of surveillance data is the responsibility of both the participating hospitals and the organization managing the surveillance system. The accuracy of the data depends on the experience, qualifications, training and awareness of the surveillance staff,[6-8] and all staff must work according to the same protocol and use the same definitions accurately. Validation is necessary to get insight into the reliability of data. Furthermore, validation may identify difficulties within each hospital and within the surveillance program.[9]

Although many countries perform nosocomial infection surveillance, hardly anyone has reported about validation of data. Most of the few published studies regarding validation were performed in only one institution or hospital,[10,11] and often only the outcome was validated and not the process.[8,11-13] To our knowledge, no national surveillance system other than that in the Netherlands validates nosocomial infection data continuously. In Germany, Gastmeier et al.[7] performed a validation study of the prevalences of nosocomial infection among 14,966 patients at 72 hospitals. A remarkable difference in accuracy was found among the institutions. Because this was a prevalence study, many patients had to be included because of the low incidence of infection, and sometimes the presence of a SSI could not be assessed because laboratory test results were not yet available. The National Nosocomial Infection Surveillance system (NNIS) performed a validation study of surveillance for nosocomial infection in intensive care units,13 but the NNIS does not validate data on SSI surveillance. Their SSI data are considered reliable because all participating infection control professionals (ICPs) undergo surveillance training for 2 weeks and because standardized and validated data collection protocols are used. In addition, because the surveillance system is voluntary and confidential, ICPs are thought to have no incentive to provide incorrect estimates of their results. In the United States, 2 separate validation studies have been performed. The hospital-wide nosocomial infection surveillance at the University of Iowa Hospitals and Clinics was validated in 1987. The validation of SSI surveillance data for 953 patients revealed a sensitivity of 81%, a specificity of 98%, a positive predictive value of 75%, and a negative predictive value of

98%.[10] During 1990 and 1991, the Regional Medical Center at Memphis (Memphis, TN) validated SSI surveillance data for 925 patients and found a sensitivity of 84% and a specificity of 99.8%. Accuracy of the data seemed to be related to experience of the surveillance staff, and incisional SSIs appeared to be more difficult to identify than deep SSIs.[11]

In this article, we describe how continuous validation is being performed in the Dutch National Nosocomial Infection Surveillance (Preventie Ziekenhuisinfecties door Surveillance [PREZIES]). Furthermore, we give the results of our validation of the process of data collection and the interpretation of the criteria used to define SSI.

METHODS

SSI surveillance

PREZIES was set up in 1996 as a collaboration between the National Institute for Public Health and the Environment (Rijksinstituut voor Volksgezondheid en Milieu), the Dutch Institute for Healthcare Improvement CBO, and participating hospitals.[14] Hospital participation in PREZIES is voluntary and confidential. Surveillance for SSI was the first component in the network, and since 1996 data have been collected from 64 of the 98 Dutch hospitals on 143,321 surgical procedures and 4,625 SSIs. Hospitals collect data prospectively according to a protocol that specifies the data to be recorded and the definitions to be used. The SSI definition used in PREZIES is based on the definition used by the Centers for Disease Control and Prevention,[15] with the additions that there must always be clinical symptoms and that diagnosis by only a surgeon or attending physician is not decisive. The method for data collection during the patient's hospital stay is not described in detail in the protocol; each hospital can organize this in a way that is optimal for their organization. Usually, data on surgical procedure and SSI are collected for each patient during ward visits by the ICP, which makes review of patient charts or reports and personal discussion with nurses or physicians possible. If an SSI is suspected, results of microbiologic analyses are also examined. Postdischarge surveillance is voluntary within PREZIES, but a method for postdischarge surveillance that is feasible to all Dutch hospitals has been recommended and is described in the protocol.[16] Currently, 50% of the participating hospitals perform postdischarge surveillance according to the recommended method and 20% according to another active postdischarge method.

On-site validation

Within the PREZIES network, a validation study was performed in 1997, comprising a process validation (involving 32 hospitals) and a prevalence study (involving 6 hospitals).[17] Voluntary on-site validation was implemented in 1999, and since 2002 validation has been mandatory for each participating hospital.

Validation of PREZIES data is a continuous process that includes investigating the quality of data collection (completeness and reliability) and interpretation of the criteria for assessing a SSI in accordance with the protocol. Each participating hospital is validated once every 3 years for every surveillance component that the hospital participates in. The hospital is visited by a validation

team, consisting of a PREZIES team member plus an ICP from a previously validated hospital. The validation visit takes 1 day. The process and the outcome of surveillance are examined. The process of surveillance is validated by means of a structured interview. The items that are discussed are shown in Table 1. For validation of the outcome data, the team aims to review the 20 most recently completed medical records of patients regardless of SSI status and the 5 most recently completed medical records of patients who received a diagnosis of SSI from the hospital ICP. In addition, the ICP can present 5 doubtful diagnoses to the validation team. The team assesses whether an SSI was present and, if present, whether it was a superficial, deep, or organ/space infection. The judgment of the validation team is considered the "gold standard". The results of the validation team are compared and discussed with those of the ICP of the hospital undergoing validation. By doing this, the ICP's interpretation and use of the criteria for diagnosing SSI can be evaluated.

Since 2005, an epidemiologist of the PREZIES team makes a prevalidation report in advance of each validation visit. The goal of the report is to improve the validation team's preparedness and enable its members to ask more-specific questions during the validation visit. The prevalidation report gives information about the surgical procedures under surveillance, the infection rate per procedure (relative to the reference rate), the method for postdischarge surveillance, the number of missing data for some important variables, and the distribution of American Society of Anesthesiologists physical status (ASA) classification and wound contamination class (relative to national data) reported by the hospital for which a validation visit is scheduled. So far, this prevalidation report has proven to be very practical, with supplemental value for both the validation team and the validated hospital.

Table 1. Checklist for interviews to validate the process of surveillance.

General
Actuality of registration plan, software, and protocol of PREZIES
Is use of patient data for surveillance mentioned in patient brochure?
Is privacy of patients guaranteed?
Is surveillance announced to the Dutch Data Protection Authority?
Process related
What type of procedures are included and why?
Method for including patients in the surveillance
Are selection criteria used for including patients?
Are responsibilities of all participating people recorded (eg, who delivers which data, who collects the data, who imports data into computer)?
Method for tracing SSIs
Feedback and application of surveillance results
Is internal validation performed (eg, check whether anesthesist reports correct ASA score and whether surgeon reports correct wound contamination class)?
Is postdischarge surveillance performed, and how?
Items from the prevalidation report (eg, completeness of the data)
Outcome
Application and interpretation of criteria for risk factors and SSI by reviewing medical records

ASA, American Society of Anesthesiologists; *PREZIES*, Preventie van Ziekenhuisinfecties door Surveillance (Dutch National Nosocomial Infection Surveillance System).

Within 2 weeks after the validation visit, the PREZIES team member writes a validation report in which all discussed items are reported. This report is sent to the hospital's ICP, who discusses it with other members of the surveillance staff.

If the validation team finds that the hospital does not follow the protocol in detail (eg, the ICP instead of the surgeon records the wound contamination class) or has not organized the surveillance in an optimal way, it will advise improvements. If major deviations from the protocol are observed (eg, excluding pediatric patients from surveillance), the data will be retrospectively adjusted, if possible. If this is impossible or too time-consuming, the data will be excluded from the national database. In addition, the hospital will be validated again within 1 year. These actions are also taken if the criteria for SSI are not used properly by the surveillance staff (eg, reporting SSI for a patient with a positive culture result but no clinical symptoms).

Analysis

From the results of the hospitals that were validated, we tried to assess the nondifferential misclassification of disease by the ICP. Possible tools for this purpose include the positive predictive value (ie, the proportion of patients for whom the ICP reported SSI who truly had SSI), the negative predictive value (ie, the proportion of patients for whom the ICP did not report SSI who truly did not have SSI), the sensitivity (ie, the proportion of patients who truly had SSI and also had SSI reported by the ICP), and the specificity (ie, the proportion of patients who truly did not have SSI and also did not have SSI reported by the ICP).

If all medical charts were selected on the basis of whether a patient truly had SSI, it would be possible to calculate the sensitivity and specificity. However, patient selection for the validation study is (partly) based on SSIs reported by the ICP, and such patients may not truly have SSI. Therefore, only the positive and negative predictive values could be assessed. Because the SSI rate in the sample undergoing validation is likely artificially higher than the overall rate in the database, calculating the sensitivity and specificity from these data would be incorrect.

We calculated 95% confidence intervals for the positive and negative predictive values, using the quadratic equation described by Fleiss.[18]

RESULTS

During 1999-2004, the validation team reviewed 859 medical charts from 40 hospitals. Table 2 shows the results of the validation of the outcome, including a positive predictive value of 0.97 (ie, 97% of the 149 patients who had SSI diagnosed by the ICP, truly had SSI) and a negative predictive value of 0.99 (ie, 99% of the 710 patients who had no SSI diagnosed by the ICP, truly had no SSI). In 30 hospitals, no disagreement occurred. In each of the remaining 10 hospitals, the opinion of the ICP regarding the presence of SSI differed on one occasion from that of the validation team, resulting in 4 false-positive diagnoses and 6 false-negative diagnoses. The results include the diagnoses that the ICP thought were doubtful.

Table 2. Validation results for surgical site infection (SSI) diagnoses reported in 859 medical records from 40 hospitals in the Dutch national nosocomial infection surveillance system, 1999-2004.

	No. of records		
	Diagnosis by validation team[a]		
Diagnosis by hospital ICP	SSI	No SSI	Total
SSI	145	4	149
No SSI	6	704	710
Total	151	708	859

The positive predictive value was 0.97 (95% confidence interval, 0.95-0.999).
The negative predictive value was 0.99 (95% confidence interval, 0.98-0.998).
ICP, infection control professional.
[a] The "gold standard" for this comparison.

The validation team often gave advice to the hospital, aimed at perfecting the process of surveillance. The most common advices was to perform internal validation more often (*see* Discussion), communicate the surveillance results more widely within the hospital, use the PREZIES criteria for defining SSI, choose procedures for which improvement is possible or procedures done by surgeons who are willing to participate, perform postdischarge surveillance, and avoid limiting surveillance to certain patients and to certain surgical procedures, because such restrictions are not allowed (eg, excluding children or excluding patients with a hospital stay of less than 24 or 48 hours).

Since we started validating the SSI surveillance, data have been removed from the database twice, because of outcomes of the validation visits. Selection bias was evident at one hospital, because surveillance data after hallux valgus procedures were only reported for patients with a hospital stay of at least 48 hours. No differences in assessment of SSI by the ICP and the validation team were observed. In another hospital, the validation visit revealed a substantial lack of information about surgical wound healing in patient medical charts, which potentially led to severe underreporting of infections. During this latter validation visit, assessments of medical charts by both the validation team and the ICP did not reveal any SSI. Retrospective review and correction of the data at each hospital was not possible. Exclusion of these data from the overall results shown in Table 2 would not change our estimation of the positive and negative predictive values.

DISCUSSION

The primary goal of validation is to ensure the quality of data. Results of the ongoing validation study within PREZIES showed that the process of data collection was accurate in 38 of 40 hospitals and that the overall accuracy of SSI assessment by ICP's was high. Validation of the outcome parameter (presence of SSI) showed that the opinion of of the ICP differed from the gold standard in only 10 (1%) of the 859 reviewed medical charts, which resulted in a positive predictive value of 0.97 and a negative predictive value of 0.99. At the time of writing, data have had to be removed from the national database on 2 occasions. The validation findings within PREZIES showed that validating must include the outcome as well as the surveillance process, to discover possible deviations from the PREZIES protocol, such as patient selection. As a result of our ongoing validation results,

PREZIES is confident that the assembled Dutch SSI surveillance data are reliable and robust and are sufficiently accurate to be used as a reference database for interhospital comparison. Data for other Dutch surveillance parameters (central-line associated sepsis, ventilator-associated pneumonia, and SSI after heart surgery) are also validated, but the number of participating and validated hospitals is currently too small for analysis.

The outcomes of the validation visits revealed high positive and negative predictive values. In fact, these may even be slightly higher than we report, because the cases of SSI indicated as doubtful by the ICP were also included in the estimation. If we analyzed the 25 most recent medical charts for validation, without specifically selecting 5 medical charts in which ICPs reported SSI, we would be able to calculate the sensitivity and specificity of the SSI data. However, in the current analyses we cannot exclude the charts in which SSI was reported by the ICP or charts with a doubtful diagnosis, because the reason for inclusion of each chart in the validation was not available. In addition, to evaluate the correct use of SSI criteria, one needs enough patients with and enough patients without true SSI. Our experience has shown that it is possible to validate 25 medical charts during a 1-day validation visit. As the SSI incidence is low in the Netherlands (3.2% overall), 25 medical charts would on average include 1 SSI, resulting in unreliable estimates of the sensitivity, the specificity, and the positive and negative predictive values. Therefore, it was decided that the validation should include 5 medical charts in which SSI was reported by ICPs.

We have chosen to perform the first validation visit during the first year after the hospital starts surveillance, so that, if necessary, surveillance methods can be improved and faulty data can be adjusted retrospectively. Because employees involved in surveillance within a hospital may change quite often, it is necessary to organize validation visits on a regular basis. Regular validation visits are also necessary because a hospital may change the types of procedures under surveillance (eg, from orthopedic surgery to general surgery), which involves other personnel. We think, therefore, that performing validation visits not only once but continuously is necessary to ensure the accuracy of the data. To our knowledge, no other country validates their national nosocomial infection surveillance data continuously. We realize that validation studies are often technically difficult and costly. The validation method used by PREZIES also requires substantial effort and cost, but it is feasible for the Dutch nosocomial surveillance system, mainly because the Netherlands is a small country. Currently, only 55 of 98 hospitals in the Netherlands participate in PREZIES, which means that 20-30 validation visits are needed every year; the visits, including traveling, can be done within a day.

Despite training and instructions, the validation visits revealed minor deviations from the protocol, but overall, surveillance was usually performed accurately. Some deviations from the protocol were caused by lack of knowledge; for example, one ICP did not realize that excluding outpatient or emergency procedures could bias results. Other deviations developed as a result of poor cooperation of personnel; for example, one ICP documented the ASA classification and wound contamination class because the anesthetist and surgeon did not record those items. In addition to detecting defections, a validation visit also offers the opportunity to improve surveillance by giving the ICP advice (eg, how to improve internal validation) or by advising the ICP to switch the

surveillance to other types of surgical procedures. Furthermore, visits improve the communication between the PREZIES team and the participating hospitals, decrease the threshold for the hospitals to ask questions, and increase PREZIES team's insight into the daily routine of surveillance at the hospitals.

In addition to on-site validation visits, several other factors contribute to the optimization of the Dutch surveillance data. First, all ICPs in the Netherlands have finished a 1.5-year education program that includes courses in surveillance and basic epidemiology. Second, data received by PREZIES are checked for obvious mistakes by software that is especially developed for this purpose. For example, the wound contamination class must be between 1-4, the date of birth must be before date of surgery, and values of mandatory variables must be recorded. In addition, each year, before the national surveillance data are reported, review of the aggregated database is conducted, including confirmation that no men are reported as having had gynecological surgery performed, that no duplicate records are present, and that no SSIs were detected later than 30 days after surgery (or 365 days after surgery, for patients who received a nonhuman implant). Third, during yearly meetings for network participants, methodological points are discussed, participants' experiences exchanged, and SSI case studies are presented and discussed. Since 2003, PREZIES has also organized a 1-day workshop for ICPs and other surveillance staff who are planning to start surveillance. During the workshop, PREZIES provides general information and tips about how to set up the surveillance. Fourth, PREZIES has a Web site on which general information, protocols, reference data, and news items are published. Surveillance staff can review SSI definitions by analyzing case studies that are published on the PREZIES Web site every 2 months. Fifth, PREZIES often publishes surveillance-related articles in the primary Dutch journal for ICPs (*Tijdschrift Voor Hygiëne en Infectie Preventie*). Finally, experiences are shared among participating hospitals through discussions on best practices, and PREZIES introduces ICPs from different hospitals in order to exchange knowledge.

Generally, several people are involved in collecting data and tracing and determining SSIs. Data are derived from various hospital information systems, and several disciplines from different departments are involved. In some organizations, a secretarial department is responsible for data entry. In PREZIES, one person – usually the ICP - is responsible for surveillance data. When part of the surveillance is done by other personnel, this person must ensure that everyone works according to the protocol, using the correct definitions for all recorded variables and SSIs. The responsible person should, therefore, perform internal validation by periodically reviewing the process, confirming that definitions are being applied correctly, and confirming that data entry accords with established protocol. Performance of internal validation is recommended in PREZIES, and guidelines for performing internal validation are described in an article published in *Tijdschrift Voor Hygiëne en Infectie Preventie*.[19] The advised method for internal validation is very similar to that for external validation, except that internal validation concerns not only the presence of SSI but also correct use of the definitions of other variables (eg, wound contamination class, ASA classification, and culture findings). Internal validation can be done regularly within a hospital after the start of data collection, especially after a change in the surgical procedures undergoing

surveillance or after changes in surveillance staff. We have observed an increase in the use of internal validation at participating hospitals, which contributes to accuracy of surveillance data.
In conclusion, to facilitate interhospital comparisons within a national surveillance network, data integrity is essential. Validation of the data from the Dutch nosocomial surveillance network PREZIES is included as an important aspect of the surveillance system. PREZIES will proceed with this strategy to keep in touch with daily surveillance practice within the hospitals, to improve the process of surveillance, and to ensure reliability of the surveillance data.

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4

Surgical site infection surveillance and the predictive power of the National Nosocomial Infection Surveillance index as compared with alternative determinants in the Netherlands

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ABSTRACT

Background: Surgical site infection (SSI) surveillance typically includes comparison between observed and expected infection risks. Expected SSI numbers are usually derived from national data by use of the National Nosocomial Infection Surveillance (NNIS) index, developed by the Centers for Disease Control and Prevention. We aimed to estimate the predictive power of alternative SSI determinants to improve estimation of expected numbers.

Methods: We considered surveillance data comprising 93,511 surgical procedures, 3494 SSIs, and 11 putative determinants in the Netherlands in 1996 to 2004. Comparable procedures were pooled into 19 groups, and logistic regression backward elimination defined corresponding alternative models. The predictive power of the alternative models and the NNIS index were compared by testing the areas under the receiver operating characteristic curves.

Results: For 9 procedure groups, the alternative models predicted SSI better than the NNIS index ($P < .05$). However, the corresponding expected SSI numbers were marginally affected.

Conclusions: Our results do not support replacement of the NNIS index with procedure-specific determinants when comparing observed and expected SSI occurrence in feedback of surveillance results to hospitals.

INTRODUCTION

Surgical site infection (SSI) ranks among the most frequent nosocomial infections and leads to increased morbidity, mortality and costs.[1-3] The burden of SSI can be addressed by preventive measures guided by surveillance results.[3-6] Key output of SSI surveillance typically includes hospital- and procedure-specific comparison between observed and expected infection risks. Expected SSI numbers are usually derived from national data by use of the National Nosocomial Infection Surveillance (NNIS) index, developed by the Centers for Disease Control and Prevention (CDC).[7] The NNIS index is composed of 3 SSI risk factors and renders comparison between hospital and national SSI occurrence more appropriate than crude comparison when there are underlying risk differences in the patient populations.

In the Netherlands, the voluntary surveillance system "Prevention of Nosocomial Infection Through Surveillance" (PREZIES) was initiated in 1996, covering several nosocomial infections (www.prezies.nl).[1] Participation in the SSI surveillance has been associated with a reduced incidence.[5,6] PREZIES applies the NNIS index to create confidential hospital feedback. However, universal application of the NNIS index has been questioned.[8-12] Expected SSI numbers may be more accurately estimated through combinations with additional determinants in a procedure-specific manner.

Identification of procedure-specific SSI determinants is in many settings hampered or impossible because of sparse data for individual procedures. PREZIES provides through its comprehensiveness a good opportunity to address this issue. Thus, we aimed to identify and estimate the predictive power of alternative SSI determinants for different surgical procedures to improve estimation of expected numbers and thus comparison between hospital and national SSI occurrence.

METHODS

PREZIES data

The present study population consisted of patients undergoing certain surgical procedures in hospitals participating in PREZIES in the Netherlands in 1996 to 2004.[1] Local infection control personnel collected data on surgical procedures, patient characteristics, and SSI occurrence. Data quality has been found to be satisfactory by validation efforts such as evaluations of participating hospitals every 3 years.[1,13]

An SSI was defined as a superficial or deep infection - the latter including organ/space infections - that occurred within 30 days after the surgical procedure. This time period was extended to 1 year for deep infections involving grafts. The SSI was deemed to be a consequence of the procedure according to CDC criteria,[14] with the specification that clinical symptoms had to be present.

The present analyses considered 11 putative determinants, including the components of the NNIS index. The NNIS index ranges from 0 to 3 with increasing risk and is raised by 1 point for each of 3 SSI predictors[7]: First, American Society of Anesthesiologists (ASA) classification >2 (range, 1-5), as a measure of poor overall preoperative physical status of the patient. Second, wound

contamination class >2 (range, 1-4), corresponding to a contaminated or dirty-infected operation. Third, duration of operation >75th percentile (P75) for the specific procedure group, associated with a greater risk of infection, for example, because of the complexity of the case. Other investigated determinants were gender, age (categorized into quartiles), antibiotic prophylaxis (yes or no), length of preoperative hospitalization (0-2 days, >2 days), whether the procedure was elective (yes or no, ie, acute), number of procedures performed simultaneously through the same incision (1 or >1), and university affiliation of the hospital (yes or no). Postdischarge surveillance was considered by comparing the recommended method with another type or no postdischarge surveillance.[13] In the recommended method, a physician documents information on clinical symptoms and SSI occurrence on a registration card in the outpatient medical record. Examples of alternative postdischarge surveillance methods are collection of information from surgeons or patients by questionnaires.

Surgical procedures that were comparable in terms of SSI risk and surgical techniques were pooled in the PREZIES database as recommended by panels of surgeons. The pooling yielded larger groups for the present analyses, which were restricted to surgical procedure groups with at least 50 SSIs because of power considerations. The pooling is also valuable for the feedback to hospitals. Expected SSI numbers were previously not calculated for rare procedures, but, by including these procedures as part of the pooled procedure groups, the corresponding expected SSI risk can be provided.

Model building

All analyses were performed separately within each procedure group. Associations between SSI and exposures were estimated by odds ratios (OR) and 95% confidence intervals (CI) obtained by logistic regression (PROC LOGISTIC; SAS 9.1.3, SAS Institute Inc., Cary, NC). Variables with univariate Wald *P* values <.20 were considered for multivariate logistic regression. From an initial multivariate model, variables were sequentially removed through manually performed backward elimination. In each step, the variable with the largest likelihood ratio test (LRT) *P* value was removed. This was repeated until all variables contributed significantly to the likelihood of the model (LRT *P* value <.05), constituting the final model. To confirm the appropriateness of the final models, we performed less stringent automated stepwise backward and forward selection with all 11 variables (STEPWISE, STATA 9; StataCorp LP, College Station, TX).[15] The LRT *P* value for removal (p_R) and entry (p_E) of a variable was 0.20 and 0.15, respectively. To take an effect of hospital into account, multilevel analyses were performed with the final models, whereby individual observations were assigned as the first level and hospitals as the second level (PROC NLMIXED; SAS 9.1.3, SAS Institute Inc.).

Comparison of SSI predictive power

The SSI predictive power was compared for each of the final alternative logistic regression models relative to a model with the NNIS index. For each model, the predicted probabilities of positive outcomes were calculated, and receiver operating characteristic (ROC) curves were constructed. A ROC curve has axes with sensitivity and 1-specificity, and the area under the curve reflects the

predictive power of the model: 1 is optimal, and 0.5 is as poor as chance. The ROC areas were compared, and a *P* value <.05 was regarded as an improved predictive power of the alternative model (ROCCOMP STATA 9; StataCorp LP).[16]

To assess the practical relevance of differences in predictive power, the expected numbers of SSI were estimated for alternative models and the NNIS index. This was done for each procedure group with an alternative model that predicted SSI risk better than the NNIS index. To reduce the influence of chance, the calculations were restricted to the 3 hospitals with the largest number of procedures for each procedure group in 1996 to 2004. Thereafter, the corresponding expected risks and the standardized infection ratio were derived, the latter obtained by dividing the observed with the expected risks.[17]

RESULTS

PREZIES included data from 69 (70%) of 98 Dutch hospitals in 1996 to 2004. Of 114 surgical procedure groups, 19 (17%) were selected for the present analyses because they contained at least 50 SSIs (Table 1). The 19 groups included 93,511 (65%) of 143,321 procedures and 3494 (76%) of 4625

Table 1. Numbers of procedures and surgical site infections in the 19 surgical procedure groups included in the present study, the Netherlands, 1996 to 2004.

Surgical procedure group	No. of procedures	No. of SSI	SSI risk (%)
All	93,511	3494	3.7
Orthopedics			
Knee prosthesis	12,726	239	1.9
Major bone	3485	70	2.0
Fracture, other	2520	51	2.0
Total hip prosthesis	30,948	853	2.8
Femur fracture*	4847	199	4.1
Femur head prosthesis	5544	281	5.1
Revision of total hip prosthesis	3006	205	6.8
Lower gastrointestinal tract			
Appendectomy	3118	147	4.7
Colon resection	3339	380	11.4
Anterior resection rectosigmoid	1495	183	12.2
Rectum extirpation	374	59	15.8
Abdomen (excluding lower gastrointestinal tract)			
Caesarean section	5269	98	1.9
Abdominal uterus extirpation	3178	61	1.9
Abdominal blood vessels	2363	113	4.8
Test laparotomy	904	60	6.6
Other			
Soft tissue	2769	55	2.0
Mastectomy without removal of axillary lymph nodes	1280	52	4.1
Mastectomy with removal of axillary lymph nodes	4770	223	4.7
Femoropopliteal or femorotibial bypass	1576	165	10.5

SSI, surgical site infection.
*Dynamic Hip Screw (DHS) type.

Table 2. Comparison of surgical site infection predictive power, as measured by the area under the receiver operating characteristic curve, between a model with the National Nosocomial Infection Surveillance index and the alternative models defined here.

Surgical procedure group	Area under ROC curve		
	NNIS index model	Alternative model	*P* value for ROC value difference
Orthopedics			
Knee prosthesis	0.54	0.61	.001*
Major bone	0.63	0.63	.963
Fracture, other	0.65	0.70	.014*
Total hip prosthesis	0.58	0.63	.000*
Femur fracture†	0.58	0.61	.072
Femur head prosthesis	0.55	0.57	.678
Revision of total hip prosthesis	0.60	0.65	.110
Lower gastrointestinal tract			
Appendectomy	0.57	0.58	.816
Colon resection	0.60	0.65	.011*
Anterior resection rectosigmoid	0.57	0.59	.042*
Rectum extirpation	0.53	0.62	.262
Abdomen (excluding lower gastrointestinal tract)			
Caesarean section	0.54	0.64	.038*
Abdominal uterus extirpation	0.60	0.71	.094
Abdominal blood vessels	0.59	0.65	.055
Test laparotomy	0.66	0.67	.837
Other			
Soft tissue	0.62	0.65	.236
Mastectomy without removal of axillary lymph nodes	0.51	0.67	.001*
Mastectomy with removal of axillary lymph nodes	0.55	0.65	.000*
Femoropopliteal or femorotibial bypass	0.59	0.66	.021*

NNIS, National Nosocomial Infection Surveillance; *ROC*, receiver operating characteristic.
*$P < .05$.
†Dynamic Hip Screw (DHS) type.

SSIs. The overall risk of SSI in the 19 procedure groups was 3.7% (3494 of 93,511) with a range of 1.9 to 15.8% between groups (Table 1). The distributions of procedures by different exposure categories are presented in a supplementary file (see supplementary Appendix online at www.ajicjournal.org).

Multivariate logistic regression backward elimination defined alternative models for each of the 19 procedure groups (see supplementary Appendix online at www.ajicjournal.org). The 19 models included a median of 3 variables (range, 1 to 6 variables). The 3 NNIS index components were the variables most frequently included in the alternative models. Wound contamination class, ASA score, and procedure duration were included in 13, 9, and 7 models, respectively. Thereafter, age, number of procedures performed through the same incision, preoperative length of hospitalization, and hospital type (university or other) were included in 6 models each.

In the less stringent automated variable selection, the final models included a median of 2 variables that were not selected in the manual backward elimination. However, none of these additional

variables contributed significantly to the likelihood of the models (LRT *P* value >.05), corroborating the appropriateness of the models obtained by backward elimination. In the multilevel analyses, the hospital level was statistically significant for 4 of the 19 procedure groups (*P* <.05). However, the OR estimates in all 19 models were marginally affected by multilevel analyses as compared to standard logistic regression. Therefore, standard logistic regression results are shown and were used in subsequent analyses.

The areas under the ROC curves varied from 0.51 to 0.66 for the NNIS index models and from 0.57 to 0.71 for the alternative models, resulting in increases in the areas between 0 and 0.16 (Table 2). The alternative models for 9 procedure groups yielded significantly larger ROC areas than the NNIS index (*P* <.05). As compared with the NNIS index, which is based on 3 variables, these 9 alternative models included 1 variable (1 model), 3 variables (1 model), or 4 to 6 variables (7 models). No difference in ROC areas could be confirmed for 10 procedure groups, of which 4 alternative models contained less than 3 variables. No relationship between the size of the procedure groups and the predictive power of the alternative models could be discerned in scatter plots.

The expected numbers of SSI calculated by using the alternative models were similar to those calculated by using the NNIS index. Expected SSI numbers were estimated in subgroups of each of the 3 hospitals with the largest number of procedures for the abovementioned 9 procedure groups. The 27 subgroups encompassed a median of 305 procedures (range, 69-1617) in 1996 to 2004. The median difference in expected numbers between the alternative models and NNIS model was 1 SSI (range, 0-5). This translated into a median difference of 11% (range, 1%-40%) in expected SSI number and a median difference of 13% (range, 1%-43%) in standardized infection ratio.

DISCUSSION

The present analyses show that, for some surgical procedure groups, alternative models can predict SSI occurrence better than the commonly used NNIS index. However, a fundamental aspect of the present study is the practical relevance of the findings, ie, whether the results could reliably improve comparison between hospital and national SSI occurrence in feedback of surveillance results to hospitals.

The SSI predictive power was generally rather low, as measured by the area under the ROC curve. The limited increase in predictive power of the alternative models as compared with the NNIS index resulted in only marginal changes in the expected numbers of SSI. Because of the small numbers of SSI per hospital, this occasionally translated into seemingly considerable fluctuations when expressed in relative terms. Nevertheless, the small changes in expected numbers do not appear to provide a reason for change of current practice. There was also no substantial gain in simplicity of the alternative models, as measured by the number of variables included. Notably, the NNIS components were frequently included in the alternative models. The NNIS index is already applied in many countries, and its usefulness for predicting SSI has been demonstrated.[7-10] The NNIS index is, at least in theory, relatively simple in terms of data collection, calculation of expected risks, and comprehensibility. Our analyses do not exclude the possibility that there

are more suitable tools than the NNIS index in some instances. At present, however, there is no evidence of substantial gain in performance or simplicity when using the variables collected in the Dutch surveillance. This argues against replacing the NNIS index with the alternative models defined here when producing feedback of surveillance results to hospitals.

The comprehensive approach of PREZIES enabled us to consider as many as 19 surgical procedure groups with nearly 100,000 procedures and 11 putative determinants. Previous similar studies have often focused on one or a few types of procedures with varying inclusion of possible determinants.[10-12,18,19] In Germany, a study similar to ours was conducted with 9 procedure categories, containing more than 200,000 procedures with information on 3 determinants (age, gender, and use of endoscopy) other than the NNIS index components.[10] Only slight improvements in ROC areas were achieved with the alternative models, as compared to the NNIS index. The authors mentioned additional information on more determinants as a way to further improve SSI prediction. Our study included additional putative SSI determinants but could not demonstrate consistent better ROC values for the corresponding procedures. However, the numbers of procedures were smaller and power limitations may have rendered identification of some determinants unfeasible.

Geubbels et al analyzed a subset of the present data from the Netherlands by selecting 5 types of procedures in 1996 to 2000.[11] These data were supplemented with patient-based data from the National Medical Register, contributing information on, for example, indication for surgery, presence of diabetes, and the number of discharge diagnoses. The results for applicable variables were comparable to the present findings, although we generally obtained somewhat lower ROC values. The higher ROC values in the previous study may be attributed to the additional determinants not routinely collected in PREZIES. SSI risk depends on numerous factors with variable contributions, of which many would probably need to be considered to predict the risk more accurately. However, to reduce the extra work-load of hospital staff, a surveillance system is often restrained as for the amount of data that can be collected for each observation. Notwithstanding that the PREZIES SSI surveillance is quite comprehensive, some aspects may not be considered for individual procedures, such as diagnoses, diabetes, body mass index, smoking, body temperature, and oxygenation. Consequently, the information collected in PREZIES would be subject to modification as motivated by new evidence or altered circumstances. For example, endoscopically performed procedures have been registered separately since 2005 and will also be separated in hospital feedback reports.

This is to our knowledge the first SSI surveillance study in which ROC values are translated into expected SSI numbers. This is an advantage because the expected numbers revealed a marginal practical relevance of the improved ROC values. However, it should also be noted that a well-functioning SSI risk prediction index does not solely depend on adequate technical performance. Other prerequisites comprise transparency and acceptability for the stakeholders (hospital staff, epidemiologists, and decision makers) upon whom the surveillance system ultimately relies. In conclusion, our results indicate that there are, at least for some surgical procedures, better models to predict SSI occurrence than the commonly used NNIS index. However, in the present context the practical relevance of these alternative models is limited. Therefore, our results do not support

replacement of the NNIS index with procedure-specific determinants when comparing hospital and national SSI occurrence in feedback of surveillance results to hospitals.

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5

Comparison of the national surgical site infection surveillance data between the Netherlands and Germany: PREZIES versus KISS

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ABSTRACT

As there has been increasing interest in comparing surgical site infection (SSI) rates between countries increases, we compared the SSI surveillance data for the Netherlands ('PREZIES') and Germany ('KISS'). Both surveillance systems have comparable protocols with many similar risk factors, including SSI definitions developed by the Centers for Disease Control and Prevention and optional postdischarge surveillance. Nine surgical procedure categories from several specialties were included, the reporting of which were similar for PREZIES and KISS with respect to content and with enough data for proper comparison. Differences for the SSI data were found between PREZIES and KISS for duration of surgery, wound contamination class, American Society of Anesthesiologists physical status classification and the postoperative duration of hospitalization. A significantly higher superficial SSI rate was found for seven surgical procedures according to PREZIES and a higher deep SSI rate for five procedures. When considering only deep SSI during hospitalization, the differences in SSI rates were much smaller. Differences in intensity of postdischarge surveillance led to 34% of SSI being detected after discharge for PREZIES and 21% for KISS. In conclusion, even though similar infection surveillance protocols were used in the Netherlands and Germany, differences occurred in the implementation. Comparison between countries are most reliable if only deep SSI during hospitalization are taken into account, since these SSI are not affected by postdischarge surveillance and the diagnostic sensitivity for deep SSI is probably more alike between countries than for superficial SSI.

INTRODUCTION

Surgical site infections (SSI) occur frequently in hospitals and have severe consequences. In recent decades, national SSI surveillance networks have been set up in many countries to monitor SSI incidence and variation between hospitals. The first nosocomial infection surveillance network, the NNIS system, was established in the USA in the 1970s.[1] Since then, many other countries have set up similar national surveillance systems using the infection definitions developed by the Centers for Disease Control and Prevention.

There is an increasing interest in comparing SSI data, not only between hospitals within a country, but also between countries. However, comparison between countries is more difficult, because the healthcare system and practices, types of hospitals, patient mix and reason for participation in a national surveillance system are likely to vary.[2]

In the Netherlands since 1996 ('PREZIES') and in Germany since 1997 ('KISS') SSI data have been recorded within a national nosocomial infection surveillance system.[3,4] These are neighbouring countries in Western Europe. The Netherlands has a population of 16 million with 100 hospitals, whereas Germany is much larger with 83 million inhabitants and 2200 hospitals. An earlier study showed that the surveillance practices in PREZIES and KISS are comparable; their protocols are based on the American NNIS protocol using the definitions developed by the Centers for Disease Control and Prevention,[5] participation is voluntary and confidential, the project is funded by the Ministry of Health and the network is coordinated centrally by a multidisciplinary team.[2] Other than this, the actual SSI data have not yet been compared in detail, apart from some surgical procedures by the European "Hospital In Europe Link for Infection Control through Surveillance" project (The Surveillance of Surgical Site Infections, Protocol Version 9.1. September 2004). In the current study, all aspects of the SSI surveillance data have been observed by comparing patient and hospital characteristics and SSI rates for several surgical procedures between PREZIES and KISS.

METHODS

Surveillance design

PREZIES aims for 100% participation. At this moment, the PREZIES SSI database contains data from 67 (68%) of the Dutch hospitals. KISS included 300 (14%) hospitals for participation. Those hospitals produce reference data for all German hospitals that register according to the same protocol but do not send in data, and therefore do not officially participate.

Both surveillance systems perform validation checks on submitted data. Both systems check the logical sequence of dates, and gender in certain procedures (e.g., caesarean section, hysterectomy, prostatectomy). The internet-based registration system in KISS, available since 2004, makes stricter validation checks during data-entry possible. Furthermore, the PREZIES team undertakes one-day visits to all participating hospitals every three years, to validate the process of the surveillance and the use of the SSI criteria.[6] KISS does not perform validation visits to participating hospitals, due to the large number of hospitals and the size of the country.

In both surveillance systems, postdischarge surveillance is voluntary. In PREZIES, a standard method is recommended and described in the protocol.[7] Currently 60% of the participating hospitals use the recommended method. In KISS, the methods used for postdischarge surveillance are not recorded. In this study, all registered SSIs were included, regardless of whether they developed during hospitalization or after discharge.
In PREZIES, hospitals receive a procedure-specific feedback report every time they send in data. In KISS, hospitals can generate a feedback report per procedure category by themselves at any time, using the internet-based registration system. National reference data are generated once a year for PREZIES and twice a year in KISS.

Surgical procedure categories

The SSI surveillance in KISS is concentrated in 27 operative procedure categories and separate procedure codes are not registered. In PREZIES, the Dutch procedure-specific financial codes are used. We matched the Dutch codes rigorously to the KISS categories where possible. Furthermore, only procedure categories with enough data for proper comparison were included in the current study, i.e. at least 1000 procedures and 50 SSI. As a result, the analyses for this study are performed on nine surgical procedure categories within several specialties: appendectomy, colon resection, abdominal hysterectomy, Caesarean section, mastectomy, arterial reconstruction of lower extremities, hip arthroplasty, knee arthroplasty, and femur fraction. These procedures are described in detail in Table 1. All PREZIES data up to 2004 were included because the data of

Table 1. Description of the surgical procedure categories.

Procedure	Description
Appendectomy	(Endoscopic) appendectomy, not in combination with another procedure.
Colon resection	Total or partial (endoscopic) colectomy, excluding rectum extirpation.
Abdominal hysterectomy	(Endoscopic) subtotal, total, or radical (=with lymphadenectomy) abdominal hysterectomy.
Caesarean section	Classical or supracervical and corporal Caesarean section, possibly in combination with another gynaecological procedure.
Mastectomy	Procedures regarding the mamma, e.g. lumpectomy, segment resection, partial excision with axillary lymphadenectomy, (extensive, supraradical, or subcutane) mastectomy possibly with axillary lympadenectomy and possibly with resection of muscles, plastic mamma reduction or reconstruction.
Arterial reconstruction of the lower extremities	Various procedures, e.g. aneurysm procedures, revascularisation, artery implants, bypasses which bridge the groin, embolectomy, thrombectomy, endarterectomy, resection and interposition of (parts of) blood vessels or aorta. Excluded: percutaneous-transluminal procedure; procedure on intracranial and intraspinal vessels; coronary arteries; shunts; venous excision or stripping.
Hip arthroplasty	Total or partial hip arthroplasty because of arthrosis or fracture. Excluded: revision, removal or reimplantation of hip arthroplasty; arthroplasty because of necrosis of head of femur; arthroplasty because of a tumor.
Knee arthroplasty	Knee arthroplasty. Excluded: revision, removal or reimplantation of knee arthroplasty; replacement of the patella.
Femur fraction	Closed or open reposition of a fracture in the area of the collum or proximal femur. Excluded: procedures with synthetic joint or bone replacement.

2005 were not yet available at the time of analyses. Only data from 2004-2005 were included for KISS, because the procedures included in KISS were modified from January 2004 thus becoming comparable to the PREZIES data.

Risk factors

In both countries, data are collected on gender, date of surgery, the American Society of Anesthesiologists physical status score for the severity of any underlying disease,[8] wound contamination class,[9] duration of surgery, date of infection, type of SSI, and type of hospital (university or other). In PREZIES, deep incisional and organ-space SSI are evaluated under the umbrella term 'deep SSI', because in practice it is often difficult to distinguish deep SSIs from organ-space SSIs. For the current analyses, we also combined deep incisional and organ-space SSI in the KISS data. Regarding the duration of surgery, KISS and PREZIES use their own procedure-specific 75th percentile in minutes. However, for the calculation of the NNIS risk index in the current analyses, we used the 75th percentile of duration of surgery in minutes of the combined data of PREZIES and KISS.[10]

Complementary variables recorded in PREZIES were: whether a non-human implant was left in place, elective or emergency surgery and date of admission. Additional variables registered in KISS were: whether an SSI occurs before or after discharge and whether a postdischarge SSI led to readmission. PREZIES uses the infection date and the date of discharge to assess whether a recorded SSI developed before or after the patient's discharge. The date of discharge was included in the protocol of KISS as an optional variable not until mid-2005.

Statistical analyses

Differences between PREZIES and KISS in the distribution of continuous variables were tested by using the Wilcoxon test. The Chi-squared test was used for binary variables, grouped ordinal variables, and the SSI rate. The increase in SSI rate with increasing NNIS score was tested by using the Cochrane-Armitage trend test. The *P*-values of all tests of significance were two-tailed, and $P < 0.05$ was considered statistically significant. All statistical analyses were performed using SAS for Windows, release 9.1 (SAS Institute Inc., Cary, NC, USA).

RESULTS

In Table 2, patient characteristics are compared between PREZIES and KISS, according to surgical procedure category. Mainly hip and knee arthroplasties were registered for both systems and additional Caesarean sections for KISS. In PREZIES, 4.5% of the operations were performed in university hospitals and 9.3% for KISS. The patients were significantly older in KISS for six procedures and older in PREZIES for two. PREZIES had significantly more male patients than KISS for arterial reconstruction of the lower extremities and more female patients for hip and knee arthroplasty. In KISS, a significantly higher ASA classification was recorded than in PREZIES for all surgical procedures.

Table 2. Comparison of patient characteristics between PREZIES and KISS, according to surgical procedure.

Procedure	No. of operations		Age (years) median (IQR[c])		Difference[a]	Gender % male		Difference[b]	ASA classification % ≥3		Difference[b]
	PREZIES	KISS	PREZIES	KISS	*P*-value	PREZIES	KISS	*P*-value	PREZIES	KISS	*P*-value
Appendectomy	3071	5744	28 (16-43)	27 (18-45)	<0.0001	49	47	0.08	3	9	<0.0001
Colon resection	3403	8023	68 (57-76)	68 (58-76)	0.32	47	46	0.88	26	48	<0.0001
Femur fraction	4847	2126	80 (69-86)	81 (73-87)	<0.0001	29	28	0.59	34	71	<0.0001
Mastectomy	7775	8972	56 (47-69)	60 (48-69)	<0.0001	1	1	0.45	5	22	<0.0001
Abdominal hysterectomy	3539	3287	47 (42-54)	50 (44-64)	<0.0001	0	0	-	4	22	<0.0001
Caesarean section	5269	20 771	31 (28-33)	31 (27-35)	<0.0001	0	0	-	1	5	<0.0001
Hip arthroplasty	36 542	30 643	72 (65-79)	71 (64-78)	<0.0001	28	36	<0.0001	16	42	<0.0001
Knee arthroplasty	12 726	13 817	72 (65-77)	71 (65-76)	<0.0001	22	30	<0.0001	13	40	<0.0001
Arterial reconstruction of lower extremities	2346	4262	68 (60-74)	69 (63-77)	<0.0001	77	67	<0.0001	34	66	<0.0001

PREZIES, SSI surveillance data for the Netherlands; *KISS*, SSI surveillance data for Germany; *ASA*, American Society of Anesthesiologists.

[a] The difference in distribution, not median, between PREZIES and KISS was tested by using the Wilcoxon test.

[b] The difference in percentage between PREZIES and KISS was tested by using the Chi-squared test.

[c] Interquartile range, 25th percentile and 75th percentile.

Table 3. Comparison of procedure characteristics between PREZIES and KISS, according to surgical procedure.

Procedure	Wound class, % ≥3		Difference[a]	Duration of surgery, median (IQR[c])		Difference[b]	Postoperative LOS, median (IQR[c])		Difference[b]
	PREZIES	KISS	*P*-value	PREZIES	KISS	*P*-value	PREZIES	KISS	*P*-value
Appendectomy	37	59	<0.0001	35 (25-45)	44 (30-60)	<0.0001	3 (3-5)	4 (3-5)	<0.0001
Colon resection	25	45	<0.0001	110 (80-147)	140 (105-180)	<0.0001	11 (8-15)	11 (8-15)	0.09
Femur fraction	1	0	0.14	60 (45-90)	55 (40-72)	<0.0001	14 (8-24)	14 (11-18)	0.70
Mastectomy	5	1	<0.0001	70 (45-95)	70 (47-98)	0.06	4 (2-7)	7 (5-10)	<0.0001
Abdominal hysterectomy	1	2	<0.0001	67 (55-90)	90 (70-122)	<0.0001	6 (5-7)	8 (7-10)	<0.0001
Caesarean section	0	16	<0.0001	35 (30-45)	36 (30-45)	0.07	5 (4-6)	6 (5-7)	<0.0001
Hip arthroplasty	0	0	0.68	76 (60-95)	80 (61-101)	<0.0001	10 (7-14)	13 (11-15)	<0.0001
Knee arthroplasty	0	0	0.07	90 (73-105)	82 (65-101)	<0.0001	10 (7-14)	14 (12-15)	<0.0001
Arterial reconstruction of lower extremities	1	2	<0.0001	180 (141-225)	120 (85-170)	<0.0001	10 (8-15)	11 (8-15)	0.03

PREZIES, SSI surveillance data for the Netherlands; *KISS*, SSI surveillance data for Germany; *LOS*, length of stay; *IQR*, interquartile range.

[a] The difference between PREZIES and KISS was tested by using the Chi-squared test.

[b] The difference between PREZIES and KISS was tested by using the Wilcoxon test.

[c] Interquartile range, 25th percentile and 75th percentile.

Table 4. Comparison of surgical site infection (SSI) rates for superficial and deep SSI between PREZIES and KISS, according to surgical procedure.

Procedure	Superficial SSI % (No.)			Deep SSI % (No.)			Deep SSI in hospital % (No.)			SSI after discharge %		
	PREZIES	KISS	*P*-value[a]	PREZIES	KISS	*P*-value[a]	PREZIES	KISS	*P*-value[a]	PREZIES	KISS	*P*-value[b]
Appendectomy	1.7 (52)	1.6 (90)	0.65	2.9 (88)	0.8 (48)	<0.0001	1.5 (47)	0.6 (32)	<0.0001	54	31	0.0002
Colon resection	4.6 (156)	3.3 (266)	0.001	6.7 (228)	4.1 (331)	<0.0001	5.9 (202)	4.0 (320)	<0.0001	12	3	<0.0001
Femur fraction	2.5 (123)	0.8 (18)	<0.0001	1.5 (71)	1.9 (41)	0.16	1.1 (52)	1.4 (30)	0.23	18	22	0.56
Mastectomy	2.7 (210)	0.8 (69)	<0.0001	1.1 (84)	0.2 (22)	<0.0001	0.5 (36)	0.1 (12)	<0.0001	49	38	0.10
Abdominal hysterectomy	1.2 (42)	1.4 (45)	0.50	0.9 (33)	0.7 (23)	0.29	0.6 (22)	0.7 (22)	0.81	32	16	0.05
Caesarean section	1.3 (67)	0.8 (168)	0.002	0.5 (28)	0.2 (40)	<0.0001	0.2 (11)	0.1 (25)	0.12	60	31	<0.0001
Hip arthroplasty	1.9 (702)	0.4 (117)	<0.0001	1.1 (415)	1.0 (315)	0.18	0.6 (210)	0.7 (213)	0.05	31	26	0.11
Knee arthroplasty	0.9 (116)	0.2 (31)	<0.0001	0.9 (119)	0.5 (66)	<0.0001	0.2 (25)	0.2 (24)	0.67	59	48	0.10
Arterial reconstruction of lower extremities	2.6 (62)	1.3 (57)	0.0001	2.2 (51)	1.6 (67)	0.08	1.6 (38)	1.1 (49)	0.11	21	24	0.70

[a] Difference in SSI rate between PREZIES and KISS, tested by using the Chi-squared test.

[b] Difference in percentage of registered SSIs that were detected after hospital discharge between PREZIES and KISS, tested by using the Chi-squared test.

Table 3 shows the comparison of procedure characteristics per surgical procedure. A substantially higher wound contamination class was recorded in KISS compared to PREZIES for appendectomy, colon resection and Caesarean section. The postoperative length of hospitalization of patients without a SSI was significantly longer in KISS for seven procedures. The surgeries lasted significantly longer in KISS than in PREZIES for appendectomy, colon resection, abdominal hysterectomy, and hip arthroplasty, whereas a significantly longer duration of surgery was observed in PREZIES for femur fraction, knee arthroplasty, and arterial reconstruction of the lower extremities. For most procedures, the duration of surgery was longer in university hospitals than in non-university hospitals, but the differences in duration of surgery between PREZIES and KISS were still apparent if only non-university hospitals were taken into account. Patients in KISS often had a higher NNIS score than those in PREZIES (data not shown), due to the higher wound class and higher ASA classification in KISS. In both surveillance systems, the SSI rate significantly increased with a higher NNIS index score for all procedures (except for Caesarean section in PREZIES). After stratification by surgical procedure and NNIS index, the absolute SSI rate was still significantly higher in PREZIES than in KISS for many strata.

In Table 4, the SSI rates are compared between PREZIES and KISS according to surgical procedure. Regarding superficial SSI, PREZIES had a significantly higher infection rate than KISS for seven of the nine procedures, except for appendectomy and abdominal hysterectomy. PREZIES had a significantly higher infection rate than KISS for deep SSI from five procedures. When considering only deep SSI during hospitalization, the differences in SSI rate were smaller, with a significantly higher SSI rate in PREZIES for only three procedures, namely appendectomy, colon resection and mastectomy. The smaller difference in deep SSI rate between PREZIES and KISS after hip and knee arthroplasty for SSI during hospitalization can be explained by the longer duration of hospitalization of three to four days in KISS for these surgical procedures. In PREZIES 34% of all registered SSIs were found after discharge and in KISS 21%. In PREZIES, more SSI were found after discharge for seven surgical procedures with a statistically significant difference for four of those procedures.

DISCUSSION

This study showed that comparison of SSI data between countries may not be reliable, even if the countries have public healthcare systems of comparable high quality and use similar infection surveillance protocols.

For some surgical procedures, the results revealed a higher SSI rate in PREZIES compared to KISS, even though in PREZIES the patients seemed to be healthier (i.e. a lower ASA classification was recorded), were less often operated on in university hospitals and had a shorter postoperative length of stay. The higher SSI rate in PREZIES might at least partly be explained by the more intensive postdischarge surveillance performed in Dutch hospitals, leading to 34% of the recorded SSI detected after discharge in PREZIES and 21% in KISS. The difference between the two countries in procedure-specific SSI rates disappeared for most surgical procedures when only deep SSIs that developed during hospitalization were taken into account.

Possible sources of bias

In KISS, patients had a longer duration of hospitalization, which is likely to result in more SSIs developing during hospital stay. In PREZIES, postdischarge surveillance was performed more intensively than in KISS, leading to more recorded SSIs after discharge. Therefore, there is no perfect method to compare the data, i.e., with or without SSIs after discharge. The inclusion of postdischarge SSIs results in more accurate and reliable SSI rates.[7]

Reasons for hospitals to participate in the national SSI surveillance might be different between the two countries. In both countries, participation is voluntary. In the Netherlands, hospitals are encouraged to participate in PREZIES for procedures where a relatively high SSI rate is expected. In PREZIES, 68% of all Dutch hospitals participate. In KISS, only 14% of the German hospitals are official participants. We cannot guarantee that participating hospitals are representative for all hospitals in either country. However, participating hospitals in both countries were not thought to be substantially different from non-participating hospitals with respect to patients and SSI risks.

In KISS, all surgical procedures within a category must be registered, whereas in PREZIES, specific surgical procedures could be chosen (e.g. partial hip arthroplasty, total hip arthroplasty, Caesarean section with preliminary treatment, or Caesarean section without preliminary treatment). Therefore, the distribution of specific procedures within a category might be slightly different. We could not assess the size of this difference because the specific procedure codes were not recorded in KISS. We do not think that this possible difference in distribution of specific surgical procedures in a category would have a major impact on the SSI rate (and the distribution of risk factors like wound class or duration of surgery) of the surgical category, as the procedures included in each category are comparable regarding surgical technique and SSI risk.

We used recent data from the KISS network (2004-2005) and all data from PREZIES (1996-2004) to obtain sufficient statistical power for the analyses. When considering only PREZIES data since 2000, the results were not much different, with still a higher SSI rate than in KISS.

Remarkable differences were found in the registered wound class and ASA classification between KISS and PREZIES, which limit the international comparison. Correct application of these variables is taught during courses and workshops in both surveillance networks. However, these meetings are mostly attended by infection control professionals, while the wound class should be recorded by the surgeon and the ASA classification by the anesthetist. The difference in recorded ASA classification may indicate the subjectiveness of this variable, because we did not expect the health of the patients to be different in these countries.[11-14] The possible difference in assigning the wound class and ASA classification makes international comparison very difficult, as these variables are assumed to be important intrinsic risk factors for which SSI rates should be adjusted before comparing SSI data. Therefore, adjustment of SSI rates by the NNIS index even may distort instead of facilitate international comparison of SSI data.

The validation visits of the PREZIES team to all participating hospitals increase the reliability of the surveillance data. The absence of validation studies in KISS is a limitation, but validation visits to the hospitals are not feasible because of the large number of hospitals and the size of the country. Ideally, validation studies in participating hospitals regarding data collection and the application of definitions should be part of national nosocomial surveillance networks.

International comparison

The NNIS risk index changed in 1998; for endoscopically or laparoscopically performed procedures one point was subtracted from the score, as a lower SSI risk was expected for these procedures.[15] However, not every national nosocomial surveillance system that registered the NNIS index adopted this change. In KISS, they do not subtract one point from the NNIS score for laparoscopic procedures, but they calculate separate reference rates for laparoscopic and non-laparoscopic procedures if analysis shows different SSI rates. In the Netherlands, before 2005 it was not recorded whether a procedure was performed endoscopically or laparoscopically.

Surveillance results published in scientific articles or on the internet usually only include the name of a procedure category and not a detailed description of the surgical procedures, e.g. whether revisions are included. This makes international comparison very difficult, as the specific procedures inlcuded within a category will influence the SSI rate of that category. In the present article we clearly described the surgical procedures included in each category.

This is not the first study comparing SSI data from different countries. Other studies have also showed differences in SSI rates and/or occurrence of risk factors between countries. Belgium and the Netherlands differed in the use of antibiotic prophylaxis, length of hospital stay and frequency of urgent appendectomies.[16] A study comparing SSI data from Hungary with the NNIS data found differences in application of NNIS risk classes, performance of postdischarge surveillance, and duration of surgery.[17] The Italian SSI rates were higher for several procedures than those of the NNIS and of Hungary, mostly due to the performance of postdischarge surveillance in Italy.[18] The Spanish SSI rates were to be higher for cholecystectomy and appendectomy than those of the NNIS, but not for herniorraphy.[19]

This study showed that even though in the Netherlands and Germany similar infection surveillance protocols were used, differences occurred in the surveillance implementation. Rigorous standardization of surveillance protocols is needed when one attempts to compare data between hospitals or countries. Furthermore, it is important to take into account possible differences between hospitals or countries in aspects that may influence the SSI rate like performance of postdischarge surveillance, length of hospitalization and the surgical procedures included. External validation visits or validation checks on the data could help to monitor the quality and reliability of the surveillance data. A comparison of infection rates is most reliable within a hospital over time. A comparison between hospitals within a country, where the health care system is quite similar, is feasible within national surveillance systems like KISS and PREZIES. Comparison between countries seems to be most reliable for deep SSIs during hospitalization, since these SSIs are not affected by postdischarge surveillance and the diagnostic sensitivity for deep SSI is probably more similar between countries than for superficial SSI.

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6

Trends in the incidence of surgical site infections in the Netherlands

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ABSTRACT

Objective: To evaluate the time-trend in surgical site infection (SSI) rate in relation to the duration of surveillance in the Netherlands.

Setting: SSI surveillance data from 42 hospitals that participated in the Dutch PREZIES network between 1996 and 2006 and registered at least one of five frequently performed surgical procedures for at least three years: mastectomy, colectomy, replacement of the head of the femur, total hip prosthesis or knee prosthesis.

Methods: Analyses were performed per surgical procedure. The surveillance time to operation was stratified in consecutive 1-year periods, with the first year as reference. Multivariate logistic regression analysis was performed using a random coefficient model to adjust for random variation among hospitals. All models were adjusted for method of postdischarge surveillance.

Results: The number of procedures varied from 3,031 for colectomy to 31,407 for total hip prosthesis and the SSI rate from 1.6% for knee prosthesis to 12.2% for colectomy. For total hip prosthesis, the SSI rate decreased significantly by 6% per surveillance year (OR: 0.94, 95% CI: 0.90-0.98), indicating a 60% decrease after 10 years. Non-significant, but substantial decreasing trends in SSI rate were found for replacement of the head of the femur (OR: 0.94, 95% CI: 0.88-1.00) and for colectomy (OR: 0.92, 95% CI: 0.83-1.02).

Conclusions: Even though most decreasing trends in SSI rate were not statistically significant, they are encouraging. To use limited recourses as efficient as possible, we would suggest switching the surveillance to another surgical specialty when the SSI rate has decreased below the target.

INTRODUCTION

Even though a lot of attention has been paid to the prevention of nosocomial infections for many years, surgical site infections (SSI) continue to present a major proportion of adverse events in surgical patients. These infections have dramatic consequences for the patient as well as the hospital, because they lead to substantial attributable morbidity and increase costs. Although probably not all SSIs are preventable, adequate measures can substantially reduce the risk of SSI.

Many countries have established a national system for the surveillance of nosocomial infections. Such surveillance systems make comparison of infection rates between hospitals possible and stimulate optimization of infection control, including improvement of compliance to guidelines. The ultimate aim is to reduce the patients' risk of nosocomial infection.

In the mid-1980s, the SENIC project reported that nosocomial infection surveillance with appropriate infection control activities and feedback of surveillance results to surgeons and other involved staff, decreased nosocomial infection rates significantly by 30%.[1] Other studies demonstrated the effectiveness of surveillance with feedback, because comparison of a surgeons infection rate relative to their peers promoted awareness.[2]

In a review of 30 reports (25 intervention studies and 5 cross-transmission studies) that had been published since the 1990s, Harbarth et al. considered at least 20% of all nosocomial infections as probably preventable.[3]

In the Netherlands, the PREZIES surveillance system started in 1996 with the surveillance of SSIs.[4] According to the SSI surveillance data, 3% of all surgical patients in Dutch hospitals develop a SSI (data on website www.prezies.nl).

A reduction in SSI rate with longer participation in PREZIES was already shown by Geubbels.[5] She used SSI surveillance data from the period 1996-2000, and analyzed the trend in SSI rates over seven pooled procedures as to increase power.

In the current study, we evaluated the time-trend in SSI rate between 1996 and 2006, separately for five frequently-performed surgical procedures, using surveillance data from the Dutch PREZIES network.

METHODS

Principles of the PREZIES system

The protocol of PREZIES regarding the surveillance of SSI is based on the US National Nosocomial Infections Surveillance (NNIS) system, with application of the standardized CDC criteria for a SSI.[4] Participation is voluntary and hospital-specific data are kept confidential. Hospitals can annually choose surgical procedures to include. Postdischarge surveillance is strongly recommended and a suggested method is described in the protocol.[6] The recommended methods for PDS are addition of a special registration card to the outpatient medical record, on which the surgeon notes clinical symptoms and whether a patient developed an SSI according to the definitions; an alternative method is examination of the outpatient medical record after the follow-up period has elapsed. A

prerequisite for this is, that the status of the wound must be clearly described in the records. Per procedure, the used postdischarge surveillance method is registered for each hospital. Validation visits by a PREZIES team-member to each participating hospital occur every three years, and provide evidence for the reliability and accuracy of the surveillance data.[7] Deep incisional and organ-space SSIs were both evaluated under the umbrella term "deep SSI". Every time a hospital sends in data, it receives a feedback report per surgical procedure, including crude and expected SSI rates adjusted for the NNIS risk index. Feedback reports are usually spread and discussed in the hospital with the infection control committee, physicians, managers and staff. The necessity of infection prevention activities is left to the hospitals' discretion. Yearly workshops are organized by the PREZIES network. Currently about 90% of acute care hospitals in the Netherlands participate.

Study population

We focused on five frequently performed surgical procedures: mastectomy, colectomy, replacement of the head of the femur, total hip prosthesis, and knee prosthesis. Per surgical procedure, the duration of participation for each hospital was calculated from the start date of the surveillance of that particular procedure. Hospitals can start participating at any time. The surveillance time to operation was stratified in consecutive 1-year periods, with the first year as reference.

Per surgical procedure, hospitals that registered the procedures for at least three consecutive years were included. Per type of procedure, latter surveillance years which covered less than 200 operations (with data from all hospitals combined) were excluded for power considerations.

Many SSIs develop after the patient has left the hospital. Because the likelihood of detecting an existing SSI is higher when postdischarge surveillance is performed, the multivariate analyses were adjusted for this by comparing the recommended method for postdischarge surveillance versus another method or no postdischarge surveillance.[6] Records with unknown postdischarge surveillance method were excluded from the analyses (3%).

All analyses were performed for each of the five selected surgical procedures separately.

If a risk factor had <1% missing values, the records with a missing value were excluded from the multivariate analyses. The missing value indicator method was used for variables with >1% missing values (1%-9%).[8] Age was categorized into tertiles. Preoperative duration of hospitalization was dichotomized, with a cutoff point of 2 or 3 days (0-1 versus 2 days was applied to mastectomy, total hip prosthesis and knee prosthesis; 0-2 versus 3 days was applied to colectomy and replacement of the head of the femur). The 75th percentile of duration of surgery per procedure was calculated in minutes, using the current data. Other risk factors were the American Society of Anesthesiologists (ASA) physical status classification (1-2 / 3-5), wound contamination class (clean or clean-contaminated / contaminated or dirty), gender (male / female), emergency procedure (yes / no), antimicrobial prophylaxis (yes / no), university-affiliated hospital (yes / no).

Questionnaire

To gain information on whether interventions to decrease the number of SSIs were performed in the participating hospitals during their surveillance period, we sent out a questionnaire to all

42 hospitals. Twenty hospitals had already filled in a questionnaire in 2005, for a similar study. However, that questionnaire was restricted to interventions that might affect the SSI risk after knee and hip prosthesis surgery. Therefore, these twenty hospitals were asked to complete the new questionnaire for interventions performed since 2005 and for interventions concerning the SSI risk after mastectomy, colectomy or replacement of the head of the femur. The hospitals were asked to describe in detail all performed interventions (goal, type, time frame, and result of each intervention) that might have influenced the SSI risk and the date the intervention was started.

Statistical analysis

The χ^2 test or Student *t* test was used to screen potential risk factors for SSIs. Variables with a *P* value of less than .2 for their univariate association with SSI were candidates for multivariable analysis.

In the present multicenter study, patients were clustered by hospital. This level of hierarchy can introduce additional sources of variability and correlation (e.g., by hospital-specific treatment policies or risk factors). Therefore, a random coefficient model (procedure NLMIXED in SAS) was used to adjust the risk estimates for random variation among hospitals. Because regular logistic regression models do not take into account interhospital variability, they might overestimate the contribution of patient- and procedure-related factors and overestimate precision.

From the basic model with surveillance time to operation and postdischarge surveillance, variables were sequentially added through manually performed forward selection. In each step, the variable with the smallest likelihood ratio test (LRT) *P* value was added. This was repeated until no other variable contributed significantly to the likelihood of the model (LRT *P* value >0.05), constituting the final model. Associations between SSI and exposures were estimated by odds ratios (OR) and 95% confidence intervals (CI) obtained by logistic regression. A *P* level of less than .05 was considered statistically significant.

All analyses were performed in SAS for Windows (SAS 9.1.3, SAS Institute Inc., USA).

RESULTS

The number of surveillance years included in the analyses (years with >200 procedures) was six years for colectomy, nine years for replacement of the head of the femur, and ten years for mastectomy, total hip prosthesis and knee prosthesis (Table 1). This indicates that, per surgical procedure, the duration of surveillance of a single hospital could vary between three years and the above-mentioned number of surveillance years. Per procedure, at least four hospitals participated during all included surveillance years.

Table 2 shows the characteristics of the study population for each of the five included surgical procedures. The number of procedures varied from 3,031 for colectomy to 31,407 for total hip prosthesis. The SSI rate varied from 1.6% for knee prosthesis to 12.2% for colectomy. Patients undergoing replacement of the head of the femur were the eldest and had the highest ASA classification score. The 75th percentile of duration of surgery was shortest for replacement of the head of the femur (75 minutes) and longest for colectomy (135 minutes). Patients undergoing

Table 1. Number of hospitals and surveillance years.

Surgical procedure	No of surveillance years[a]	No of hospitals[b]	No of hospitals all years[c]
Mastectomy	10	19	4
Colectomy	6	19	6
Replacement head of femur	9	27	4
Total hip prosthesis	10	34	8
Knee prosthesis	10	33	7

[a] Only years included with at least 200 operations.
[b] In this study hospitals are included that registered the surgical procedure for at least three years.
[c] All years means the total number of years mentioned in the second column.

Table 2. Study population.

	Mastectomy	Colectomy	Replacement head of femur	Total hip prosthesis	Knee prosthesis
Procedures – no.	5785	3031	6113	31407	15176
SSIs – no. (%)	258 (4.5)	370 (12.2)	268 (4.4)	766 (2.4)	249 (1.6)
Age – median (25^{th} percentile;75^{th} percentile)	58 (49;70)	69 (57;77)	82 (77;87)	70 (63;77)	72 (64;77)
Gender – % woman	99	53	76	71	76
Wound contamination class – % ≥3	<1	24	<1	<1	<1
ASA classification – % ≥3	6	27	38	13	15
Duration of surgery – 75^{th} percentile in minutes	90	135	75	95	105
Type of procedure – % emergency	<1	15	55	3	<1
Prophylaxis – % administrated	6	93	96	96	98
Preoperative hospitalization – % ≥2 days	3	39	26	7	4
Postdischarge surveillance – % recommended method	31	33	31	45	45
Type of hospital – % university-affiliated	9	1	0	4	3

colectomy or replacement of the head of the femur had on average a longer preoperative duration of hospitalization than the other three types of procedures. Overall, postdischarge surveillance was performed according to the recommended method by PREZIES in 42% of the data.

Figure 1 shows crude SSI rates according to surveillance time to operation, per surgical procedure. The results of the multilevel logistic modeling are presented in Table 3. The models were adjusted for the method of postdischarge surveillance and for risk factors. For total hip prosthesis, the SSI rate decreased significantly by 6% per surveillance year, indicating a 60% decrease after 10 years of surveillance. Non-significant decreasing trends in SSI rate were found for colectomy (8% per surveillance year), for replacement of the head of the femur (6% per surveillance year), and for knee prosthesis (3% per surveillance year). For mastectomy, the SSI rate hardly changed with increasing duration of surveillance.

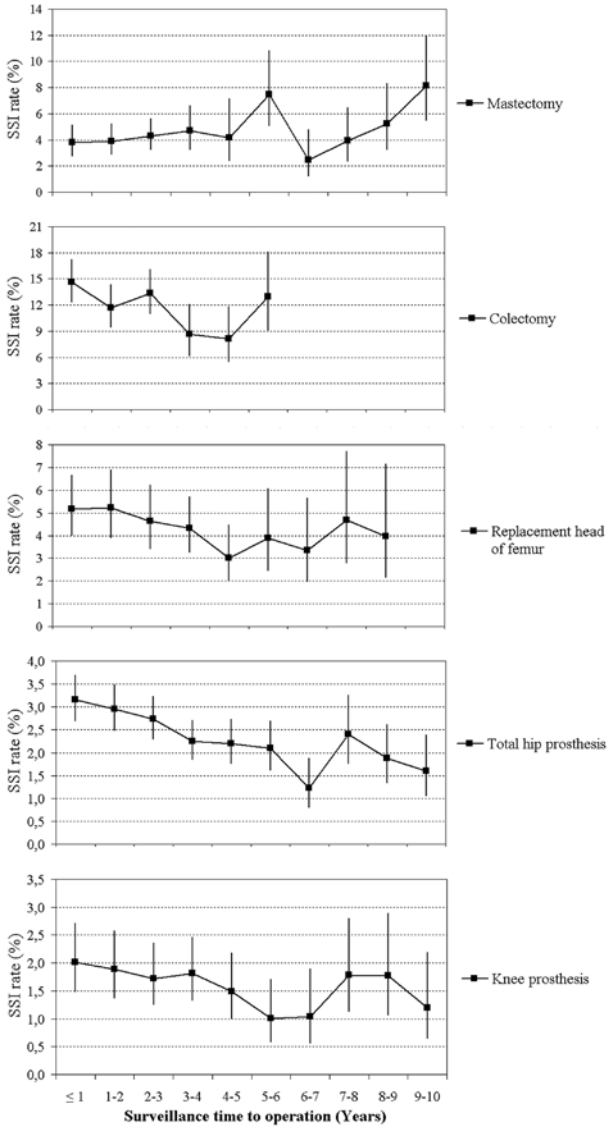

Figure 1. Crude SSI rates (with 95% confidence intervals) according to surveillance time to operation, per surgical procedure.

Overall, information regarding interventions to decrease the number of SSIs was received from 33 of the 42 hospitals. The performed interventions comprised improvements regarding preoperative administration of antimicrobial prophylaxis, hand hygiene, preoperative hair removal, and discipline and airflow in the operating room. For mastectomy, eight hospitals completed the questionnaire and five of them performed at least one intervention. However, no SSI data are available of the post-intervention period yet. Table 4 reveals that the SSI rate of patients undergoing

Table 3. Results of multilevel logistic regression analysis: change in SSI rate **per 1-year increase** in surveillance time to operation.

	OR (95% CI)	***P***
Mastectomy[1]	1.02 (0.96-1.09)	0.46
Colectomy[2]	0.92 (0.83-1.02)	0.10
Replacement of the head of the femur[3]	0.94 (0.88-1.00)	0.07
Total hip prosthesis[4]	0.94 (0.90-0.98)	0.01
Knee prosthesis[5]	0.97 (0.91-1.03)	0.32

OR, odds ratio; *95% CI*, 95% confidence interval.

[1] Adjusted for: postdischarge surveillance, age, duration of surgery, gender.

[2] Adjusted for: postdischarge surveillance, ASA classification, wound contamination class, duration of surgery, duration of preoperative hospitalization, emergency procedure.

[3] Adjusted for: postdischarge surveillance.

[4] Adjusted for: postdischarge surveillance, age, ASA classification, duration of preoperative hospitalization, wound contamination class, duration of surgery.

[5] Adjusted for: postdischarge surveillance, university-affiliated hospital, duration of surgery, gender, age.

mastectomy in the hospitals without interventions was lower than the SSI rate in the hospitals that did perform interventions. These hospitals probably saw no need to change infection control activities considering they performed relatively well compared to the other Dutch hospitals participating in the PREZIES surveillance system. For replacement of the head of the femur and for knee prosthesis, the SSI rate decreased after the interventions, but the change was not statistically significant. For total hip prosthesis, the SSI rate after the interventions was significantly lower than before the interventions, but was still higher than the SSI rate of hospitals that did not perform an intervention. Strangely, regarding colon resection the SSI rate increased after the interventions.

DISCUSSION

This study showed a decreasing trend in SSI risk with increasing surveillance time for some surgical procedures. For total hip prosthesis a significant decrease in SSI rate of 6% per surveillance year was observed, indicating a 60% decrease after 10 years of surveillance. For knee prosthesis, replacement of the head of the femur, and colectomy the decreasing trend was 3%, 6% and 8% per surveillance year, respectively. Even though these latter trends were not statistically significant, they are encouraging. Hospitals are heterogeneous in their environment, patient-care practices, healthcare providers and patient population. By applying multilevel analysis, SSI risk estimates were adjusted for random variation between hospitals. In the multivariate analysis, the patients' and operations' characteristics were taken into account in the SSI risk estimation. Therefore, the observed decreasing trends are most likely a result of an improvement in the quality of care in the hospitals.

We think that the sensitivity of infection detection has not changed during the study period as the execution of the surveillance was validated in all participating hospitals.[7] Other favorable aspects of the current study are that the results were adjusted for the performed method of postdischarge surveillance and that a large dataset was used with data from 42 hospitals and ten surveillance years. In this study, the trend in SSI rate was analyzed for each surgical procedure separately, hereby allowing adjusting for procedure-specific risk factors.

Table 4. The SSI rate before and after an intervention for hospitals that did perform at least one intervention, and the overall SSI rate for hospitals without an intervention.

	Before intervention				After intervention			
	No of procedures	**No of SSIs**	**SSI rate**	**95% CI**	**No of procedures**	**No of SSIs**	**SSI rate**	**95% CI**
Mastectomy								
No intervention (n*=3)	747	24	3.2	(2.2-4.7)				
Intervention (n=5)	2957	161	5.4	(4.7-6.3)	0	-	-	-
Colectomy								
No intervention (n=2)	265	26	9.8	(6.8-14.0)				
Intervention (n=8)	739	73	9.9	(7.9-12.2)	858	161	18.8	(16.3-21.5)
Replacement of head of femur								
No intervention (n=6)	1578	74	4.7	(3.8-5.8)				
Intervention (n=12)	1412	70	5.0	(3.9-6.2)	1436	61	4.2	(3.3-5.4)
Total hip arthroplasty								
No intervention (n=7)	5909	88	1.5	(1.2-1.8)				
Intervention (n=14)	6966	196	2.8	(2.5-3.2)	9494	207	2.2	(1.9-2.5)
Knee arthroplasty								
No intervention (n=6)	2375	29	1.2	(0.9-1.7)				
Intervention (n=12)	2776	46	1.7	(1.2-2.2)	4562	58	1.3	(1.0-1.6)

* Number of hospitals.

The decreases in SSI rates found in this study are smaller than the decreasing trend that Geubbels et al. described earlier with a different subset of the PREZIES database.[5] They found a decrease in SSI rate of 31% in the fourth surveillance year and of 57% in the fifth year compared with the first year of surveillance. There were several differences in methodology between these two studies that might partly explain the different results. Geubbels et al. included only five surveillance years, additionally included hospitals with a surveillance period less than three years, pooled data from seven surgical procedures, and included hospital-related factors.

The limitation of this study was that the trend in SSI risk was not adjusted for changes in length of hospitalization. The average length of hospitalization reduced over the ten years included in this study. This reduction was larger per calendar year than per surveillance year, because many hospitals started participating in PREZIES later than 1996. Only for 16 of the 42 hospitals (38%) that started SSI surveillance in 1996 (of at least one of the five included types of procedures), the first surveillance year corresponded to the calendar year 1996. Ten (24%) hospitals started not earlier than January 2001. The largest decrease in median length of hospitalization was recorded for total hip prosthesis and knee prosthesis, i.e., a decrease of five days between the 1st and 10th surveillance year. We think that this decrease can not solely have caused the reduction in SSI rate of 6% per surveillance year (60% after ten years) for total hip prosthesis. Besides, because of the fact that many hospitals perform postdischarge surveillance, the length of hospitalization has only a minimal effect on the detection of SSIs. This was supported by the fact that the time between operation and SSI diagnosis did not decrease but even increased with increasing surveillance time (data not shown). The shorter length of stay led to an increase in the relative number of SSIs that were diagnosed after discharge, which were captured by postdischarge surveillance.

Feedback of infection rates to hospital staff can make them more aware of infection risk and increase their discipline in working according to infection prevention protocols. As early as 1970s, the American NNIS data demonstrated the benefits of properly designed wound infection surveillance. Haley et al. suggested that an effective infection surveillance program can reduce a hospital's wound infection rate by 30%.[1]

During the last decade, some other SSI surveillance networks have also investigated the change in SSI rate with increasing duration of surveillance. In Germany, the KISS surveillance network was set up in 1997, and recently two studies have been performed on the effect of surveillance on the SSI rate. The first included data between 1997 and 2003.[9 10] The SSI rate of the third surveillance year was compared with the first year. For total hip arthroplasty the SSI decreased with 43% (95% CI: 22-58%), for cesarean section with 36% (95% CI: 17-51%), and the trend for knee arthroplasty was not statistically significant. Most hospitals did not perform any particular intervention, and some improved the administration of antimicrobial prophylaxis or skin disinfection. The second German study compared the fourth surveillance year with the first.[11] A decreasing trend in SSI rate was found for 14 of the 19 included procedure categories. Overall, the SSI rate decreased with 25% (95% CI: 17-32%) as a result of surveillance-induced infection control efforts. Limiting factors of these German studies were that the results were not adjusted for a reduced postoperative length of stay, nor for postdischarge surveillance, and that multilevel analysis was not applied.

A study in Northern France included six years of SSI surveillance data, with postdischarge surveillance until 30 days.[12] All types of procedures were pooled. The crude SSI rate decreased from 3.8% to 1.7% (*P* for trend <.0001), and the standardized infection ratio decreased from 1.24 to 0.74. Recently, a comparable study with data from the SSI surveillance network in southeast France reported an overall decrease in SSI rate of 5% per year (45% after 9 years), which was observed for almost all different types of surgical specialties.[13] They included hospitals that participated for at least two years. Only this last study included many of the aspects that we consider vital for analyzing trends in SSI risk, namely adjust for random variation between hospitals, adjust the SSI risk estimates for surgical specialty or perform separate analyses per procedure, and follow up all patients after surgery for at least 30 days or one year if a prosthesis had been implanted or adjust for the performed method of postdischarge surveillance.

At least one study observed no general preventive effects of the continuous monitoring of SSI rates, maybe because of the short study period of two years.[14] Of course, this might be an underestimation as results of studies that revealed a positive effect of SSI surveillance are probably more often published than those of studies that failed to do so.

Many studies have measured the effect of surveillance combined with several interventions on the SSI risk.[15-17] In our study, about two thirds of the hospitals executed at least one intervention. However, as the implementation of interventions was inquired retrospectively, it was difficult to link these interventions to the SSI data in order to assess its effectiveness. We would suggest to more often link SSI surveillance data to multicenter intervention studies, like done in a Dutch study on improvement of antimicrobial prophylaxis[18] and in Breakthrough series.

In conclusion, a high-quality surveillance system might be an effective strategy to reduce the SSI incidence. As the applied methodology of analyzing trends in SSI risk might influence the results it is essential to pay attention to these methods when comparing results with those of other surveillance networks.

To use limited recourses as efficient as possible, we would suggest switching the surveillance to another surgical specialty when the SSI rate has decreased below the target. The next step is to estimate the savings due to the observed decrease in SSI rate and thus the cost effectiveness of the national SSI surveillance system.

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7

Effect of optimized antibiotic prophylaxis on the incidence of surgical site infections

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ABSTRACT

Objective: To compare the rate of surgical site infection (SSI) before and after an intervention period in which an optimized policy for antibiotic prophylaxis was implemented. To demonstrate that a more prudent, restrictive policy would not have a detrimental effect on patient outcomes.
Design: Before-after trial with prospective SSI surveillance in the Dutch nosocomial surveillance network (Preventie Ziekenhuisinfecties door Surveillance [PREZIES]), using the criteria of the Centers for Disease Control, including postdischarge surveillance for up to 1 year.
Setting: During a preintervention period and a post-intervention period (both 6-13 months), 12 Dutch hospitals collected data on antimicrobial prophylaxis and SSI rates. The study was limited to commonly performed surgical procedures in 4 specialties: vascular, intestinal, gynecological and orthopedic surgery. Selected risk factors for analysis were gender, age, American Society of Anesthesiologists classification, wound contamination class, duration of surgery, length of hospital stay before surgery, and urgency of surgery (elective or acute).
Results: A total of 3,621 procedures were included in the study, of which 1,668 were performed before the intervention and 1,953 after. The overall SSI rate decreased from 5.4% to 4.5% (P = .22). Among the procedures included in the study, the largest proportion (55%) were total hip arthroplasty, and the smallest proportion (2%) were replacement of the head of the femur. The SSI rates varied from 0% for vaginal hysterectomy to 21.1% for femoropopliteal or femorotibial bypass surgery. Crude and adjusted odds ratios showed that there were no significant changes in procedure-specific SSI rates after the intervention ($P > .1$).
Conclusions: An optimized and restrictive prophylactic antibiotic policy had no detrimental effect on the outcome of clean and clean contaminated surgery, as measured by SSI rate.

INTRODUCTION

Surgical site infections (SSIs) account for 38% of surgical infections and 17% of all nosocomial infections.[1,2] In the United States in the 1990s, SSIs prolonged hospital stay by an average of 6.5 days, doubled the risk of death, and were associated with a risk of readmission to the hospital 5 times that for patients without SSI.[3] In the Netherlands, the mean postoperative length of stay for patients with an SSI is 8.2 days longer than for patients without an SSI.[4]

Decades ago, the effectiveness of antimicrobial prophylaxis in reducing SSI rates was demonstrated in randomized clinical trials.[5-10] For optimal prophylaxis, an antibiotic with a targeted spectrum should be administered at sufficiently high concentration in the serum, tissue, and the surgical wound during the entire time that the incision is open and at risk of bacterial contamination.[11] In the United States, the Surgical Infection Prevention Guideline Writers Workgroup (SIPGWW) reached a consensus that infusion of the first dose of antimicrobial should begin within 60 minutes before surgical incision and that antimicrobial prophylaxis should be discontinued within 24 hours after the end of surgery.[12] Studies showed that the prolonged use of antibiotic prophylaxis leads to emergence of bacterial resistance[13-15] and high costs,[16,17] and inappropriate timing of the administration leads to decreased efficacy.[18,19]

As part of the prospective, multisite, Surgical Prophylaxis and Surveillance (CHIPS) project, an optimized and restrictive antibiotic policy based on the national guideline was implemented in the Netherlands.[20] This guideline recommends prophylaxis with a single dose of antimicrobial administered intravenously within 30 minutes before the first incision. In view of the very low incidence of infection with methicillin-resistant *Staphylococcus aureus* in the Netherlands (less than 1% of all *S. aureus* infections), cefazolin (combined with metronidazole, if coverage for anaerobic pathogens is needed) is recommended.

The goal of the study intervention was to slow down the development of antibiotic resistance and reduce the costs of antimicrobial prophylaxis without decreasing the efficacy of prophylaxis, as measured by a higher SSI incidence. In the present report, the patient outcome of this optimized and restrictive antimicrobial prophylaxis policy is assessed by comparing the SSI rate before and after the intervention.

METHODS

Setting

The CHIPS project was a prospective intervention study conducted at 13 Dutch hospitals, which participated voluntarily. These hospitals give a representative picture of inpatient care in the Netherlands, since they were geographically spread over the country, according to the population density (Figure 1), various types of hospitals (small, large, university and general hospitals) were included. At 1 of the 13 hospitals, data on SSIs could not be recorded because of the sudden absence of the infection control professional (ICP).

Data on antimicrobial prophylaxis and SSIs were collected in these 12 hospitals between January 2000 and November 2001 (the preintervention period) and between July 2001 and November 2002 (the postintervention period). The duration of these periods in each hospital ranged from 6 to 13

Figure 1. Locations of participating hospitals (*filled circles*) in the Netherlands (population, 16 million; area, 41,526 km^2).

months, depending on how often the selected procedures were performed. During the intervention period, which lasted 6-11 months, a restrictive antibiotic-use policy was implemented. The policy was based on the national guideline for surgical prophylaxis issued by the Dutch Working Party on Antibiotic Policy (SWAB).[21]

Four major surgical specialties were selected for this study: vascular, intestinal, gynecological and orthopedic surgery. The study was limited to frequently performed procedures for which antimicrobial prophylaxis is generally recommended[21,22]: grafting of the aorta, femoropopliteal or femorotibial bypass, various colorectal procedures, abdominal and vaginal hysterectomy with or without vaginal repair, total hip arthroplasty and replacement of the head of the femur.

Only elective procedures were included, so that the normal daily routine of administering antimicrobial prophylaxis would be observed. To avoid assessment of procedures in which antibiotics were given for therapeutic reasons rather than prophylactic, procedures with a dirty or infected wound (i.e., wound contamination class 4)[1,23] were excluded.

Data collection

The methods used to collect data on antimicrobial prophylaxis have been described elsewhere.[20,24] Data were collected prospectively by infection control professionals from medical, nursing, anesthetic, and medication records. Before the start of the project, as well as during the study, the collection of data on antimicrobial prophylaxis was validated at regular intervals through on-site review of the 20 most recently recorded patient files.

All CHIPS hospitals participated in the module "Surgical site infections" of the Dutch national

nosocomial infections surveillance network (Preventie Ziekenhuisinfecties door Surveillance; PREZIES[4]; general information is available at the network's Web site, http://www.prezies.nl). From 1996 to 2003 within the PREZIES network, 62 of the 98 Dutch hospitals participated and collected SSI data on 129,142 procedures. According to the PREZIES protocol, infection control professionals collected information on the demographic characteristics of patients and on the surgical procedure, risk factors for SSI, and incidence of SSI. The selection of risk factors was based on the literature and included the patient's sex, age, and physical condition (American Society of Anesthesiologists classification);[25] wound contamination class; duration of surgery; preoperative length of hospital stay; and whether surgery was elective or acute.[26-29] The criteria of the Centers for Disease Control and Prevention were used for the assessment of SSIs.[22,30] If an SSI occurred in a patient, the surveillance staff recorded the day the SSI became manifest, whether it was a superficial or deep SSI, and which micro-organisms were isolated. Deep incisional SSIs and organ/space SSIs were combined and termed deep SSIs. All patients were followed up to 30 days postoperatively; in case of insertion of a prosthetic implant the duration of follow-up was 1 year. To monitor the quality and reliability of the surveillance data used in this study, SSI surveillance was validated in each participating hospital.

To achieve a significance level of 5% and a power of 80%, the required sample size for observing a change in the SSI rate was 1,600 surgical procedures before the intervention and 1,600 after. This was calculated using the assumptions that the overall risk of SSI before the intervention was 7.5% and that the estimated achievable SSI rate after the intervention was 5%. The figure of 7.5% was based upon PREZIES data for the selected procedures in previous years and assumed an equal distribution of the selected procedures (orthopedic, gynecological, vascular and bowel surgery) in the CHIPS study. However, the CHIPS study was dependent on the PREZIES protocol, according to which hospitals were free to choose the type of procedures for surveillance.

Data analysis

The χ^2 test or Student *t* test was used to screen potential risk factors for SSIs. Variables with a *P* value of less than .2 for their univariate association with SSI were candidates for multivariable analysis. Logistic regression analysis was used to calculate odds ratios (ORs) for SSI after the intervention compared with before the intervention, according to the type of surgical procedure, and after adjusted for procedure-specific confounders. The best model was selected by considering the -2 log likelihood as well as the c-index. The c-index is a measure of predictive performance and represents the proportion of instances in which a patient who develops an SSI is assigned a higher probability of SSI than a patient who does not develop an SSI.[31]

As recommended by the Cochrane Effective Practice and Organization of Care Group (EPOC),[32] we used segmented time series analysis, which includes changes in level and in trend, to estimate the effect size of the intervention. Data were collected on individual patient level, whereas the interventions were targeted towards hospitals with different mixes of surgical procedures. Therefore, the resulting hierarchical structure was taken into account in the analyses. As the response variable was binary (SSI present or absent), a non-linear mixed model analysis was

applied using SAS Proc NLmixed, version 8.2 (SAS Institute). In the model, the hospital where the procedure was performed was treated as a random variable, and surgical procedure and calendar time of the preintervention, intervention and postintervention periods were treated as covariables. In this way, the model corrected for unequal distribution of procedures in the preintervention and postintervention periods, for unequal distribution within hospitals, and for differences in length of registration and intervention periods. The following outcome measurements were generated: mean SSI rates in the preintervention and postintervention periods, change in SSI rate immediately after the intervention, and the slopes of the curve of the SSI rates before and after the intervention.

All analyses were performed in SAS for Windows, release 8.2 (SAS Institute). A *P* level of less than .05 was considered statistically significant.

RESULTS

Overall results of the optimized antibiotic policy

The optimized antibiotic policies led to a decrease of 35% in the use of prophylactic antibiotics (calculated as the number of Defined Daily Doses (DDD) per procedure) and a decrease of 25% in the costs per procedure, mainly as a result of a shorter period of administration of prophylaxis.[24] After the intervention, antibiotics were administered inappropriately in 37.5% of the procedures, instead of the expected 93.5% had the intervention not occurred. Administration of doses after closure of the wound, instead of the recommended single dose before the first incision (with a second dose if there is major blood loss or the procedure has a long duration), was observed in 31.4% of procedures instead of the expected in 46.8%. Inappropriate timing of antibiotic administration (ie, not within 30 minutes before the first incision) was observed in 39.4% of procedures, instead of the expected 51.8%. Time series analysis showed that these improvements were statistically significant ($P < .01$) and that they could be fully attributed to the intervention.[24] The percentage of procedures in which antimicrobial prophylaxis was administered within 1 hour before the first incision changed only slightly, from 72% to 79%.[24]

Results before and after the intervention

The results described here are for a total of 3,621 procedures, of which 1,668 were performed before the intervention and 1,953 after. The overall SSI rate decreased from 5.4% (95% confidence interval [CI]: 4.3%–6.5%) before to 4.5% (95% CI, 3.6%-5.4%) after the intervention ($P = .22$).

Table 1 summarizes the characteristics of each participating hospital. Three of the 12 hospitals had fewer than 400 beds, and 3 hospitals had more than 800 beds. There were 5 teaching hospitals, of which 2 were university hospitals. The total recorded number of surgical procedures at each hospital varied from 97 to 581. Vascular procedures were recorded at 4 hospitals, intestinal procedures at 6 hospitals, gynecological procedures at 4 hospitals, and orthopedic procedures at 11 hospitals.

Table 1. Characteristics of the 12 study hospitals and number of surgical procedures performed during the 2 study periods.

			No. of procedures recorded before and after study intervention									
			Total		Vascular surgery		Intestinal surgery		Gynecological surgery		Orthopedic surgery	
Hospital	No. of beds	Type of hospital	Before	After	Before	After	Before	After	Before	After	Before	After
A	> 800	Teaching	271	310	…	…	…	…	131	175	140	135
B	400-800	General	206	254	…	…	…	…	…	…	206	254
C	400-800	General	94	103	…	…	…	…	…	…	94	103
D	< 400	General	114	131	…	…	40	49	…	…	74	82
E	> 800	University	165	181	…	…	39	43	67	70	59	68
F	400-800	Teaching	136	135	87	87	49	48	…	…	…	…
G	400-800	General	41	80	…	…	…	…	…	…	41	80
H	< 400	Teaching	134	178	…	…	…	…	68	88	66	90
I	400-800	General	50	47	…	…	…	…	…	…	50	47
J	< 400	General	99	86	9	5	41	26	…	…	49	55
K	400-800	General	182	238	23	15	45	45	…	…	114	178
L	> 800	University	176	210	46	45	36	46	62	69	32	50

Table 2. Comparison of risk factors identified before and after the intervention.

	Percentage of procedures with risk factor present		
Risk factor	**Before intervention (n = 1668)**	**After intervention (n = 1953)**	***P***
Age >65	56.4	58.1	.30
Male sex	30.9	30.4	.76
ASA classification ≥3	17.7	17.6	.89
Wound class ≥2	34.7	33.7	.54
Duration of surgery >P75	24.6	24.1	.76
Teaching hospital	48.9	47.3	.33
University hospital	20.4	20.0	.75

ASA, American Society of Anesthesiologists; *P75*, 75th percentile.

Table 3. Surgical site infection (SSI) rates in the Dutch national nosocomial infection surveillance (PREZIES) network and in the surgical prophylaxis and surveillance (CHIPS) project.

		CHIPS			
	PREZIES[a]	**Before intervention**		**After intervention**	
Procedure	**SSI rate, % (95% CI)**	**n**	**SSI rate, % (95% CI)**	**n**	**SSI rate, % (95% CI)**
Reconstruction of the aorta	1.9 (0.4-3.5)	95	5.3 (0.8-9.8)	95	7.4 (2.1-12.6)
Femoropopliteal or femorotibial bypass	6.3 (3.7-8.9)	70	14.3 (6.1-22.5)	57	21.1 (10.5-31.6)
Colorectal procedures	7.3 (5.6-9.0)	250	14.8 (10.4-19.2)	257	10.9 (7.1-14.7)
Abdominal hysterectomy	1.6 (0.6-2.5)	205	2.4 (0.3-4.6)	239	1.7 (0.0-3.3)
Vaginal hysterectomy	0.3 (0.0-0.8)	123	0	163	1.2 (0.0-2.9)
Replacement of the head of the femur	3.5 (2.5-4.5)	25	20.0 (4.3-35.7)	42	11.9 (2.1-21.7)
Total hip arthroplasty	2.8 (2.4-3.2)	900	3.1 (2.0-4.2)	1100	2.7 (1.8-3.7)

CI, confidence interval.

[a] PREZIES data between 2000-2002, without the CHIPS data.

The distribution of risk factors before and after the intervention is shown in Table 2. More than half of the patients were over 65 years old, 31% of the patients were male, and less than 20% of the patients had an American Society of Anesthesiologists classification of 3 or higher; 66% of the procedures were classified as clean procedures. Twenty percent of the recorded procedures were performed in university hospitals and 32% in other teaching hospitals. There were no significant differences in the distribution of the risk factors before and after the intervention ($P \geq .3$).

Table 3 shows PREZIES SSI rates[4] and SSI rates before and after the intervention in the present CHIPS study, according to the type of surgical procedure. The distribution of the surgical procedures was fairly similar before and after the intervention. However, the recorded number of femoropopliteal or femorotibial bypasses decreased significantly ($P = .04$).

For 4 procedures the SSI rate decreased after the intervention, and for 3 procedures the SSI rate increased after the intervention. Table 4 shows the crude and adjusted ORs, according to the type of procedure, for the comparison of the SSI rate after the intervention with the rate before the

Table 4. Crude odds ratio (OR) and adjusted OR of the surgical site infection rate after the intervention, compared with before the intervention.

Procedure	Crude OR (95% CI)	Adjusted OR (95% CI)	Variables adjusted for
Reconstruction of the aorta	1.4 (0.4-4.7)	1.4 (0.4-4.6)	Gender
Femoropopliteal or femorotibial bypass	1.6 (0.6-4.0)	1.1 (0.4-3.1)	Age (≥65 years), university hospital
Colorectal procedures	0.7 (0.4-1.2)	0.7 (0.4-1.1)	Age (≥65 years)
Abdominal hysterectomy	0.7 (0.2-2.6)	0.6 (0.2-2.4)	Duration of surgery (>P75)
Vaginal hysterectomy	Not calculable	Not calculable	
Replacement of the head of the femur	0.5 (0.1-2.1)	0.6 (0.1-2.6)	Age (continuous), duration of surgery (>P75)
Total hip arthroplasty	0.9 (0.5-1.5)	0.9 (0.5-1.5)	Age (≥75 years), ASA classification (≥3), duration of surgery (>P75)

ASA, American Society of Anesthesiologists; *CI*, confidence interval; *P75*, 75th percentile.

intervention, adjusted for procedure-specific confounders. These ORs did not differ significantly from 1, indicating that the SSI rates had not changed remarkably during the intervention.

Time series analysis that took into account possible changes over time in hospitals concerning unmeasured factors confirmed that the optimized and more-restrictive administration of antibiotic prophylaxis did not have a significant impact on the SSI rate (P = .99) and that there were no significant trends in SSI rates during the preintervention and postintervention periods. Specific changes in different aspects of prophylaxis (e.g. choice, timing, and duration of antibiotic prophylaxis) after the intervention are described elsewhere.[21]

DISCUSSION

Our results demonstrate that implementing an optimized and more-prudent antibiotic policy in hospitals did not change the risk of SSI. Our findings are in line with the results of studies that have shown that narrow-spectrum antimicrobials are as effective as broad-spectrum antimicrobials for preventing SSIs[33-35] and that single-dose prophylaxis is as effective as multiple-dose prophylaxis.[34-39] Furthermore, Classen et al.[18] have demonstrated that the SSI incidence is lower if antimicrobial prophylaxis is administered within 2 hours before the first surgical incision, compared with administration earlier or later. Despite the evidence, surgeons are still reluctant to follow guidelines that advocate use of narrow-spectrum antibiotics and single-dose prophylaxis, because they fear an increase in the incidence of SSI. Many guidelines, therefore, have not found their way into daily practice. However, in the present study, implementation of these recommendations was successful, and the improvement in quality resulted in less use and improved use of antibiotics,[24] and the effectiveness of the antibiotics concerning SSI prevention did not diminish. Since the timing of prophylaxis only slightly improved after the intervention, the positive effect of this improvement on the incidence of SSI might have been limited, although pharmacokinetic data indicate the desirability of administration as close as possible to the time of the first incision.[40,41]

The CHIPS multiple-site study was unique in several aspects. It involved 12 hospitals; measured

SSIs as patient-outcome in addition to the process-outcome parameters; and considered various common procedures in 4 surgical specialties. Of the many studies that have tried to implement an improved antibiotic prophylaxis policy, only a few considered an outcome parameter. A study by Gyssens et al.[17] recorded the number of nosocomial infections per 100 bed days. Two other implementation studies recorded the SSI rate but included only 2 hospitals[42] and 6 hospitals.[43] Schell et al.[42] focused solely on bowel surgery, and Weinberg et al.[43] focused on cesarean section. The present CHIPS study was conducted within PREZIES. Therefore, SSI surveillance was performed according to a standardized protocol, which included postdischarge surveillance and validation of the data collection in the hospitals, which yielded reliable data on SSIs.

A limitation of our study is the lack of a control group. However, it did not seem feasible to include a control group of hospitals that would be motivated to invest a lot of effort in the data collection without the possibility of implementing the national guideline and improving the overall quality of antimicrobial prophylaxis. The participating hospitals had agreed not to introduce any other intervention during this study. Consequently, there was no change in surgical personnel, surgical methods, operating room protocols, or postoperative wound care in the participating hospitals. Despite this agreement, changes in SSI rates could still have been the result of a gradual change in practices not related to the study intervention. However, by using segmented time series analysis, trends over time not related to the intervention could be excluded.

Another limitation might be that the preintervention SSI rate was 5.4%, mainly because of overrepresentation of orthopedic procedures in the study, which is less than the 7.5% on which the power calculation was based. However, more procedures were included in the study than we had anticipated: 1,668 before and 1,953 after intervention, instead of 1,600. With this sample size and given the preintervention SSI rate, the study had enough power to demonstrate a decrease in the overall SSI rate to 3.4% or lower or an increase to 7.7% or higher. However, we observed no change in overall SSI rate before and after intervention; the observed difference was minor, with overlapping 95% CIs. Unfortunately, this study had not enough power to demonstrate a significant change in SSI rate according to the type of procedure.

In this study, no data on antibiotic resistance were collected. Therefore, we were not able to investigate how antibiotic use was affected by the decreased use of antibiotics (from 121 to 79 defined daily doses per 100 procedures) and the decreased use of agents with a broader spectrum than cefazolin (from 85% to 34% of procedures).[24] However, it might be expected that the restricted antibiotic use that was achieved in this study will contribute to a decrease in antimicrobial selective pressure.[13]

Most aggregated procedure-specific SSI rates reported in the present CHIPS study were higher than the national SSI rates from PREZIES. It appeared that the national rates during the CHIPS study (during 2000-2002) were, by coincidence, lower than the average infection rates during the total national surveillance period of 1996-2004. A possible explanation for the higher rates in the CHIPS hospitals might be that the SSI surveillance during the CHIPS study was performed more accurately and thoroughly, resulting in a higher proportion of SSIs detected. Another explanation could be that not all hospitals participating in PREZIES performed postdischarge surveillance,

whereas all CHIPS hospitals did perform postdischarge surveillance. However, when only SSIs that developed during hospitalization were considered, the trend of higher SSI rates in the CHIPS study was still apparent. The difference in SSI rates might also be caused by differences in present risk factors between the CHIPS and PREZIES study population, since only the crude infection rates were compared.
In conclusion, this study shows that the implementation of an optimized and restrictive antibiotic policy had no detrimental effect on the outcome of clean and clean-contaminated surgery, as measured by SSI rate.

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8

Antibiotic prophylaxis and the risk of surgical site infections following total hip arthroplasty: timely administration is the most important factor

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ABSTRACT

Background: Surgical site infections (SSIs) following total hip arthroplasty can lead to prolonged hospitalization, increased morbidity and mortality, and high costs. This article analyzes the effect of various parameters of surgical antibiotic prophylaxis on the risk of SSI following total hip arthroplasty.

Methods: Data about SSI and potential prophylaxis-, patient-, and procedure-related risk factors were prospectively collected for 1922 patients who underwent elective total hip arthroplasty in 11 hospitals that participated in the Dutch intervention project, Surgical Prophylaxis and Surveillance. Multilevel logistic regression analysis was performed to correct for random variation among hospitals.

Results: SSIs (superficial and deep) occurred in 50 patients (2.6%). The highest odds ratios for SSI were found in patients who received prophylaxis after incision (2.8, 95% confidence interval [CI], 0.9-8.6; $P = .07$), had an American Society of Anesthesiology score that was >2 (2.8, 95% CI, 0.8-9.2; $P = .09$), and experienced a duration of surgery that was >75th percentile (2.5, 95% CI, 1.1-5.8; $P = .04$). Prolonged prophylaxis after the end of surgery and the use of antibiotic impregnated cement did not contribute to fewer SSIs in this study.

Conclusion: This study suggests that intervention programs in search of amendable factors to prevent SSI should focus on timely administration of antibiotic prophylaxis.

INTRODUCTION

Surgical site infection (SSI) following total hip arthroplasty (THA) can lead to prolonged hospitalization, increased morbidity and mortality, and high costs.[1,2] The health and economic burdens of SSI are not restricted to patients' hospital stays.[3] Deep-implant SSI following THA is almost always diagnosed after discharge. Deep-implant SSIs following THA occur infrequently (0.3%-1.3%)[4-6] but can lead to severe incapacitation.[7] Known risk factors for SSI are related to the environment, surgeon, and patient.[8] Some of these factors are amenable to intervention (e.g., conditions in the operating room). Other factors, such as advanced age and diabetes mellitus, are intrinsic patient risks and cannot be modified.[9] Antimicrobial prophylaxis contributes to the reduction in incidence of SSI and is standard practice for THA. Specific recommendations are available regarding the choice of the antibiotic, duration of prophylaxis, and timing of the first dose.[8,10-12] The cephalosporins cefazolin and cefuroxime are considered to have equal prophylactic efficacy. Available evidence suggests that administration of the first dose as near to the incision time as possible will achieve a decreased likelihood of SSI. However, controversy exists regarding the optimal duration of prophylaxis in connection with THA. The US advisory statement recommends that antimicrobial prophylaxis be administered within one hour before incision and discontinued within 24 hours after the end of the operation.[12] However, European guidelines recommend a single-dose within 30 minutes before the incision.[11,13] In addition, despite the potential benefits of antibiotic-impregnated bone cement for joint arthroplasty, controversies remain regarding its use.[12]

Most studies that have analyzed risk factors for SSI following THA have mainly focused on patient, procedure, or hospital characteristics.[4,14-16] However, prospective studies of the contribution of the qualitative aspects of surgical prophylaxis to the prevention of SSI following THA are scarce. We conducted a prospective, multisite intervention study (the Surgical Prophylaxis and Surveillance [CHIPS] project), to research the quality of surgical prophylaxis in the Netherlands and documented patient outcome by surveillance of SSI.[17-19] This project aimed at narrowing the spectrum, shortening the duration, and optimizing the time of administration of prophylactic antibiotics without impairing the incidence of SSI by implementing the national guidelines for surgical prophylaxis. These guidelines, developed by the Dutch Working Party on Antibiotic Policy, recommend intravenous single-dose cefazolin administered within 30 minutes before the first incision for THA.[13] Here, we explore the contribution of the prophylaxis process to the incidence of SSI for the population undergoing THA, with an emphasis on the timing of administration of prophylaxis.

METHODS

During 2000-2002, 11 of the 13 Dutch hospitals of the CHIPS project provided data on elective, primary THA before and after the implementation of the national guidelines for surgical prophylaxis. Procedures for revision of a hip prosthesis were excluded.

Data collection

All hospitals participated in the national SSI surveillance network PREZIES (Preventie van Ziekenhuisinfecties door Surveillance). Data about the surgical procedure, potential SSI risk factors, and infections for patients who developed SSI were collected according to the PREZIES protocol,[20] using the criteria of the US Centers for Disease Control and Prevention.[21] Local infection-control professionals prospectively collected the data and identified cases of SSI. SSIs following THA were categorized as superficial (involving skin or subcutaneous tissue) or deep (involving fascia, muscle, or joint space). Postdischarge surveillance was performed for all patients. Surgeons were requested to describe clinical symptoms and whether a patient had developed an SSI on a registration card that was added to the outpatient medical record. The records were reviewed by the infection-control professional at 30 days and one year after discharge.[15] Data about the quality of prophylaxis were collected from medical, anesthetic, and nursing records and medication charts. The method of prophylaxis data collection and validation are described elsewhere.[17] The choice of the antibiotic, number of doses, time of administration of the first dose and subsequent doses, use of antibiotic-impregnated bone cement, time of induction of anesthesia, and time of incision and closure of the wound were recorded.

Prophylaxis- , patient- and procedure-related risk factors

Duration of prophylaxis was divided into three categories: single-dose (one or, in case of prolonged surgery, more doses, as recommended by the national guidelines), 24 hours (postoperative dosing for 24 hours), and >24 hours (postoperative dosing for >24 hours). Timing of administration of prophylaxis was assessed as the interval (in minutes) between the administration of the first dose and the incision. If prophylaxis was administered by intravenous infusion, the point at which one-half of the infusate had been administered was noted as the time of administration. Timing of administration was divided in four categories: within 30 minutes before incision (as recommended by the national guidelines), 31-60 minutes before incision, >60 minutes before incision, and during or after incision. The use of antibiotic-impregnated bone cement was considered a potential confounder of the effect of systemic prophylaxis.

The selection of potential patient- and procedure-related risk factors for SSI included in the national PREZIES surveillance was based on the literature to allow comparison with data generated by surveillance systems of other countries and was limited by feasibility.[20,22] The factors included sex, age, physical condition of the patient (according to the American Society of Anesthesiology [ASA] score)[23], wound class, duration of surgery >75th percentile, National Nosocomial Infections Surveillance score[24], and duration of preoperative hospital stay (Table 1). The annual volume of surgery and the teaching status of the hospital, which were recently described as important risk factors for THA,[15] were also considered as possible confounders. Data about the quality of prophylaxis were linked to the PREZIES SSI database by matching date of birth, admission, and surgery.

The CHIPS prophylaxis database contained 2031 consecutive patients who underwent elective primary THA. Linkage with the SSI database was successful for 1999 procedures. For 1922 (96%),

the data on the timing of antibiotic administration were complete. This data set was considered appropriate for analysis. Missing data for ASA score (n = 19), duration of surgical procedure (n = 7), and duration of surgical prophylaxis (n = 32) were adjusted using the missing value indicator method.[25]

Statistical analysis

Statistical analysis was performed using SAS Software, release 9.1 (SAS Institute). The correlation between antibiotic prophylaxis parameters and potential patient and procedure related risk factors for SSI was tested univariately with the chi-square test or Student's t test. Pearson's correlation coefficient was used to assess the correlation between the annual number of arthroplasties performed per hospital and the incidence of SSI. Multivariable regression analysis was performed to account for these possibly confounding risk factors. According to our hypothesis, the variables duration and timing of prophylaxis and the use of antibiotic-impregnated bone cement were forced into the multivariable model. The patient- and procedure-related risk factors for SSI, with a threshold of statistical significance of P <.1 in crude analyses, were included in the model. The National Nosocomial Infections Surveillance score was not included in the multivariate analysis because all procedures were clean (value, 0), and its other components (the ASA score and duration of surgery of >75th percentile) were already included in the model.

In the present multicenter study, patients were clustered by hospital. This level of hierarchy can introduce additional sources of variability and correlation (e.g., by hospital-specific treatment policies, risk factors, and the diagnostic accuracy of the infection-control professional). Therefore, a random coefficient model (procedure NLMIXED in SAS) was used to adjust the risk estimates for random variation among hospitals. In this model, both fixed and random effects can be entered nonlinearly. This model is basically a logistic regression model, supplemented with an extra term in the equation for the random effects associated with differences in infection risk among hospitals. Because regular logistic regression models do not take into account interhospital variability, they might overestimate the contribution of patient- and prophylaxis-related factors.

The final multivariate model was used to calculate the predicted probability of developing an SSI for each patient. These probabilities were averaged separately for patients with and for those without an SSI. The mean predicted probability for patients with an SSI was divided by the mean predicted probability for patients without an SSI. This ratio represents a measure of the goodness of fit of the model, with a ratio of 1 indicating that the risk factors in the model do not contribute to the prediction of developing an SSI. Adjusted ORs were expressed with 95% confidence intervals [CI]. P < .05 was considered to be statistically significant.

RESULTS

All 11 hospitals had operating rooms with laminar air-flow conditions. Drains were routinely used in all hospitals. The annual number of THA per hospital varied from 47 to 249. Of the 1922 patients included in the analysis, 69% were female, with a mean age (±SD) of 68.8 ± 10.8

years. The ASA score was >2 for 12% of patients. The mean duration of preoperative stay (±SD) was 1.2 ± 2.1 days, the mean duration of the procedure (±SD) was 78.6 ± 35.3 minutes, and the mean duration of postoperative stay (±SD) was 8.8 ± 5.6 days. All patients received antimicrobial prophylaxis. The antibiotics that were administered were classified according to the Dutch Working Party on Antibiotic Policy guidelines as effective with a narrow spectrum (cefazolin [*n* = 947], flucloxacillin [*n* = 48], and erythromycin [*n* = 8] or clindamycin [*n* = 1] in cases of allergy) or with a broader spectrum (cefamandole [*n* = 39], cefuroxime [*n* = 873], amoxicillin plus netilmicin [*n* = 1], clindamycin plus gentamicin [*n* = 1]). No antibiotic with a very short half-life (e.g., cephalothin; half-life, 0.5 h) was used. For the two patients receiving >1 prophylactic antibiotic, the combination was assessed as a single course. In 49% of the procedures, the antibiotic choice was completely according to the guideline. Prophylaxis with an antibiotic of a broader spectrum was not associated with fewer SSIs than prophylaxis with an antibiotic with a more narrow spectrum (OR, 0.7; 95% CI, 0.5-1.4; *P* = .43). Prophylaxis with an antibiotic with a longer half-life (erythromycin [half-life, 1.75 h] and cefazolin [half-life, 2 h]) was not associated with fewer SSIs than prophylaxis with an antibiotic with a shorter half-life (flucloxacillin and cefamandole [half-lives, 0.75 h] and cefuroxime [half-life, 1 h]; OR, 1.1; 95% CI, 0.5–2.3; *P* = .75). For 34% of the procedures, no postoperative doses were administered, and for 59%, the first dose was administered within 30 minutes before incision, according to the guidelines. Antibiotic-impregnated bone cement was used in 757 case patients (39%). SSI occurred in 50 patients (2.6%). Of these infections, 40 were superficial (2.1%), and 10 (0.5%) were deep (including prosthesis-related). The average duration of stay for patients without SSI was 9.9 ± 6.0 days, compared with 14.1 ± 12.0 days for patients with SSI.

Univariate analysis

The crude association of the selected prophylaxis-, patient-, and procedure-related variables with SSI is presented in Table 1. Administration of the first dose of prophylactic antibiotics after incision was associated with an increased (although statistically nonsignificant) incidence of SSI. Dividing the timing of prophylaxis into three categories - within 60 minutes before incision, >60 minutes before incision, and during or after incision - did not change the results (OR for timing during or after incision, 2.9; *P* = .06). Postoperative antibiotic doses and the use of antibiotic-impregnated bone cement were not inversely associated with SSI risk. Older age, comorbidity expressed by ASA classification of >2, and prolonged surgery were associated with a higher rate of SSI. Undergoing surgery in a teaching hospital did not affect the risk of SSI (*P* = .30, by chi-square for risk). The incidence of SSI per hospital was not correlated with the annual volume of total hip procedures (Pearson R, -0.19; *P* = .58). Rates of SSI according to the time of administration of the first dose are shown in Figure 1.

Multivariate logistic regression analysis

The multivariable analysis confirmed that multiple-dose postoperative prophylaxis and the use of antibiotic-impregnated bone cement were not inversely associated with the rate of SSI. Of the

four potential patient- and procedure-related risk factors that reached the threshold of statistical significance and therefore were included in the model, only duration of surgery of >75th percentile was independently and significantly associated with SSI (OR, 2.5; 95% CI, 1.1-5.8) (Table 2). Relatively high ORs could be calculated for the independent associations of rate of SSI with ASA score of >2 (OR, 2.8; 95% CI, 0.8-9.2) and with timing of administration of prophylaxis after incision (OR, 2.8; 95% CI, 0.9-8.6).

Table 1. Univariate analysis: association of selected variables with surgical site infection (SSI) following total hip arthroplasty.

Variable	Patients who experienced an SSI (*n* = 50)	Patients who did not experience an SSI (*n* = 1872)	OR (95% CI)	*P*[a]
Antibiotic prophylaxis variables				
Duration of prophylaxis				
Single dose[b]	16 (33)	633 (34)	Reference	
Multiple postoperative doses for ≤24 h	26 (54)	782 (42)	1.4 (0.7-2.5)	.29
Multiple postoperative doses for >24 h	6 (13)	427 (23)	0.6 (0.2-1.4)	.22
Timing of administration of first dose				
>60 min before incision	6 (12)	109 (6)	2.0 (0.8-5.4)	.16
31-60 min before incision	14 (28)	524 (28)	1.2 (0.6-2.3)	.60
1-30 min before incision	23 (46)	1118 (60)	Reference	
During or after incision	7 (14)	121 (6)	2.2 (0.9-5.6)	.08
Use of antibiotic-impregnated bone cement	25 (50)	723 (39)	1.5 (0.9-2.7)	.14
Patient- and procedure-related variables				
Age, mean years ± SD[c]	72 ± 10	68 ± 11	1.5 (1.1-2.0)	.01
Female sex	40 (80)	1278 (68)	1.9 (0.9-3.7)	.08
ASA score [23][d]				
1	8 (16)	507 (27)	Reference	
2	29 (59)	1130 (61)	1.6 (0.7-3.6)	.23
3+	12 (24)	217 (12)	3.5 (1.4-8.7)	.007
NNIS surgical wound infection risk index [24][e]				
0	22 (46)	1267 (69)	Reference	
1	20 (42)	516 (28)	2.2 (1.2-4.1)	.01
2	6 (13)	65 (4)	5.3 (2.1-13.6)	<.001
Duration of preoperative hospital stay, days				
0-1	47 (94)	1766 (94)	Reference	
≥2	3 (6)	106 (6)	1.1 (0.3-3.5)	.92
Duration of surgery of >75th percentile	20 (41)	435 (23)	2.3 (1.3-4.1)	.006

Data are no. (%) of patients, unless otherwise indicated.

ASA, American Society of Anesthesiology; *NNIS*, National Nosocomial Infection Surveillance; *OR*, odds ratio; *CI*, confidence interval.

[a] Univariate analysis by χ^2 and Student's *t* test.

[b] Zero postoperative doses.

[c] Per 10-year increase.

[d] One, healthy; 2, mild systemic disorder; ≥3, severe systemic disorder.

[e] Includes the following elements: ASA score, wound contamination class, and duration of surgery.

Table 2. Multivariate analysis of risk factors for surgical site infection following total hip arthroplasty corrected for clustering of effects within hospitals.

Variable	OR (95% CI)	*P*[a]
Antibiotic prophylaxis variables		
Duration of prophylaxis		
Single dose[b]	Reference	
Multiple postoperative doses for ≤24 h	2.0 (0.6-7.0)	.26
Multiple postoperative doses for >24 h	1.4 (0.2-9.2)	.69
Timing of administration of first dose		
>60 min before incision	1.3 (0.4-4.4)	.68
31-60 min before incision	0.9 (0.4-2.1)	.82
1-30 min before incision	Reference	
During or after incision	2.8 (0.9-8.6)	.07
Use of antibiotic-impregnated bone cement	0.8 (0.3-1.9)	.57
Patient- and procedure-related variables		
Age, years[c]	1.4 (1.0-2.1)	.08
Female sex	1.7 (0.7-3.9)	.19
ASA score [23][d]		
1	Reference	
2	1.5 (0.6-3.8)	.39
3+	2.8 (0.8-9.2)	.09
Duration of surgery of >75th percentile	2.5 (1.1-5.8)	.04

ASA, American Society of Anesthesiology; *OR*, odds ratio; *CI*, confidence interval.
[a] Random coefficient model procedure NLMIXED in SAS software (SAS Institute).
[b] Zero postoperative doses.
[c] Per 10-year increase.
[d] One, healthy; 2, mild systemic disorder; ≥3, severe systemic disorder.

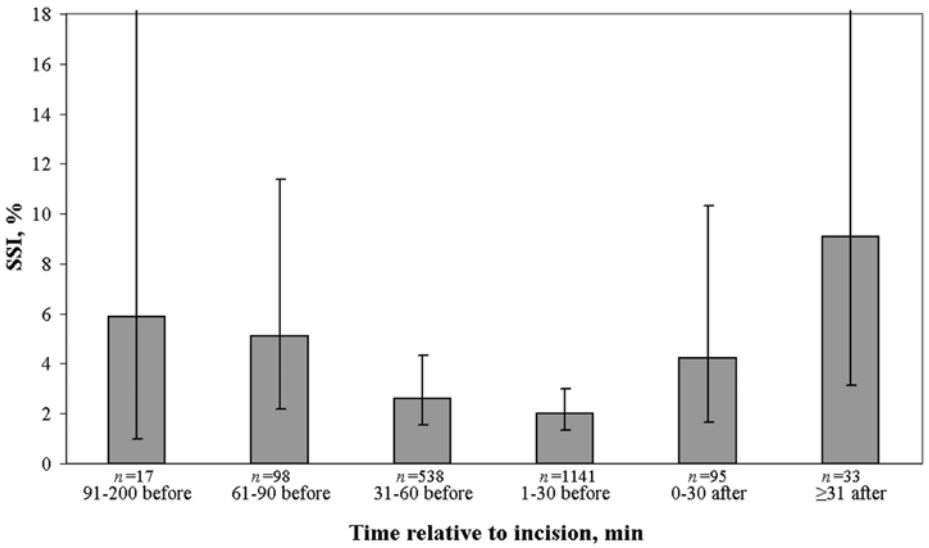

Figure 1. The association between the timing of administration of prophylaxis and the incidence of surgical site infection (SSI) following total hip arthroplasty.

The mean predicted probability of the model was .076 for patients with an SSI and .024 for patients without an SSI. The ratio of the means was 3.2, which indicated that according to the model, the likelihood of developing an SSI was 3.2 times higher for patients with the selected risk factors than for patients without the risk factors.

DISCUSSION

In this multivariable analysis of prophylaxis-, patient-, and procedure-related risk factors for SSI following THA, prolonged duration of surgery (>75th percentile) was the only independent and statistically significant confounding risk factor. Although it did not reach statistical significance, failure to administer the first dose of antibiotic before incision seemed the most important prophylaxis-related factor for increasing the risk of SSI. These findings are important for clinical practice. Although several other studies have made risk assessments for SSI in orthopedic surgery,[4,14,15,26] this is, to our knowledge, the first study to have evaluated the association of SSI with duration and timing of administration of prophylaxis, and use of antibiotic cement. In addition, by excluding emergencies and revisions, the findings indicate the net effect of antibiotic prophylaxis on incidence of SSI in patients undergoing primary elective THA; previously studies included both emergency and elective surgery.[14,15,26] In our surveillance, postdischarge surveillance was performed until one year after surgery, and therefore, the incidence of SSI might be higher than in other studies that did not perform postdischarge surveillance. Yet, the SSI incidence rate of 2.6% is comparable with incidence rates found in other surveillance studies of THA.[4,27]

Although not significant, the OR for timing of administration of prophylaxis after incision suggests that the relative risk of SSI increases in the presence of this factor. The number of patients in some timing categories was too small to draw firm conclusions about the optimal preincisional timing period. Previous studies of general and colorectal surgery also found that administering prophylaxis after incision had a detrimental effect on the incidence of SSI.[28,29]

Previous experimental studies have shown the importance of the presence of antibiotics in the tissue at the moment of potential contamination.[30,31] In another study,[32] injection of antibiotics as an intravenous bolus immediately prior to incision resulted in adequate antibiotic levels in the tissue at the start of surgery. During orthopedic surgery, administration of cephalosporins during incision resulted in sufficiently high concentrations of antibiotics in bone at the moment of removal of the femoral head.[33,34] An advantage of the administration of antibiotics shortly before the incision is that, in most procedures, the concentration of the antibiotic will still be high enough to prevent infection at the end of the procedure, and repeated dosing during prolonged surgery is less often required. The importance of a sufficient concentration of an antibiotic at the time of closure of the wound on the SSI rate was recently established for gentamicin in colorectal surgery.[35]

In the present analysis, duration of prophylaxis was not correlated with the rate of SSI. In a report that included data from 22,000 THA procedures in the Norwegian Arthroplasty Register (during 1987-2001), the incidence of SSI in the group who received single-dose prophylaxis was equal to that in the group who received four doses. However, the incidence of aseptic loosening of the

joint was higher in the single-dose group.[36] Unfortunately, the authors did not provide data on dosing intervals and timing of administration of the first and subsequent doses, which may have confounded the effect on outcome in this long-term cohort. This is especially important because, in the majority of the cases, cephalothin was used - which has a very short half-life - and consequently, tissue concentrations quickly decrease.[37] It is likely that the use of cephalotin has confounded the results. Cefazolin, which has a much longer half-life and is recommended by many guidelines,[11,13] is likely to negate the use of repeated dosing, as was convincingly demonstrated in our study.

The duration of surgery - identified in our study as the most important risk factor for SSI - could be potentially confounded by other unmeasured factors. Detailed data about complications that could affect duration of surgery (e.g., bleeding, resulting in low antibiotic concentrations) were not collected in our study. Furthermore, duration of surgery seems not readily amenable to change by an intervention. The unchangeable patient risk factors of older age and higher ASA score also resulted in higher ORs for SSI. These risk factors are also described in other studies.[4,26,29] In contrast to findings by others, the duration of preoperative hospital stay could not be identified as a risk factor in our study. This discrepancy was probably because of the fact that almost 95% of the patients in our study had a preoperative hospital stay of ≤1 day.

Apart from patient- or procedure-related risk factors, hospital-related factors (e.g., surgical technique) can influence the incidence of SSI. By using the procedure NLMIXED in SAS with hospital as a level, we took the hierarchical structure of the data into account and thereby corrected for possible random variation among hospitals.

Our study does have some limitations. First, the number of risk factors included in our study was limited to those reported within the PREZIES network. Although diabetes mellitus, malignancy, and corticosteroid use are reflected in the ASA score, separate reporting of these known risk factors might have rendered risk assessment more precise. Other risk factors that are not reflected in the ASA score (e.g., obesity, perioperative body temperature, and oxygenation) were shown to be relevant in other studies.[38-40] Another limitation of our analysis was the relatively low number of SSIs (n = 50), which was the dependent outcome variable of our analysis. Of the 77 patients from the CHIPS database to whom prophylaxis was administered but who were excluded from this analysis because information on timing was not known, 8 patients (10.3%) developed an SSI, compared with 50 (2.6%) of 1922 patients who were included in our analysis (P < .0003). This difference could be because of the characteristics of these patients or could imply that reporting the time of administration of prophylaxis is in itself a marker of correct performance. Finally, the fact that the postdischarge surveillance depended on reporting by the surgeon could have resulted in the underreporting of SSI.

In conclusion, prolonged duration of surgery was the only significant risk factor for SSI following THA. Although it did not reach statistical significance, the timing of the administration of the first dose of an antibiotic after incision seems to be the most important prophylaxis parameter. Multiple postoperative dosing did not contribute to reduction of the incidence of SSI. We strongly recommend that intervention programs on surgical prophylaxis focus on timely administration of the prophylactic antibiotic.

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9

Summary

In the Netherlands, about 3% of surgical patients develop a surgical site infection (SSI), which makes this the most-common nosocomial infection among surgical patients. SSIs have adverse consequences like a longer duration of hospitalization, an increase in morbidity and mortality rates, and an increase in costs. A substantial part of the occurring SSIs can and should be avoided. The American Institute for Healthcare Improvement developed a tool for testing changes in healthcare, namely the PDSA-cycle: *Plan – Do – Study – Act.* Surveillance of nosocomial infections is characterized by this PDSA-cycle, as it is the ongoing systematic collection, analysis, interpretation, and feedback of data, followed if necessary by evaluation of processes, implementation of interventions, and measurement of their effect by ongoing surveillance. Surveillance has been accepted worldwide as a primary step toward prevention of nosocomial infections. In recent decades, national SSI surveillance networks have been set up in many countries to monitor the SSI incidence and variation between hospitals. Within such a network, every participating hospital must use standardized methods and the same definitions, for accurate SSI rates that make comparison reliable.

The underlying question of this thesis is to assess the quality of the Dutch national surveillance of SSIs within the PREZIES network ('Prevention of nosocomial infections through surveillance'), and whether it could be optimized. Therefore, the methods and applications of the surveillance were critically evaluated and the trend in SSI incidence studied.

The structure of this thesis follows the steps of the *Plan – Do – Study – Act* cycle (Figure 1).

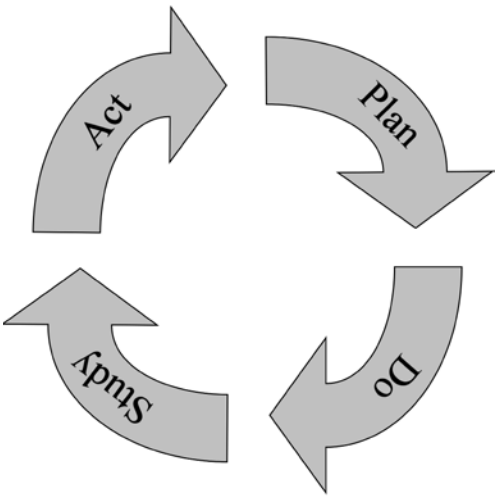


Figure 1. The *Plan – Do – Study - Act* cycle.

PLAN

Methods of the Dutch PREZIES network

PREZIES was initiated in 1996, and so far, 90% of all acute care hospitals in the Netherlands have participated for a period between 3 months and 11 years. Participation in PREZIES is voluntary and confidential, and participating hospitals should follow the protocols and use the definitions of the PREZIES network. The hospitals that participate in the SSI module may choose the specific surgical procedures they want to include in the surveillance. The SSI definition of PREZIES is based on the one developed by the American Centers for Disease Control and Prevention (CDC). In PREZIES, deep incisional SSIs and organ-space SSIs are evaluated under the umbrella term 'deep SSI'. Participating hospitals collect data on many putative determinants, based on international studies. Workshops for participants are organized yearly by PREZIES to give information, discuss positive and negative experiences, consider possible prevention strategies, and practice cases studies.

DO

Postdischarge surveillance

According to the CDC definition, a SSI can develop until 30 days or 1 year (if a non-human-derived implantable foreign body is left in place) after surgery. Over the past decade, there has been an increasing trend toward shorter length of hospital stay and use of ambulatory day surgery. Thus, an increasing proportion of SSIs occur after the patient has left the hospital, which makes follow-up of patients after discharge ('postdischarge surveillance' (PDS)) increasingly important. Without PDS, SSIs will be missed, and the recorded infection rates will be underestimations of the real infection rates. Currently, there is no international consensus on the optimal method for PDS.

PDS is voluntary in PREZIES, but strongly recommended. The recommended methods for PDS are addition of a special registration card to the outpatient medical record, on which the surgeon notes clinical symptoms and whether a patient developed an SSI according to the definitions; an alternative method is examination of the outpatient medical record after the follow-up period has elapsed. A prerequisite for this is, that the status of the wound must be clearly described in the records. The follow-up rates in Dutch hospitals are high, as (almost) every patient returns to the hospital or outpatient clinic after discharge.

In ***Chapter 2*** of this thesis, SSI rates obtained with the recommended PDS methods are compared with those obtained with other active PDS methods and with passive PDS (i.e., only register postdischarge SSIs if patients are readmitted with an SSI). In this study, PREZIES data between 1996 and 2004 were included, with data on 131,798 surgical procedures, performed in 64 hospitals. PDS was performed according to one of the two recommended methods in 24% of the patients, according to another active method in 25%, and passive PDS was performed in 52%. The percentage of hospitals that predominantly performed PDS according to one of the recommended methods increased from 24% in 1996 to 50% in 2003, and to 70% in 2005 as shown by more recent data.

A higher proportion of SSIs were found after discharge if PDS was performed according to a recommended method (43%), than if another active PDS method (30%) or passive PDS (25%) was used. The highest proportion of SSI after discharge was found for appendectomy (79% of SSIs). Relatively more superficial than deep SSIs were recorded when PDS was performed according to one of the recommended PDS methods.
Thus, for comparison of SSI rates between hospitals or countries, it is extremely important to know whether and how PDS was performed in each hospital.
This study shows that the method for performing PDS recommended by PREZIES is feasible and sensitive, and may be suitable internationally, supposing patients routinely return to the hospital for postdischarge checkup and healthcare workers can be convinced of the importance and value of PDS.

Validation

To ensure the quality and reliability of surveillance data, surveillance methods should be standardized, and a clear statement of the criteria for the patients, procedures and infection variables must be included. Validation is the only independent means to determine the accuracy for surveillance data, which makes it essential for determining the reliability of a SSI surveillance network in which data are aggregated from multiple data collectors and used for comparisons between hospitals. In ***Chapter 3***, the validation method used by PREZIES is described and the results are presented. Since 2002, on-site validation has been mandatory for each participating hospital, once every three years. The hospital is visited by a validation team, consisting of a PREZIES team member plus an ICP from a previously validated hospital. The quality of the process of surveillance (data collection) is validated by means of a structured interview. For validation of the interpretation of the SSI criteria, the validation team aims to review 25 medical records. The results of the validation team (SSI diagnosis per patient) are compared and discussed with those of the ICP of the hospital being validated. So far, the validation team reviewed 859 medical charts from 40 hospitals. Validation results of the SSI assessment showed a positive predictive value of 0.97, which indicates that 97% of the 149 patients who had an SSI diagnosed by the ICP, truly had a SSI. The negative predictive value was 0.99, which indicates that 99% of the 710 patients who had no SSI diagnosed by the ICP, truly had no SSI. Data have been removed from the national PREZIES database twice, because the validation visits showed unsatisfactory execution of the surveillance in those hospitals.
To our knowledge, no other country validates their national nosocomial infection surveillance data continuously, which is necessary because the employees involved in surveillance within a hospital may change quite regularly.
Because of these validation results, PREZIES is confident that the assembled Dutch SSI surveillance data are reliable and robust and are sufficiently accurate to be used as a reference database for interhospital comparison.

STUDY

Risk adjustment of SSI surveillance results in feedback reports

Before surveillance data can be compared between hospitals, the SSI rates should be adjusted for risk factors. Nowadays, the NNIS risk index (composed of the wound contamination class, ASA classification, and duration of surgery) is used for risk-adjustment of SSI surveillance data by many countries. However, recent studies have shown that adjustment for the NNIS index might not be optimal for all surgical procedures. In ***Chapter 4*** of this thesis, the national nosocomial surveillance data of the Dutch PREZIES network were used to estimate the predictive power of alternative determinants, to improve the SSI risk estimation and concurrently the reliability of comparison between hospitals. Surveillance data between 1996 and 2004 were included. The study was restricted to 19 common surgical procedure groups with at least 50 SSIs due to power considerations. In total, these data comprised 11 putative determinants and as many as 93,511 surgical procedures and 3,494 SSIs. Logistic regression with manually performed backward elimination, using the likelihood ratio test, defined alternative models for each surgical procedure group. To account for random variation between hospitals, multilevel analyses were performed with the final models. The SSI predictive power of the alternative models and the NNIS index were compared by testing the areas under the receiver operating characteristic (ROC) curves. To assess the practical relevance of differences in predictive power, the expected numbers of SSIs were estimated for alternative models and the NNIS index.

The SSI predictive power was generally rather low, since the areas under the ROC curves varied from 0.51 to 0.66 for the NNIS index models and from 0.57 to 0.71 for the alternative models. The three NNIS index components were the variables most frequently included in the alternative models. There was no substantial gain in simplicity of the alternative models, as the 19 alternative models included a median of three variables (range 1 to 6 variables). The odds ratio estimates in all 19 models were marginally affected by multilevel analyses as compared to standard logistic regression.

For nine procedure groups, the alternative models predicted SSI significantly better than the NNIS index. However, the corresponding expected SSI numbers were marginally affected. Additional determinants might be able to increase the predictive power. However, because surveillance should be feasible for all hospitals, a surveillance system is restrained as for the amount of data that can be collected for each observation.

Because the gain in performance or simplicity of the alternative models was limited, the results do not support replacement of the NNIS index with procedure-specific determinants when comparing hospital and national SSI occurrence in feedback of surveillance results to hospitals.

Comparison of SSI surveillance between the Netherlands and Germany

There is an increasing interest in comparing SSI data, not only between hospitals within a country, but also between countries. The SSI surveillance system in the Netherlands ('PREZIES') and Germany ('KISS') have comparable protocols with many similar risk factors, using the SSI

criteria developed by the Centers for Disease Control and Prevention, with optional postdischarge surveillance, and with validation checks on submitted data. Therefore, in ***Chapter 5*** of this thesis, the SSI surveillance data for PREZIES and KISS are compared regarding the patient and hospital characteristics and SSI rates for nine surgical procedures.
At patient level, differences were found between PREZIES and KISS for duration of surgery, wound contamination class, American Society of Anesthesiologists (ASA) physical status classification and the postoperative duration of hospitalization. The possible difference in assigning the wound class and ASA classification makes international comparison very difficult, as these variables are assumed to be important intrinsic risk factors for which SSI rates should be adjusted before they can be reliably compared between hospitals or countries.
For some surgical procedures, the results revealed a higher SSI rate in PREZIES compared to KISS, even though the patients in PREZIES seemed to be healthier (i.e. a lower ASA classification was recorded), were less often operated on in university hospitals and had a shorter postoperative length of stay. The higher SSI rate in PREZIES might at least partly be explained by the more intensive postdischarge surveillance performed in Dutch hospitals, which led to 34% of the recorded SSIs detected after discharge in PREZIES and 21% in KISS. The difference between the two countries in procedure-specific SSI rates disappeared for most surgical procedures when only deep SSIs that developed during hospitalization were taken into account.
In conclusion, even though similar infection surveillance protocols were used in the Netherlands and Germany, differences occurred in the application. This study showed that comparison of SSI data between countries may not be reliable, even if the countries have public healthcare systems of comparable high quality and use similar infection surveillance protocols. Comparison between countries seems to be most reliable for deep SSIs during hospitalization, since these SSIs are not affected by postdischarge surveillance and the diagnostic sensitivity for deep SSI is probably more similar between countries than for superficial SSI.

The time-trend in SSI rate

The ultimate aim of the PREZIES network is to reduce the patients' risk of nosocomial infection. In ***Chapter 6*** of this thesis, the time-trend in SSI rate in relation to the duration of surveillance was evaluated. SSI surveillance data were included from 42 hospitals that participated in the Dutch PREZIES network between 1996 and 2006 and registered at least one of five frequently performed surgical procedures for at least three years: mastectomy, colectomy, replacement of the head of the femur, total hip prosthesis or knee prosthesis. Analyses were performed per surgical procedure. The surveillance time to operation was stratified in consecutive 1-year periods, with the first year as a reference. Multivariate logistic regression analysis was performed using a random coefficient model to adjust for random variation among hospitals. All models were adjusted for method of postdischarge surveillance. The number of procedures varied from 3031 for colectomy to 31,407 for total hip prosthesis and the SSI rate from 1.6% for knee prosthesis to 12.2% for colectomy. For total hip prosthesis, the SSI rate decreased significantly by 6% per surveillance year (odds ratio, OR: 0.94, 95% confidence interval, CI: 0.90-0.98), indicating a 60% decrease after 10 years. Non-

significant, but substantial decreasing trends in SSI rate were found for replacement of the head of the femur (OR: 0.94, 95% CI: 0.88-1.00) and for colectomy (OR: 0.92, 95% CI: 0.83-1.02). For knee prosthesis and mastectomy, the SSI rate barely changed with increasing surveillance time.
Even though most decreasing trends in SSI rate were not statistically significant, they are encouraging. To use limited resources as efficient as possible, we would suggest switching the surveillance to another surgical specialty when the SSI rate has decreased below the target.

ACT

Interventions that change infection control in the hospital can lead to improvements in the quality of care and consequently may reduce the number of nosocomial infections. The PREZIES surveillance network contributed to a multicenter intervention study. PREZIES provided the SSI data (outcome measure) for the intervention study that tried to optimize the administration of surgical prophylaxis (process measure) in the Netherlands.
The goal of prophylactic antibiotics is to eradicate or retard the growth of contaminant microorganisms such that SSIs can be avoided. Its efficacy has been demonstrated repeatedly. In 2000, the Dutch Working Party on Antibiotic Policy specified a guideline for perioperative prophylaxis in Dutch hospitals. This guideline recommends intravenous single-dose prophylaxis of an inexpensive non-toxic antibiotic with a limited spectrum, which is not used extensively in therapy, administered within 30 minutes before the first incision; in order to slow down the development of antibiotic resistance and reduce the costs of antimicrobial prophylaxis.
In 2000-2002, the Surgical Prophylaxis and Surveillance project (CHIPS) took place, which tried to implement this national guideline in thirteen voluntarily participating hospitals. All CHIPS hospitals participated in the component "Surgical site infections" of the Dutch PREZIES network, performed postdischarge surveillance, and were validated. The CHIPS study focused on commonly performed surgical procedures in 4 specialties: vascular, intestinal, gynecological and orthopedic surgery. Only elective procedures were included, so that the normal daily routine of administering antimicrobial prophylaxis would be observed. As a result of the intervention, the antimicrobial use decreased, costs reduced, and antibiotic choice and duration improved.
In ***Chapter 7*** of this thesis, the effect of the more prudent antimicrobial policy on the efficacy of prophylaxis in preventing SSIs was assessed. Logistic regression analysis was used to calculate odds ratios for SSI after the intervention compared with before the intervention, according to the type of surgical procedure, and after adjustment for procedure-specific confounders. Data were collected on individual patient level, whereas the interventions were targeted towards hospitals. By applying multilevel analysis, SSI risk estimates were adjusted for random variation between hospitals. By using segmented time series analysis, possible changes over time concerning unmeasured factors were taken into account.
A total of 3621 procedures were included in the study, of which 1668 were performed before the intervention and 1953 after. There were no significant differences in the distribution of risk factors before and after the intervention. The distribution of the surgical procedures was fairly similar

before and after the intervention. The overall SSI rate decreased from 5.4% (95% CI: 4.3%–6.5%) to 4.5% (95% CI: 3.6%-5.4%), which was not a statistically significant difference (P = .22). For four procedures the SSI rate decreased after the intervention, and for three procedures the SSI rate increased after the intervention. However, this study had not enough power to demonstrate a significant change in SSI rate according to the type of procedure.
The results demonstrate that implementing an optimized and more-prudent antibiotic policy in hospitals did not change the effectiveness of the prophylactic antibiotics concerning SSI prevention.

Most studies that analyzed risk factors for SSIs following total hip arthroplasty mainly focused on patient, procedure, or hospital characteristics. However, prospective studies on the contribution of the qualitative aspects of surgical prophylaxis to the prevention of SSIs following total hip arthroplasty are scarce. In ***Chapter 8*** of this thesis, we explored the effect of various parameters of surgical antibiotic prophylaxis on the risk of SSIs for the population in the CHIPS study undergoing primary total hip arthroplasty. Timing of administration of prophylaxis was emphasized because of the importance of the presence of antibiotics in the tissue at the moment of potential contamination.
Data about the surgical procedure, potential SSI risk factors, and type of SSI were collected according to the PREZIES protocol. The antibiotic drug, the dosage, duration and timing of the prophylaxis, and the use of antibiotic-impregnated bone cement were recorded according to the CHIPS protocol.
Multivariable regression analysis was performed to account for possibly confounding factors. Because of the hierarchical structure of the data (i.e., patients clustered by hospital), a random coefficient model was used.
An SSI developed in 50 of the 1922 patients (2.6%). Duration of surgery longer than the national 75th percentile was the only independent and statistically significant confounding factor. Antibiotics with a broader spectrum or a longer half-life (>1.5 hours) were not associated with fewer SSIs than antibiotics with a narrower spectrum or a shorter half-life, respectively. Although it did not reach statistical significance, administering the first antibiotic dose during or after incision seemed the most important prophylaxis-related factor for increasing SSI risk. The number of patients in some timing categories was too small to draw firm conclusions about the optimal preincisional timing period. Multiple postoperative dosing did not contribute to reduction of the incidence of SSI.
This study suggests that intervention programs in search of amendable factors to prevent SSI following total hip arthroplasty should focus on timely administration of antibiotic prophylaxis.

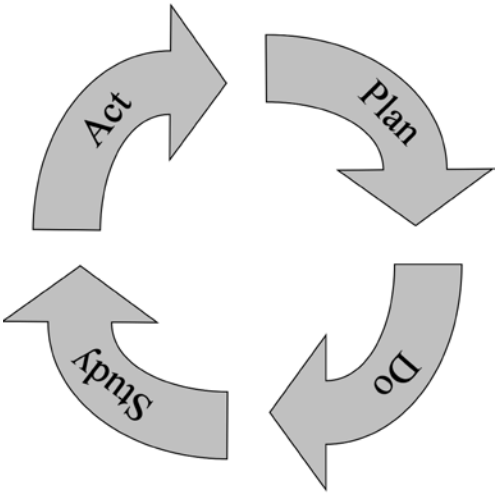
After studying the results of an intervention, new plans can be invented, which brings you back to the first step of the *Plan – Do – Study – Act* cycle. This shows that infection control is a continuous process, with each change in infection prevention activities providing material and evidence for the next quality improvement.

10

Samenvatting

In Nederland krijgt ongeveer 3% van de chirurgische patiënten een postoperatieve wondinfectie (POWI), waardoor dit de meest voorkomende ziekenhuisinfectie is bij chirurgische patiënten. POWI's hebben nadelige gevolgen zoals een langere opnameduur in het ziekenhuis, een verhoogde morbiditeit en mortaliteit, en een toename in kosten. Een aanzienlijk deel van de optredende POWI's kunnen en zouden moeten worden voorkómen. Het Amerikaanse 'Institute for Healthcare Improvement' ontwikkelde een middel/instrument om veranderingen in gezondheidszorg te toetsen, namelijk de PDSA-cyclus: *Plan – Do – Study – Act*. Surveillance van ziekenhuisinfecties wordt gekenmerkt door de PDSA-cyclus aangezien het de doorgaande systematische verzameling, analyse, interpretatie, en terugkoppeling van gegevens naar het ziekenhuispersoneel is, zonodig gevolgd door de evaluatie van processen, implementatie van interventies, en meting van het effect daarvan door continue registratie. Surveillance is over de hele wereld geaccepteerd als een eerste stap in de preventie van ziekenhuisinfecties. In de afgelopen decennia hebben veel landen een nationaal POWI surveillance netwerk opgezet, om toezicht te houden op de incidentie van POWI's en de variatie daarin tussen ziekenhuizen. Binnen zo'n netwerk moet elk deelnemend ziekenhuis werken volgens gestandiseerde methoden en dezelfde definites gebruiken om correcte infectiepercentages te verkrijgen voor een betrouwbare vergelijking.

De onderliggende vraag van dit proefschrift was om de kwaliteit van de Nederlandse nationale surveillance van POWI's binnen het PREZIES netwerk (PREventie van ZIEkenhuisinfecties door Surveillance) te beoordelen en na te gaan of deze surveillance verbeterd kan worden. Daarvoor zijn de methoden en toepassingen van de surveillance kritisch geëvalueerd en de trend in POWI incidentie bestudeerd.
De opbouw van dit proefschrift volgt de stappen van de *Plan-Do-Study-Act* cyclus (Figuur 1).



Figuur 1. De *Plan – Do – Study - Act* cyclus.

PLAN

Methodologie van het Nederlandse PREZIES netwerk

PREZIES was opgericht in 1996 en tot nu toe heeft 90% van alle ziekenhuizen in Nederland deelgenomen gedurende een periode variërend van 3 maanden tot 11 jaar. Deelname aan PREZIES is vrijwillig en anoniem, en deelnemende ziekenhuizen moeten werken volgens het protocol met toepassing van de bijbehorende definities van het PREZIES netwerk. De ziekenhuizen die deelnemen aan de module Postoperatieve Wondinfecties mogen kiezen welke specifieke operaties ze in de surveillance willen opnemen. De POWI-definitie van PREZIES is gebaseerd op die van de Amerikaanse 'Centers for Disease Control and Prevention' (CDC). In PREZIES zijn diepe incisionele POWI's en POWI's van organen en anatomische ruimte samengevoegd onder de naam 'diepe POWI's'. Deelnemende ziekenhuizen verzamelen gegevens over verscheidene potentiële risicofactoren, gebaseerd op internationale studies. Jaarlijks organiseert PREZIES een workshop voor deelnemers om informatie te verstrekken, positieve en negatieve ervaringen te bespreken, te praten over mogelijke preventiestrategieën en om de toepassing van de POWI-definitie te oefenen.

DO

Surveillance na ontslag

Volgens de CDC-definitie kan een POWI zich ontwikkelen tot 30 dagen of 1 jaar (als lichaamsvreemd materiaal is ingebracht) na de operatie. Gedurende het afgelopen decennium is de gemiddelde verblijfsduur van patiënten in het ziekenhuis verkort en hebben er meer ambulante dagopnames plaatsgevonden. Daardoor treedt een groter deel van de POWI's op nadat de patiënt het ziekenhuis heeft verlaten, waardoor het belang van het volgen van patiënten na ontslag ('surveillance na ontslag' (SNO)) toeneemt. Zonder SNO zullen er POWI's gemist worden en zullen de geregistreerde infectiepercentages onderschattingen zijn van de daadwerkelijke infectiepercentages. Er is nog geen internationale overeenstemming bereikt over wat de optimale methode voor SNO is.

Binnen PREZIES is de uitvoering van SNO vrijwillig, maar wordt dit wel sterk aanbevolen. De aanbevolen methode voor SNO is de toevoeging van een speciale registratiekaart aan de polikliniekstatus waarop de arts klinische verschijnselen noteert en of de patiënt een POWI heeft ontwikkeld volgens de definitie; een alternatieve methode is onderzoek van de polikliniekstatus nadat de follow-up periode is verstreken. Voorwaarde is dat in de status de toestand van de wond duidelijk wordt beschreven. In Nederland is het percentage patiënten dat vervolgd kan worden hoog aangezien vrijwel elke patiënt na ontslag terugkeert naar het ziekenhuis of de polikliniek voor controle.

In ***Hoofdstuk 2*** van dit proefschrift wordt de POWI incidentie verkregen met de aanbevolen SNO methoden vergeleken met de incidentie verkregen met een andere actieve SNO methode en met passieve SNO (d.w.z. dat alleen POWI's na ontslag worden geïncludeerd als patiënten worden heropgenomen met een POWI). In deze studie zijn PREZIES gegevens van 1996 tot en met 2004

meegenomen, betreffende 131.798 operaties uitgevoerd in 64 ziekenhuizen. SNO werd uitgevoerd volgens één van de aanbevolen methoden bij 24% van de patiënten, volgens een andere actieve methode bij 25%, en passieve SNO was uitgevoerd bij 52%. Het percentage ziekenhuizen dat voornamelijk SNO uitvoerde volgens één van de aanbevolen methoden nam toe van 24% in 1996 tot 50% in 2003.
Een hoger percentage van de POWI's werd gevonden na ontslag wanneer SNO was uitgevoerd volgens een aanbevolen methode (43%) dan wanneer een andere actieve methode voor SNO (30%) of passieve SNO (25%) werd gebruikt. Het hoogste percentage POWI's na ontslag trad op bij appendectomieën (79% van de POWI's). Relatief meer oppervlakkige dan diepe POWI's werden geregistreerd wanneer SNO werd gedaan volgens één van de aanbevolen methoden.
Dus, voor de vergelijking van de incidentie van POWI's tussen ziekenhuizen of landen is het buitengewoon belangrijk om te weten of en hoe SNO werd uitgevoerd in elk ziekenhuis.
Deze studie laat zien dat de methode die wordt aanbevolen door PREZIES voor de uitvoering van SNO uitvoerbaar en accuraat is en dat hij mogelijk geschikt is voor internationaal gebruik, indien patiënten routinematig terugkeren naar het ziekenhuis voor controle en ziekenhuispersoneel overtuigd kan worden van het belang en de waarde van SNO.

Validatie

Om de kwaliteit en betrouwbaarheid van surveillancegegevens te kunnen garanderen, moet de methodologie van de surveillance gestandaardiseerd zijn en moeten de criteria voor de patiënt-, operatie- en infectiegegevens duidelijk zijn beschreven. Validatie is het enige onafhankelijke middel om de nauwkeurigheid van surveillancegegevens te kunnen bepalen. Daarom is validatie essentieel om de betrouwbaarheid te bepalen van een POWI surveillance netwerk waarin gegevens worden samengevoegd van verschillende gegevensverzamelaars en worden gebruikt voor vergelijking tussen ziekenhuizen. In ***Hoofdstuk 3*** is de validatiemethode van PREZIES beschreven en zijn de resultaten gepresenteerd. Sinds 2002 is validatie verplicht voor elk deelnemend ziekenhuis, eens in de drie jaar. Het ziekenhuis wordt bezocht door een validatieteam, bestaande uit een PREZIES-teamlid plus een hygiënist van een eerder gevalideerd ziekenhuis. De kwaliteit van het surveillanceproces (de gegevensverzameling) wordt gevalideerd door middel van een gestructureerd interview. Voor validatie van de interpretatie van de POWI-criteria dient het validatieteam 25 medische statussen te beoordelen. De resultaten van het validatieteam (POWI diagnose per patiënt) worden vergeleken en bediscussieerd met die van de hygiënist van het ziekenhuis dat de validatie ondergaat. Tot nu toe heeft het validatieteam 859 medische statussen beoordeeld van 40 ziekenhuizen. Resultaten van de validatie met betrekking tot de POWI diagnose lieten een positief voorspellende waarde zien van 0,97, wat aangeeft dat 97% van de 149 patiënten die door de hygiënist als positief was beoordeeld ook daadwerkelijk een POWI had. De negatief voorspellende waarde was 0,99, wat aangeeft dat 99% van de 710 patiënten die door de hygiënist als negatief was beoordeeld ook daadwerkelijk geen POWI had. Twee maal zijn er gegevens verwijderd uit het nationale gegevensbestand van PREZIES, omdat de validatiebezoeken aantoonden dat de uitvoering van de surveillance in die ziekenhuizen ontoereikend was.

Naar wij weten, vindt er in geen enkel ander land continue validatie plaats van nationale surveillancegegevens over ziekenhuisinfecties, wat noodzakelijk is aangezien de ziekenhuismedewerkers die betrokken zijn bij de surveillance regelmatig kunnen wisselen.
Door deze validatieresultaten is PREZIES ervan overtuigd dat de samengevoegde Nederlandse POWI surveillancegegevens betrouwbaar en robuust zijn en voldoende accuraat om te gebruiken als referentiegegevens voor vergelijking tussen ziekenhuizen.

STUDY

Risicocorrectie van POWI surveillanceresultaten op terugrapportages
Voordat surveillancegegevens kunnen worden vergeleken tussen ziekenhuizen moeten de POWI incidenties gecorrigeerd worden voor risicofactoren. Tegenwoordig wordt de NNIS risico-index (opgebouwd uit de wondcontaminatie klasse, ASA klasse en operatieduur) door veel landen gebruikt voor risicocorrectie van POWI surveillancegegevens. Echter, recente studies hebben aangetoond dat correctie voor de NNIS index mogelijk niet optimaal is voor alle chirurgische ingrepen. In ***Hoofdstuk 4*** van dit proefschrift zijn de surveillancegegevens van het Nederlandse PREZIES netwerk gebruikt om de voorspellende waarde te schatten van alternatieve factoren om de risicoschatting voor een POWI te verbeteren en daarmee de betrouwbaarheid van vergelijking tussen ziekenhuizen. Surveillancegegevens van 1996 tot en met 2004 werden geïncludeerd. De studie beperkte zich tot 19 groepen van chirurgische ingrepen met ten minste 50 POWI's omwille van het onderscheidingsvermogen. Totaal omvatte deze gegevens 11 vermoedelijke risicofactoren en zoveel als 93.511 operaties en 3.494 POWI's. Logistische regressie met handmatig uitgevoerde achterwaartse eliminatie, met behulp van de 'likelihood ratio test', resulteerde in alternatieve modellen voor elke chirurgische operatiegroep. Om rekening te houden met de willekeurige variatie tussen ziekenhuizen, werd multilevel analyse uitgevoerd op de uiteindelijke modellen. De voorspellende waarde voor een POWI van de alternatieve modellen en van de NNIS index werden met elkaar vergeleken door de oppervlakte onder de 'receiver operating characteristic' (ROC) grafieken te testen. Om de praktische relevantie te bepalen van de verschillen in de voorspellende waardes, werden de verwachte aantallen POWI's geschat voor de alternatieve modellen en voor de NNIS index modellen.
De voorspellende waarde voor een POWI was over het algemeen vrij laag aangezien de oppervlakten onder de ROC grafieken varieerde van 0,51 tot 0,66 voor de NNIS index modellen en van 0,57 tot 0,71 voor de alternatieve modellen. De drie componenten van de NNIS index waren de variabelen die het meest-frequent onderdeel uitmaakten van de alternatieve modellen. Er was geen substantiële winst in eenvoud van de alternatieve modellen aangezien de 19 alternatieve modellen bestonden uit gemiddeld drie variabelen (met een spreiding van 1 tot 6 variabelen). De odds ratio schattingen van alle 19 modellen werden nauwelijks beïnvloed door de multilevel analyses in vergelijking met standaard logistische regressie.
Bij negen operatiegroepen voorspelden de alternatieve modellen de kans op een POWI significant beter dan de NNIS index. Echter, de bijbehorende verwachte aantallen POWI's veranderden

nauwelijks. Aanvullende risicofactoren zouden de voorspellende waarde kunnen verhogen. Echter, om surveillance uitvoerbaar te laten zijn voor alle ziekenhuizen, is een surveillance systeem beperkt in de hoeveelheid gegevens die kan worden verzameld voor elke patiënt.
Omdat de toename in doeltreffendheid en eenvoud van de alternatieve modellen beperkt was, wordt vervanging van de NNIS index met operatiegroep-specifieke factoren, bij het vergelijken van POWI incidenties op ziekenhuis en nationaal niveau in terugrapportages van surveillanceresultaten naar ziekenhuizen, niet door de resultaten van deze studie ondersteund.

Vergelijking van de POWI surveillance tussen Nederland en Duitsland

Er is een toenemende interesse in het vergelijken van POWI gegevens, niet alleen tussen ziekenhuizen binnen een land, maar ook tussen landen. De POWI surveillance systemen in Nederland ('PREZIES') en Duitsland ('KISS') hebben vergelijkbare protocollen met veel overeenkomstige risicofactoren, met gebruikmaking van de POWI criteria zoals opgesteld door het Amerikaans CDC, met surveillance na ontslag als optioneel item, en met controles op ingestuurde gegevens ter validatie. Daarom zijn in ***Hoofdstuk 5*** van dit proefschrift de POWI surveillancegegevens van PREZIES en KISS met elkaar vergeleken wat betreft de patiënt- en ziekenhuiskenmerken en de incidentie van POWI, voor negen chirurgische ingrepen.
Op patiëntniveau werden verschillen tussen PREZIES en KISS waargenomen in operatieduur, wondcontaminatie klasse, fysieke gesteldheid volgens de 'American Society of Anesthesiologists' (ASA) klasse en de postoperatieve opnameduur. Mogelijke verschillen in het bepalen van de wondklasse en ASA klasse maakt internationale vergelijking erg moeilijk, aangezien er wordt verondersteld dat deze variabelen belangrijke intrinsieke factoren zijn waarvoor POWI incidenties zouden moeten worden gecorrigeerd voordat ze betrouwbaar kunnen worden vergeleken tussen ziekenhuizen of landen.
Voor enkele chirurgische ingrepen lieten de resultaten een hogere POWI incidentie zien in PREZIES vergeleken met KISS, ondanks dat de patiënten in PREZIES gezonder leken (d.w.z. er was een lagere ASA klasse geregistreerd), minder vaak werden geopereerd in academische ziekenhuizen, en een kortere postoperatieve opnameduur hadden. De hogere POWI incidentie in PREZIES kan mogelijk deels verklaard worden door de intensievere surveillance na ontslag in Nederlandse ziekenhuizen, wat ertoe leidde dat in PREZIES 34% van de geregistreerde POWI's werd waargenomen na ontslag, en in KISS 21%. Het verschillen tussen de twee landen in ingreep-specifieke POWI incidenties verdween voor de meeste chirurgische ingrepen als alleen werd gekeken naar diepe POWI's die ontstonden tijdens het verblijf in het ziekenhuis.
Samenvattend waren er verschillen in de uitvoering van de surveillance tussen Nederland en Duitsland, ook al gebruikten ze vergelijkbare protocollen voor de POWI surveillance. Deze studie heeft aangetoond dat de vergelijking van POWI gegevens tussen landen mogelijk niet betrouwbaar is, ook al hebben de landen gezondheidszorgsystemen van vergelijkbare hoge kwaliteit en gebruiken ze overeenkomstige surveillanceprotocollen. Vergelijking tussen landen lijkt het meest betrouwbaar te zijn voor diepe POWI's tijdens ziekenhuisopname, aangezien deze POWI's niet worden beïnvloed door surveillance na ontslag en doordat de diagnostische sensitiviteit voor diepe POWI's waarschijnlijk meer overeenkomt tussen landen dan voor oppervlakkige POWI's.

De trend in POWI incidentie over de tijd

Het uiteindelijke doel van het PREZIES netwerk is om het risico van patiënten op een ziekenhuisinfectie te verminderen. In ***Hoofdstuk 6*** van dit proefschrift is de trend over de tijd in POWI incidentie in relatie tot de surveillance duur geëvalueerd. POWI surveillancegegevens werden geïncludeerd van 42 ziekenhuizen die deelnamen in het Nederlandse PREZIES netwerk tussen 1996 en 2006 en die ten minste één van de vijf meest frequent uitgevoerde chirurgische ingrepen registreerden gedurende ten minste drie jaar: mastectomie, colectomie, kophalsprothese, totale heupprothese of knieprothese. Analyses werden uitgevoerd per chirurgische ingreep. De surveillanceduur tot aan de operatie was gestratificeerd in periodes van 1 jaar, met het eerste jaar als referentie. Multivariate logistische regressie analyse was uitgevoerd met gebruik van een 'random coefficient' model om te corrigeren voor willekeurige variatie tussen ziekenhuizen. Alle modellen werden gecorrigeerd voor de methode van surveillance na ontslag. Het aantal operaties varieerde van 3.031 voor colectomie tot 31.407 voor totale heupprothese en de POWI incidentie van 1,6% voor knieprothese tot 12,2% voor colectomie. Voor totale heupprothese nam de POWI incidentie significant af met 6% per surveillancejaar (odds ratio, OR: 0,94; 95% betrouwbaarheidsinterval, BI: 0,90-0,98), wat duidt op een afname van 60% na 10 jaar. Niet-significante, maar substantieel dalende trends in POWI incidentie werden waargenomen voor kophalsprothese (OR: 0,94; 95% CI: 0,88-1,00) en voor colectomie (OR: 0,92; 95% BI: 0,83-1,02). Voor knieprothese en mastectomie veranderde de POWI incidentie nauwelijks met toenemende surveillanceduur.

Ondanks dat de meeste dalende trends in POWI incidentie niet statistisch significant waren, zijn ze wel bemoedigend. Om beperkte middelen zo efficiënt mogelijk te gebruiken, raden we aan om de surveillance te verschuiven naar een ander chirurgisch specialisme als de POWI incidentie is afgenomen tot onder het doel.

ACT

Interventies die de infectiepreventie in ziekenhuizen veranderen, kunnen leiden tot verbeteringen in de kwaliteit van zorg en daarmee mogelijk tot een afname van het aantal ziekenhuisinfecties. Het PREZIES surveillance netwerk heeft meegewerkt aan een multi-center interventiestudie. PREZIES leverde de POWI gegevens (uitkomstmaat) voor een interventiestudie die de toediening van chirurgische profylaxe in Nederland trachtte te verbeteren (procesmaat).

Het doel van profylactische antibiotica is om de groei van microorganismen te vertragen of ze uit te roeien zodat POWI's kunnen worden voorkómen. De werkzaamheid ervan is herhaaldelijk aangetoond. In 2000 heeft de Nederlandse Stichting Werkgroep Antibiotica Beleid een richtlijn opgesteld voor perioperatieve profylaxe in Nederlandse ziekenhuizen. Deze richtlijn beveelt intraveneuze eenmalige profylaxe aan met een goedkoop niet-toxisch antibioticum, met een beperkt spectrum, die niet op grote schaal wordt gebruikt als therapie, toegediend binnen 30 minuten voor de eerste incisie; om de ontwikkeling van antibioticaresistentie te vertragen en de kosten van antibioticaprofylaxe te verlagen.

Tussen 2000 en 2002 vond het project Chirurgische Profylaxe en Surveillance (CHIPS) plaats,

waarin de nationale richtlijn werd geïmplementeerd in 13 vrijwillig deelnemende ziekenhuizen. Alle CHIPS-ziekenhuizen participeerden in de module "Postoperatieve Wondinfecties" van het Nederlandse PREZIES netwerk, voerden surveillance na ontslag uit, en werden gevalideerd. De CHIPS-studie richtte zich op veelvuldig uitgevoerde chirurgische ingrepen binnen vier specialismen: vaatchirurgie, interne chirurgie, gynaecologie, en orthopedie. Alleen electieve ingrepen werden geïncludeerd zodat de normale dagelijkse routine van de toediening van antimicrobiële profylaxe kon worden geobserveerd. Als gevolg van de interventie daalden het antibioticagebruik en de kosten, en verbeterden de keuze en duur van de antibiotica.
In ***Hoofdstuk 7*** van dit proefschrift is bepaald wat het effect was van het restrictieve antibioticabeleid op de effectiviteit van de profylaxe in het voorkómen van POWI's. Logistische regressie was gebruikt om de odds ratio's te berekenen voor POWI's na de interventie ten opzichte van voor de interventie, per chirurgische ingreep en na correctie voor ingreep-specifieke risicofactoren. Gegevens werden verzameld op individueel patiëntniveau terwijl de interventies gericht waren op ziekenhuisniveau. Door multilevel analyses uit te voeren, werden de risicoschattingen voor POWI's gecorrigeerd voor willekeurige variatie tussen ziekenhuizen. Door gesegmenteerde tijdtrend analyse toe te passen, werd er rekening gehouden met mogelijke veranderingen in de tijd betreffende onbekende factoren.
Totaal zijn 3.621 operaties geïncludeerd in de studie waarvan er 1.668 waren uitgevoerd voor de interventie en 1.953 erna. Er was geen significant verschil in de verdeling van risicofactoren voor en na de interventie. De verdeling van chirurgische ingrepen was grotendeels gelijk voor en na de interventie. Het totale percentage wondinfecties daalde van 5,4% (95% BI: 4,3%–6,5%) naar 4,5% (95% BI: 3,6%-5,4%), wat geen statistisch significant verschil was (P = 0,22). Voor vier ingrepen daalde de POWI incidentie na de interventie en voor drie ingrepen nam de POWI incidentie toe na de interventie. Echter, deze studie had niet genoeg onderscheidingsvermogen om per chirurgische ingreep een significante verandering in POWI incidentie aan te kunnen tonen.
De resultaten laten zien dat de implementatie van een geoptimaliseerd en restrictief antibioticabeleid in ziekenhuizen geen invloed had op de effectiviteit van de profylactische antibiotica aangaande de preventie van POWI's.

Het grootste deel van de studies die risicofactoren voor een wondinfectie na een totale heupprothese bestudeerden, heeft zich vooral geconcentreerd op patiënt-, operatie- of ziekenhuiskenmerken. Echter, prospectieve studies naar het aandeel van de kwalitatieve aspecten van chirurgische profylaxe in de preventie van wondinfecties na een totale heupprothese zijn schaars. In ***Hoofdstuk 8*** van dit proefschrift is het effect van verscheidene parameters van chirurgische antimicrobiële profylaxe op het POWI risico bestudeerd voor de populatie in de CHIPS-studie die een totale heupprothese operatie hebben ondergaan. Het accent lag op de timing van de toediening van profylaxe vanwege het belang van de aanwezigheid van het antibioticum in het weefsel op het moment van potentiële contaminatie.
Gegevens over de chirurgische ingreep, potentiële risicofactoren voor een POWI, en type POWI werden verzameld volgens het PREZIES protocol. Het antimicrobiële middel, de dosering, duur

en timing van de profylaxe, en het gebruik van geïmpregneerd botcement werden geregistreerd volgens het CHIPS protocol.
Multivariate regressie analyse was uitgevoerd om rekening te kunnen houden met mogelijke verstorende factoren. Vanwege de hiërarchische structuur van de gegevens (patiënten geclusterd in ziekenhuizen) werd een 'random coefficient' model toegepast.
Vijftig van de 1.922 patiënten (2,6%) kregen POWI. Een operatieduur langer dan het landelijke 75ste percentiel was de enige onafhankelijke en statistisch significante risicofactor. Antibiotica met een breder spectrum of een langere halfwaardetijd (>1,5 uur) waren niet gerelateerd aan minder POWI's dan antibiotica met een smaller spectrum of een kortere halfwaardetijd respectievelijk. Ondanks dat het niet statistisch significant was, leek het erop dat de toediening van de eerste dosering van antibiotica tijdens of voorafgaande aan de incisie de meest belangrijke profylaxe-gerelateerde factor was voor een toenemend risico op een POWI. In enkele timing-categorieën was het aantal patiënten te klein om ferme conclusies te kunnen trekken over de optimale timing voorafgaand aan de incisie. Veelvoudige postoperatieve doseringen bevorderden de reductie in de POWI incidentie niet.
Deze studie suggereert dat interventiestudies die onderzoek doen naar beïnvloedbare factoren om POWI's na een totale heupprothese te voorkómen, zouden moeten focussen op het tijdig toedienen van antimicrobiële profylaxe.

Na bestudering van de resultaten van een interventiestudie, kunnen nieuwe plannen worden uitgedacht, wat je terugbrengt naar de eerste stap van de Plan – Do – Study – Act cyclus. Dit toont aan dat infectiepreventie een continu proces is, waarbij elke verandering in infectiepreventie activiteiten materiaal en bewijs levert voor de volgende kwaliteitsverbetering.

11

General discussion

Surveillance has been accepted worldwide as a primary step toward prevention of healthcare-associated infections. In order to generate accurate and reliable data and to be successful in reducing infections, a surveillance system should comply with several criteria. In the Netherlands, a national network for the surveillance of nosocomial infections was set up in 1996 and called PREZIES ('PREventie van ZIEkenhuisinfecties door Surveillance'). It started with the surveillance of surgical site infections (SSIs), and so far 90% of all acute care hospitals in the Netherlands have participated for a period between 3 months and 11 years.
In this thesis, the quality of the SSI surveillance within the Dutch PREZIES network is evaluated. Therefore, the methods and applications of the surveillance were critically evaluated and the trend in SSI incidence studied. Our study proved that the method for postdischarge surveillance recommended by PREZIES is feasible and effective and that the mandatory validation visits ensure the reliability and robustness of the surveillance data. Furthermore, the predictive power of the NNIS risk index was sufficient for several surgical procedures and could not be significantly improved by using other procedure-specific determinants. Analysis of the time-trend in SSI rates for 5 surgical procedures showed encouraging decreasing trends, although mostly not statistically significant. Comparison of the Dutch and German SSI surveillance data revealed that even though similar infection surveillance protocols were used, differences occurred in the implementation which hampered the comparison of SSI rates. Additionally, PREZIES contributed to a multi-center intervention project to improve the quality of surgical prophylaxis. The implementation of an optimized and more-prudent antibiotic policy in hospitals did not change the effectiveness of the antibiotic prophylaxis concerning SSI prevention. Detailed analysis of the effect of various prophylaxis parameters following total hip arthroplasty showed that the timing of administration of the first dose (and not the duration) was the most important prophylaxis-related factor for the risk of SSI.

The structure of this thesis is characterized by the *Plan – Do – Study – Act* cycle, developed by the American Institute for Healthcare Improvement for evaluating the effect of changes in e.g., infection prevention activities.[1]

PLAN – Develop a surveillance plan with included surgical procedures, period, tasks of involved personnel, and objectives.

Within PREZIES, hospitals have always been allowed to choose any surgical procedure for inclusion in the surveillance. Sometimes, this led to the surveillance of rarely performed procedures, which resulted in low reliability of the SSI rates (i.e., wide confidence intervals). Furthermore, national reference rates were often lacking for these procedures because reference rates are only generated for procedures with at least 100 records (for reliability) that are registered in at least three hospitals (for confidentiality). Therefore, we feel that limiting the SSI surveillance of PREZIES to regularly performed procedures and to procedures where SSIs have severe consequences (e.g., replacement of hip prosthesis as a result of an SSI) will result in more-efficient use of limited resources and

in more-precise SSI rates. The German KISS network, for example, already focuses their SSI surveillance on 25 so-called 'indicator procedures'.[2] Because a hospital should be able to get insight into the overall SSI problem, the 'indicator procedures' should be carefully chosen and all surgical specialties should be represented.

Because hospitals can determine the surveillance period for each surgical procedure, some hospitals have followed the same procedure for over 10 years. To enlarge the effectiveness of surveillance and use limited recourses as efficient as possible, we would suggest switching the surveillance to another procedure when the SSI rate has decreased below the target. This indicates once again the significance of specifying aims before starting the surveillance.

The value of the PREZIES nosocomial surveillance network has been recognized by the Dutch authorities. The Dutch Healthcare Inspectorate (IGZ) has included SSI surveillance as a hospital-wide structure indicator in the basic set of Hospital Performance Indicators since 2004. The Healthcare Inspectorate is of opinion that active surveillance should be part of the infection prevention policy and recommends that hospitals should participate at least once a year in one of the modules of PREZIES. Since then, the number of PREZIES participants further increased, probably because the hospitals fell obliged to participate. In the hospitals, the responsible person for the surveillance is usually the infection control professional (ICP). However, currently in rarely any Dutch hospital the desired standard of 1 full-time equivalent ICP per 5000 admissions is reached.[3] Besides, this standard does not say anything about how much time an ICP can or may truly spend on surveillance. We would recommend that hospitals appoint as many ICPs as needed according to the standard, with enough time available for the execution of surveillance. The availability of electronic data is increasing and will make surveillance less time-consuming.

DO – Execute the surveillance.

The results and universal applicability of the Dutch validation method

Validating surveillance data is of the utmost importance for ensuring the accuracy of the data. PREZIES uses a validation method in which the execution of the surveillance in each participating hospital is validated at least once every three years. During the validation visits, the method of data collection according to the protocol (by means of a structured interview) and the application of definitions (by reviewing medical records) are assessed. In *Chapter 3* we described the validation method in detail and the validation results showed that this method appeared to be feasible and valuable. The positive results of the validation visits indicate that the sensitivity of case-finding was high and that the criteria for assessing a SSI were applied correctly, which ensures the reliability of the surveillance data accumulated in the PREZIES database.

An international 'gold standard' for performing validation of surveillance data has not yet been defined. Many validation studies have been reported, with various methods revealing different sensitivity and specificity.[4-7] To our knowledge, no other national SSI surveillance system executes

validation continuously. Combining the experience of all European validation studies performed might be helpful in order to develop a protocol for a meaningful and cost-effective method for performing validation studies, as Gastmeier suggested.[8]

The value of the validation method used by PREZIES seems high, but the method might not be feasible in larger countries, where the distance to hospitals is too far to perform one-day onsite visits and where the number of participating hospitals might be too large to validate them all every three years. A possible solution might be that ICPs perform the validation visits in nearby hospitals. To warrant the quality of the validation, ICPs should be trained to perform validation visits in other hospitals. Alternatively, validation visits might be restricted to a random sample of the participating hospitals, but then the reliability of all surveillance data can not be guaranteed.

Besides validation visits, another item of the PREZIES surveillance that contributes to the accuracy of the data and might be implemented in other SSI surveillance networks is elucidation of all items of the protocol, like emergency procedure, revision surgery, wound contamination class and ASA classification. These clarifications are published on the network's website as well as in some publications in a Dutch journal intended for ICPs. Furthermore, every two months a case study is published on the website of PREZIES, by which ICPs may practice the application of SSI definitions.

The value and difficulties of postdischarge surveillance

Another aspect of the PREZIES surveillance that contributes to the quality assurance of the national SSI data is postdischarge surveillance (PDS), i.e., the follow-up of patients after hospital discharge. PDS helps to avoid underreporting of SSIs and to obtain true infection rates. Besides, PDS diminishes or even eliminates the effect of changes over time or differences between hospitals in length of stay on SSI rates. Internationally, a gold standard for performing PDS has not yet been specified. In 1998, PREZIES developed a method for the performance of PDS, which is addition of a special registration card to the outpatient medical record, on which the surgeon notes clinical symptoms and whether a patient developed an SSI according to the definitions.[9] Examination of all outpatient medical records is the alternative method for PDS. These methods for PDS are recommended and assumed feasible and reliable, because in the Netherlands almost every patient is seen again by the surgeon after hospital discharge. For each hospital, the performed method for PDS is recorded. Therefore, surveillance results can be compared between hospitals that perform PDS according to the same method (recommended method, other active method, or no PDS). This increases the reliability of the comparison of infection rates. In *Chapter 2* we showed that the number of hospitals performing PDS increased yearly, with almost 70% of the participating hospitals performing PDS according to the recommended method in 2005. The recommended method for PDS seemed effective because 43% of all included SSIs were recorded after discharge, compared with 30% after discharge when another method for PDS was used, and 25% in case no (active) PDS was carried out. The highest percentage of postdischarge SSIs (i.e., postdischarge SSI as a percentage of all SSIs) identified by recommended PDS was found for appendectomy (76%), followed by knee prosthesis surgery (64%) and mastectomy (61%). Some studies detected more

SSIs after discharge,[10-12] however, the results are probably influenced by differences in the average length of hospitalization, which hinders reliable comparison.

Because most SSIs after discharge were detected by use of the recommended method for PDS, we modified the hospital-specific feedback report of PREZIES in 2006: observed and expected SSI rates were reported separately for recommended PDS and for other or no PDS, instead of overall observed and expected SSI rates. These changes increased the accuracy of the comparison of hospital-specific data with national reference numbers.
In many other national SSI surveillance systems, SSIs after discharge are not included and/or the performed method of PDS in the participating hospitals is rarely recorded, which makes the correctness of inter-hospital comparison in those countries questionable. For example, in Germany, postdischarge surveillance is strongly recommended but not mandatory, because systematic postdischarge surveillance is not yet feasible in Germany. SSIs after discharge are included, but it is not recorded which and how hospitals perform PDS.[13] In Australia, SSIs after discharge are not included in the national database, unless the patient was readmitted to the same hospital.[14] In Scotland, SSI surveillance is mandatory for National Health Service hospitals, but they publish only in-hospital rates of SSI.[15]
Because of a decreasing trend in patients' postoperative hospital stay *{see discussion of Chapter 6}*, more SSIs will develop after the patient has left the hospital, which makes PDS increasingly important. In order to obtain highly accurate SSI surveillance data, we think that the performance of PDS according to a high-quality method should be obliged. Therefore, we decided that all participating hospitals in PREZIES must perform PDS according to our recommended method from 2009 onwards. Because PDS is time-consuming and requires cooperation with surgeons, PDS might be difficult to organize and achieve in some hospitals. Thus, making PDS mandatory might reduce the number of participating hospitals. However, because almost 80% of the Dutch hospitals that participate in PREZIES currently performs PDS in one way or another, this reduction in number of participants is probably limited and will not outweigh the advantage of the increase in quality of the surveillance data.
The major difficulty of postdischarge surveillance is to reach a 100% follow up rate. In the Netherlands almost every patient returns to the hospital where the surgery has taken place for checkup. This is probably not the case in many other countries. In this view, it might be useful to consider the number of patients that were lost to follow-up.

STUDY – Analyze the surveillance results and give feedback to involved staff.

Risk adjustment: is there room for improvement?

For reliable comparison of SSI surveillance data between hospitals, adjustment of SSI rates for relevant risk factors that may vary between patients and hospitals is very important. The NNIS risk index was developed in the United States in 1991. Since, this risk index has been used for

risk adjustment by many countries, also by PREZIES. More recently, it has been questioned whether adjustment for the NNIS index is valuable for all surgical procedures.[16-20] In *Chapter 4* we compared the predictive value of the NNIS index with alternative determinants that are routinely collected in PREZIES for several surgical procedures. That study showed that for some surgical procedure groups, alternative models can predict SSI occurrence better than the commonly used NNIS index. However, the practical relevance of the findings was limited, as changes in expected SSI numbers were small and there was no substantial gain in simplicity of the alternative models, as measured by the number of variables included. Therefore, we decided not to replace the NNIS index with procedure-specific determinants when comparing hospital and national SSI occurrence in feedback reports to hospitals.

The study also showed that the predictive power of the models was generally rather low (as measured by the area under the receiver operating characteristic curve) which indicates that there is still room for improvement. Notwithstanding that the PREZIES SSI surveillance is quite comprehensive, some aspects that may influence the SSI risk are lacking. Currently, mainly non-modifiable risk factors are included in the PREZIES protocol, e.g., age, gender, wound contamination class, and ASA classification. This was chosen because the main goal of PREZIES is to compare SSI rates between hospitals accurately and reliably. Judgment of the necessity of infection prevention activities is left to the hospitals' discretion. The aim of PREZIES is not (in the first place) to measure effects of interventions regarding modifiable factors.

In the future, we should consider whether the practicability of the surveillance data can be extended by inclusion of more non-modifiable risk factors (e.g., diabetes, body mass index, smoking and revision surgery)[21 22] or process measures that are known to affect the SSI risk (e.g., timing of antimicrobial prophylaxis, glucose control, routine on the OR, body temperature and oxygenation during surgery)[23-28]. However, for the feasibility of the surveillance, the extra time-investment that accompanies the registration of additional data should be watched. Furthermore, some factors affect the SSI risk only following specific surgical procedures, and recording procedure-specific risk factors would make the surveillance more complicated.

The influence of surveillance in reducing SSI rates

The ultimate goal of PREZIES is to decrease the number of nosocomial infections. The value of feedback of surveillance results to healthcare providers has been demonstrated earlier.[29 30] Therefore, in *Chapter 6* we evaluated the time-trend in SSI rate in relation to the duration of surveillance, separately for five frequently-performed surgical procedures, using data from 1996 to 2006. This study showed a decreasing trend in SSI risk with increasing surveillance time for some surgical procedures. Even though most decreasing trends in SSI rate were not statistically significant, they are encouraging. We cannot assert that the detected association between duration of surveillance and SSI rate was a causal relation and we do not know what exactly caused the decrease in SSI risk. We speculate that the reduced SSI rate might have been a result of improvements in the quality of care in the hospitals over time, like improved compliance with infection prevention guidelines. We somewhat expected a significant decrease in infection incidence for all procedures included in the

study. Possible reasons why the (indirect) effect of surveillance was limited are power deficiency and that feedback of the results did not reach all necessary staff or, more importantly, the results were spread but not comprehensively discussed with surgeons, operating room personnel, nurses, and the infection prevention committee. We think that the surveillance is more profitable if conclusions are drawn from the results (e.g., whether the SSI rate has decreased below the target) followed by actions to reduce the SSI risk or plans to switch the surveillance to other surgical procedures. Furthermore, whether feedback of surveillance results actually leads to a decrease in infection rates depends strongly on the motivation and discipline of all healthcare professionals to change their behavior and work according to protocols and guidelines.[31] Continuous education and repeatedly drawing attention to the risks linked to improper actions might contribute to this.
Another important factor that may influence the effectiveness of SSI surveillance is whether the ICP, who is usually responsible for the surveillance in a hospital, is able to form a partnership with the surgical staff. Creating a sense of ownership of the surveillance initiative amongst the surgical staff enhances co-operation and ensures that the best use is made of the information generated. Sharing information enables influencing behavior to reduce the incidence of SSI.[32] Communication and collaboration with anesthesiologist, the infection control committee and the management is also important, i.e., the execution of SSI surveillance should be multidisciplinary. From our experience we have observed that the degree and quality of collaboration between ICPs and surgical staff is suboptimal in some Dutch hospitals, which might interfere with improving infection control in the hospitals. The PREZIES surveillance network might help to optimize the collaboration by convincing the surgical staff of the value of surveillance, e.g., by organizing a meeting to inform them on the methods of the surveillance network (including the confidentiality of the data), on the workload of performing surveillance, and on how the surveillance results (on feedback reports) can be used for infection control.

Comparing SSI surveillance data between countries

We wondered how the Dutch procedure-specific SSI rates related to those of other countries. Registered SSI rates depend on the surveillance methods and on the healthcare system in a country. In *Chapter 5,* we decided to compare the SSI surveillance data from PREZIES with those from the German national nosocomial infection surveillance network (KISS), because they have comparable surveillance protocols and public healthcare systems.[33] Despite these conformities, differences occurred in the execution of the surveillance which made comparison of SSI rates less reliable than expected. We think that comparing SSI data between countries will be most reliable for deep SSIs during hospitalization, since these SSIs are not affected by postdischarge surveillance and the diagnostic sensitivity for deep SSIs is probably more similar between countries than for superficial SSIs.
As mentioned earlier, in KISS and many other surveillance networks, continuous validation of all participating hospitals does not take place and PDS is not mandatory and/or the performed method of PDS is not recorded per hospital. This is also the case for the NNIS network in the United States which serves as an example for many other surveillance systems. Thus, we think

that the value of comparing SSI surveillance results between countries is questionable and that countries should preferably focus on improvements within their country over time.

ACT – Specify essential proceedings and prepare a new plan.

Surveillance data regarding nosocomial infections give insight into problem areas which can encourage taking specific measures. The *Act*-step of the PDSA-cycle is an essential part for improving infection control and reducing the number of infections. It will mainly consist of performing interventions, improving compliance with current guidelines, or specifying and implementing new guidelines. However, this part was not the main goal of the PREZIES surveillance network when it was set up in 1996. The focus of PREZIES was to collect and publish infection data that could serve as a benchmark, with the hospitals themselves being responsible for starting prevention activities. Currently, the PREZIES-team occasionally gives advice to a hospital regarding interventions, discusses possible interventions during workshops, or brings a hospital in contact with a 'best practicing' hospital. It is outside the range of duties of PREZIES to actively monitor which infection control measures are performed by each hospital and what the results were of those actions. ICPs probably have the best view of what changes in infection control are needed in their hospitals and to what degree the healthcare activities deviate from the guidelines. However, changing behavior of healthcare workers is a complex and multi-faceted process affected by several factors, including knowledge, attitudes, expectations, and motivations.[31 34 35] We think that it might be helpful if PREZIES would organize specific workshops for ICPs to share their experiences in setting up and carrying out interventions, with discussion of perceived barriers and learned lessons.

Cooperation of PREZIES with other infection prevention activities

In the CHIPS study, PREZIES closely cooperated with an intervention study where the Dutch national guideline for antimicrobial prophylaxis was successfully implemented in 13 hospitals (*Chapter 7 and 8*). In this study, the PREZIES network provided a valuable framework for the set up of the study (hospitals were recruited mainly from the network), the data management and analyses (by epidemiologists of the PREZIES team) and the execution of the study (by ICPs, which kept staff expenses of the study low). A major strength of the CHIPS study was the multi-center approach of both measurement of the effect on process outcome (quantity and quality of surgical prophylaxis) and on patient outcome (SSI). The SSI surveillance data of PREZIES made it possible to show that the implementation of the more-prudent and restrictive antimicrobial policy had no detrimental effect on the efficacy of prophylaxis in preventing SSIs. Documentation of this patient outcome is very important for making restrictive measurements regarding prophylaxis acceptable for surgeons and for wider implementation (national and international). Furthermore, the CHIPS study provided scientific evidence that the timing of administration of the first dose of antibiotic prophylaxis (and not a longer duration of prophylaxis) was the most important prophylaxis-related factor for the risk of SSI after total hip arthroplasty.

However, a shortcoming of the design of the CHIPS study was that the CHIPS team was mainly in contact with ICPs and infection committees. Surgeons and anesthesiologists were limited involved, partly because surgeons were less accessible. This was detrimental, because surgeons are primarily responsible for the administration of surgical antibiotic prophylaxis.

More recently, two national initiatives were invented that cooperated with PREZIES, namely the 'Breakthrough' and 'Faster Better' projects. Between 2002 and 2004, 17 Dutch hospitals participated in two SSI 'Breakthrough' series, which were set up and coordinated by the Dutch Institute for Healthcare Improvement (CBO). Those hospitals tried to improve infection control by changing many process indicators that were derived from the literature and/or were successful in another hospital. One of the goals was to reach an SSI incidence below the 25th percentile at that time. Between 2004 and 2008, 24 Dutch hospitals participate in three 'Faster Better' tranches, in order to realize substantial quality improvements for patients and healthcare workers regarding safety and logistics. 'Faster Better' is a joint initiative of the Ministry of Health, the Dutch Hospital Association, the Order of Medical Specialists, and others. It consists of several sub-projects, one of which is the SSI Breakthrough project. Breakthrough series also use the *Plan – Do – Study – Act* cycle and the goal is a 50% reduction in SSI rate or an SSI rate below the national average. The hospitals that participated in one of these programs were encouraged to simultaneously participate in the SSI surveillance of PREZIES, which enabled linkage of the process and outcome measurements. The strength of Breakthrough programs is the multidisciplinary cooperation within the hospital, and the cooperation beyond the walls of a hospital. Support from colleagues is very important for the execution of surveillance as well as for the implementation or change of guidelines. In the Breakthrough series, key figures are appointed in each organization, who can help improvement-teams with financial and/or material barriers (e.g., the management) and/or with convincing specific disciplines to participate in interventions. The medical specialists are key figures for creating support and motivation for the SSI Breakthrough project within their own partnership.

Cooperation with and recognition by hospitals and experts becomes increasingly important and it might be of vital importance for PREZIES to seek further alliance with intervention programs. We think that more attention should be paid to embedding the surveillance in the total of infection prevention activities in the Netherlands. In that way, the surveillance results might be more extensively used for improvements in infection control with better guidance from experts, and thus might increase the effectiveness of the surveillance in reducing the number of nosocomial infections. Such initiatives are usually multi-center programs, which leads to more interaction between the hospitals. That enables hospitals to learn from each other about how processes and intervention measures can be organized optimally or how changes can be implemented more easily and effectively. These studies can vary widely regarding subject and design, like a cost-effectiveness study or a clinical study to investigate the value of a patient-related risk factor (e.g., glucose control) or a process factor (e.g., timing of antimicrobial prophylaxis).

Bundling best practices

Currently of interest is the new safety program 'Prevent injury, work safe in Dutch hospitals' (2008-2012), developed by the Ministry of Health, the Healthcare Inspectorate, the Dutch Hospitals Association, and others. The prevention of SSIs is the first of ten themes and the goal is to reach an SSI rate below the current 25th percentile per surgical procedure as measured in PREZIES in all hospitals. In the scope of the safety program, PREZIES has been asked to include a bundle of process measurements in the SSI module. A few years ago, the American Institute for Healthcare Improvement (IHI) introduced the term *bundle* into the field of infection control. However, the concept of bundles has been in use for many years, for example in the field of antibiotic policy (e.g., type of drug + dosage + timing + duration). A *bundle* consists of generally accepted best practices needed to effectively and safely care for patients undergoing particular treatments with inherent risks.[36] Bundling essential practices is an implementation strategy, with the idea that, when combined, the practices will considerably improve patient care outcomes. It is a cohesive unit of steps, i.e., all components must be completed to succeed; it's all or nothing. A *bundle* should be small and straightforward.[36] The *bundle* approach is growing in popularity and is quickly becoming a standard in healthcare quality improvement strategies.

Even though a SSI-bundle will consist of modifiable processes, and the PREZIES surveillance currently focuses on non-modifiable risk factors, we think that the value and power of *bundles* will justify including them in the surveillance. However, beforehand we should consider whether the increase in work-load for ICPs, to collect information regarding all elements included in the bundle, is acceptable. By including a bundle of process measurements in the SSI module, and thus collaborating with the new national safety program, the recognition of PREZIES might increase.

After studying the results of an intervention, new plans can be invented, which brings you back to the first step of the *Plan – Do – Study – Act* cycle. This shows that infection control is a continuous process, with each change in infection prevention activities providing material and evidence for the next quality improvement. Surveillance is a useful instrument to guide this process in order to prevent healthcare associated infections. Recommendations for the PREZIES network and for the hospitals in order to optimize the SSI surveillance have resulted from the studies described in this thesis.

Recommendations for the PREZIES network:

- Restrict SSI surveillance to 'indicator procedures'.
- Make postdischarge surveillance mandatory according to the recommended method.
- Keep validating the surveillance in all participating hospitals continuously.
- Include bundles of process measurements in the surveillance.
- Cooperate more often and more closely with other healthcare improvement initiatives.

Recommendations for the hospitals:

- Appoint more ICPs for the execution of surveillance (i.e., invest in human recourses and continuous education).

- Use electronically available data as much as possible, to minimize the work-load.
- Set targets before starting surveillance and switch the surveillance to another surgical procedure when the SSI rate has decreased below the target.
- Use the surveillance results extensively for improvements in infection control.
- Ensure close cooperation between the ICP and all other involved healthcare providers, especially surgeons.

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Curriculum Vitae

CURRICULUM VITAE

Judith Manniën is geboren op 30 Augustus 1978 in Goirle. Ze behaalde haar VWO-diploma aan het Theresialyceum te Tilburg in 1996. Daarna heeft ze de studie Voeding en Gezondheid gevolgd aan de Wageningen Universiteit en in maart 2001 haar Masters of Science diploma behaald. Haar eerste afstudeervak heeft ze uitgevoerd bij de vakgroep Humane voeding van de Wageningen Universiteit en bestond uit onderzoek naar het effect van koolhydraten versus enkelvoudig onverzadigde vetzuren op de HDL-cholesterolconcentratie. Daarna heeft ze stage gelopen bij de Adelaide University in Australië, waar ze onderzoek heeft gedaan naar borstvoedingartikelen in de Australische kranten tussen 1996 en 1999 en naar de relatie tussen gewicht, lengte en hoofdomtrek van zuigelingen en de ontwikkeling op 1- en 2-jarige leeftijd. Tot slot heeft ze een afstudeervak gedaan bij Numico Research (tegenwoordig Danone) in Wageningen waarbij ze onderzoek heeft gedaan naar de effecten van bijvoedingproducten met toegevoegde niet-verteerbare koolhydraten op de ontlasting en op de maagdarmgesteldheid van zuigelingen aan het begin van bijvoeden. Sinds mei 2001 werkt ze bij het Centrum voor Infectieziekten Epidemiologie (sinds 2007 genaamd 'Epidemiologie en Surveillance') van het Rijksinstituut voor Volksgezondheid en Milieu (RIVM) in Bilthoven. Als onderzoekster/epidemioloog bij de projectgroep Zorggerelateerde Infecties, houdt zij zich vooral bezig met de surveillance van ziekenhuisinfecties binnen het nationale PREZIES netwerk (Preventie van Ziekenhuisinfecties door Surveillance). Haar onderzoekswerkzaamheden binnen dat project richten zich vooral op postoperatieve wondinfecties, wat heeft geleid tot het schrijven van dit proefschrift.