Impact of obesity on the risk of wound infection following surgery: results from a nationwide prospective multicentre cohort study in England

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Abstract

We sought to assess the impact of body mass index on the risk of surgical site infection in a prospective cohort study of 206 National Health Service (NHS) hospitals in England between 2007 and 2011. Body mass index was available for 159 720 of 350 089 operations among patients undergoing abdominal hysterectomy, coronary artery bypass graft, hip replacement, knee replacement, or large-bowel surgery. Among these patients, the risk of surgical site infection ranged from 0.65% for knee replacement to 11.04% for large-bowel surgery. Overall, 127 512 (79.8%) patients were overweight or obese (body mass index of ≥25 kg/m^2). Obesity was associated with a 1.1-fold to 4.4-fold increase in the adjusted odds of developing surgical site infection as compared with normal weight, depending on the type of surgery. The population-attributable fraction (PAF) for body mass index was greatest in overweight (body mass index of 25.0–29.9 kg/m^2) patients undergoing coronary artery bypass graft, accounting for 15% of their overall risk of surgical site infection (PAF 0.15; 95% CI 0.09–0.22). Being overweight or obese substantially increased the likelihood of patients developing surgical site infection. Given the increasingly high proportion of the surgical population who are overweight, this is likely to place a considerable additional burden on the NHS. Strategies for mitigating this excess risk need to be found.

Keywords: Arthroplasty, colorectal surgery, coronary artery bypass, epidemiology, hip replacement, hysterectomy, knee replacement, morbid obesity, surgical wound infection

Original Submission: 20 March 2015; **Revised Submission:** 3 July 2015; **Accepted:** 3 July 2015

Editor: M. Paul

Article published online: 18 July 2015

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Introduction

Infections of surgical wounds can have serious consequences, both for the patient and for the care facility: surgical site infection (SSI) increases the length of postoperative stay, patient mortality, and the need for re-operation [1]. Revision of infected total hip replacement has been estimated to cost an average of €32 000 [2]. Once the acute infection is resolved, the patient's mobility may be impaired, further reducing quality of life [3]. The most recent estimate suggests that 15.7% of hospital-acquired infections are SSIs, making SSI the third most prevalent form of healthcare-associated infection [4].

Global trends in obesity are showing a consistent increase, with the age-standardized mean global body mass index (BMI) increasing by 0.4 kg/m^2 to 0.5 kg/m^2 per decade between 1980 and 2008 [5]. In England, the prevalence of obesity or being overweight in adults has increased considerably in the past 7 years, from 52.9% of the population in 1993 to 62.8% in 2010 [6]. The concomitant impact on population health is projected to inflate the cost of providing healthcare by £1.9–2 billion per year in the UK and by $48–66 billion per year in the USA by 2030 [7]. Obesity has a wide range of consequences, increasing the risk of type 2 diabetes, coronary heart disease, and osteoarthritis [8]. To this list we can add an increase in the risk of infection [9].

http://dx.doi.org/10.1016/j.cmi.2015.07.003

Given the increasing prevalence of obesity, we sought to determine the additional risk of developing SSI attributable to being overweight or obese in England. We analysed data submitted by participating hospitals to the national Surgical Site Infection Surveillance Service in England.

Materials and methods

Public Health England provides an infrastructure facilitating hospital surveillance of SSI in England. Since 2004, all National Health Service (NHS) Hospitals in England that perform orthopaedic surgery have been required to submit data on operations conducted in three consecutive months in at least one of four orthopaedic categories within a financial year to the Surgical Site Infection Surveillance Service managed by Public Health England [10]. Hospitals could choose from the following orthopaedic categories: hip replacement, knee replacement, repair of neck of femur, or reduction of long bone fracture. The Surgical Site Infection Surveillance Service offers surveillance for an additional 13 categories of surgery in which hospitals may opt to participate [10].

The study cohort was composed of patients undergoing surgery in one of five categories of surveillance (hip replacement, knee replacement, coronary artery bypass graft, large bowel surgery, and abdominal hysterectomy) in NHS hospitals in England between 1 January 2007 and 31 December 2011. Surgical categories for inclusion in the study were selected on the basis of having >25% completion for height and weight fields and >20 participating hospitals in the past 5 years. All patients undergoing procedures included in a predefined list of Office of Population Censuses and Surveys surgical operations [11] were included in the study. Because of the low risk of infection, patients undergoing surgery performed solely laparoscopically were not included in the SSI surveillance, and were therefore not available for inclusion in the cohort.

Case ascertainment

All patients were prospectively monitored by hospital surveillance staff for SSI for a minimum of 30 days. Patients receiving permanent prosthetic implants were followed up for 1 year. Any patients re-admitted to hospital for management of SSI during the follow-up period were identified. To ensure consistency and accuracy of data collection, hospital staff involved in the data collection were required to attend training provided by Public Health England. Further quality checks were performed by Public Health England staff when data were submitted to them.

Case and clinical definitions

SSIs were broadly defined according to internationally accepted CDC criteria [12], with cases being defined on the basis on any of the following: purulent drainage from the incision, laboratory confirmation, radiological examination, spontaneous dehiscence or surgical opening of a deep wound, or the presence of clinical signs combined with a clinician's diagnosis [10]. Infections were classified as superficial (those affecting only skin or subcutaneous tissue within 30 days of operation), deep (affecting fascial or muscle tissues) or organ-space (any part of the body opened or manipulated during surgery, excluding skin, muscle or fascial tissue) by clinicians. The minor deviations from CDC definitions were that infections detected by swab also required the presence of pus cells, and that superficial infection defined by the clinician's diagnosis also required the presence of two clinical signs (heat, redness, swelling, or pain). BMI was defined as the patient's weight in kilograms divided by the square of the height in metres. Classification of the BMI index followed international guidelines: underweight (<18.5), normal weight (18.5–24.99), overweight (25–29.99), obese I (30–34.99), obese II (35–39.99), and obese III (>40) [13]. Patients aged <18 years were excluded from analysis, as BMI is not an appropriate measure of obesity in children [14].

Data source, extraction, and analysis

Data for operations performed in NHS hospitals in England between 1 January 2007 and 31 December 2011 were extracted from Public Health England's surgical site infection surveillance database for analysis.

The core dataset required for each patient included the patient's date of birth, surgical procedure, operation duration, wound class, American Society of Anesthesiologists score, and prosthetic implant insertion. Hospitals were also expected to provide data on additional risk factors, including whether the operation was performed as an emergency or as a result of trauma, and whether multiple procedures through the same incision were performed. Hospitals had the option to contribute data on patient height and weight, and these data were used to calculate BMI.

All statistical analyses were performed in Stata version 12. Differences in proportions were assessed with the χ^2 test. Differences in distribution for non-normally distributed data (operation duration and patient age) were tested with the Wilcoxon rank sum test. To adjust for the effect of factors other than BMI on the risk of SSI, stepwise multivariable logistic regression was performed, with adjustment for age, sex, American Society of Anesthesiologists score, wound class, duration of operation, whether surgery was due to trauma, whether an implant was inserted, lead surgeon grade, and whether multiple surgical procedures were performed through the same incision. Interactions were tested with the χ^2 test of heterogeneity in Mantel–Haenszel stratification. The outputs of the multivariable regression models were used to calculate the population-attributable fraction (PAF). The PAF represents the proportion of SSIs that would be avoided if all patients were of normal weight, assuming a causal relationship between BMI and the risk of SSI.

Results

Between 1 January 2007 and 31 December 2011, 206 hospitals submitted data on 350 089 operations, from which 4832 inpatient and re-admission SSIs were identified. The overall risk of SSI was 1.38%, ranging from 0.59% (929/156 598) for knee replacement surgery to 10.34% (1522/14 716) for large-bowel surgery.

BMI data were available for 159 720 records (45.62%), with completion varying by surgical category. Coronary artery bypass graft patients had the highest proportion of records with BMI data (18 580 of 27 014 records, 68.78%), whereas large-bowel surgery patients had the lowest (4158 of 14 716 records, 28.25%; Table 1).

Of those patients for whom BMI data were available, 67 606 (42.33%) were classed as obese, 59 906 (37.51%) were overweight, 31 102 (19.47%) were of normal weight, and 1106 (0.69%) were underweight. For coronary artery bypass graft patients, there was evidence of a substantial difference in the risk of SSI between patients for whom BMI data were available and patients for whom BMI data were not available (2.74% vs. 5.02%, p <0.001). Smaller, statistically significant differences similarly existed for hip replacement patients (0.84% vs. 0.7%, p <0.01) and knee replacement patients (0.54% vs. 0.65%, p <0.01). Differences in patient characteristics between patients for whom BMI was or was not reported are given in Table 2, and further detailed by surgical category in Table S1. In a multivariable analysis of variables associated with missing BMI data, hospital identity had the strongest association (data not shown). After adjustment for hospital identity, the presence of an SSI was not was not associated with completion of BMI.

TABLE 1. Distribution of surgical site infections by surveillance category in England (2007–2011)

	Without BMI		With BMI	
Surgical category	No. of operations	No. (%) of SSIs	No. of operations	No. (%) of SSIs
Abdominal hysterectomy	3331	46 (1.38)	2130	32 (1.50)[a]
Coronary artery bypass graft	8434	231 (2.74)	18 580	932 (5.02)[b]
Hip replacement	83 624	699 (0.84)	62 676	441 (0.70)[b]
Knee replacement	84 422	457 (0.54)	72 176	472 (0.65)[b]
Large-bowel surgery	10 558	1063 (10.07)	4158	459 (11.04)[b]
Total	190 369	2496 (1.31)	159 720	2336 (1.46)[b]

BMI, body mass index; SSI, surgical site infection.
[a]p <0.05.
[b]p <0.001.

TABLE 2. Characteristics of patients undergoing surgery in five surveillance categories in England (2007–2011)

	Without BMI		With BMI	
Patient characteristic	No. of operations	%	No. of operations	%
ASA score >2	70 085	36.82	57 510	36.01[a]
Wound class contaminated or dirty	2966	1.56	1140	0.71[a]
Operation duration > T-time[b]	28 934	15.20	19 560	12.25[a]
Prosthesis inserted	174 017	91.41	151 169	94.65[a]
Revision[c]	16 771	9.98	10 377	7.70[a]
Male	80 128	42.84	72 070	45.73[a]
Trauma	4919	2.58	796	0.50[a]
Emergency[d]	1016	4.55	401	1.61[a]
Multiple surgical procedures[d]	8136	36.45	6263	25.18[a]
Antimicrobial prophylaxis	171 933	90.32	145 049	90.81[a]
Antibiotic cement[c]	106 222	63.21	84 931	62.98[a]
Median duration (IQR)	90 (69–118)		88 (67–120)	
Median age in years (IQR)	70.1 (62.14–77.01)		69.85 (62.07–76.57)	

ASA, American Society of Anesthesiologists; BMI, body mass index; IQR, interquartile range.
[a]p <0.001.
[b]75th percentile of the duration of operation for given category of surgery.
[c]Hip and knee replacement only.
[d]Abdominal hysterectomy, coronary artery bypass graft and large-bowel surgery only.

The risk of a patient developing an SSI increased with increasing degree of obesity as compared with normal-weight patients for all categories of surgery (Fig. 1). The relationship between the degree of being overweight or obese and the increase in risk of SSI varied by surgical category. For abdominal hysterectomy, knee replacement and large-bowel surgery patients, the risk of SSI increased approximately linearly with increasing BMI. For coronary artery bypass graft patients, the increase in risk of SSI between obese I and obese II patients was much greater than the increase between other sequential categories of BMI. Small differences in risk existed between normal-weight patients and obese III patients for hip and knee replacement (0.48% vs. 2.27% for hip replacement, and 0.43% vs. 1.27% for knee replacement). Larger differences existed between normal-weight patients and obese III patients undergoing abdominal hysterectomy and coronary artery bypass graft (1.14% vs. 3.55% for abdominal hysterectomy, and 3.00% vs. 9.59% for coronary artery bypass graft). For large-bowel surgery, 25.29% (95% CI 16.16–34.42) of obese III patients developed SSI, and 7.53% (95% CI 6.18–8.88) of normal-weight patients developed SSI.

Complete data were available for 139 901 procedures for use in multivariable logistic regression. After adjustment for clinical and demographic risk factors, the odds of developing SSI were 1.28–1.66-fold greater in overweight patients than in normal-weight patients (Table 3).

For obese I patients, the adjusted odds of SSI were 1.09–2.13-fold higher, for obese II patients, the odds of SSI were 1.78–3.79-fold higher, and for obese III patients, the odds of SSI were 2.71–4.40-fold higher. The low numbers of patients in the abdominal hysterectomy category meant that the relationship

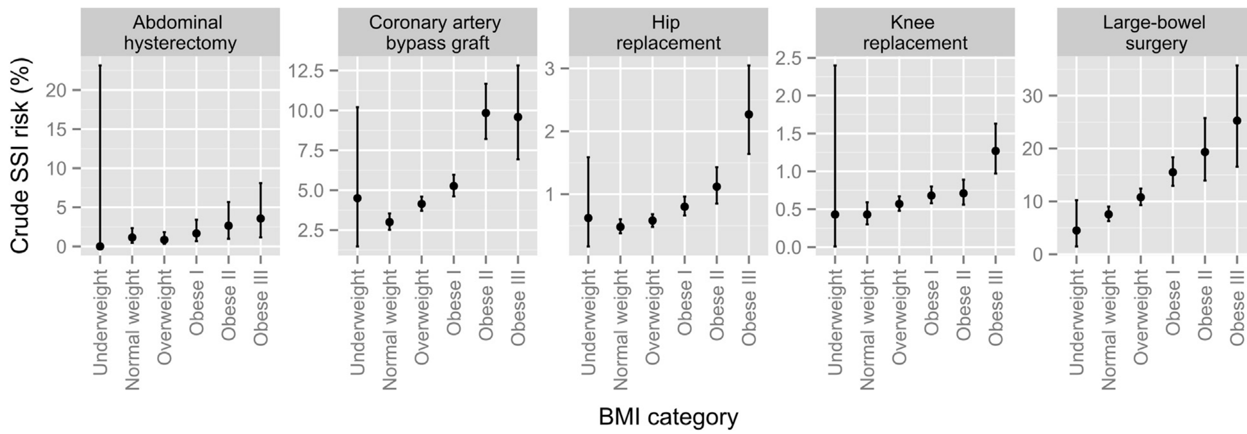

FIG. 1. Unadjusted risk of surgical site infection (SSI) by body mass index (BMI) and surgical category, England 2007–2011.

between increasing BMI and increasing odds of SSI was underpowered, but the trend was towards a positive association.

Although obese III patients had the greatest increase in odds of SSI, the greatest PAF was for overweight patients undergoing coronary artery bypass graft surgery, with 15% of the infection risk being attributable to being overweight (PAF 0.15; Table 3). In contrast, being obese I accounted for 14% of SSIs occurring among overweight patients (PAF 0.14), 9% among obese II patients (PAF 0.09) and 3% among obese III patients (PAF 0.03) undergoing coronary artery bypass graft surgery.

Obesity may lead to a greater duration of operation, so some of the increased risk of SSI posed by obesity might be mediated through the duration of operation. To investigate this, regression analyses were repeated, excluding duration of operation. Exclusion of operation duration from multivariable adjustments did not substantially change the effect of BMI on the odds of SSI.

The distribution of organisms identified from surgical wounds varied little by BMI category (Table 4). Enterococci were identified from a greater proportion of SSIs among overweight or obese patients undergoing coronary artery bypass grafting than of SSIs among normal-weight or underweight patients (6.5% vs. 0%, p 0.018). Among coronary artery bypass graft patients, other Gram-negative bacteria were more frequently identified among underweight or normal-weight patients than among overweight or obese patients (3.7% vs. 0.2%, p 0.001). Among hip replacement patients, members of the Enterobacteriaceae were more frequently identified among normal-weight patients than among overweight or obese patients (27.5% vs. 18.6%, p 0.048).

Discussion

The results of this large, multicentre, multi-category study indicate that being overweight or obese significantly increased the risk of postsurgical infection in a number of surgical categories. This increase in risk persisted after adjustment for other risk factors, including the degree of wound contamination, the preoperative physical status of the patient, and the duration of the operation.

This study confirms the findings of previous, smaller-scale studies. A multicentre nested case–control study of 460 patients undergoing coronary artery bypass grafting in Australia found an adjusted OR for SSI of 3.91 for obese II and obese III patients [15]. In comparison, a single-centre cohort study of 591 patients undergoing surgery in a range of different specialties in the USA found an OR of 1.3 for obese patients [16].

Mechanism of effect

The mechanism by which obesity increases the risk of SSI is likely to be multifactorial [17]. Obese surgical patients have been shown to have reduced subcutaneous tissue oxygenation and to require a greater fraction of inspired oxygen to achieve the same arterial oxygen tension as normal-weight patients, thus predisposing them to SSI [18]. Wound hypoxia impairs healing by a number of potential mechanisms; healing wounds have high metabolic demands, and insufficient oxygen will slow the healing process. Immune cells also have high oxygen demands, requiring oxygen for the formation of microbicidal reactive oxygen species [19].

In addition to poor tissue oxygenation, adequate tissue levels of prophylactic antibiotics may be harder to achieve in obese patients [20]. Antimicrobials show different pharmacokinetics when administered to obese patients, with both hydrophilic and hydrophobic compounds generally having a higher volume of distribution, requiring a higher dose to reach the same plasma drug concentrations as for non-obese patients [20]. Hepatic clearance may also be increased in obese patients [21]. Therefore, obese patients may need to be dosed differently from non-obese patients [22].

TABLE 3. Multivariable analysis of risk factors for surgical site infection in five categories of surveillance in England (2007–2011)

BMI category	Abdominal hysterectomy (n = 1601)		Coronary artery bypass graft (n = 15 138)		Hip replacement (n = 55 717)		Knee replacement (n = 63 950)		Large-bowel surgery (n = 3495)	
	OR (95% CI)	PAF	OR (95% CI)	PAF	OR (95% CI)	PAF	OR (95% CI)	PAF	OR (95% CI)	PAF
Underweight	—	—	1.65 (0.65–4.19)	0.00 (0.00–0.01)	1.02 (0.32–3.26)	0.00 (−0.01 to 0.01)	1.20 (0.16–8.81)	0.00 (0.00–0.01)	0.59 (0.23–1.52)	—
Normal weight	1.00	—	1.00	—	1.00	—	1.00	—	1.00	—
Overweight	1.32 (0.37–4.74)	0.07 (−0.3 to 0.33)	1.66 (1.32–2.09)[a]	0.15 (0.09–0.22)	1.22 (0.90–1.66)	0.06 (−0.03 to 0.14)	1.28 (0.89–1.86)	0.07 (−0.03 to 0.15)	1.50 (1.14–1.97)[b]	0.12 (0.03–0.19)
Obese I	1.09 (0.24–4.94)	0.01 (−0.22 to 0.20)	2.13 (1.67–2.73)[a]	0.14 (0.09–0.18)	1.75 (1.27–2.40)	0.12 (0.05–0.18)[b]	1.59 (1.09–2.30)[b]	0.12 (0.03–0.20)	2.02 (1.48–2.76)[a]	0.10 (0.05–0.15)
Obese II	2.70 (0.64–11.40)	0.12 (−0.10 to 0.29)	3.79 (2.82–5.08)[a]	0.09 (0.07–0.12)	2.30 (1.58–3.34)	0.08 (0.04–0.11)[a]	1.78 (1.18–2.69)[b]	0.07 (0.02–0.12)	2.99 (1.90–4.70)[a]	0.05 (0.02–0.07)
Obese III	3.45 (0.76–15.64)	0.13 (−0.07 to 0.30)	3.67 (2.41–5.59)[a]	0.03 (0.02–0.05)	4.40 (2.88–6.70)	0.08 (0.04–0.10)[a]	3.20 (2.06–4.97)[a]	0.09 (0.05–0.12)	2.71 (1.46–5.01)[b]	0.02 (0.01–0.04)

Models were adjusted for American Society of Anesthesiologists (ASA) score, wound class, duration of operation, patient age, patient sex, trauma, whether surgery was performed as an emergency, whether an implant was inserted, surgeon grade, and whether multiple surgical procedures were performed through the same incision. The model for abdominal hysterectomy was not adjusted for patient sex. Hip replacement and knee replacement models were not adjusted for emergency status, prosthetic implant, or multiple procedures.
BMI, body mass index; PAF, population-attributable fraction.
[a] p <0.001.
[b] p <0.05.

Clinical implications

Trends in population health suggest that obesity is likely to become a more significant factor in predisposing to wound infection. In 2010, the proportion of adults in England who were overweight or obese was 62.8%; by 2020, the prevalence of overweight and obesity among adults and children in England is expected to reach 70% [7]. National Joint Registry data show that, for primary hip replacement, the proportion of patients with a BMI between 30 and 44 has increased from 69% to 77% [23]. The same report shows an increase in the number of primary hip and primary knee replacements being performed, a trend mirrored in many developed countries. In contrast, however, the number of patients undergoing coronary artery bypass graft surgery has remained approximately level since 1997 [24].

To determine the proportion of the infections attributable to being overweight or obese, PAFs were calculated. We found that, although the greatest OR was for obese III patients, the greatest excess infection risk was contributed by being overweight rather than by being obese. This is because, among cases in this study, the prevalence of being overweight is greater than the prevalence of being obese III, resulting in a greater population at risk. As the PAF is a function of both the prevalence of the risk factor and the risk posed by the risk factor, the proportion of infections attributable to being overweight and obese will continue to increase if the current trends in obesity continue.

Reducing the weight of prospective overweight surgical patients would perhaps reduce the numbers of patients requiring surgery, and could reduce the number of infections in those that go on to undergo surgery. The idea that 15% of SSIs could be prevented by eliminating overweight in patients undergoing coronary artery bypass graft surgery is appealing, but impractical. The degree to which obesity can be reduced prior to surgery or the degree to which the effects of obesity can be mitigated is not clear. A recent cohort study comparing patients undergoing joint replacements 6 months before bariatric surgery with patients undergoing joint replacements 6 months after bariatric surgery failed to show a significant difference in the 30-day joint infection rate, suggesting that weight loss prior to surgery may not improve SSI outcomes [25].

As short-term weight loss for the majority of these patients is unlikely to be achievable preoperatively, other approaches are needed to mitigate against the effects of obesity. One option is the use of alternative antibiotic prophylaxis regimens. A randomized controlled trial on high-risk coronary artery bypass graft patients (which included obesity as a high-risk indicator) found that extended broad-spectrum prophylaxis with a weight-based dosing regimen significantly reduced the rate of sternal wound infection as compared with a shorter duration of prophylaxis with cefuroxime alone [26]. A cohort study of

TABLE 4. Organisms identified as causing surgical site infection

Category of surgery	Organism	Underweight or normal weight, *n* (%)	Overweight or obese, *n* (%)	p[a]
Abdominal hysterectomy	Enterobacteriaceae	1 (25.0)	9 (60.0)	—
	Staphylococcus aureus (MSSA)	1 (25.0)	4 (26.7)	—
	CoNS	0 (0.0)	1 (6.7)	—
	Clostridium difficile	0 (0.0)	1 (6.7)	—
	Pseudomonas species	0 (0.0)	1 (6.7)	—
	Anaerobes	0 (0.0)	1 (6.7)	—
	Enterococci	1 (25.0)	1 (6.7)	—
	S. aureus (MRSA)	0 (0.0)	1 (6.7)	—
	Streptococci	1 (25.0)	0 (0.0)	—
Coronary artery bypass graft	Enterobacteriaceae	35 (42.7)	202 (43.4)	0.898
	CoNS	19 (23.2)	136 (29.2)	0.260
	Pseudomonas species	21 (25.6)	88 (18.9)	0.162
	S. aureus (MSSA)	12 (14.6)	86 (18.5)	0.401
	Enterococci	0 (0.0)	30 (6.5)	0.018
	Other bacteria	2 (2.4)	15 (3.2)	0.705
	Fungi	2 (2.4)	14 (3.0)	0.777
	S. aureus (MRSA)	5 (6.1)	13 (2.8)	0.122
	Anaerobes	1 (1.2)	8 (1.7)	0.742
	Other Gram-positive	2 (2.4)	8 (1.7)	0.654
	Non-fermenting Gram-negative rods	0 (0.0)	7 (1.5)	0.263
	Streptococci	2 (2.4)	5 (1.1)	0.311
	Other Gram-negative	3 (3.7)	1 (0.2)	0.001
Hip and knee replacement	*S. aureus* (MSSA)	28 (30.8)	201 (33.7)	0.585
	CoNS	25 (27.5)	163 (27.3)	0.973
	Enterobacteriaceae	25 (27.5)	111 (18.6)	0.048
	Enterococci	13 (14.3)	68 (11.4)	0.425
	S. aureus (MRSA)	11 (12.1)	47 (7.9)	0.178
	Other Gram-positive	4 (4.4)	44 (7.4)	0.299
	Pseudomonas species	3 (3.3)	43 (7.2)	0.165
	Streptococci	8 (8.8)	28 (4.7)	0.102
	Other bacteria	0 (0.0)	11 (1.8)	0.192
	Anaerobes	4 (4.4)	9 (1.5)	0.059
	Non-fermenting Gram-negative rods	2 (2.2)	5 (0.8)	0.228
	Fungi	1 (1.1)	3 (0.5)	0.486
	Other Gram-negative	0 (0.0)	2 (0.3)	0.580
Large-bowel surgery	Enterobacteriaceae	46 (64.8)	143 (61.1)	0.576
	Anaerobes	19 (26.8)	55 (23.5)	0.575
	Pseudomonas species	7 (9.9)	34 (14.5)	0.312
	S. aureus (MSSA)	11 (15.5)	29 (12.4)	0.498
	Enterococci	6 (8.5)	27 (11.5)	0.463
	Streptococci	7 (9.9)	23 (9.8)	0.994
	S. aureus (MRSA)	2 (2.8)	13 (5.6)	0.350
	CoNS	2 (2.8)	6 (2.6)	0.907
	Other bacteria	0 (0.0)	4 (1.7)	0.267
	Other Gram-negative	0 (0.0)	4 (1.7)	0.267
	Other Gram-positive	0 (0.0)	4 (1.7)	0.267
	Fungi	1 (1.4)	3 (1.3)	0.935
	Non-fermenting Gram-negative rods	0 (0.0)	2 (0.9)	0.434

CoNS, coagulase-negative staphylococci; MRSA, methicillin-resistant *S. aureus*; MSSA, methicillin-susceptible *S. aureus*.
[a]χ^2 test for independence.

obese patients undergoing combined hysterectomy and panniculectomy found that extended prophylaxis with ciprofloxacin in combination with a single dose of cefalozin reduced the rates of SSI as compared with a single dose of cefalozin alone [26]. The reduced tissue penetration of prophylactic antibiotics in obese surgical patients raises the possibility that obesity may predispose the patients to infection with resistant strains by selecting for these through exposure to suboptimal antibiotic levels [27,28].

Given the wider implications for the selection of antibiotic-resistant strains of bacteria, strategies to achieve adequate tissue levels at the surgical site should be developed and implemented, ensuring that the choice of agent (i.e. one with good tissue penetration), dose and duration of therapy are all optimized. Other approaches might include ensuring that skin preparation is performed stringently, oxygenation is optimized and strict glycaemic control is established in diabetic patients and those with impaired glucose tolerance [29].

Limitations

Owing to the limitations of the routine surveillance data collection, data on a number of potentially significant risk factors were not collected. Diabetic status is a known risk factor for SSI, and was not captured by the surveillance. As a result, diabetic status was not available for this study. The diabetic status of a patient is likely to lie on the causal pathway between BMI and the risk of SSI. The effect measures estimated here therefore estimate the total effect of increased body mass on the risk of SSI, and the direct effect that is not mediated through diabetes status is not estimated [30–32]. Prior studies have failed to demonstrate a clear association between diabetic status and risk of SSI after adjustment for BMI, possibly illustrating the need for capture of data on glycaemic control at the time of surgery to understand the interplay between these factors regarding infection risk (Mihalkova *et al*., Proceedings of the Public Health England Annual Conference 2014 poster number 143).

Some differences in the distribution of organisms identified from surgical wounds between overweight and obese patients as compared with normal-weight and underweight patients were noted. However, the p-values for the differences in distributions of causative organisms were generally large. Because multiple comparisons were performed, some of the observed differences are likely to have occurred by chance. The difference in distribution of other Gram-negative bacteria among coronary artery bypass graft patients seems less likely to have occurred by chance, as indicated by the small p-value for this association (p 0.001).

BMI data were not recorded for a considerable proportion of patients undergoing abdominal hysterectomy (62%) or large-bowel surgery (72%). In these categories, there were no significant differences in the rates of SSI between patients for whom BMI data were available and patients for whom data were not available, suggesting an absence of selection bias. Significant differences in the rates of SSI did exist between patients with and without BMI data for patients undergoing coronary artery bypass graft, hip replacement, and knee replacement, suggesting a possible bias in the provision of height and weight data for patients in these categories. However, once the hospital identity had been adjusted for, there was no difference in SSI risk between patients with and without BMI data. Certain patient characteristics may indicate possible reasons for the lack of BMI data; patients undergoing surgery because of trauma were less likely to have BMI data than patients not undergoing surgery because of trauma.

The results of this study are likely to be generalizable to other populations. The study had a large sample size drawn from a large number of centres. The fact that all patients undergoing surgery in the named categories were required to be followed up mitigates against the risk of selection bias.

Conclusion

This study has shown that being overweight or obese increases the odds of SSI in patients undergoing surgery in England. Continued surveillance of SSIs of arthroplasty procedures and other categories of surgery will provide a means of monitoring the impact of changing obesity rates on postsurgical wound infection.

This effect is likely to continue to increase with the rising rates of obesity in the general population, and new approaches are therefore needed to both understand the pathophysiology of the increase in infection rates in obese surgical patients and to develop means of reducing rates of infection. The specific needs of these patients could be addressed by an increased focus on weight loss programmes in the time before elective surgery.

A key approach is to ensure that antimicrobial prophylaxis is adequate. Current guidelines for the prevention of SSI do not make specific recommendations about the prevention of SSI in obese patients [29]. Guidance on antibiotic prophylaxis is limited to recommending that prophylactic agents are administered within 1 h prior to incision and to administer repeat doses in operations of extended duration. Further research may provide evidence to refine the current guidelines. Research into improving other factors such as oxygenation, skin preparation and glycaemic control in overweight people is also needed.

Continued surveillance of SSI is also essential to provide a means of monitoring the impact of the changing obesity rate on postsurgical wound infection, and interventions introduced to counteract the effects of obesity on the risk of infection.

Transparency declaration

The authors declare that they have no conflicts of interest.

Author contributions

S. Thelwall conceived the study and performed the analysis. S. Thelwall, T. Lamagni, P. Harrington and E. Sheridan drafted the paper. P. Harrington managed the surveillance system. All authors edited the paper. T. Lamagni is the guarantor. All authors had full access to all of the data, and take responsibility for the integrity of the data and the accuracy of the data analysis.

Acknowledgements

We thank the hospital surveillance staff for their considerable efforts in collecting and providing the data used in this study, and F. Michelet and M. Mihalkova for assistance with data administration. We also thank N. Verlander for his advice on statistical analyses.

Appendix A. Supplementary data

Supplementary data related to this article can be found online at http://dx.doi.org/10.1016/j.cmi.2015.07.003.

References

[1] Coello R, Charlett A, Wilson J, Ward V, Pearson A, Borriello P. Adverse impact of surgical site infections in English hospitals. J Hosp Infect 2005;60:93–103.
[2] Klouche S, Sariali E, Mamoudy P. Total hip arthroplasty revision due to infection: a cost analysis approach. Orthop Traumatol Surg Res 2010;96:124–32.
[3] Garvin KL, Konigsberg BS. Infection following total knee arthroplasty: prevention and management. J Bone Joint Surg Am 2011;93:1167–75.
[4] Health Protection Agency. English national point prevalence survey on healthcare-associated infections and antimicrobial use. Health Protection Agency, 2012; 2011. preliminary data.
[5] Finucane MM, Stevens GA, Cowan MJ, Danaei G, Lin JK, Paciorek CJ, et al. National, regional, and global trends in body-mass index since 1980: systematic analysis of health examination surveys and epidemiological studies with 960 country-years and 9.1 million participants. Lancet 2011;377:557–67.
[6] Craig R, Mindell J. Health survey for England 2010. Leeds: The NHS Information Centre; 2011.
[7] Wang YC, McPherson K, Marsh T, Gortmaker SL, Brown M. Health and economic burden of the projected obesity trends in the USA and the UK. Lancet 2011;378:815–25.
[8] Pi-Sunyer FX. The obesity epidemic: pathophysiology and consequences of obesity. Obes Res 2002;10(Suppl. 2):97S–104S.
[9] Huttunen R, Syrjänen J. Obesity and the risk and outcome of infection. Int J Obes (Lond) 2013 Mar;37(3):333–40.
[10] Health Protection Agency. Protocol for the surveillance of surgical site infection. Version 5 April 2011. Health Protection Agency; 2011. Available at: [accessed 11.04.13].
[11] Public Health England. OPCS operating procedure codes. Public Health England; 2011.
[12] Horan TC, Gaynes RP, Martone WJ, Jarvis WR, Emori TG. CDC definitions of nosocomial surgical site infections, 1992: a modification of CDC definitions of surgical wound infections. Am J Infect Control 1992;20:271–4.
[13] World Health Organization. Physical status: the use and interpretation of anthropometry. Geneva: WHO; 1995.
[14] Cole TJ, Freeman JV, Preece MA. Body mass index reference curves for the UK, 1990. Arch Dis Child 1995;73:25–9.
[15] Chen LF, Anderson DJ, Kaye KS, Sexton DJ. Validating a 3-point prediction rule for surgical site infection after coronary artery bypass surgery. Infect Control Hosp Epidemiol 2010;31:64–8.
[16] Waisbren E, Rosen H, Bader AM, Lipsitz SR, Rogers Jr SO, Eriksson E. Percent body fat and prediction of surgical site infection. J Am Coll Surg 2010;210:381–9.
[17] Falagas ME, Kompoti M. Obesity and infection. Lancet Infect Dis 2006;6:438–46.
[18] Kabon B, Nagele A, Reddy D, Eagon C, Fleshman JW, Sessler DI, et al. Obesity decreases perioperative tissue oxygenation. Anesthesiology 2004;100:274–80.
[19] Sen CK. Wound healing essentials: let there be oxygen. Wound Repair Regen 2009;17:1–18.
[20] Falagas ME, Karageorgopoulos DE. Adjustment of dosing of antimicrobial agents for bodyweight in adults. Lancet 2010;375:248–51.
[21] Martin JH, Saleem M, Looke D. Therapeutic drug monitoring to adjust dosing in morbid obesity—a new use for an old methodology. Br J Clin Pharmacol 2012;73:685–90.
[22] Chopra T, Zhao JJ, Alangaden G, Wood MH, Kaye KS. Preventing surgical site infections after bariatric surgery: Value of perioperative antibiotic regimens. Expert Rev Pharmacoecon Outcomes Res 2010;10:317–28.
[23] National Joint Registry for England and Wales. 9th Annual Report 2012, Surgical data to 31st December 2011. London: National Joint Registry and Healthcare Quality Improvement Partnership; 2012.
[24] Dhadwal Kay, Al-Ruzzeh Sharif, Athanasiou Thanos, Choudhury Marina, Tekkis Paris, Vuddamalay Pynee, et al. Comparison of clinical and economic outcomes of two antibiotic prophylaxis regimens for sternal wound infection in high-risk patients following coronary artery bypass grafting surgery: a prospective randomised double-blind controlled trial. Heart 2007;93:1126–33.
[25] Kulkarni A, Jameson SS, James P, Woodcock S, Muller S, Reed MR. Does bariatric surgery prior to lower limb joint replacement reduce complications? Surgeon 2011;9:18–21.
[26] El-Nashar SA, Diehl CL, Swanson CL, Thompson RL, Cliby WA, Famuyide AO, et al. Extended antibiotic prophylaxis for prevention of surgical-site infections in morbidly obese women who undergo combined hysterectomy and medically indicated panniculectomy: a cohort study. Am J Obstet Gynecol 2010;202:306–9.
[27] Toma O, Suntrup P, Stefanescu A, London A, Mutch M, Kharasch E. Pharmacokinetics and tissue penetration of cefoxitin in obesity: Implications for risk of surgical site infection. Anesth Analg 2011;113:730–7.
[28] Niederman MS. Principles of appropriate antibiotic use. Int J Antimicrob Agents 2005;26(Suppl. 3):S170–5.
[29] National Collaborating Centre for Women's and Children's Health. Surgical site infection—prevention and treatment of surgical site infection. Clinical Guideline. NICE; 2008. Available at:, http://www.nice.org.uk/nicemedia/pdf/CG74FullGuideline.pdf [accessed 06.11.12].
[30] Harrington G, Russo P, Spelman D, Borrell S, Watson K, Barr W, et al. Surgical-site infection rates and risk factor analysis in coronary artery bypass graft surgery. Infect Control Hosp Epidemiol 2004;25:472–6.
[31] Haley VB, Van Antwerpen C, Tsivitis M, Doughty D, Gase KA, Hazamy P, et al. Risk factors for coronary artery bypass graft chest surgical site infections in New York State, 2008. Am J Infect Control 2012;40:22–8.
[32] Olsen MA, Lefta M, Dietz JR, Brandt KE, Aft R, Matthews R, et al. Risk factors for surgical site infection after major breast operation. J Am Coll Surg 2008;207:326–35.