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Quality and Patient Safety

QUALITY AND PATIENT SAFETY

Prospective observational study of postoperative infection and outcomes after noncardiac surgery: analysis of prospective data from the VISION cohort

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Abstract

Background: Infection is a frequent cause of postoperative morbidity and mortality. The incidence, risk factors, and outcomes for postoperative infections remain poorly characterised.

Methods: This is a secondary analysis of a prospective international cohort study of patients aged ≥45 yr who had noncardiac surgery (VISION), including data describing infection within 30 days after surgery. The primary outcome was postoperative infection. The secondary outcome was 30 day mortality. We used univariable and multivariable logistic regression to identify baseline risk factors for infection. Results are presented as *n* (%) or odds ratio (OR) with 95% confidence intervals. Some denominators vary according to rates of missing data.

Results: Among 39 996 surgical patients, 3905 (9.8%) experienced 5152 postoperative infections and 715 (1.8%) died. The most frequent infection was surgical site infection (1555/3905 [39.8%]). Infection was most strongly associated with general surgery (OR: 3.74 [3.11–4.49]; $P<0.01$) and open surgical technique (OR: 2.03 [1.82–2.27]; $P<0.01$); 30 day mortality was greater amongst patients who experienced infection (262/3905 [6.7%] *vs* 453/36 091 patients who did not [1.3%]; OR: 3.47 [2.84–4.22]; $P<0.01$). Mortality was highest amongst patients with CNS infections (OR: 14.72 [4.41–49.12]; $P<0.01$).

Conclusions: Infection is a common and important complication of noncardiac surgery, which is associated with high mortality. Further research is needed to identify more effective measures to prevent infections after surgery.

Keywords: epidemiological studies; infection; postoperative complications; risk factors; sepsis

Editor's key points

- Data from a 40 000 patient observational study were analysed to yield information regarding risk factors for, incidence of, and consequences of postoperative infection after noncardiac surgeries.
- Infections occurred in about 10% of patients, with surgical site infection, pneumonia, and urinary tract infection occurring most commonly.
- Of those who had an infectious complication, roughly 20% experienced more than a single postoperative infection, and infection was associated with approximately 5% absolute increased risk of 30-day mortality.
- Strong patient risk factors for infection included older age, smoking, and co-morbidities, and strong surgical risk factors included general and open surgical procedures.

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There are more than 310 million surgical procedures worldwide each year.[1] In the UK, 1 in 10 adults has a surgical procedure each year, and the annual number of procedures is increasing steadily.[2] Estimates of postoperative morbidity and mortality vary, but approximately seven million patients worldwide experience a postoperative complication each year.[3–5] Postoperative infections increase morbidity and mortality, and prolong intensive care and hospital stays.[6,7]

Postoperative infections are a common cause of postoperative death, although estimates of incidence vary widely. For example, organ space infection has reported mortality rates between 4% and 9%, and mortality ranges from 28% to 46% in those patients who develop septic shock.[8,9] However, many postoperative infections do not cause severe sepsis or septic shock, and the mode of death for such patients is unclear in many cases. The literature remains unclear about the overall rates of postoperative infection and subsequent outcomes.[10] Despite many studies focused on specific types of surgery, the relationships between different types of infection, surgical procedures, and other adverse outcomes are still not clearly defined.[11–13] Source control and antimicrobial therapy are the mainstays of treatment for postoperative infection. However, widespread use of broad-spectrum agents has led to increasing concerns about antimicrobial resistance, which in itself carries a significant socio-economic burden and a high mortality.[14,15]

There are few large epidemiological studies that explore potential risk factors for and outcomes of postoperative infection. We, therefore, report a prospective analysis of data collected during the multinational prospective cohort study called the Vascular Events in Non-cardiac Surgery Patients Cohort Evaluation (VISION) study to evaluate risk factors for postoperative infection, the incidence of different types of infection, and subsequent morbidity and mortality.

Methods

Study cohort

This is a prospective analysis of data collected during the VISION study. The methods of this prospective international observational cohort study have been described in detail elsewhere.[16] The study was approved by institutional review boards or ethics committees at each site, and was registered at https://www.clinicaltrials.gov/ (NCT00512109). Participants were aged 45 yr or older and underwent noncardiac surgery using general or regional anaesthesia, with at least an expected overnight hospital stay. The participants were approached for written informed consent before surgery. When this was not possible (e.g. before emergency surgery), written consent was sought within 24 h after surgery. In eight sites, where patients had no next of kin and were unable to provide consent before surgery (e.g. trauma surgery cases), a deferred consent process was used.

Data collection

The data set for these analyses includes all patients with outcome data restricted to 30 days after surgery. Detailed and standardised data were collected before surgery, during hospital stay until discharge, and then at 30 days after surgery. Where an infection occurred, additional data were collected. Full definitions of the variables included in this analysis are documented in the Supplementary information.

Outcome measures

The primary outcome measure was infection within 30 days after surgery. Diagnosis of infection was made by clinical evidence meeting CDC/NHSN Surveillance definitions for specific types of infections.[17] Infection outcomes were graded by severity using Clavien–Dindo classification (Supplementary file).[18,19] The secondary outcome measure was 30 day mortality. As an exploratory objective, we also evaluated the association between postoperative infection and myocardial injury after noncardiac surgery (MINS) (Supplementary file). To determine whether the presence of postoperative infection influenced the delivery of care, we used the following tertiary process measures: hospital length of stay and admission to intensive care.

Statistical analysis

A prospective statistical analysis plan was completed before commencing any analyses (Supplementary file). All analyses were performed using Stata 15.1 (StataCorp, TX, USA). Cases that were missing outcome data were excluded by list-wise deletion. We present descriptive statistics for baseline characteristics for patients with and without postoperative infection, and different types of infection. For patients who had more than one incidence of infection, we included only the event with the highest Clavien–Dindo severity grading to prevent duplication of patients included in analyses. A number of patients had more than one category selected for type of surgery. We excluded these in the main analyses to evaluate the impact of each type on infection risk. We then evaluated the impact of having more than one type of surgery separately. Categorical data are reported *n* (%). Normally distributed data are expressed as mean and standard deviation; non-normally distributed data are expressed as median and inter-quartile range.

We used univariable and multivariable logistic regression analyses to test for association between postoperative infection within 30 days after surgery and known risk factors for perioperative morbidity and mortality. Postoperative infection was the dependent variable, and the following risk factors were included as independent variables: age (<65, 65–85, and ≥85 yr), male sex, smoking status (never, ex-smoker, and current smoker), BMI (<18.5, 18.5–24.9, ≥25, and ≥30), comorbidities (current atrial fibrillation, previous atrial fibrillation, congestive heart failure, coronary artery disease, cerebral vascular event, peripheral vascular disease, hypertension, chronic obstructive pulmonary disease, diabetes, and active cancer), preoperative haemoglobin concentration, preoperative estimated glomerular filtration rate (eGFR) (<30, 30–44, 45–60, and >60 ml min^{-1}), urgency of surgery (<72 h; all other), type of surgery (vascular, general, thoracic, major urology or gynaecology, major orthopaedic, major neurosurgery, and low-risk surgery), surgical technique (endoscopic only and open), and type of anaesthetic (general, regional, and combined). Results of logistic regression analyses are presented as odds ratios (ORs) with 95% confidence intervals (CIs).

Secondary and tertiary analyses

To determine whether postoperative infection was associated with the secondary outcome measure defined as 30 day mortality, we conducted univariable and multivariable logistic regression analyses. We used postoperative infection within

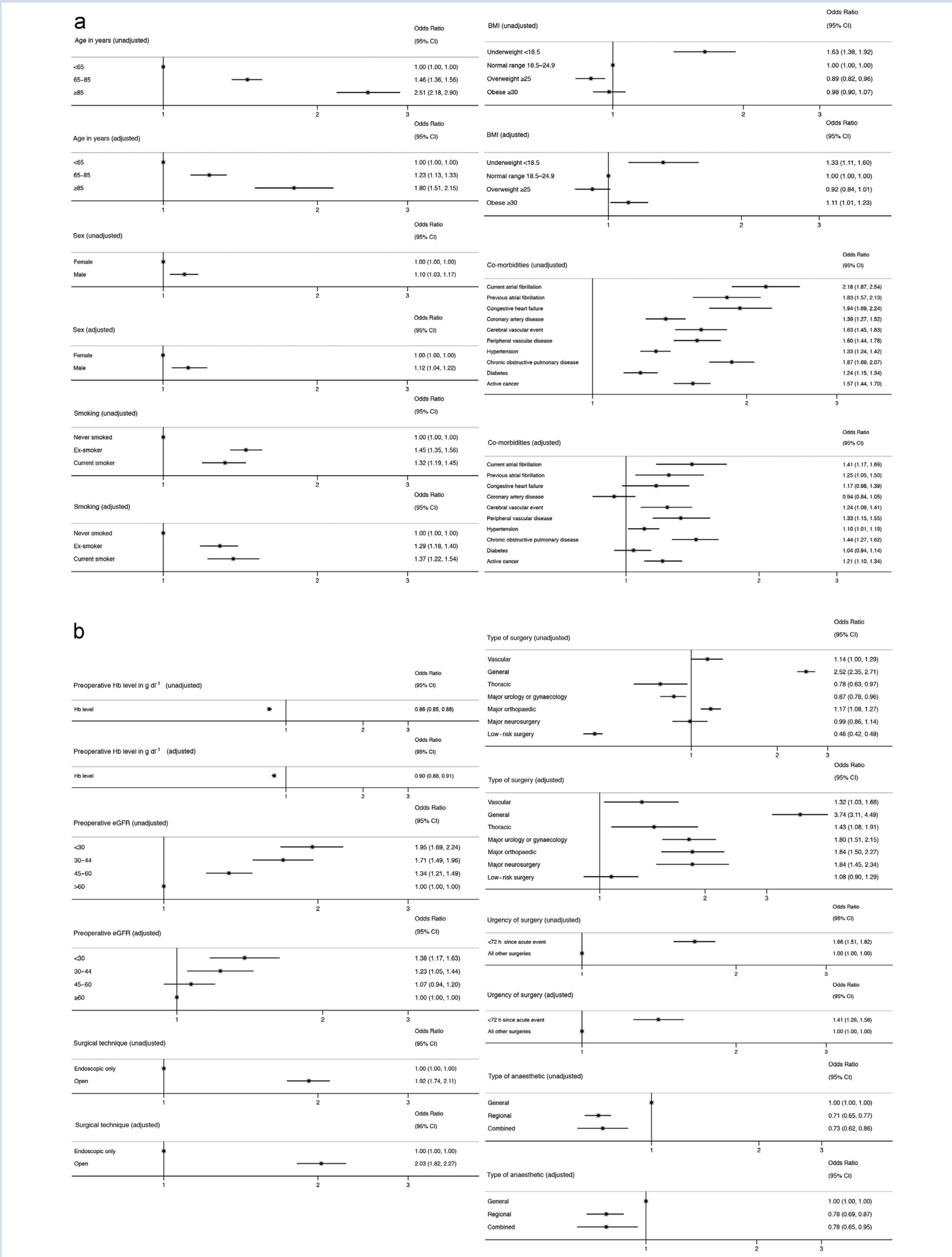

Fig 1. Forest plots showing the logarithmic odds ratios for postoperative infection at 30 days for different baseline characteristics. CI, confidence interval; eGFR, estimated glomerular filtration rate; Hb, haemoglobin. Current smoker defined as within 30 days before surgery. 1, BMI was calculated using height and weight values; height outside of range 1.40–2.00 m and weight outside of range 40–150 kg were excluded for biological plausibility and to eliminate extreme outliers. 2, Hb values greater than 20.0 g dl^{-1} were also excluded for biological plausibility and to eliminate extreme outliers. 3, Based on n=33 564 after excluding missing data. See Supplementary Table 3 for tabulated format.

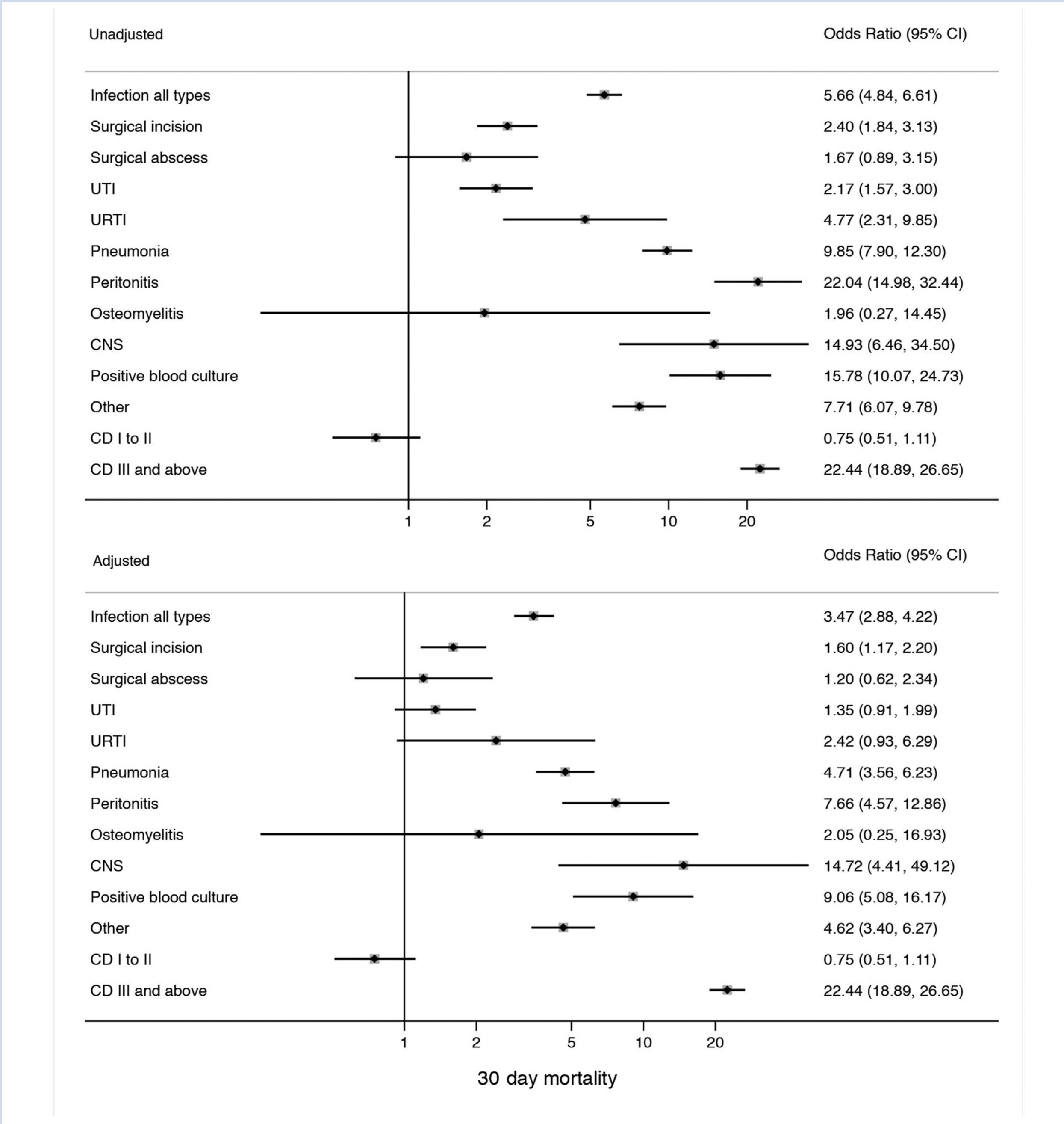

Fig 2. Forest plots showing the logarithmic odds ratios for mortality at 30 days for different surgical infection sites. Results from unadjusted and adjusted logistic regression analyses against no infection as the baseline. CD, Clavien–Dindo grade; CI, confidence interval; URTI, upper respiratory tract infection; UTI, urinary tract infection.

30 days after surgery as the independent variable and 30 day mortality as the dependent variable. Models were corrected for previously identified covariates in the primary analysis. The outcome variables were categorised by presence of infection, type of infection, and severity of infection. Forest plots for risk of 30 day mortality show the impact of each infection type using univariable analyses.

We performed time-to-event analysis and provide Kaplan–Meier plots for the relationship between postoperative infection and mortality. To determine whether the presence of postoperative infection influenced delivery of care, we used hospital length of stay as a tertiary process measure. We constructed univariable linear and logistic regression models with postoperative infection within 30 days after surgery as the independent variable and hospital length of stay as the dependent variable. The results are presented as beta coefficients with 95% CI for the linear regression model.

Results

A total of 40 037 patients were recruited to the VISION study between August 6, 2007 and January 11, 2011, of whom 40 004 had baseline data available for inclusion into this study. We excluded eight patients with missing outcome data for postoperative infection, leaving 39 996 for inclusion in the primary analyses (Supplementary Fig. 1: STROBE flow diagram). Postoperative infection within 30 days after surgery occurred in 3905 (9.8%) patients. The baseline characteristics for all patients and patients categorised by presence of postoperative infection are presented in Table 1. The majority of patients in our cohort underwent low-risk surgery (38.3%), general surgery (19.9%), and orthopaedic surgery (17.5%). The age of patients who developed postoperative infection was higher than those who did not. A higher proportion of patients with infection were current smokers or ex-smokers, had a comorbidity, lower preoperative haemoglobin, and lower preoperative eGFR. Patients who developed infection were more likely to have undergone urgent surgery and open surgical technique.

Baseline characteristics for patients categorised by type of infection are presented in Table 2. A number of patients developed more than one infection. There was a total of 5152 infection events among 3905 patients. Surgical site infection (n=1555), urinary tract infection (n=1086), and pneumonia (n=771) were the most common types of infection. More than one in five patients who had an infection (n=843; 21.6%) experienced more than one infection during their hospital stay; 590 patients had two, 164 patients had three, 49 patients had four, 30 patients had five, and 10 patients had more than five infections. Incidences listed as ‘other’ included infection types that did not fall under the other categories, such as gastroenteritis, methicillin-resistant *Staphylococcus aureus*, and iatrogenic line infections. A greater proportion of patients who developed upper respiratory tract infection had a current or ex-smoker history (73.0%) compared with other types of infection ranging from 13.3% (CNS) to 62.1% (peritonitis).

In patients who developed infection, 35.8% had undergone a general surgical procedure. General surgery was the surgical category with the highest rate of infection (1400/7950 [17.6%]). Patients who did not develop postoperative infection most commonly underwent low-risk surgery (35.9%). A number of patients had surgery that came under more than one category, 1099 patients had two (2.7%), and 66 patients had three (0.2%). These patients were excluded from our main analyses to test the effect different types of surgery had on development of infection. We then replaced the type of surgery variable with numbers of surgery performed, and showed that having more than one category of surgery carried higher risk of postoperative infection compared with having only one category (Supplementary Table 1). Distribution of different types of infection varied between different types of surgery. The majority of patients who developed infection after general surgery had incision site (41.1%) and urinary tract (22.0%) infections.

Development of postoperative infection was associated with increasing age (≥85 yr, OR: 1.80 [1.51–2.15]; P<0.01); 65–85 yr, OR: 1.23 [1.13–1.33]; P<0.01; both compared with <65 yr), male sex (OR: 1.12 [1.04–1.22]; P<0.01), smoking history (current smoker, OR: 1.37 [1.22–1.54]; P<0.01; ex-smoker, OR: 1.29 [1.18–1.40]; P<0.01). In this cohort, patients with a higher preoperative haemoglobin concentrations had lower rates of postoperative infection (OR: 0.90 [0.88–0.91] g^{-1} unit rise; P<0.01). Patients at the extremes of BMI range had higher rates of postoperative infection compared with those within normal range (BMI 18.5–24.9), underweight (BMI <18.5) (OR: 1.33 [1.11–1.60]; P<0.01), and obese (≥30) (OR: 1.11 [1.01–1.23]; P=0.03). Rates of infection were higher in patients with lower preoperative eGFR <30 ml min^{-1} (OR: 1.38 [1.17–1.63]; P<0.01) or 30–44 ml min^{-1} (OR: 1.23 [1.05–1.44]; P=0.01) compared with >60 ml min^{-1} (See Fig. 1).

Rates of postoperative infection were higher in patients who had urgent surgery within 72 h of acute event defined as an acute illness admission (OR: 1.41 [1.26–1.58]; P<0.01), and an open surgical technique (OR: 2.03 [1.82–2.27]; P<0.01). Compared with using general anaesthesia, regional anaesthesia was associated with lower postoperative infection rates both used alone (OR: 0.78 [0.69–0.87]; P<0.01) or in a combined regional and general anaesthesia approach (OR: 0.78 [0.65–0.95]; P=0.01) (See Fig. 2).

Secondary analyses

Patients who developed postoperative infection had a higher 30 day mortality rate (OR: 3.47 [2.82–4.22]; P<0.01) (Fig. 3). When categorised by infection type, statistically significant associations were observed for all types apart from surgical abscess, urinary tract infection, upper respiratory tract infection, and osteomyelitis. The highest mortality risks were with CNS infections (OR: 14.72 [4.41–49.12]; P<0.01) and positive blood culture without a clear primary source (OR: 9.06 [5.08–16.17]; P<0.01). Severe infection within Clavien–Dindo Grading III and above was associated with higher mortality (OR: 13.55 [10.80–17.01]; P<0.01). In the adjusted analyses, less severe infection within Clavien–Dindo Grading I to II had lower mortality rates compared with no infection (OR: 0.51 [0.33–0.79]; P<0.01). Presence of postoperative infection was associated with longer hospital length of stay (12.75 days [12.39–13.12]; P<0.01).

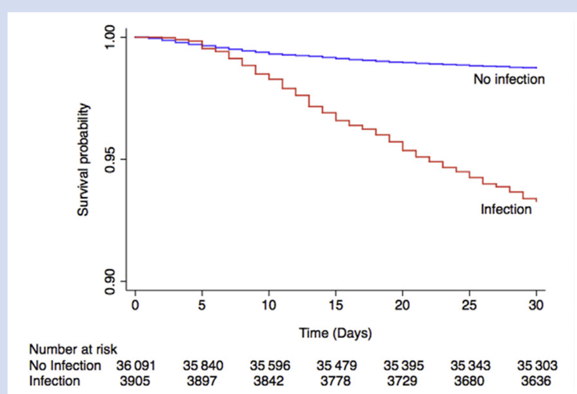

Fig 3. Kaplan–Meier 30-day survival curves in patients who developed postoperative infection and those who did not. Log rank P<0.001.

Table 1 Baseline characteristics for all patients, categorised by infection status. All data presented as *n* (%) unless otherwise specified; total *n* for variables with missing data listed as [*n*]. eGFR, estimated glomerular filtration rate; Hb, haemoglobin; IQR, inter-quartile range; SD, standard deviation. Current smoker defined as within 30 days before surgery. *Eight patients had missing infection outcome. †BMI was calculated using height and weight values; height outside of range 1.40–2.00 m and weight outside of range 40–150 kg were excluded for biological plausibility and to eliminate extreme outliers. ‡Hb values greater than 20.0 g dl^{-1} were also excluded for biological plausibility and to eliminate extreme outliers. ¶1165 patients had surgery, which came under more than one category: 1099 had two and 66 had three.

	All patients (*n*=40 004)	No infection* (*n*=36 091)	Infection* (*n*=3905)
Age (yr)			
Mean (SD)	64.0 (11.3)	63.7 (11.2)	66.8 (11.9)
Median (IQR)	63.2 (54.8–72.5)	62.9 (54.7–72.0)	66.4 (57.4–75.9)
<65	22 141 (55.3)	20 350 (56.4)	1786 (45.7)
65–85	16 434 (41.1)	14 570 (40.4)	1861 (47.7)
≥85	1429 (3.6)	1171 (3.2)	258 (6.6)
Sex			
Male	20 127 (50.3)	18 075 (50.1)	2047 (52.4)
Smoking status			
Never smoked	21 195 (53.8)	19 422 (54.6)	1766 (46.1)
Ex-smoker	12 591 (32.0)	11 124 (31.3)	1467 (38.3)
Current smoker	5615 (14.3)	5015 (14.1)	600 (15.7)
	[39 401]	[35 561]	[3833]
BMI†			
Underweight: <18.5	1227 (3.3)	1042 (3.1)	185 (5.1)
Normal range: 18.5–24.9	13 327 (35.4)	12 013 (35.3)	1311 (36.3)
Overweight: ≥25	13 093 (34.8)	11 936 (35.1)	1154 (31.9)
Obese: ≥30	9976 (26.5)	9012 (26.5)	964 (26.7)
	[37 623]	[34 003]	[3614]
Co-morbidities			
Current atrial fibrillation	1123 (2.8)	914 (2.5)	209 (5.4)
	[39 876]	[35 980]	[3889]
Previous atrial fibrillation	1262 (3.2)	1058 (2.9)	204 (5.3)
	[39 827]	[35 943]	[3878]
Congestive heart failure	1424 (3.6)	1182 (3.3)	241 (6.2)
	[39 870]	[35 973]	[3890]
Coronary artery disease	5159 (12.9)	4512 (12.5)	646 (16.6)
	[39 876]	[35 979]	[3890]
Cerebral vascular event	2582 (6.5)	2206 (6.1)	375 (9.6)
Peripheral vascular disease	3203 (8.0)	2748 (7.6)	455 (11.7)
Hypertension	20 152 (50.5)	17 933 (49.8)	2217 (56.9)
	[39 917]	[36 013]	[3897]
Chronic obstructive pulmonary disease	3165 (7.9)	2658 (7.4)	506 (13.0)
Diabetes mellitus	8332 (20.9)	7383 (20.5)	947 (24.3)
	[39 905]	[36 001]	[3897]
Active cancer	6168 (15.4)	5333 (14.8)	834 (21.4)
	[40 002]	[36 091]	[3903]
Preoperative Hb concentration (g dl^{-1})‡			
Mean (SD)	13.0 (2.0)	13.1 (1.9)	12.5 (2.1)
Median (IQR)	13.2 (11.9–14.3)	13.2 (12.0–14.4)	12.7 (11.0–14.0)
	[38 614]	[34 769]	[3841]
Preoperative eGFR			
<30	1515 (4.1)	1265 (3.8)	250 (6.7)
30–44	1774 (4.8)	1512 (4.5)	262 (7.0)
45–60	3707 (9.9)	3262 (9.7)	444 (11.9)
>60	30 294 (81.2)	27 499 (82.0)	2792 (74.5)
	[37 290]	[33 538]	[3748]
Urgency of surgery			
<72 h since acute event	4189 (10.5)	3585 (9.9)	604 (15.5)
All other surgeries	35 815 (89.5)	32 506 (90.1)	3301 (84.5)
Type of surgery			
Vascular	2642 (6.6)	2354 (6.5)	287 (7.4)
	[39 997]	[36 085]	[3904]
General	7950 (19.9)	6549 (18.2)	1400 (35.9)
Thoracic	1165 (2.9)	1074 (3.0)	91 (2.3)
Major urology or gynaecology	4827 (12.1)	4407 (12.2)	420 (10.8)
Major orthopaedic	6982 (17.5)	6216 (17.2)	764 (19.6)
Major neurosurgery	2341 (5.9)	2114 (5.9)	227 (5.8)
Low-risk surgery	15 308 (38.3)	14 394 (39.9)	910 (23.3)
Surgical technique			
Endoscopic only	8683 (21.7)	8167 (22.6)	516 (13.2)
Open	31 288 (78.3)	27 901 (77.4)	3381 (86.8)

Continued

Table 1 Continued

	All patients (n=40 004)	No infection* (n=36 091)	Infection* (n=3905)
	[39 971]	[36 066]	[3899]
Type of anaesthetic			
General	27 069 (69.3)	24 164 (68.6)	2903 (75.4)
Regional	10 005 (25.6)	9218 (26.2)	786 (20.4)
Combined	1997 (5.1)	1836 (5.2)	161 (4.2)
	[39 071]	[35 218]	[3850]

Discussion

The principal finding of this analysis is that 1 in 10 patients developed an infection within 30 days of surgery, and 1 in 5 of these patients developed multiple infections; 30 day mortality rates were more than three times greater for surgical patients who experienced an infection. Surgical site infection, urinary tract infection, and pneumonia were the most frequent events. Infection was most common among patients recovering from general surgery and those who had general anaesthesia. This could be related to the risk profile of surgery or could be causative from increased infective risks after general anaesthesia, including procedures, such as urinary catheterisation. The frequency with which different types of infection occur varied between different surgical specialties. Having multiple surgical categories also increased risk of postoperative infection. Multi-specialty involvement may imply a higher degree of surgical complexity, and therefore a higher risk of postoperative complications.

The strongest risk factors for infection were older age, smoking history, and co-morbid disease. This is important because the number of older patients undergoing surgery continues to rise, with one in five people in England aged ≥75 yr undergoing surgery in 2015.[20] Patients who were either underweight or obese experienced more infections, as did patients with anaemia and impaired renal function. There have been a number of previously published studies measuring postoperative infection rates and outcomes. Most of them are within single surgical specialties or even specific procedures, and focusing on reporting one type of infection only. Mostly commonly, these have been surgical site infection, urinary tract infections, and pneumonia because these infections are most frequent, with orthopaedic surgery being most often evaluated.[21,22] The most extensively reported has been surgical site infection with rates ranging from 3% (multiple surgical categories combined; cost-analysis study) to 36% (otolaryngology; cohort study).[23,24]

Our findings are consistent with identifying previously reported risk factors. Various pathophysiological consequences of smoking have been proposed to explain the increased development of infection, particularly surgical site infection. These include impaired early host cellular defences reducing the ability to control bacterial wound contamination and prolonged tissue acidosis.[25] For orthopaedic surgery joint replacement, evidence to support preoperative modification of risk factors is strongest for diabetes and smoking.[26] Malnutrition has been thought to impair wound healing and prolong inflammation via mechanisms such as impaired fibroblast proliferation and collagen synthesis.[27] Patients undergoing primary hip and knee arthroplasty have previously had improved perioperative outcomes after neuraxial *vs* general anaesthesia, including reduced infections.[28] Similarly, general anaesthesia for caesarean sections was also associated with a higher incidence of surgical site infection compared with neuraxial anaesthesia.[29] Furthermore, our findings support those from a meta-analysis of joint arthroplasty procedures showing lower rates of surgical site infection after neuraxial anaesthesia.[30] Conversely, the effects of co-morbidities, such as coronary artery disease, hypertension, and diabetes, have not been replicated following our adjusted analyses.[31,32] This may reflect the fact that the underlying mechanisms behind these co-morbidities may interact and therefore not demonstrate an effect because of loss of statistical power. The finding of less severe infection within Clavien–Dindo Grading I to II on adjusted analyses having lower mortality rates compared with no infection is a likely artifact because of the low-risk nature of patient groups that have Clavien–Dindo I and II infection compared with the high-risk nature of those who develop Grade III and above infection. These patient groups are likely to have additional co-morbidities and confounding risk factors not taken into account in adjusted analyses.

Development of postoperative infection was associated with mortality, particularly when patients developed CNS infections or peritonitis. This supports multiple studies that have previously reported associations between postoperative infection and mortality across surgical specialties.[33] The increased risk seen from our results is consistent with a previous study reporting that 3 year mortality after radical cystectomy is 10.2% amongst patients developing surgical site infection compared with only 4.2% in non-infected patients.[34]

The strengths of our analyses are that we evaluated risk factors and patterns of development of various postoperative infections across a range of surgical specialties within a single large cohort. Our multicentre study design and the large varied population make our results broadly generalisable to patients having noncardiac surgery. The statistical analyses were prespecified and multivariable models used to correct for confounding factors. However, the limitation of our study is the observational design. Many important factors were prospectively recorded, but there will be a degree of unmeasured confounding, for example between cardiovascular risk factors, and it is difficult to estimate how residual confounding may have altered our conclusions. We excluded patients with multiple infection events and patients categorised into more than one type of surgery when analysing the effect of each variable. Looking specifically between different types of infections resulted in smaller sample sizes in some categories, and so we have not assessed whether certain risk factors conferred a greater risk of various types of postoperative infection within surgical specialties. The true associations with individual risk factors remain unclear because of likely interactions between risk factors both from residual confounding and potential effect modification. These may include, smoking history and co-morbidities such as coronary artery disease and diabetes, or reduced renal function and preoperative anaemia. Limitations of the data set include

Table 2 Baseline characteristics for patients with infection, categorised by infection type. All data presented as *n* (%) unless otherwise specified; total *n* for variables with missing data listed as [*n*]. Hb, haemoglobin; IQR, inter-quartile range; SD, standard deviation; URTI, upper respiratory tract infection; UTI, urinary tract infection. Current smoker defined as within 30 days before surgery. *BMI was calculated using height and weight values; height outside of range 1.40–2.00 m and weight outside of range 40–150 kg were excluded for biological plausibility and to eliminate extreme outliers. Note that a number of patients had incidences of more than one infection: 590 had two, 164 had three, 49 had four, 30 had five, three had six, three had seven, three had eight, and one had nine. Only the infection event with the highest severity grading was included for each patient. ‡1165 patients had surgery, which came under more than one category: 1099 had two and 66 had three. An extended table, including co-morbidities, preoperative Hb concentration, estimated glomerular filtration rate, and surgical technique, is included in the Supplementary material Table 2.

	Surgical incision (*n*=1555)	Surgical abscess (*n*=340)	UTI (*n*=1086)	URTI (*n*=101)	Pneumonia (*n*=771)	Peritonitis (*n*=134)	Osteomyelitis (*n*=29)	CNS (*n*=33)	Blood culture (*n*=115)	Other (*n*=761)
Age (yr)										
Mean (SD)	64.9 (11.4)	63.7 (10.9)	70.0 (12.4)	68.2 (10.9)	63.9 (11.3)	66.2 (11.7)	63.4 (13.4)	56.9 (9.5)	65.9 (11.9)	66.5 (11.8)
Median (IQR)	64.5 (55.8–73.6)	63.2 (54.9–72.3)	71.0 (60.9–79.5)	67.8 (61.3–76.4)	63.1 (54.8–72.4)	66.5 (57.4–74.9)	61.2 (51.0–75.6)	56.5 (49.1–60.3)	65.6 (55.7–74.9)	65.9 (57.4–74.7)
<65	799 (51.4)	196 (57.7)	378 (34.8)	40 (39.6)	310 (40.2)	59 (44.0)	19 (65.5)	27 (81.8)	55 (47.8)	351 (46.1)
65–85	702 (45.1)	135 (39.7)	583 (53.7)	54 (53.5)	403 (52.3)	69 (51.5)	8 (27.6)	6 (18.2)	53 (46.1)	365 (48.0)
≥85	54 (3.5)	9 (2.7)	125 (11.5)	7 (6.9)	58 (7.5)	6 (4.5)	2 (6.9)	0 (0)	7 (6.1)	45 (5.9)
Sex										
Male	836 (53.8)	188 (55.3)	422 (38.9)	70 (69.3)	474 (61.5)	87 (64.9)	22 (75.9)	14 (42.4)	69 (60.0)	435 (57.2)
Smoking status										
Never smoked	703 (46.0)	155 (46.0)	547 (51.1)	26 (27.1)	307 (41.0)	50 (37.9)	14 (50.0)	26 (86.7)	55 (49.6)	315 (42.3)
Ex-smoker	573 (37.5)	97 (38.3)	408 (38.1)	47 (49.0)	302 (40.4)	56 (42.4)	10 (35.7)	3 (10.0)	39 (35.1)	303 (40.7)
Current smoker	254 (16.6)	53 (15.7)	115 (10.8)	23 (24.0)	139 (18.6)	26 (19.7)	4 (14.3)	1 (3.3)	17 (15.3)	126 (16.9)
	[1530]	[337]	[1070]	[96]	[748]	[132]	[28]	[30]	[111]	[744]
BMI*										
Underweight: <18.5	65 (4.5)	12 (3.7)	45 (4.5)	2 (2.2)	66 (9.3)	7 (5.6)	0 (0)	0 (0)	3 (2.8)	39 (5.6)
Normal range: 18.5–24.9	478 (33.1)	138 (42.6)	364 (36.2)	34 (37.0)	285 (40.2)	48 (38.1)	8 (32.0)	11 (50.0)	37 (34.3)	248 (35.4)
Overweight: ≥25	445 (30.8)	95 (29.3)	346 (34.4)	30 (32.6)	203 (28.6)	41 (32.5)	9 (36.0)	4 (18.2)	44 (40.7)	228 (32.5)
Obese: ≥30	456 (31.6)	79 (24.4)	250 (24.9)	26 (28.3)	155 (21.9)	30 (23.8)	8 (32.0)	7 (31.8)	24 (22.2)	186 (26.5)
	[1444]	[324]	[1005]	[92]	[709]	[126]	[25]	[22]	[108]	[701]
Urgency of surgery										
<72 h since acute event	203 (13.1)	35 (10.3)	191 (17.6)	9 (8.9)	167 (21.7)	39 (29.1)	4 (13.8)	9 (27.3)	15 (13.0)	115 (15.1)
All other surgeries	1352 (87.0)	305 (89.7)	895 (82.4)	92 (91.1)	604 (78.3)	95 (70.9)	25 (86.2)	24 (72.7)	100 (87.0)	646 (84.9)
	[1555]	[340]	[1086]	[101]	[771]	[134]	[29]	[33]	[115]	[761]
Type of surgery‡										
Vascular	116 (7.5) [1555]	9 (2.7) [339]	57 (5.3) [1086]	11 (10.9) [101]	65 (8.4) [771]	3 (2.2) [134]	1 (3.5) [29]	1 (3.0) [33]	10 (8.7) [115]	81 (10.6) [761]
General	576 (37.0) [1555]	221 (65.0) [340]	308 (28.4) [1086]	43 (42.6) [101]	292 (37.9) [771]	111 (82.8) [134]	2 (6.9) [29]	1 (3.0) [33]	41 (35.7) [115]	282 (37.1) [761]
Thoracic	20 (1.3) [1555]	3 (0.9) [340]	13 (1.2) [1086]	2 (2.0) [101]	54 (7.0) [771]	1 (0.8) [134]	0 (0) [29]	0 (0) [33]	5 (4.4) [115]	22 (2.9) [761]
Major urology or gynaecology	141 (9.1) [1555]	39 (11.5) [340]	200 (18.4) [1086]	5 (5.0) [101]	56 (7.3) [771]	5 (3.7) [134]	0 (0) [29]	0 (0) [33]	9 (7.8) [115]	68 (8.9) [761]
Major orthopaedic	307 (19.7) [1555]	21 (6.2) [340]	278 (25.6) [1086]	11 (10.9) [101]	126 (16.3) [771]	0 (0) [134]	11 (37.9) [29]	2 (6.1) [33]	19 (16.5) [115]	134 (17.6) [761]

Major neurosurgery	56 (3.6)	11 (3.2)	81 (7.5)	12 (11.9)	72 (9.3)	1 (0.8)	2 (6.9)	13 (39.4)	8 (7.0)	44 (5.8)
	[1555]	[340]	[1086]	[101]	[771]	[134]	[29]	[33]	[115]	[761]
Low-risk surgery	415 (26.7)	56 (16.5)	234 (21.6)	19 (18.8)	145 (18.8)	16 (11.9)	13 (44.8)	18 (54.6)	24 (20.9)	154 (20.2)
	[1555]	[340]	[1086]	[101]	[771]	[134]	[29]	[33]	[115]	[761]
Type of anaesthetic										
General	1118 (73.2)	291 (86.9)	773 (71.8)	83 (82.2)	630 (82.8)	125 (94.0)	12 (42.9)	33 (100)	97 (84.4)	591 (78.9)
Regional	343 (22.5)	33 (9.9)	265 (24.6)	15 (14.9)	103 (13.5)	5 (3.8)	13 (46.4)	0 (0)	12 (10.4)	127 (17.0)
Combined	67 (4.4)	11 (3.3)	38 (3.5)	3 (3.0)	28 (3.7)	3 (2.3)	3 (10.7)	0 (0)	6 (5.2)	31 (4.1)
	[1528]	[335]	[1076]	[101]	[761]	[133]	[28]	[33]	[115]	[749]

incomplete data and lack of variables, such as aggregated scoring systems, to measure the burden of co-morbidities, frailty, socio-economic status, and elective *vs* emergency surgery. Surgical categories were also not able to be categorised by level of contamination.

Conclusions

We have described postoperative infection rates in a large international cohort of patients undergoing noncardiac surgery. This has allowed us to provide accurate and generalisable estimates of the key risk factors for infection and subsequent patient outcomes. Infection is a common and important complication of noncardiac surgery, which is associated with high mortality. We have also shown an association with MINS, but are unable to explore the underlying cause of this. New treatment approaches are needed to prevent infection, which rely less on antimicrobial drugs and focus on better prevention strategies warranting further research. The risks of infection should be discussed with patients before surgery.

Authors' contributions

Study design: all authors
Statistical analysis: YIW, AP
Drafting: YIW, RMP
Critical review/approval of final manuscript: all authors

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Declarations of interest

RMP holds research grants and has given lectures or performed consultancy work for Nestlé Health Sciences, B. Braun, Medtronic, GlaxoSmithKline, Intersurgical, and Edwards Lifesciences, and is a member of the associate editorial board of the *British Journal of Anaesthesia*. GLA is a member of the editorial advisory board for *Intensive Care Medicine Experimental*, editor for *British Journal of Anaesthesia*, and has undertaken consultancy work for GlaxoSmithKline. ED was co-applicant on investigator-initiated research grants received from Roche Diagnostics and Abbott Diagnostics. All other authors declare no conflicts of interests. PJD is part of a group that has a policy of not accepting honoraria or other payments from industry for their own personal financial gain. Members of this group accept honoraria or other payments from industry to support research endeavours and for reimbursement of costs to participate in meetings, such as scientific or advisory committee meetings. Based on study questions PJD originated and grants he wrote, he has received grants from Abbott Diagnostics, AstraZeneca, Bayer, Boehringer Ingelheim, Bristol Myers Squibb, Covidien, Philips Healthcare, Stryker, and Roche Diagnostics. PJD has also participated in an advisory boarding meeting for GlaxoSmithKline and an expert panel meeting for AstraZeneca.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bja.2020.03.027.

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