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A bundle of infection control measures reduces postoperative sternal wound infection due to *Staphylococcus aureus* but not Gram-negative bacteria: a retrospective analysis of 6903 patient episodes

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SUMMARY

Background: Prevention of cardiac surgical site infection has largely focused on reducing infection due to *Staphylococcus aureus*, although other bacteria also play an important role in this complication.
Aim: To assess the impact of an evolving infection control programme on the incidence of sternal wound infection (SWI), and the changing incidence of non-staphylococcal infections.
Methods: A retrospective cohort study of all patients who underwent primary sternotomy at a single UK centre between September 2010 and May 2018 was undertaken. Data were collated from the 2 years preceding the stepwise introduction of a broad-ranging infection control programme, including *S. aureus* decolonization.
Findings: In total, 6903 primary sternotomies were performed, of which 2.6% (N=178) were complicated by SWI. Gram-negative bacteria (GNB) and *S. aureus* were most commonly identified as causative pathogens (45.5% and 30.3%, respectively). Following programme introduction, there was a reduction in the rate of SWI from 3.9 to 1.8 cases/100 patients/month. This was mainly due to a sustained reduction in cases of *S. aureus* infection, with no discernible impact on GNB. Multi-variable logistic regression analysis identified coronary artery bypass grafting, procedural urgency, and procedures performed in the third quarter of the calendar year (July to September) as independent risk factors for postoperative infection.
Conclusion: A multi-faceted infection control programme was successful at reducing the rate of SWI, primarily due to a reduction in *S. aureus* infections. GNB also play an important role in SWI, and traditional preventative measures fail to address these. Future

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intervention and impact assessments should consider GNB infections when measuring effectiveness.

Introduction

Sternal wound infection (SWI) continues to be a serious complication of cardiac surgery, and is associated with a complicated and prolonged postoperative recovery and high mortality. Reported rates of postoperative SWI vary by centre, with recent reports ranging from 0.79% to 4.1% [1–3]. Prevention of surgical site infection (SSI) often involves a bundled approach including skin/hair preparations, topical antiseptic agents, peri-operative prophylactic antibiotics, maintenance of peri-operative homeostasis, and postoperative wound care [4]. The majority of these interventions focus on the operative site specifically, and try to reduce infection principally by targeting common skin commensals such as *Staphylococcus aureus*. However, Gram-negative bacteria (GNB) also play an important role in SWI, and are frequently associated with more complex infections requiring additional surgical management and prolonged courses of broad-spectrum antibiotics [5].

As there is an increasing focus on antimicrobial stewardship with rising global rates of antimicrobial resistance, there is an urgent need to develop preventative strategies to address non-staphylococcal causes of SSI to limit antimicrobial requirement and exposure in these vulnerable populations. The primary objective of this work was to assess the impact of an infection control programme on the incidence of SWI, and describe the changing microbiological profile associated with these interventions. Secondary objectives included characterizing the infected and non-infected cohorts in more detail, with the aim of identifying further modifiable risk factors.

Methods

Setting and patients

This retrospective cohort study was performed at Sheffield Teaching Hospitals (STH), a tertiary cardiothoracic referral centre in the UK. All patients who had undergone primary median sternotomy between 1st September 2010 and 1st June 2018 were eligible for inclusion, and were identified by reviewing registry data. Exclusion criteria included sternotomy not performed by the local cardiothoracic team, and surgery performed outside of the operating theatres. Each case was only included once regardless of the number of further operative procedures required, and SWI had to occur as a complication of the primary procedure. Further data including microbiological results and clinical observations were extracted from electronic databases. The study was approved as a service evaluation without need for NHS Research Ethics Committee review by the Clinical Effectiveness Unit at STH, who provide oversight on research and data governance at STH.

Case definitions

A modified version of the US Centers for Disease Control and Prevention's SSI criteria was used to define SWI, with the time limit extended to 180 days in order to capture delayed infections [6]. All cases required documentation of a clinical diagnosis of SSI. Superficial SWI was confined to the skin or subcutaneous tissue of the incision site with an organism isolated from a superficial wound swab and/or blood culture. Deep SWI cases involved the deeper tissues with an organism isolated from a bone, tissue or pus sample and/or blood culture. If deep samples were culture negative, cases were still included if the surgeon reported compatible intra-operative findings.

Sample collection and microbiological procedures

Samples for microbiological analysis were obtained at the clinician's discretion within the hospital or the community following discharge. Sampling and subsequent microbiological analysis were performed in accordance with national standards [7–10]. Organism identification was based on morphological appearance, phenotypic tests and matrix-assisted laser desorption/ionization-time of flight analysis (MALDI Biotyper, Bruker, Germany). The causative pathogen(s) was the isolate(s) cultured from the earliest relevant clinical sample and any other isolates obtained in the following 7 days (later isolates were felt to be more reflective of evolving flora associated with antibiotic exposure). Cases were labelled 'mixed' if more than one pathogen was isolated.

Outcome measures and endpoints

The date of infection was recorded as the date of the first significant culture result, or first clinical documentation of SWI if culture negative. Procedure-related outcome measures included death and hospital re-admission (to the operating hospital alone) within 12 months of the initial procedure. Infection outcome measures were determined by the last available clinical assessment within a 6-month period from the date of infection, and included cured (full resolution), improved (symptoms improved but unresolved infection), ongoing (no improvement), unknown and death. Patients who were lost to follow-up were still included in the overall analysis.

Statistical analysis

Risk factors associated with SWI were identified using univariate testing (Pearson's Chi-squared test, Fisher's exact test or Mann–Whitney *U*-test) prior to selection for inclusion in regression analysis. Following this, multi-variable logistic regression [with 95% confidence intervals (CI)] was used to assess which features were associated with SWI. An initial model was formed using the patient and operative factors, with step-wise removal of non-significant ($P\geq0.05$) variables. Analysis was repeated with the inclusion of infection control measure time periods. All analyses were performed using R Version 4.0.3 and RStudio Version 1.3 [11,12].

Results

Patient and operation characteristics

Over the study period (7 years and 8 months), 6903 primary sternotomies were performed. The median patient age was 68 (range 16–91) years and most patients were male (4953/6903, 71.8%). The median length of stay was 10 [interquartile range (IQR) 7-18] days and most patients survived to discharge (6723/6903, 97.4%). Multiple different surgical procedures were performed, frequently in combination, including coronary artery bypass grafting (CABG) (4111/6903, 59.6%), procedures involving cardiac valves (3308/6,903 47.9%) or the aorta (419/6903, 6.1%), and miscellaneous other procedures (853/6903, 12.4%; Table I). The most common procedures were CABG alone (3175/6903, 46.0%), valve procedures alone (1830/6903, 26.5%), and combined CABG and valve procedures (651/6903, 9.4%). Overall, 68.9% (4759/6903) procedures were elective, with the remainder classified as urgent (required surgery before discharge after an acute hospital admission; 1989/6903, 28.8%), emergency (operation required before the beginning of the next working day; 145/6903, 2.1%) or salvage (requiring cardiopulmonary resuscitation en route to the operating theatre or prior to induction of anaesthesia; 10/6903, 0.1%).

Sternal wound infection

SWI complicated 2.6% (178/6903) of procedures performed. The majority (167/178, 93.8%) of SWI were diagnosed within the first 90 postoperative days. For patients with SWI, the length of hospital admission and number of further surgical procedures during the first hospital episode were greater compared with patients who remained uninfected (Table I). Of the SWI identified, 50% (89/178) were classified as deep (Table II). Superficial infections were diagnosed earlier and less frequently required further surgical procedures during the initial admission compared with deep infections.

SWI caused by a single attributable Gram-negative (GN) pathogen was the most common finding (61/178, 34.3%), followed by infection caused by *S. aureus* alone (46/178, 25.8%) or mixed infection (28/178, 15.7%; Table II). GN pathogens were isolated either alone or in combination in 45.5% (81/178) of cases, with *S. aureus* isolated in 30.3% of cases (54/178). Specific GN organisms included *Klebsiella* spp. (N=28), *Escherichia coli* (N=19), *Enterobacter* spp. (N=18), *Pseudomonas* spp. (N=18), *Proteus* spp. (N=14) and miscellaneous others (N=23). Where tested, antibiotic resistance was detected at the following rates: co-amoxiclav, 42.9% (39/91); cefuroxime, 20.0% (20/100); gentamicin, 1.7% (2/118); and ciprofloxacin, 0.8% (1/118). An AmpC beta-lactamase was detected in 22.0% (26/118) of GN isolates. Just over one-fifth of patients had concurrent bacteraemia (38/178, 21.3%), and it was more commonly identified in patients with deep SWI.

Patient outcomes

Half of the patients with confirmed SWI were re-admitted to the study centre at least once, compared with 19.2% in the non-SWI group (Table I). Data on the specific reason for re-admission were not available. Re-admission was more common amongst those with deep SWI compared with superficial SWI (Table II). All-cause mortality was higher in those with SWI compared with uninfected patients, including death during the first hospitalization episode and the following 12 months.

Table I

Baseline, operative and postoperative characteristics for all patients, subdivided into sternal wound infection (SWI) and no SWI

	SWI	Non-SWI	*P*-value
Total, % (*N*)	2.6 (178)	97.4 (6725)	–
Age, years, median (IQR)	69.0 (60–76)	68.0 (60–75)	0.74
Male, % (*N*)	69.1 (123)	71.8 (4830)	0.48
EuroSCORE, median (IQR)	4.6 (2.5–8.9)	4.2 (2.1–8.1)	0.09
Operation type, % (*N*)			
Isolated CABG	64.0 (114)	45.5 (3062)	<0.001
Isolated valve procedure	11.8 (21)	26.9 (1809)	<0.001
Isolated other procedure	0.6 (1)	3.2 (212)	0.05
Isolated aortic procedure	1.1 (2)	1.4 (97)	1.0
CABG and valve	10.1 (18)	9.4 (633)	0.85
Other combinations	12.4 (22)	13.6 (912)	0.73
Operative urgency, % (*N*)			
Elective	54.5 (97)	69.3 (4662)	<0.001
Urgent	43.8 (78)	28.4 (1911)	<0.001
Emergency	1.7 (3)	2.1 (142)	1.0
Salvage	0 (0)	0.1 (10)	1.0
Return to theatre during primary admission, % (*N*)	28.1 (50)	4.5 (300)	<0.001
Length of stay, days, median (IQR)	22.0 (30.8)	10.0 (10)	<0.001
Alive at discharge, % (*N*)	93.3 (166)	97.5 (6557)	0.001
Re-admission within 12 months of primary sternotomy, % (*N*)	50.0 (89)	19.2 (1293)	<0.001
Death within 12 months of primary sternotomy, % (*N*)	11.8 (21)	5.0 (337)	<0.001
One-year survival rate, %	88.2	95.0	<0.001

IQR, interquartile range; EuroSCORE, European System for Cardiac Operative Risk Evaluation; CABG, coronary artery bypass grafting.

Table II
Infection-related characteristics and outcomes for all cases of sternal wound infection (SWI), subdivided into superficial and deep SWI

	Superficial SWI	Deep SWI	*P*-value
Total, % (*N*)	50.0 (89)	50.0 (89)	–
Time to diagnosis, days, median (IQR)	15 (24)	24 (30)	0.001
Infections occurring 90–180 days postoperatively, % (*N*)	1.1 (1)	11.2 (10)	0.13
Microbiology, % (*N*)			
Staphylococcus aureus alone	31.5 (28)	19.1 (17)	0.12
MRSA	0 (0)	1.1 (1)	–
GNB alone	42.7 (38)	25.8 (23)	0.03
Mixed	16.9 (15)	14.6 (13)	0.84
Other	9.0 (8)	13.5 (12)	0.48
Culture negative	0 (0)	27.0 (24)	<0.001
Total including *Staphylococcus aureus*	38.2 (34)	22.5 (20)	0.03
Total including GNB	56.2 (50)	34.8 (31)	0.007
Bacteraemia, % (*N*)	12.4 (11)	30.3 (27)	0.007
Infection-related outcomes (within 6 months of diagnosis), % (*N*)			
Cured	57.3 (51)	34.8 (31)	0.004
Improved	29.2 (26)	36.0 (32)	0.42
Ongoing	5.6 (5)	18.0 (16)	0.02
Died	4.5 (4)	10.1 (9)	0.25
Unknown	3.4 (3)	1.1 (1)	0.62
Return to theatre during primary admission, % (*N*)	9.0 (8)	47.2 (42)	<0.001
Alive at discharge, % (*N*)	94.4 (84)	92.1 (82)	0.77
Death within 12 months of primary sternotomy, % (*N*)	11.2 (10)	12.4 (11)	1.0
Re-admission within 12 months of primary sternotomy, % (*N*)	41.6 (37)	58.4 (52)	0.04

IQR, interquartile range; MRSA, meticillin-resistant *Staphylococcus aureus*; GNB, Gram-negative bacteria.

Infection outcome data were available for 97.8% (174/178) of cases of SWI, and were assessed a median of 55.5 days from the date of infection (IQR 36.0 - 103.3). The majority were classified as either 'cured' or 'improved' (78.7%, 140/178). Outcomes were worse for the deep SWI group, with fewer cases considered cured and higher rates of ongoing symptoms compared with those diagnosed with superficial SWI (Table II).

Factors predisposing to SWI

To assess the contribution of the infection control interventions, we aimed to identify pre-operative factors which might increase the risk of SWI. No significant differences in age, sex or pre-operative EuroSCORE were found between patients who did or did not develop postoperative SWI (Table I). Procedures classified as urgent and those involving CABG (either alone or in combination) were significantly associated with risk of subsequent SWI.

Multi-variable logistic regression analysis demonstrated that procedures performed urgently [adjusted odds ratio (aOR) 1.59, 95% CI 1.16–2.16], those involving CABG (aOR 2.98, 95% CI 2.03–4.50), and those performed in the third quarter of the calendar year (July–September, aOR 1.65, 95% CI 1.08–2.55) were independently associated with increased pre-operative risk of SWI. Male sex was associated with decreased risk (aOR 0.69, 95% CI 0.50–0.97).

Effect of infection control interventions to reduce SWI

In total, 1834 procedures were performed during the pre-intervention observation period (2 years and 1 month; 1st September 2010 to 30th September 2012). Following this, a series of interventions were introduced in a bid to reduce the incidence of SWI, and these have been grouped into three phases.

Phase 1 (1st October 2012 to 1st January 2013, $N = 192$) included theatre etiquette guidance, theatre deep clean, change in peri-operative antibiotic prophylaxis (co-amoxiclav to gentamicin with flucloxacillin or gentamicin with vancomycin if allergic to penicillin or colonized with meticillin-resistant *S. aureus*), wound care education, and defined minimum surgical training grades for sternotomy wound closure. Phase 2 (2nd January 2013 to 7th March 2016, $N = 2836$) included a pre-operative *S. aureus* screening programme (nasal, axillary and groin swabs) with decolonization of those found to be carriers for 5 days prior to the procedure (continued postoperatively if urgency required). In Phase 3 (8th March 2016 to 1st June 2018, $N = 2041$), there was a switch to a universal *S. aureus* decolonization programme regardless of carriage status.

During the pre-intervention period, 3.9% (71/1834) of procedures were complicated by SWI (mean rate of 3.9 infections/100 patients/month). Following the intervention, the overall rate of SWI decreased to 2.1, 1.8 and 2.5 infections/100 patients/month in Phases 1, 2 and 3, respectively (Figure 1). Introduction of control measures appeared to principally impact the rate of *S. aureus* infection rather than infections caused by GNB.

A further multi-variable logistic regression was performed that also included the three phases of intervention. This demonstrated the impact of Phase 2 and, to a lesser extent, Phase 3 interventions on overall rates, principally through a significant reduction in the risk of postoperative *S. aureus*

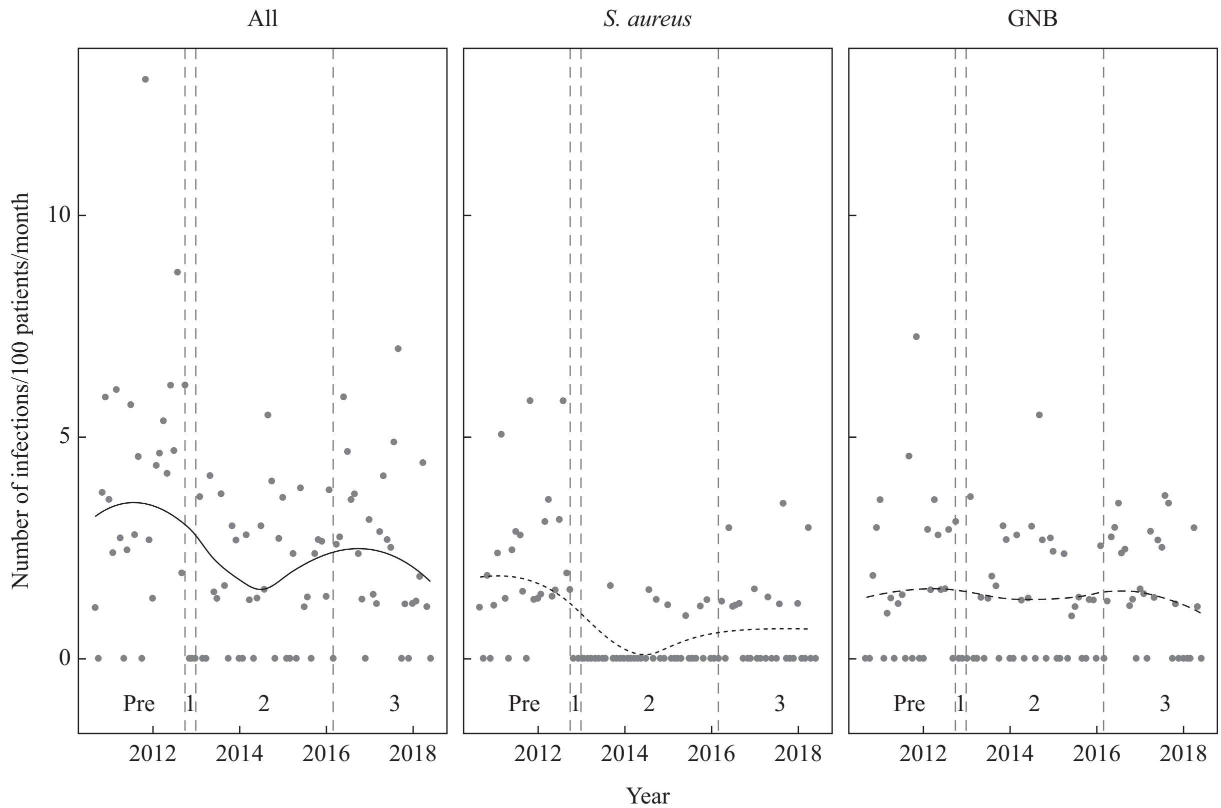

Figure 1. Rate of sternal wound infection in relation to a phased infection control programme, shown as all infections and those caused by *Staphylococcus aureus* and Gram-negative bacteria (GNB) alone.

infection (Table III). Interestingly, while CABG remained a risk factor for infection with both *S. aureus* and GNB, procedures performed urgently, female sex and season remained risk factors for infection caused by GNB alone.

Discussion

SWI is a devastating consequence of cardiothoracic sternotomy, and has high health and economic costs to both the individual and the broader healthcare system. Postoperative mortality is much higher in those with SWI, and this risk appears to persist for many years [13,14]. Many patients require further surgical procedures and suffer medical complications that can contribute to chronic organ failure [13,14]. Healthcare costs have been estimated to be nearly three-fold higher compared with those without SWI [15]. Cardiac surgery remains a relatively common procedure, with over 32,000 cases performed in the UK in 2017 and over 200,000 cases performed in the USA in 2016 [16,17]. This review demonstrates a reduction in the incidence of SWI over a period of nearly 6 years of intervention, with the greatest impact achieved through early simple measures targeting human factors and prior to an *S. aureus* decolonization programme. However, none of these measures had any discernible impact on the incidence of GNB SWI.

At the study institution, the baseline rate of SWI in the 2 years preceding any specific intervention was 3.9%, with deep infection accounting for half of these cases. The rate following CABG (either alone or with another procedure) was 5.0%, and the rate following non-CABG cardiac surgery was 2.0%. For comparison, surveillance data from England show a pooled national SWI rate of 3.0% following CABG, and 1.3% following other cardiac surgical procedures (2014–2019) [5]. At an international level, the rate of SWI varies more widely, with recent reports ranging from 0.79% to 4.1% [1,3,13,18]. GNB and *S. aureus* were the most commonly isolated organisms in the study dataset, and similar microbiological profiles are reported elsewhere [3,5,13]. Outcomes were worse in the SWI group (particularly in those with deep infection) with higher rates of mortality, re-admission, further surgical procedures and persistence of symptoms.

Three independent risk factors were identified for the development of SWI following sternotomy: CABG; procedures classed as urgent; and procedures performed during the third quarter of the calendar year (July to September). Cardiac surgery involving CABG has frequently been reported as a risk factor for subsequent SWI [3,18]. Specifically, procedures that involve bilateral internal thoracic artery harvesting appear to be riskier, although we did not have access to this level of operative detail [2]. Urgent cases will have undergone the same pre-operative preparation as elective cases, including decolonization if during the appropriate phase. However, by definition, urgent cases were more likely to be acutely unwell compared with those undergoing elective procedures. Urgent cases also spent longer in hospital prior to surgery (median 11 vs 2 days), and this additional pre-operative healthcare exposure may have increased the risk of nosocomial infection and the likelihood of pre-operative antibiotic exposure with subsequent disruption of normal colonizing flora. This theory is supported by the higher rates of GNB SWI seen in urgent cases (53.8% vs 39.2%), with comparable rates of *S. aureus* infection

Table III
Multi-variable logistic regression analysis of predictors for postoperative sternal wound infection for all cases of sternal wound infection (SWI) and subdivided into those with infection due to *Staphylococcus aureus* and Gram-negative bacteria (GNB)

	All SWI aOR (95% CI)	*P*-value	*Staphylococcus aureus* aOR (95% CI)	*P*-value	GNB aOR (95% CI)	*P*-value
Male sex	**0.69 (0.50–0.97)**	0.03	0.95 (0.54–1.76)	0.86	**0.48 (0.32–0.73)**	<0.001
CABG	**2.9 (2.0–4.5)**	<0.001	**2.17 (1.19–4.20)**	0.02	**3.04 (1.82–5.35)**	<0.001
Operative urgency						
Elective	1		1		1	
Urgent	**1.7 (1.3–2.3)**	0.001	1.38 (0.79–2.35)	0.25	**2.31 (1.53–3.50)**	<0.001
Emergency	1.3 (0.3–3.5)	0.67	1.12 (0.06–5.35)	0.91	0.83 (0.05–3.88)	0.85
Salvage	NA	0.98	NA	0.98	NA	0.98
Seasonality						
Jan–Mar	1		1		1	
Apr–Jun	1.3 (0.82–2.0)	0.28	0.95 (0.45–1.99)	0.89	1.54 (0.84–2.91)	0.17
Jul–Sep	**1.6 (1.0–2.4)**	0.04	1.43 (0.74–2.83)	0.29	**2.02 (1.13–3.74)**	0.02
Oct–Dec	1.1 (0.7–1.9)	0.59	0.69 (0.30–1.53)	0.37	1.40 (0.74–2.69)	0.30
Intervention						
Pre-intervention	1		1		1	
Phase 1	0.48 (0.14–1.2)	0.18	0.31 (0.02–1.68)	0.27	0.54 (0.08–1.94)	0.41
Phase 2	**0.44 (0.30–0.63)**	<0.001	**0.11 (0.05–0.24)**	<0.001	0.70 (0.43–1.16)	0.17
Phase 3	**0.65 (0.44–0.93)**	0.02	**0.35 (0.18–0.62)**	0.001	0.94 (0.57–1.58)	0.83

aOR, adjusted odds ratio; CI, confidence interval; CABG, coronary artery bypass grafting.
Figures in bold font are those with a significant impact on infection.
Hosmer–Lemeshow test: P=0.341; c-statistic: P=0.688.

(26.9% vs 33.0%) compared with elective cases. Finally, seasonality of infection risk is well described for both surgical site and bloodstream infection, with a trend towards higher rates during warmer months [19–21]. Proposed mechanisms include the influence of ambient temperature on environmental bacterial levels, which may, in turn, affect human bacterial colonization [19,22,23]. Concern has been raised about the influence of junior, less experienced medical staff who tend to rotate to new posts in the summer months, although there are few data to support this association [19]. Human factors may also contribute; for example, increased frequency of door opening during cardiac surgery was found to be associated with subsequent SSI, although it is not clear whether room temperature influenced this behaviour [24]. In the study cohort, the observed seasonal risk appeared to be specifically associated with GNB SWI and female sex. No explanation for this finding is offered, but this association has been reported previously [25].

We introduced a phased bundle of infection control measures that led to a significant and sustained reduction in the overall rate of SWI. Time series analysis suggests that the earlier phases of intervention had the greatest impact. These interventions were primarily focused on addressing human factors, such as theatre etiquette and postoperative wound care. However, a change in antibiotic prophylaxis, standards regarding sternal wound closure, and the early stages of the *S. aureus* decolonization programme also occurred at this time point. The specific technique chosen for sternal wound closure can influence surgical site healing, and therefore likely plays a role in the risk of SWI [26]. However, the quality of comparative studies in this field is considered to be low, and infection is not always included as an outcome measure [26]. In the absence of any formal guidelines, the final choice should be based upon the surgeon's skill set, equipment availability and the patient's risk factors [26]. Current evidence suggests that pre-operative *S. aureus* decolonization may reduce SSI, although there are few randomized controlled trials evaluating this intervention [27–30]. Poor patient compliance with topical therapies, particularly in the community setting, may reduce the efficacy, and a pre-operative 'screen and treat' approach also has added administrative challenges [29]. This was one of the main drivers of the shift to a 'universal' decolonization programme, particularly as many patients at STH are referred from out of region. In addition, this approach may actually be cheaper than 'screen and treat' for the same level of benefit [31]. In contrast, the potential role of interventions aimed at addressing human factors has received much less attention [24,32].

This study has several limitations. Firstly, due to the phased nature of the interventions and retrospective analysis, it is not possible to determine whether the greatest impact came from a single intervention or was a cumulative effect. We are also mindful of the influence of the Hawthorne effect, specifically that staff awareness of a new infection prevention programme and an increased level of attention on infection rates may have introduced bias that favoured the earlier phases of intervention. Reassuringly, we did not observe a subsequent rebound in the rate of infection, suggesting that adherence to the interventions and infection control awareness in general was maintained.

Secondly, the methodology may have underestimated the true incidence of SWI, as cases would have been missed if sampling did not take place, and/or microbiological analysis or management occurred at a different hospital. However, given the typical practice in the region, it is suspected that most cases of SWI would have been referred back to the study centre for assessment at an early stage.

Thirdly, we were not able to quantify the coverage of the nasal decolonization programme, as we did not have access to dispensary data and there is no system to monitor patient compliance. It is hoped that a shift to universal decolonization in Phase 3 would have helped here, by simplifying the process for all parties. Furthermore, the sustained decline in *S. aureus* cases alone may point towards good compliance with this intervention.

Finally, the authors had limited access to detail on the specific surgical techniques and methods of sternal wound closure employed, both of which can influence the risk of SWI. The longitudinal nature of the study over a number of years will have meant it captured an evolving roster of surgeons and shifts in standard surgical practice. Given the diverse range of cardiac surgical procedures performed via median sternotomy, it would also be an oversimplification to consider this group to have an equal pre-operative infection risk. However, it is hoped that the strict definition of infection and rigorous search strategy will have provided an accurate assessment of the postoperative infection risk in this tertiary cardiac surgery unit.

The reduction in the overall rate of SWI during the time period studied was largely due to a decline in *S. aureus* infections specifically. There was no discernible impact on the rate of SWI due to GNB throughout the observation period. This is perhaps to be expected given that *S. aureus* SWI is likely related to pre-existing skin colonization, whereas GNB infection typically occurs as a consequence of peri-operative infection at a distal site [33]. The study interventions, as per most general SSI prevention guidelines, were predominantly focused on the pre-/intra-operative phase and the surgical site itself, and therefore had little impact on GNB infection. This is of particular importance as GNB are more commonly isolated in SWI compared with other types of SSI [5]. Furthermore, GNB SWI seems to follow a more severe and complex course, with higher mortality rates, longer periods of postoperative hospitalization, and the need for long courses of broad-spectrum antibiotics [25,34]. However, despite this, there has been very little evaluation of this specific group in the literature [25,34]. Future preventative measures must redress this imbalance by broadening their focus to incorporate all stages of the patient's journey, including the early postoperative period. This is recognized, in part, by the Enhanced Recovery After Surgery initiative, and recent publication of cardiac-surgery-specific guidelines is encouraging [35]. However, many of our interventions and established local practice already align with these recommendations, and therefore our experience would suggest that additional interventions are also required to reduce the risk of GNB SWI specifically. This would align with other international drives to reduce GNB bloodstream infections, and may include timely removal of indwelling prosthetic devices (e.g. urinary catheters and intravascular access) and measures to reduce the risk of hospital-acquired pneumonia.

In conclusion, this study demonstrates the serious consequences of SWI for the individual, and points to the additional demand that this complication places on healthcare systems. A phased bundle of interventions resulted in a significant decrease in the rate of *S. aureus* SWI; however, there was no discernible impact on SWI caused by GNB. GNB SWI tend to be more complex and often require long courses of broad-spectrum antibiotics. Significant risk factors for the development of GNB postoperative SWI were identified, including operations performed in late summer and female sex. Assessment of specific interventions to address the risk of GNB infection is required to have any further success in improving infection outcomes following cardiac surgery.

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