ORIGINAL ARTICLE

Efficacy of new multimodal preventive measures for post-operative deep sternal wound infection

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Abstract

Background Deep sternal wound infection (DSWI) is a critical complication of cardiovascular surgery. This study aimed to confirm the efficacy of new, multimodal preventive measures for post-operative DSWI.

Methods From January 2008 to December 2012, 1240 patients underwent cardiovascular surgery via median sternotomy at our hospital. The patients were divided into two groups according to the period in which surgery was performed: those treated before and those treated after January 2011, which was when we implemented the new preventive measures against DSWI. The preventive measures included routine use of an off-pump technique in coronary artery bypass grafting, higher body temperature of pump cases, screening and pre-operative eradication of nasal methicillin-resistant *Staphylococcus aureus* colonization, and use of a microbial sealant. We compared the incidence of DSWI between the two time periods. Univariate and multivariate analyses were also performed for the entire period to identify DSWI risk factors.

Results Only 1 case (0.2%) of DSWI was noted among 554 patients in the latter period while 25 patients (3.6%) experienced DSWI among the 686 patients in the earlier period ($p < 0.0001$). The risk factors for DSWI were body mass index (BMI) ≥ 25 kg/m^2 and operation time ≥ 8 h.

Conclusions We observed a marked decrease in the incidence of DSWI after the implementation of multimodal preventive measures. The risk factors for DSWI were BMI ≥ 25 kg/m^2 and operation time ≥ 8 h.

Keywords Deep sternal wound infection · Multimodal preventive measures

Introduction

Deep sternal wound infection (DSWI) is one of the most critical complications following cardiovascular surgery [1, 2] and is observed in 0.5–10% of all cases of cardiovascular surgery [3–6]. Post-operative DSWI is also one of the major risk factors for post-operative mortality; the post-operative mortality rate associated with DSWI is 8.1–14.8%. However, there are no standard precautionary measures for the prevention of post-operative DSWI [4, 6]. This study aimed to confirm the efficacy of new multimodal preventive measures for post-operative DSWI.

Patients and methods

Patient allocation and implementation of preventive measures

In this study, we included 1240 consecutive cases of cardiovascular surgery involving median sternotomy performed from January 2008 to December 2012 in our hospital. The patients were divided into two groups. A total of 686 patients were operated upon through December 2010, while 554 patients were operated upon after January 2011. We implemented our multimodal new preventive measures for post-operative DSWI from January 2011. The new strategy included the following measures.

In the latter period, we changed the basic procedure of coronary artery bypass grafting (CABG) from on-pump

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beating to off-pump. Although in the early period the target lowest body temperature for thoracic aortic surgery was 20 °C, we increased the temperature to 28 °C for total arch replacement and to 30 °C for ascending aortic replacement in the latter period. We also changed the target lowest body temperature for other open-heart surgery procedures from 30 or 32 to 34 °C in the latter period.

The following preventive measures were stipulated and disseminated to the whole surgical team in the later period. For elective surgery, pre-operative nasal screening for methicillin-resistant *Staphylococcus aureus* (MRSA) was performed at the outpatient clinic. This enabled us to begin the application of mupirocine for patients with MRSA before their hospitalization. The surgical team wore a hood-type hat and the surgery gown prescribed by the Association for the Advancement of Medical Instrumentation (AAMI) level four. We wore double gloves and exchanged them after surgical draping, before implanting of the prosthesis, before wound closure, and every 3 h. We performed whole body disinfection using povidone-iodine for all cases before scrubbing. The legs of the patient were fixed to the operating table and were not to be lifted up. We used a trapezoid-shaped sterilized drape for the inner side of both legs and the genital area. We applied a microbial sealant (INTEGU-SEAL, Halyard Health Inc., Alpharetta, GA, USA) along the skin incision after disinfection. We used an argon laser for sternal hemostasis and did not use bone wax. We washed the pericardial sac and wound thoroughly with normal saline before closure of the chest. We used antibacterial monofilament sutures for wound closure (PDS PLUS, Ethicon Inc., Somerville, NJ, USA). We applied dressing material with a highly absorbent pad and breathable film (OPSITE Post-OP Visible, Smith & Nephew plc., London, UK). Two grams of cefazolin was administered every 4 h as intra-operative prophylaxis. One gram of cefazolin was administered every 8 h until 72 h after surgery. One gram of vancomycin was additionally administered at the start of the operation for emergency or urgent case and for carriers of MRSA.

There was a transitional phase for the implementation of these preventive measures in the later time period. We started reviewing our standard precaution protocol from January 2011, and began changing the CABG surgical procedures, body temperature requirements, and other factors beginning in May 2011. In the operation room, 22.5% of cardiovascular surgeries were performed with an air cleanliness of class 5 (ISO 14644-1 [7]) or class 100 (FED-STD-209 [8]) and other surgeries were performed with an air cleanliness of class 6 (ISO 14644-1) or class 1,000 (FED-STD-209) until June 2011; however, 70.7% of cardiovascular surgeries were performed with an air cleanliness of class 5 (ISO 14644-1) or class 100 (FED-STD-209) after July 2011. All new preventive measures were implemented by the late 2011.

We recorded patient demographic information, operative data, and data on the operative outcomes of the patients in the two time periods.

Next, we compared the same characteristics between the two groups of patients with post-operative DSWI and without post-operative DSWI and identified risk factors for post-operative DSWI.

Statistical analysis

All clinical data were obtained from the hospital records of the Japan Adult Cardiovascular Surgery Database Version 4 (Japan Cardiovascular Surgery Database Organization, Tokyo, Japan). Predictors for post-operative DSWI were identified using univariate and multivariate analyses. Continuous variables were compared by the Student's *t* test and differences in proportions were analyzed by the Chi-square test. *p* values less than 0.05 were considered statistically significant. Variables found to be significant in the univariate analysis were considered for the multivariate analysis using the logistic regression model. The odds ratio was used to estimate the relative risk. Data were analyzed using the statistical software JMP 5.1.1 (SAS Institute Inc., Cary, NC, USA).

Results

Comparison of patient characteristics in the early and latter period

The comparison of patients' characteristics in the early and latter period is shown in Table 1. Of 1240 cases, the total number of cases of post-operative DSWI during the total study period was 26 (2.1%). Hospital mortality occurred in 48 patients (3.9%), and there were 7 cases (0.6%) of post-operative DSWI-related death (0.6%). DSWI-related death accounted for 14.6% of hospital deaths. There was only 1 patient with post-operative DSWI among the 554 patients from the latter period, while post-operative DSWI occurred in 25 patients among the 686 patients from the earlier period (0.2% vs. 3.6%, *p* < 0.0001). The patient with post-operative DSWI in the latter period was identified early in the transitional implementation period of our new preventive measures protocol. DSWI did not occur in 531 consecutive patients up to the end of the study period. There were no differences in sex, body mass index (BMI), history of smoking, medical history of diabetes, chronic kidney disease, or cardiovascular surgery. In the early period, patient age (64.8 ± 13.4 vs. 66.4 ± 13.8, *p* = 0.0394) was slightly lower. In the latter period, the proportion of cases of aortic disease due to the main procedure increased from 8.6 to 16.6% (*p* < 0.0001); in contrast, the proportion of cases of

Table 1 Comparison of patients' clinical characteristics between the former and the latter period

	Former period ($n = 686$)	Latter period ($n = 554$)	p value
Age (years)	64.8 ± 13.4	66.4 ± 13.8	0.0394
Female	275 (40.1%)	211 (38.1%)	0.4731
BMI (kg/m^2)	22.7 ± 3.6	22.4 ± 3.2	0.1208
History of smoking	304 (44.3%)	261 (47.1%)	0.3255
Diabetes	150 (21.9%)	131 (23.6%)	0.6280
Use of insulin	38 (5.5%)	27 (4.9%)	0.6010
Creatinine $\geq$ 1.5 mg/dl	81 (11.8%)	85 (15.3%)	0.0691
Hemodialysis	30 (4.4%)	34 (6.1%)	0.1628
Previous cardiac surgery	101 (14.7%)	82 (14.8%)	0.9691
NYHA III, IV	143 (20.8%)	108 (24.2%)	0.5561
LVEF (%)	59.6 ± 12.6	59.2 ± 11.1	0.5460
Coronary artery disease	206 (30.0%)	157 (28.3%)	0.5156
Main procedure: aortic	59 (8.6%)	92 (16.6%)	< 0.0001
Ischemic	173 (25.2%)	137 (24.7%)	0.8431
Valvular	421 (61.4%)	296 (53.4%)	0.0049
Combined surgery	236 (34.4%)	174 (31.4%)	0.2651
Operation time (min)	431.8 ± 146.0	381.4 ± 126.0	< 0.0001
Use of CPB	658 (95.9%)	464 (83.7%)	< 0.0001
CPB time (min)	193.7 ± 94.0	192.1 ± 84.7	0.7761
AoX time (min)	135.7 ± 68.7	127.2 ± 52.5	0.0336
Lowest temperature (°C)	29.9 ± 5.1	31.4 ± 3.2	< 0.0001
Use of bilateral IMA	12 (1.7%)	59 (10.6%)	< 0.0001
Emergency or urgent surgery	89 (13.0%)	89 (16.0%)	0.1227
Operation in bio-clean room	158 (23.0%)	332 (59.9%)	< 0.0001
Intubation time $\geq$ 72 h	66 (10.6%)	50 (9.0%)	0.7202
Hospital stay (days)	36.1 ± 35.7	28.1 ± 34.4	< 0.0001
DSWI	25 (3.6%)	1 (0.2%)	< 0.0001
In hospital mortality	30 (4.4%)	24 (4.3%)	0.9791
DSWI-related death	7 (1.0%)	0 (0.0%)	0.0414

DSWI deep sternal wound infection, *BMI* body mass index, *LVEF* left ventricular ejection fraction, *CPB* cardiopulmonary bypass, *AoX* aortic cross clamping, *IMA* internal mammary artery

valvular diseases decreased from 61.4 to 53.4% ($p = 0.0049$). Although there was no difference in the proportion of case of coronary artery disease (25.2% vs. 24.7%, $p = 0.8431$), the frequency of the use of bilateral IMA increased in the latter period (1.7% vs. 10.6%, $p < 0.0001$). In the latter period, the rate of cardiovascular surgeries performed with an air cleanliness of class 5 (ISO 14644-1) or class 100 (FED-STD-209), also called bio-clean room, was increased from 23.0 to 59.9% ($p < 0.0001$). As a result of changing the basic procedure for CABG from on-pump beating to off-pump, the frequency of the use of CPB decreased from 95.9% to 83.7% ($p < 0.0001$). Operation time (431.8 ± 146.0 min vs. 381.4 ± 126.0 min, $p < 0.0001$) and AoX time (135.7 ± 68.7 min vs. 127.2 ± 52.5 min, $p = 0.0336$) were shorter in the latter period. There was no difference in CPB time (193.7 ± 94.0 min vs. 192.1 ± 84.7 min, $p = 0.7761$). Intra-operative lowest body temperature was higher in the latter period (29.9 ± 5.1 °C vs. 31.4 ± 3.2 °C, $p < 0.0001$).

Although there was no difference in the proportion of urgent or emergency cases (13.0% vs. 16.0%, $p = 0.1227$), the number of combined procedures (34.4% vs. 31.4%, $p = 0.2651$), number of cases with post-operative intubation longer than 72 h (10.6% vs. 9.0%, $p = 0.7202$), and the duration of hospital stay were shorter in the latter period (36.1 ± 35.7 days vs. 28.1 ± 34.4 days, $p < 0.0001$).

Risk factors for post-operative DSWI

The same characteristics were compared for the 26 patients with post-operative DSWI (group A) and 1214 patients without post-operative DSWI (group B) (Table 2).

The pathogenic bacterial species responsible for post-operative DSWI in ten patients was MRSA (38.5%); methicillin-resistant *Staphylococcus capitis* caused DSWI in eight patients (30.8%); there were three cases of methicillin-resistant *Staphylococcus epidermidis* (11.5%) infection,

Table 2 Comparison of the clinical characteristics between groups with or without deep sternal wound infection

	DSWI (+) $n = 26$	DSWI (−) $n = 1214$	p value
Age (years)	68.3 ± 10.7	65.5 ± 13.6	0.2868
Female	7 (26.9%)	479 (39.5%)	0.1952
BMI (kg/m^2)	24.3 ± 4.5	22.6 ± 3.4	0.0100
History of smoking	17 (65.4%)	547 (45.1%)	0.0394
Diabetes	7 (26.9%)	272 (22.4%)	0.5852
Use of insulin	3 (13.0%)	62 (5.4%)	0.1454
Creatinine ≥ 1.5 mg/dl	3 (11.5% %)	154 (12.7%)	0.8619
Hemodialysis	1 (3.8%)	63 (5.2%)	0.7594
Previous cardiac surgery	6 (23.1%)	177 (14.6%)	0.2268
NYHA III, IV	11 (42.3%)	240 (24.6%)	0.0047
LVEF (%)	58.2 ± 11.9	59.5 ± 12.0	0.5937
Coronary artery disease	13 (50.0%)	425 (%)	0.1135
Main procedure: aortic	4 (15.4%)	147 (12.1%)	0.6133
Ischemic	8 (30.8%)	302 (24.9%)	0.4923
Valvular	14 (15.4%)	703 (57.9%)	0.0045
Combined surgery	15 (57.7%)	395 (32.5%)	0.0070
Operation time (min)	553.8 ± 156.4	406.2 ± 137.7	<0.0001
Use of CPB	26 (100%)	1095 (90.2%)	0.0931
CPB time (min)	257.3 ± 105.4	191.5 ± 89.4	0.0002
AoX time (min)	182.3 ± 67.5	130.8 ± 61.5	<0.0001
Lowest temperature (°C)	27.5 ± 6.1	30.6 ± 4.4	0.0004
Use of bilateral IMA	2 (7.7%)	69 (5.7%)	0.6627
Emergency or urgent surgery	3 (11.5%)	174 (14.3%)	0.6869
Operation in bio-clean room	5 (19.2%)	485 (40.0%)	0.0529
Blood transfusion	23 (88.5%)	856 (70.5%)	0.0462
Intubation time	144.8 ± 363.8	107 (8.8%)	<0.0001
Intubation time ≥ 72 h	8 (30.8%)	38.7 ± 227.1	0.0204
ICU stay (days)	15.9 ± 24.1	4.1 ± 7.4	<0.0001
Hospital stay (days)	110.8 ± 70.8	30.8 ± 32.2	<0.0001

DSWI deep sternal wound infection, *BMI* body mass index, *LVEF* left ventricular ejection fraction, *CPB* cardiopulmonary bypass, *AoX* aortic cross clamping, *IMA* internal mammary artery, *ICU* intensive care unit

one case of methicillin-susceptive *Staphylococcus aureus* (3.8%) infection, one case of *Pseudomonas aeruginosa* (3.8%) infection, one case of *Stenotrophomonas maltophilia* (3.8%) infection, and one case of *Corynebacterium* species (3.8%) infection. The pathogenic bacteria were not identified in 1 case (3.8%).

BMI (24.3 ± 4.5 kg/m^2 vs. 22.6 ± 3.4 kg/m^2, $p = 0.0100$), pre-operative NYHA III or IV (42.3% vs. 24.6%, $p = 0.0047$), and the proportion of the patients with smoking history (65.4% vs. 45.1%, $p = 0.0394$) were higher in group A than in group B. The rate of operations performed in bio-clean room was lower in group A than in group B (19.2% vs. 40.0%, $p = 0.0529$). Moreover, the operation time (553.8 ± 156.4 min vs. 406.2 ± 137.7 min, $p < 0.0001$), CPB time (257.3 ± 105.4 min vs. 191.5 ± 89.4 min, $p = 0.0002$), and AoX time (182.3 ± 67.5 min vs. 130.8 ± 61.5 min, $p < 0.0001$) were longer, intra-operative lowest body temperature

(27.5 ± 6.1 °C vs. 30.6 ± 4.4 °C, $p = 0.0004$) was lower, and the frequency of blood transfusion (88.5% vs. 70.5%, $p = 0.0462$) was higher in group A. The post-operative ventilation time (144.8 ± 363.8 min vs. 38.7 ± 227.1 min, $p = 0.0204$), duration of post-operative ICU stay (15.9 ± 24.1 days vs. 4.1 ± 7.4 days, $p < 0.0001$), and the duration of hospital stay (110.8 ± 70.8 days vs. 30.8 ± 32.2 days, $p < 0.0001$) were longer in group A. In the multivariate analysis of these variables using the logistic regression model, BMI ≥ 25 kg/m^2 and operation time ≥ 8 h were identified as risk factors for post-operative DSWI (Table 3).

Table 3 Risk factors for post-operative deep sternal wound infection

Risk factor	Odds ratio	p value	95% confidence interval
Latter period	0.071	0.0102	− 2.7736 to − 0.5307
BMI ≥ 25	2.577	0.0231	0.0609 to 0.8859
Operation time ≥ 8 h	3.414	0.0148	0.1378 to 11.373

Results are derived from the multivariate analysis of these variables using the logistic regression model

BMI body mass index

Discussion

The mortality rate of post-operative DSWI is high, up to 14% [3, 6]. Post-operative DSWI is the greatest risk factor for post-operative death [1, 2]. Diabetes, obesity, renal dysfunction, angina (CCS > 3), smoking history, chronic obstructive pulmonary disease (COPD), use of bilateral internal thoracic artery, prolonged operation time, prolonged ventilation time after surgery have been reported as risk factors for post-operative DSWI in previous studies [1, 4, 5, 9–13]. In this study, the risk factors based on the patients' background were BMI ≥ 25 kg/m² and operation time ≥ 8 h.

We previously analyzed the risk factors for surgical site infection (SSI) after valvular surgery, and reported that a post-operative blood glucose level of 150 mg/dl or higher recorded early in the morning was a risk factor for SSI [14]. Guidelines for the prevention of surgical site infection published by the Centers for Disease Control and Prevention recommend controlling the blood glucose levels to below 200 mg/dl within 48 h after surgery [15]. Although we did not examine the blood glucose levels in the immediate post-operative period in this study, it is thought that, based on our former study, blood glucose control in the immediate post-operative period contributed to reducing SSI and post-operative DSWI in the latter period. Although diabetes and use of insulin were not risk factors for post-operative DSWI in this study, we can adequately prevent post-operative DSWI by providing appropriate blood glucose control even if the patient has diabetes.

The use of bilateral IMA was not a risk factor of DSWI in this study. Since the use of bilateral IMA for CABG may cause blood flow obstruction in the anterior mediastinum, it is considered a risk factor of post-operative DSWI [4, 5, 9–12]. However, although the frequency of use of bilateral IMA increased in the latter period, the incidence of post-operative DSWI decreased in our study. The risk of SSI following CABG was increased in patients with HbA1c levels greater than 7.0% [13]. Even in patients with insulin-dependent diabetes, if the blood glucose was adequately maintained and HbA1c level was less than 7.0%, we used bilateral IMA for CABG.

Long operation time is a risk factor for SSI. The 75th percentile value of operation time is defined as a prolonged operation [16]. Long operation time was identified as a risk factor for post-operative DSWI in this study. The 75th percentile value of the operation time in our hospital was 8 h. The duration of surgery was higher than that reported in prior studies, but the comparison with values reported for other hospitals is difficult because the type of disease or the severity of illness varies among hospitals.

According to the standard testing method for the evaluation of the effectiveness of pre-operative skin preparation drug products specified by the American Society for Testing and Materials (ASTM) and US-TFM, the efficacy of the patients' pre-operative skin preparation drug products is assessed by determining the decrease in the bacterial count 2 log10 per cm² on an abdomen test site within 10 min after product use, and the bacterial cell count for each test site dose should not subsequently exceed the baseline count 6 h after product use [17]. The effectiveness of the disinfection drug gradually decreases more than 6 h after the start of the operation. Thus, it is reasonable that long operation time is a risk factor for DSWI.

We changed the basic procedure of CABG from on-pump beating to off-pump beating in the latter period. We also changed the target lowest body temperature to 28–30 °C for thoracic aortic surgery and 34 °C for other open-heart surgery using CPB. It is thought that the omission of the procedure for CPB in CABG and the decrease in the body cooling time and rewarming time led to shortening of the average operation time in the latter period. The shortening of the average operation time in the latter period was considered to contribute to the prevention of post-operative DSWI.

Peri-operative hypothermia lessens immunoactivity and is a risk factor for SSI [18–20]. However, it is difficult to avoid peri-operative hypothermia in thoracic aortic surgery with systemic circulatory arrest for the protection of the internal organs. We set the target lowest body temperature in thoracic aortic surgery higher than 27 °C in the latter period. Body temperature less than 27 °C was a risk factor for post-operative DSWI in this study. We set the temperature to 28 °C for total arch replacement, 30 °C for ascending aortic replacement, and 34 °C for other open-heart surgery with the use of CPB. The incidence of gastrointestinal complications (2.3% vs. 0.6%, $p = 0.0149$) and cerebrovascular complications (1.2% vs. 2.1%, $p = 0.2208$) was not higher in the latter period. The lowest body temperature was not a risk factor for DSWI on multivariate analysis; however, it is suggested that in the latter period, maintaining the target lowest body temperature higher than that previously maintained contributed to reducing post-operative DSWI.

In this study, BMI ≥ 25 kg/m² was a risk factor for post-operative DSWI. A BMI of more than 25 kg/m² is

defined as obesity in Japan. Obesity is a risk factor for SSI, as reported in previous studies, including ours [1, 5, 21, 22].

The environment of the operation room is also important for the prevention of SSI. Approximately 10–20% of healthcare-associated infections involved air-borne microorganisms [23]. Lidwell and his colleagues reported a strong connection between air-borne contamination during joint replacement surgeries and SSI rates [24, 25]. SSI is strongly influenced by the quality of operating room [26]. CDC guidelines and those of other governing bodies recommend intra-operative air ventilation for preventing SSI [27–29]; however, there is no consensus and prospective studies comparing air cleanliness of the operating room with SSI rates are lacking. ISO 14644-1 and FED-STD-209 are often used for the environmental infection control in healthcare facilities. Class 5 air cleanliness of ISO 14644-1 or class 100 air cleanliness of FED-STD-209, generally called bio-clean room, is recommended for joint and cardiovascular surgeries. In our study, during the former period, the rate of cardiovascular surgeries performed in the bio-clean room was 23.0% and five cases (20.0%) of DSWIs occurred from surgeries performed in the bio-clean room. However, there was no significant difference between DSWI and bio-clean rooms in the former period ($p = 0.6388$) and also in whole study period ($p = 0.0529$) (Table 2). Lidwell and his colleagues reported in another multicenter study that the clean air had little effect for the incidence of SSI following artificial joint surgeries [30]. However, in the latter period of our study, the rate of cardiovascular surgeries performed in the bio-clean room was increased from 23.0 to 59.9%; thus, we think the air cleanliness of the operation room played an important role in reducing post-operative DSWIs.

In this study, we focused on post-operative DSWI, which is an organ/space SSI after cardiovascular surgery by median sternotomy, and examined its risk factors. In our previous study, the frequency of SSI decreased from 6.0 to 0.8% before versus after implementation of preventive measures and surveillance for SSI events [14]. It is thought that the result of our hospital's overall effort to prevent SSI led to significant reduction in the incidence of post-operative DSWI.

Limitations of this study

This investigation has some limitations. This study is based on retrospectively collected data from a single center and is nonrandomized. Furthermore, there was transitional period for the implementation of the preventive measures in the later period.

Conclusion

The risk factors for post-operative DSWI were BMI and operation time. We were able to markedly reduce the incidence of post-operative DSWI by implementing multimodal preventive measures, such as shorter operation time and higher lowest body temperature.

Compliance with ethical standards

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