A predictive scoring system for deep sternal wound infection after bilateral internal thoracic artery grafting

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Accepted 4 May 2015

Abstract

OBJECTIVES: Despite long-term survival benefits, the increased risk of sternal complications limits the use of bilateral internal thoracic artery (BITA) grafts for myocardial revascularization. The aim of the present study was both to analyse the risk factors for deep sternal wound infection (DSWI), which complicates routine BITA grafting and to create a DSWI risk score based on the results of this analysis.

METHODS: BITA grafts were used as skeletonized conduits in 2936 (70.6%) of 4160 consecutive patients with multivessel coronary artery disease who underwent isolated coronary bypass surgery at the authors' institution from 1 January 1999 to 2013. The outcomes of these BITA patients were reviewed retrospectively and a risk factor analysis for DSWI was performed.

RESULTS: A total of 129 (4.4%) patients suffered from DSWI. Two multivariable analysis models were created to examine preoperative factors either alone or combined with intraoperative and postoperative factors. Female gender, obesity, diabetes, poor glycaemic control, chronic lung disease and urgent surgical priority were the predictors of DSWI common to both models. Two (preoperative and combined) models of a new scoring system were devised to predict DSWI after BITA grafting. The preoperative model performed better than five of six scoring systems for sternal wound infection that were considered; the combined model performed better than three considered scoring systems.

CONCLUSIONS: A weighted scoring system based on risk factors for DSWI was specifically created to predict DSWI risk after BITA grafting. This scoring system outperformed the existing scoring systems for sternal wound infection after coronary bypass surgery. Prospective studies are needed for validation.

Keywords: Arterial grafts • Coronary artery bypass grafts • Quality improvement • Sternal wound infection

INTRODUCTION

Deep sternal wound infection (DSWI) occurs in 1–4% of patients after coronary artery bypass graft (CABG) surgery performed via a median sternotomy and is associated with increased early mortality [1] and poor late outcomes [2]. In CABG surgery, the use of bilateral internal thoracic artery (BITA) grafting remains an independent risk factor for sternal complications [3, 4], although skeletonizing the grafts has been proven useful in reducing the incidence mainly in diabetic patients [4, 5]. Therefore, in order to minimize sternal complications, BITA grafts should be used only in selected patients without the well-known risk factors for sternal wound infection, such as obesity, diabetes mellitus, chronic lung disease, renal impairment and peripheral vascular disease [6–12]. However, this strict selection would deprive too many patients from the long-term survival benefits derived from BITA grafting [13–15]. Moreover, patients suffering from diabetes or renal failure are the patients who would most benefit from the good long-term patency rate of the BITA grafts even in the presence of these two strong comorbidities [13–16]. In this context, it seems ever more urgent the need for a predictive scoring system focused specifically on sternal wound infection following BITA grafting.

In the present study, the authors have reviewed retrospectively their 15-year experience in routine BITA grafting. The aim of the study was both to analyse the risk factors for severe forms of sternal wound infection (namely DSWI) complicating BITA grafting and create a risk score based on the results of this analysis.

PATIENTS AND METHODS

From 1 January 1999 throughout 2013, a total of 4160 consecutive patients with multivessel coronary artery disease underwent isolated CABG surgery at the authors' institution. BITA grafting was performed in 2936 (70.6%) cases (Table 1).

Table 1: Preoperative patients' characteristics and risk profiles[a]

Characteristics	Patients (N = 2936)
Age (years)	66.3 ± 9.0 (60–73)
<70	1752 (59.7)
70–80	1054 (35.9)
>80	130 (4.4)
Female gender	460 (15.7)
Hypertension	2109 (71.8)
Former smoker	654 (22.3)
Current smoker	112 (3.8)
Hyperlipidaemia	2620 (89.2)
BMI (kg/m^2)	27.2 ± 3.6 (24.7–29.4)
<20	37 (1.3)
>30	586 (20.0)
Diabetes	865 (29.5)
On oral hypoglycaemic agents	652 (22.2)
On insulin	213 (7.3)
Poor glycaemic control[b]	137 (4.7)
Serum haemoglobin (g/l)	13.3 ± 1.6 (12.1–14.4)
<12	708 (24.1)
Poor mobility[c]	14 (0.5)
Chronic lung disease[c]	134 (4.6)
GFR (ml/min)[d]	78.5 ± 27.7 (60.1–93.3)
50–85	1515 (51.6)
<50	365 (12.4)
Chronic dialysis	35 (1.2)
Extracardiac arteriopathy[c]	192 (6.5)
Atrial fibrillation	12 (0.4)
Congestive heart failure	135 (4.6)
Unstable angina	860 (29.3)
Silent myocardial ischaemia	47 (1.6)
Recent myocardial infarction[c]	366 (12.5)
Coronary artery disease	
Left main	1062 (36.2)
One-vessel	14 (0.5)
Two-vessel	375 (12.8)
Three-vessel	2547 (86.8)
LVEF (%)	55.2 ± 10.3 (50–60)
30–50	710 (24.2)
<30	85 (2.9)
Previous PCI	94 (3.2)
Previous cardiac operation[c]	31 (1.1)
Previous CABG surgery	12 (0.4)
Cardiogenic shock	5 (0.2)
Aborted sudden death	7 (0.2)
Use of IABP	96 (3.3)
Urgent surgical priority[c]	1750 (59.6)
Emergency[c]	53 (1.8)
Expected operative risk (by EuroSCORE II[e]) (%)	3.6 ± 5.1 (1.1–3.9)
>10	205 (7.0)

BMI: body mass index; CABG: coronary artery bypass graft; EuroSCORE: European System for Cardiac Operative Risk Evaluation; GFR: glomerular filtration rate; IABP: intra-aortic balloon pumping; LVEF: left ventricular ejection fraction; PCI: percutaneous coronary intervention; SD: standard deviation.
[a]Values are number of patients with percentages in brackets, or mean ± SD with interquartile range in brackets.
[b]See 'Definitions'.
[c]Definitions were those employed for the EuroSCORE II (Ref. [16]).
[d]The creatinine clearance rate, calculated according to the Cockcroft-Gault formula, was used for approximating the GFR.
[e]Ref. [16].

To evaluate the suitability of both internal thoracic arteries (ITAs) to be used as coronary grafts, all patients had undergone bilateral selective angiography of the sub-clavian artery during preoperative coronary angiography. All diabetic patients were treated during operation and then in intensive care unit with a continuous intravenous insulin infusion. Prophylactic antibiotics were administered before surgical incision. A first-generation cephalosporin (cefazolin) was usually chosen. Vancomycin was used if there was a severe allergy to β-lactam antibiotics, or in the event of mediastinal re-exploration; in the last case, the addition of an aminoglycoside was considered.

Definitions

Unless otherwise stated, definitions of preoperative clinical variables were those employed for the European System for Cardiac Operative Risk Evaluation II (EuroSCORE II) [16]. Poor preoperative glycaemic control was defined as basal serum glucose >200 mg/dl at three consecutive measurements before surgery. Atherosclerosis of the ascending aorta was demonstrated using the epiaortic ultrasonography scan, which was performed intraoperatively in every patient. A porcelain aorta was defined as a diffusely calcified and unclampable ascending aorta. The risk profile for each patient was calculated according to EuroSCORE II.

Postoperatively, low cardiac output was defined as three consecutive cardiac index measurements <2.0 l/min/m^2 despite adequate preload, afterload and inotropic support or intra-aortic balloon pumping. Acute kidney injury was defined as postoperative serum creatinine >2.0 mg/l in the patients without preoperative renal impairment, and postoperative increase in serum creatinine of at least 1.0 mg/l above baseline in the patients with preoperative renal impairment.

The Centers for Disease Control and Prevention classification of the surgical site infections was adopted to define sternal wound infection. In brief, superficial incisional infection involves only skin or subcutaneous tissues, deep incisional infection involves deep soft tissues (fascial and muscle layers) with or without the sternal bone and organ/space infection involves the mediastinum (mediastinitis) [17]. For the purposes of this study, deep incisional infection and mediastinitis were considered to be DSWI.

Surgery

A careful skin preparation was performed with iodine–alcohol. Chlorhexidine–alcohol was used only for patients with iodine allergy. Surgery was carried out via a median sternotomy either with cardiopulmonary bypass, with or without cross-clamping the aorta or off-pump technique. When a period of myocardial ischaemia was used, myocardial protection was usually achieved with multidose cold blood cardioplegia delivered in both antegrade and retrograde mode. A single-dose crystalloid solution (Custodiol–histidine–tryptophan–ketoglutarate® solution; Essential Pharma, Newtown, Pennsylvania, PA, USA) was sometimes preferred, especially when longer ischaemic times were expected. Off-pump and beating heart on-pump techniques were adopted only in the presence of a porcelain aorta to avoid the risk of cracking atherosclerotic plaques with the aortic cross-clamp [15].

Both internal thoracic arteries (ITAs) were harvested as skeletonized conduits with low-intensity bipolar coagulation forceps, extending from the inferior border of the sub-clavian vein distally to the bifurcation into the superior epigastric and musculophrenic arteries. The BITA harvesting technique did not change during the study period. Both ITAs were used as *in situ* grafts when possible.

The right ITA was preferentially directed to the left anterior descending coronary artery, and the left ITA to the posterolateral cardiac wall. The anteaortic crossover right ITA bypass graft was protected by means of a pedicled flap taken from the thymic remnants [18]. Additional coronary bypasses, usually for the right coronary artery, were performed with radial artery (rarely) or saphenous vein grafts. Endoscopic vein harvesting was adopted in the last period of the study. Sometimes, the ITA was taken down and used as a free-graft from either the *in situ* contralateral ITA (Y-graft) or the proximal (aortic) end of a saphenous vein graft (Supplementary Table 1) [15].

Standard single-loop sternal wiring technique was preferentially used as a sternal closure system until 2009. Since 2010, the double-loop sternal wiring technique was adopted systematically. Bone wax was forbidden.

All perioperative data were prospectively and meticulously recorded for every patient in a computerized data registry (FileMaker Pro 12.0; FileMaker, Inc., Santa Clara, CA, USA). Post-discharge surveillance of the surgical wounds was performed for every patient in a specifically dedicated surgical outpatient. All the patients with a surgical site complication were referred to this outpatient, at any time after hospital discharge. The data were recorded in File Maker Pro 12.0. Approval to conduct the study was acquired from the Hospital Ethics Committee, based on retrospective data retrieval, having waived the need for patients to provide their individual consent.

Statistical methods

Data were expressed as number of patients, mean ± standard deviation or median, with the percentage or the range between the first and the third quartile (interquartile range) in brackets. Preoperative clinical characteristics of the patients, operative data and perioperative complications were compared using the χ^2 or Fisher's exact test for dichotomous variables and the Student's *t*-test or the Mann–Whitney *U*-test for continuous variables, as appropriate. All variables from the logistic regression univariable analysis with a *P*-value <0.1 were entered into a backward step-wise multivariable logistic regression analysis. Odds ratio, with 95% confidence interval (CI), was computed for each variable. Risk indices were constructed from the independent risk factors identified from the final multivariable logistic regression model. Variables were eligible for inclusion at *P*-value <0.1. Each of the risk indices had the variable weighted according to its regression coefficient. The function 'nomogram' in the 'rms' package for R was used to convert the multivariable model into a scoring system [19]. Two multivariable analysis models and two corresponding models of a new predictive scoring system for DSWI were created. The preoperative model included only preoperative characteristics of the patients. The combined model included both preoperative and intraoperative and postoperative variables. The predictive power of the models was assessed using the Goodman–Kruskal non-parametric correlation coefficient *G*. According to Haley [20], the predictive power was defined as low ($G < 0.3$), moderate (G 0.3–0.5) and high ($G > 0.5$). The discrimination power of the models was assessed with the receiver-operating characteristic curve and the calculation of the area under the receiver-operating characteristic curve (AUC). According to arbitrary guidelines [21], the accuracy of prediction was defined as low (AUC: 0.5–0.7), moderate (AUC: 0.7–0.9) and high (AUC: 0.9–1). The new predictive scoring system was compared (using the method of DeLong *et al.* [22]) with some existing scoring systems for surgical site infection following cardiac surgery [7–11, 23]. Finally, an internal validation procedure based on bootstrap was performed for both models by computing the Somers' Dxy rank correlation, the estimated shrinkage and the maximum error in predicted probability [19]. Analyses were performed with IBM SPSS Statistics (IBM Software Group).

RESULTS

In-hospital mortality

Fifty-seven (1.9%) patients died before hospital discharge (44 patients within the postoperative day 30). These patients were not excluded from the following analysis.

Risk factors for deep sternal wound infection and multivariable analysis models

A total of 129 (4.4%) patients suffered from DSWI (Table 2). These patients were compared with 2743 (93.4%) patients who experienced no sternal complications. Older age, female gender, obesity, diabetes, poor glycaemic control, severe anaemia, chronic lung disease, severe renal impairment, chronic dialysis, extracardiac arteriopathy, congestive heart failure, left ventricular dysfunction, previous CABG surgery, urgent surgical priority, high expected operative risk (by EuroSCORE II), use of chlorhexidine–alcohol, porcelain aorta (by intraoperative epiaortic ultrasonography scan), and postoperative prolonged invasive ventilation, atrial fibrillation, low cardiac output, acute kidney injury, blood transfusion, multiple blood transfusion and mediastinal re-exploration were risk factors for DSWI according to the univariable analysis (Table 3). Using these dependent risk factors for DSWI, two multivariable analysis models were created to examine either preoperative alone or combined (preoperative, intraoperative and postoperative) risk factors. Female gender, body mass index >30 kg/m^2, diabetes, poor glycaemic control, chronic lung disease and urgent surgical priority were the predictors of DSWI common to both models (Table 4).

The new predictive scoring system for deep sternal wound infection after bilateral internal thoracic artery grafting

According to the corresponding multivariable analysis models (Table 4), two models, preoperative and combined, of a new scoring system (the Gatti score) were created to predict DSWI after BITA grafting (Tables 5 and 6). The Goodman–Kruskal

Table 2: Surgical site complications[a]

Event	Patients (n = 2936)
Sternal wound infection	185 (6.3)
Superficial incisional[b]	56 (1.9)
Deep incisional[b,c]	117 (4.0)
Mediastinitis[b,c]	12 (0.4)
Sternal separation without infection	8 (0.3)
Leg wound complication (severe)	24/2085[d] (1.2)

[a]Values are number of patients with percentages in brackets.
[b]See 'Definitions'.
[c]Deep sternal wound infection.
[d]Patients who received concomitant saphenous vein grafts.

Table 3: Risk factors for DSWI[a] (univariable analysis) (n = 2872)[b,c]

Variable	DSWI (n = 129)	No sternal complication (n = 2743)	P-value
Age (years)	68.2 ± 7.9 (63–74)	66.2 ± 9.1 (60–73)	0.012
>70	67 (51.9)	300 (10.9)	<0.0001
Female gender	45 (34.9)	396 (14.4)	<0.0001
Former smoker	33 (25.6)	606 (22.1)	0.35
Current smoker	5 (3.9)	105 (3.8)	0.56
BMI (kg/m^2)	28.0 ± 4.3 (25.0–30.3)	27.1 ± 3.6 (24.7–29.4)	0.0097
<20	2 (1.6)	33 (1.2)	0.47
>30	35 (27.1)	537 (19.6)	0.036
Diabetes	60 (46.5)	782 (28.5)	<0.0001
On oral hypoglycaemic agents	37 (28.7)	601 (21.9)	0.071
On insulin	23 (17.8)	181 (6.6)	<0.0001
Poor glycaemic control[a]	15 (11.6)	120 (4.4)	0.0001
Serum haemoglobin (g/dl)	12.7 ± 1.6 (11.6–13.8)	13.3 ± 1.6 (12.2–14.5)	<0.0001
<12	40 (31.0)	555 (20.2)	0.0032
Chronic lung disease[c]	12 (9.3)	116 (4.2)	0.0063
GFR (ml/min)[d]	70.6 ± 27.6 (52.7–84.9)	79.0 ± 27.7 (60.6–93.6)	0.0007
50–85	70 (54.3)	1411 (51.4)	0.53
<50	27 (20.9)	329 (12.0)	0.0026
Chronic dialysis	5 (3.9)	29 (1.1)	0.016
Extracardiac arteriopathy[c]	15 (11.6)	171 (6.2)	0.015
Congestive heart failure	13 (10.1)	118 (4.3)	0.0021
Unstable angina	44 (34.1)	797 (29.1)	0.22
Recent myocardial infarction[c]	18 (14.0)	345 (12.6)	0.65
LVEF (%)	54.6 ± 10.0 (49–60)	55.2 ± 10.2 (50–60)	0.5
<50	43 (33.3)	732 (26.7)	0.097
Cardiogenic shock	1 (0.8)	4 (0.1)	0.21
Preoperative IABP	5 (3.9)	87 (3.2)	0.4
Previous cardiac operation[c]	2 (1.6)	29 (1.1)	0.41
Previous CABG surgery	2 (1.6)	10 (0.4)	0.098
Urgent surgical priority[c]	92 (71.3)	1619 (59.0)	0.0054
Emergency[c]	3 (2.3)	48 (1.7)	0.4
Expected operative risk (by EuroSCORE II[e]) (%)	5.7 ± 7.2 (1.9–5.8)	3.4 ± 4.9 (1.0–3.7)	<0.0001
>10	20 (15.5)	174 (6.3)	<0.0001
Use of chlorhexidine-alcohol due to iodine allergy	6 (4.7)	50 (1.8)	0.038
Porcelain aorta (by intraop. EAS)[a,f]	14 (10.9)	154 (5.6)	0.013
Duration of surgery (min)	289 ± 60 (250–320)	283 ± 61 (245–310)	0.23
Cardiopulmonary bypass time (min)	101 ± 32 (78–119)	101 ± 35 (78–119)	0.93
Aortic cross-clamp time (min)	79 ± 27 (62–92)	79 ± 26 (62–92)	0.93
Use of a standard single-loop sternal wiring technique	100 (77.5)	1954 (71.2)	0.12
Postoperative			
Prolonged (>48 h) invasive ventilation	27 (20.9)	213 (7.8)	<0.0001
Atrial fibrillation, new-onset	42/127 (33.1)	638/2733[g] (23.3)	0.012
Myocardial infarction[a]	3 (2.3)	64 (2.3)	0.59
Low cardiac output[a]	7 (5.4)	18 (0.7)	<0.001
Use of norepinephrine	41 (31.8)	921 (33.6)	0.67
Acute kidney injury[a]	12 (9.3)	152 (5.5)	0.072
48-h Chest tube drainage (ml)	1122 ± 959 (500–1400)	1083 ± 887 (600–1300)	0.63
48-h Chest tube drainage/weight (ml/kg)	14.7 ± 13.3 (7.2–16.4)	13.9 ± 12.1 (7.3–16.3)	0.47
Blood transfusion	62 (48.1)	1010 (36.8)	0.0099
Multiple blood transfusion (>2 RBCs)	30 (23.3)	285 (10.4)	<0.0001
Mediastinal re-exploration[h]	14 (10.9)	122 (4.4)	0.0008

BMI: body mass index; CABG: coronary artery bypass graft; EAS: epiaortic ultrasonography scan; EuroSCORE: European System for Cardiac Operative Risk Evaluation; GFR: glomerular filtration rate; IABP: intra-aortic balloon pumping; LVEF: left ventricular ejection fraction; SD: standard deviation; RBCs: packed red blood cells.

[a]See 'Definitions'.

[b]Both patients with superficial incisional sternal wound infection (n = 56) and patients with sternal separation without infection (n = 8) were excluded from this analysis.

[c]Values are number of patients with percentages in brackets, or mean ± SD with interquartile range in brackets.

[c]Definitions were those employed for the EuroSCORE II (Ref. [16]).

[d]The creatinine clearance rate, calculated according to the Cockcroft-Gault formula, was used for approximating the GFR.

[e]Ref. [16].

[f]See 'Surgery'.

[g]Patients with preoperative sinus rhythm.

[h]Through resternotomy or subxiphoid window.

Table 4: Risk factors for DSWI[a] (multivariable analysis) (n = 2872)[b]

Factor	Preoperative evaluation		Combined evaluation	
	OR (95% CI)	*P*-value	OR (95% CI)	*P*-value
Female gender	2.96 (2.01–4.37)	<0.0001	3.00 (2.02–4.46)	<0.0001
BMI >30 kg/m^2	1.43 (0.95–2.17)	0.087	1.49 (0.98–2.26)	0.061
Diabetes on oral hypoglycaemic agents	1.71 (1.12–2.63)	0.014	1.69 (1.10–2.61)	0.017
Diabetes on insulin	2.63 (1.52–4.56)	0.0005	2.45 (1.41–4.26)	0.0014
Poor glycaemic control[a]	1.88 (0.99–3.59)	0.055	2.14 (1.12–4.10)	0.021
Chronic lung disease[c]	2.98 (1.56–5.69)	0.0009	2.83 (1.47–5.47)	0.0019
Chronic dialysis	2.73 (0.97–7.69)	0.057	–	–
Congestive heart failure	1.89 (1.00–3.57)	0.05	–	–
Urgent surgical priority[c]	1.69 (1.13–2.53)	0.011	1.61 (1.07–2.41)	0.022
Use of chlorhexidine-alcohol[d]	–	–	2.35 (0.95–5.80)	0.063
Porcelain aorta (by intraop. EAS)[a,d]	–	–	1.83 (0.99–3.36)	0.053
Postoperative				
Low cardiac output[a]	–	–	5.34 (1.95–14.61)	0.0011
Multiple blood transfusion (>2 RBCs)	–	–	1.79 (1.07–2.99)	0.026
Mediastinal re-exploration[e]	–	–	1.94 (0.98–3.85)	0.059

BMI: body mass index; CI: confidence interval; DSWI: deep sternal wound infection; EAS: epiaortic ultrasonography scan; EuroSCORE: European System for Cardiac Operative Risk Evaluation; OR: odds ratio; RBCs: packed red blood cells.
[a]See 'Definitions'.
[b]Both patients with superficial incisional sternal wound infection (n = 56) and patients with sternal separation without infection (n = 8) were excluded from this analysis.
[c]Definitions were those employed for the EuroSCORE II (Ref. [16]).
[d]See 'Surgery'.
[e]Through resternotomy or subxiphoid window.

Table 5: The predictive scoring system for DSWI[a] after BITA grafting: the scoring

Risk factor	Preoperative model (points)	Combined model (points)
Female gender	99	66
BMI >30 kg/m^2	33	24
Diabetes on oral hypoglycaemic agents	49	31
Diabetes on insulin	89	54
Poor glycaemic control[a]	58	46
Chronic lung disease[b]	100	62
Chronic dialysis	92	–
Congestive heart failure	58	–
Urgent surgical priority[b]	48	28
Use of chlorhexidine-alcohol[c]	–	51
Porcelain aorta (by intraoperative EAS)[a,c]	–	36
Postoperative		
Low cardiac output[a]	–	100
Multiple blood transfusion (>2 RBCs)	–	35
Mediastinal re-exploration[d]	–	39

BITA: bilateral internal thoracic artery; BMI: body mass index; DSWI: deep sternal wound infection; EAS: epiaortic ultrasonography scan; EuroSCORE: European System for Cardiac Operative Risk Evaluation; RBCs: packed red blood cells.
[a]See 'Definitions'.
[b]Definitions were those employed for the EuroSCORE II (Ref. [16]).
[c]See 'Surgery'.
[d]Through resternotomy or subxiphoid window.

Table 6: The predictive scoring system for DSWI[a] after BITA grafting: total score and expected risk

Total score		Expected risk of DSWI[a] (%)
Preoperative model (points)	Combined model (points)	
<180	<127	<10
180–222	127–154	10
223–254	155–175	15
255–280	176–192	20
281–303	193–207	25
304–324	208–221	30
325–343	222–233	35
344–362	234–246	40
363–380	247–258	45
381–399	259–270	50
400–417	271–282	55
418–437	283–295	60
438–458	296–308	65
>458	>308	70 or more

BITA: bilateral internal thoracic artery; DSWI: deep sternal wound infection.
[a]See Definitions.

coefficient G for the preoperative and the combined model was of 0.76 ($P < 0.0001$) and 0.84 ($P < 0.0001$), respectively. The discrimination power of both models was moderate (Fig. 1). The preoperative model of the Gatti score was equivalent to the corresponding combined model ($P = 0.25$; Fig. 1) and the preoperative model of the Society' of Thoracic Surgeons risk score

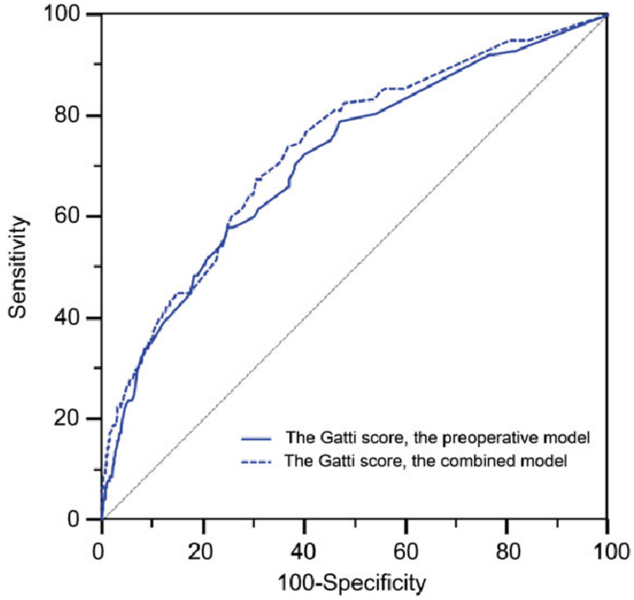

Figure 1: The new predictive scoring system for DSWI after BITA grafting (the Gatti score).The preoperative (AUC = 0.72, 95% CI: 0.7–0.73) versus the combined model (AUC = 0.73, 95% CI: 0.72–0.75; *P* = 0.25). AUC: area under the receiver-operating characteristic curve; BITA: bilateral internal thoracic artery; CI: confidence interval; DSWI: deep sternal wound infection.

(*P* = 0.14; Fig. 2A) [10]. It was superior to the sternal wound infection prediction scale (*P* = 0.012; Fig. 2A) [8], the Northern New England Cardiovascular Disease Study Group prediction rule for mediastinitis (*P* = 0.0046; Fig. 2B) [7], the additive EuroSCORE (*P* = 0.0007; Fig. 2B) [23], the Friedman score (*P* = 0.0002; Fig. 2C) [11] and the Alfred Hospital risk index A (*P* < 0.0001; Fig. 2C) [9]. The combined model of the Gatti score was superior to the combined model of the Society of Thoracic Surgeons risk score (*P* = 0.002) [10], the sternal wound infection prediction scale-revisited (*P* = 0.0012) [8] and the Alfred Hospital risk index B (*P* < 0.0001) [9] (Fig. 2D). Internal validation (averaging over 40 permutations) on the preoperative model achieved a randomization estimate of optimism of 0.04, yielding a corrected Dxy of 0.39 with respect to the original 0.44 (i.e. the expected estimate of Dxy that would be obtained by a future independent validation corresponds to the 89% of the original one); the estimated shrinkage (slope) was 0.9 and the maximum error in predicted probability was 0.07 (i.e. the calibration curve to be used in internal validations is very near to the original one). In the combined model, nearly the same results were obtained, with a lower difference in Dxy (original = 0.46; corrected = 0.43, i.e. 93% of the original one).

DISCUSSION

Sternal wound infections are a major source of physical, emotional and economic stress in cardiac surgery [1], although the extensive use of the vacuum-assisted closure therapy and advances in reconstructive surgery of the sternum have improved results dramatically [24]. Throughout the years, several models have been devised to predict the risk of developing sternal wound infection after median sternotomy [2, 7–11, 23]. However, these predictive models arose from a series of patients undergoing various surgical procedures or preselected cohorts of CABG patients where most of the patients have received single ITA (and saphenous vein) grafts for myocardial revascularization. Moreover, some models were tested for every surgical site infection after CABG surgery including also leg wound complications. Unfortunately, the predictive power of these models is limited mainly due to the complex pathogenesis of sternal wound infection, which involves specific comorbidities, periprocedural factors and postoperative complications [2, 25]. According to these analyses, BITA grafting is a commonly accepted strong predictor of sternal complications and concerns about the high risk of DSWI have limited its more extensive use in CABG surgery [3, 4].

The aim of the present study was both to analyse the risk factors for DSWI, which complicates BITA grafting and create a risk score based on the results of this analysis. To date, no risk factor analysis for DSWI has been performed exclusively on patients undergoing routine BITA grafting. To date, there is no scoring system specifically created to predict DSWI risk after BITA grafting.

Since 1986, the authors of the present study have been routinely performing BITA grafting at their institution. Since 1999, they have been prospectively recording all perioperative data for every patient in a computerized data registry, the rate of BITA use being increased from ∼60% in 1999 to over 80% in the last 3 years. All patients with multivessel coronary artery disease who required left-sided myocardial revascularization were potential candidates for BITA grafting; the sole exceptions being the rare cases in which one or both ITAs were unsuitable as coronary grafts, or when there was an unexpected operative finding of severe cardiac dysfunction or when rapid worsening of haemodynamics due to ischaemia required immediate institution of cardiopulmonary bypass. Moreover, there have been even some (exceptional) cases where a second ITA graft was harvested during cardiopulmonary bypass [15].

Among the patients of the present study, DSWI occurred in 4.4% of the cases. It was an expected and frequent postoperative complication. It was more frequent than reported in the cohort of patients who have received single ITA grafts at the present authors' institution during the same period of the study (1.8%). It was more frequent than reported by other authors [1, 3–5]. In the present authors' opinion, the higher rate of sternal complications of the present series was due to the use of BITA grafts on a routine basis, without any preoperative selection of candidates for left-sided BITA grafting, the high prevalence among the study patients of obesity, diabetes and urgent surgical priority and the relatively high rate of postoperative complications such as multiple blood transfusion and mediastinal re-exploration (Tables 1, 3 and 4).

Like other investigators [8–10], two multivariable analysis models were created to examine either preoperative factors alone or in combination with intraoperative and postoperative factors. The female gender, obesity, diabetes, poor glycaemic control, chronic lung disease and urgent surgical priority were the predictors of DSWI common to both models. The models showed high predictive power and moderate accuracy of prediction. The preoperative model performed better than five of six scoring systems for sternal wound infection that were considered [7–11, 23]; the combined model performed better than three considered scoring systems [8–10]. Of the six scoring systems that were considered for comparison, three had been tested for sternal wound infection after CABG surgery [7, 23] or any cardiac operation [8] and three for (any) surgical site infection after CABG surgery [9–11], whereas the focus of the present analysis was on DSWI following BITA grafting; therefore, the target of the Gatti score is the DSWI after BITA use. Thus, it was expected that the Gatti score would perform better than the other scoring systems considered in predicting

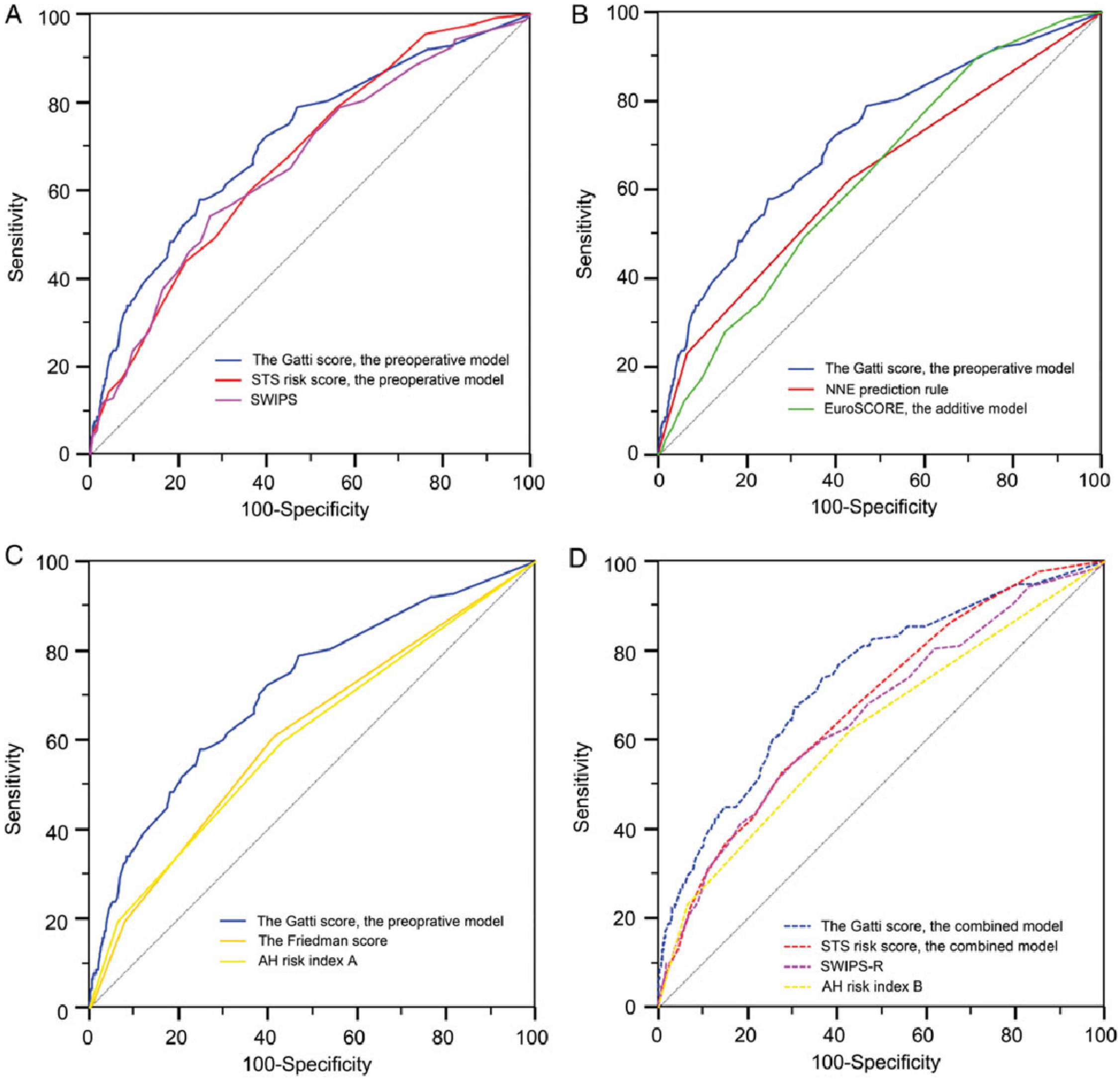

Figure 2: The new predictive scoring system for DSWI after BITA grafting (the Gatti score, the preoperative model; AUC = 0.72, 95% CI: 0.7–0.73) versus: (**A**) STS risk score, the preoperative model (AUC = 0.69, 95% CI: 0.67–0.71; $P = 0.14$) and SWIPS (AUC = 0.65, 95% CI: 0.64–0.67; $P = 0.012$); (**B**) NNE prediction rule for mediastinitis (AUC = 0.65, 95% CI: 0.63–0.67; $P = 0.0046$) and EuroSCORE, the additive model (AUC = 0.62, 95% CI: 0.6–0.64; $P = 0.0007$) and (**C**) the Friedman score (AUC = 0.62; 95% CI: 0.6–0.63; $P = 0.0002$) and AH risk index A (AUC = 0.59, 95% CI: 0.57–0.61; $P < 0.0001$). (**D**) The new predictive scoring system for DSWI after BITA grafting (the Gatti score, the combined model; AUC = 0.73, 95% CI: 0.72–0.75) versus: STS risk score, the combined model (AUC = 0.66, 95% CI: 0.64–0.68; $P = 0.002$); SWIPS-R (AUC = 0.64, 95% CI: 0.63–0.66; $P = 0.0012$) and AH risk index B (AUC = 0.6, 95% CI: 0.58–0.61; $P < 0.0001$). AH: Alfred Hospital; AUC: area under the receiver-operating characteristic curve; BITA: bilateral internal thoracic artery; CI: confidence interval; DSWI: deep sternal wound infection; EuroSCORE: the European System for Cardiac Operation Evaluation; NNE: the Northern New England Cardiovascular Disease Study Group; STS: the Society of Thoracic Surgeons; SWIPS(-R): sternal wound infection prediction scale (-revisited).

DSWI after BITA grafting because of its absolute specificity in respect to the relatively low specificity of the others (even though there are no other more specific scoring systems for DSWI after CABG surgery [25]).

Study limitations

The primary limitation of the present study is the retrospective nature of the analysis performed on a relatively small number of patients operated on in a single institution. The present authors' predictive scoring system has not been validated by using other more numerous datasets. Of course, this validation will be performed with further data collected prospectively. However, a positive internal validation procedure based on bootstrap was performed for both models. Although the surgeons' notes on wound revisions have been reviewed to ensure that the definitions were in accordance with The Centers for Disease Control and Prevention classification of the surgical site infections [17], there is the possibility that some superficial incisional infections were misclassified as deep incisional infections. Since serum levels of glycated haemoglobin have not been available, preoperatively, for every patient of this retrospective study, basal serum glucose >200 mg/dl at three consecutive measurements before surgery was adopted as the marker of poor preoperative glycaemic control. The predictive system has to be implemented with the use of preoperative glycated haemoglobin according to internationally agreed guidance [1]. This study did not evaluate the contribution to DSWI risk of potentially important factors such as causative pathogens, antibiotic prophylaxis and preoperative patient preparation. Last but not least, the impact of operative methods such as off-pump technique on the risk of DSWI was not analysed. However, according to the present authors' institutional policy, off-pump and beating heart on-pump techniques were adopted only in the presence of a calcified ascending aorta. Thus, there is a significant selection bias that prevents this analysis.

How to use the predictive scoring system

There are many ways of using the present predictive scoring system by the surgeon for her/his patient, depending on the relative weight in the choice of the following variables: (i) the age of the patient; (ii) the depth of surgeon's persuasion about the long-term survival benefits from the use of BITA grafting and (iii) the rate of DSWI after CABG surgery at the surgeon's institution and the percentage of successful treatment. For example, the surgeon persuaded of the long-term survival benefits from BITA grafting but, concerned about the risk of DSWI due to the high rate of sternal complications after CABG surgery at her/his institution, would choose the preoperative model of the scoring system in order to exclude from the use of BITA graft patients aged 70 (or 75) or older with an expected risk of DSWI >10%; the surgeon persuaded of the long-term benefits from BITA use and, working at an institution with a low rate of sternal complications, would use the preoperative model of the scoring system to exclude patients aged 70 (or 75) or older with an expected risk of DSWI >15% and every patient with an expected risk of DSWI >20% (regardless of age); the surgeon, firmly convinced of the BITA benefits, would adopt BITA grafting for every patient regardless of age and use the combined model of the scoring system to identify the high-risk patients for DSWI in order to follow them closely early on after surgery and to perform a more aggressive treatment of superficial wound infections.

In principle, to limit the risk of sternal wound infection after BITA grafting, three requirements are needed for the surgeon: (i) to know about the risk factors for sternal wound infection of the patient that he/she will operate on; (ii) to perform a reasonable preoperative selection of the patients according to these risk factors and (iii) to adopt effective measures of prevention and treatment. It was the intention of the present authors to create a predictive scoring system in order to reduce the rate of DSWI following CABG surgery without giving up too much in the sense of the long-term survival benefits derived from the use of BITA grafts. The authors do not presume to assign rigid rules; their intention was simply to suggest humbly a way to perform the selection of the patients.

Conflict of interest: none declared.

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