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Open chest and delayed sternal closure after cardiac surgery

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Abstract *Objectives:* Open chest (OC) and subsequent delayed sternal closure (DSC) has been described as a useful method in the treatment of the severely impaired heart after cardiac surgery.
Methods: Prolonged open chest was used in 142 to 3373 adult cardiac operations (4.2%) between January 1987 and December 1993. The indications were: hemodynamic compromise (121), intractable bleeding (9) and arrhythmias (12). Delayed sternal closure was carried out in 123 of 142 patients at a mean of 2.0 ± 1.4 days (range 0.5–8 days). Open chest and DSC were used proportionally more frequently after combined cardiac surgery (28/293, 9.6%) than after coronary artery bypass grafting (CABG) alone (108/2891, 3.7%) or valve operation (6/230, 2.6%).
Results: Ninety-seven of the 123 who had DSC (78.9%) survived and were discharged an average of 8.6 ± 4.2 days after closure. Fourty-five patients died: 19 before DSC and 26 after this method. Mortality was related to indications for OC: when the indication was low cardiac output the mortality was 38.6%, for hemodynamic collapse on closure 0%, diffuse bleeding 33.3% and arrhythmias 27.3%. Delayed sternal closure in patients without intra-aortic balloon pump support was more likely to be successful (mortality rate 4/25, 16.0% versus 35/76, 46.3%, $P < 0.01$). Superficial sternal wound infection occurred in 2 of 123 (1.6%) patients after DSC, mediastinitis in 1 (0.8%) and sternal dehiscence in 3 (2.4%) patients, which does not differ from a control population that had primary sternal closure. The follow-up of 97 survivors at an average of 28 ± 4 months revealed an improvement of NYHA class by 1.4 ± 0.4. There were 16 deaths (13 cardia-related) during the follow-up period and 3 redo CABG. One case of sternal osteomyelitis occurred without any other late sternal morbidity.
Conclusions: This study shows that OC with DSC is a beneficial adjunct in the treatment of postoperatively impaired cardiac function, profuse hemorrhage and persistent arrhythmias. It can be performed without increased sternal morbidity. Long-term results are also encouraging. [Eur J Cardio-thorac Surg (1996) 10: 305–311]

Key words Cardiac surgery · Open chest · Delayed sternal closure · Complications · Intra-aortic balloon pump

Introduction

Open chest (OC) with subsequent delayed sternal closure (DSC) has been described as a useful method in the treatment of severely impaired heart [3, 12, 13, 18], uncontrollable hemorrhage [14, 22], intractable arrhythmias [13, 15], reperfusion myocardial edema [3, 16] or when either ventricular assist devices [13] or transthoracic intra-aortic balloon pumps (IABP) [17, 22] are required after cardiac surgery. Most of the reports in the literature involve either small groups of patients, 10–60 [12, 19, 20] or are case reports [3, 9, 22]. The only large series of patients treated with open chest and delayed sternal closure as yet presented in the literature is that of Furnary et al. [13], who described the outcome and results of DSC in 107 patients.

This report describes our experience with the OC/DSC technique after cardiac operations in 142 patients. We have tried to identify the risks and benefits of this technique and to delineate variables associated with the outcome.

Patients and methods

Three thousand, three hundred seventy-three patients underwend cardiac surgery, using cardiopulmonary bypass (CPB), at Hôpital de la Tour, Geneva, Switzerland between January 1987 and December 1993. Since May 1990 operations have also been performed at Clinique de Genolier, Genolier. All operations were carried out by the same surgical team. Because of our special interest and wide experience, our patient population has a much larger proportion of high risk patients than normally encountered at most cardiovascular counterpart institutions, e.g. those undergoing redo and re-redo coronary artery bypass grafting (CABG, 20%) and those with diffuse coronary disease and extremely poor preoperative left ventricular function (5%) [4–6, 25]. Standard anesthesia, CPB and surgical techniques were employed. For myocardial protection we used cold intermittent cardioplegic solution (St Thomas' II, including allopurinol) infused with low pressure into the aortic root (or directly into the coronary ostia in cases of aortic valve surgery) together with topical hypothermia with slush. The myocardial protection remained the same throughout the study period. All patients received prophylactic antibiotics, cephalosporine (cefamandole or ceftriaxone) at induction of anesthesia and, as a routine, for 48 h postoperatively. In cases of DSC intravenous antibiotics were continued until the removal of the mediastinal drains. Nasogastric tubes were placed in all patients. Antacids and H2-blockers were routinely administered for prophylaxis against stress ulcerations. The patients were normally extubated within 24 h and oral fluids were started.

Open sternotomy and DSC was used in 142 (4.2%) of these patients. There were 94 men and 48 women, with an average age of 62.3±9.6 years (range 27–81 years). The operations included are summarized in Table 1. Redo operations (61) accounted for 43% of the total series of OC. The operative procedures were classified as elevative in 78% (111), urgent in 16% (22) and emergency in 6% (9). One hundred twenty-four patients (87%) were in NYHA (New York Heart Association) functional class 3 or 4 preoperatively. The mean preoperative left ventricular ejection fraction (LVEF), as calculated from the preoperative ventriculography, was 46.2±19.6% (range 15–84%). Preoperative LVEF less than 40% was seen in 43 patients (30%). Aortic cross-clamping times ranged from 0 to 177 min (mean 76.6±29.8 min), and the total CPB time ranged from 33 to 328 min (mean 129.0±63.6 min).

Table 1 Incidence of open chest and delayed sternal closure according to type of operation, January 1, 1987–December 31, 1993

	Total no.	Open chest	%Open chest
CABG alone	2891	108	3.7
CABG + Jatene corr.	60	3	5.0
CABG + valve	121	15[a]	12.4
CABG + carotid TEA	69	5	7.2
CABG + valve + carotid TEA	6	1	16.7
CABG + ascending aorta	8	4	50.0
Valve alone	227	6[b]	2.6
Valve + ascending aorta	22	0	0.0
Total	3373	142	4.2

[a] 11 aortic valves, 4 mitral valves (ischemic)
[b] 5 double valve operations and 1 single valve operation

Table 2 Indications for open chest and delayed sternal closure after cardiac operations in 142 patients

Postoperative low cardiac output	101	71.1%
With IABP 76 patients		
Without IABP 25 patients		
Hemodynamic breakdown on closure	20	14.1%
Diffuse bleeding	9	6.3%
Arrhythmias	12	8.5%

Table 3 Cause of low postoperative cardiac output and hemodynamic breakdown at attempted sternal closure in 121 patients

Perioperative myocardial infarction		48	39.4%
Left ventricle	29		
Right ventricle	19		
Low cardiac output due to poor ventricular function without obvious reasons		53	43.8%
Myocardial edema		20	13.0%

The indications for OC and DSC are presented in Table 2. Postoperative low cardiac output was defined as a cardiac index less than 2.0 l/min per m^2 requiring combined pharmacologic inotrope support (dopamine, dobutamine, epinephrine, amrinone) administered intravenously with or without additional IABP. One of the surgeons (MS) preferred the aortic route of insertion of IABP, whenever required, leaving the chest open when indicated, followed by DSC. The intra-aortic insertion of the IABP is easy and has a direct and safe access for insertion under vision. Even though the sternum can be closed using the aortic route of IABP and can be brought out by a substernal graft, we opted for the less complicated alternative, namely leaving the chest open, since we found earlier that DSC did not lead to any added complications [20]. The safety of using the ascending aorta for insertion of IABP has been verified by others [23]. A total of 57 IABP were inserted through the ascending aorta and this group was separately analyzed in order to evaluate its influence on the total series. The underlying causes of postoperative low cardiac output and hemodynamic breakdown on attempting sternal closure in 121 patients are shown in Table 3.

All patients that became hemodynamically unstable upon attempted sternal closure had markedly edematous ventricles. Nine pa-

tients (6%) had massive coagulopathic postoperative bleeding, which prevented safe closure of the sternum. These wounds were packed with sterile laparotomy pads, which were frequently changed while coagulation factors were replaced. Twelve patients (9%) were left with OC because of relentless arrhythmias requiring multiple cardioversions and frequent open cardiac massage that necessitated rapid and repeated access to the heart.

Maintainance of the open chest

The temporary closure of the wound was achieved by a sterile zipper (Ethizip)[1] fashioned to fit the open sternotomy and thereafter sutured to the skin by a continuous suture [1], followed by a second cover using a Steri-Drape plastic film[2]. No local antibiotics were used, but all exposures were performed using strict, sterile techniques, including povidone-iodine (Betadine)[3] preparation of the entire chest wall and rinsing of the chest cavity with Betadine.

The delayed sternal closure

The timing for the DSC was determined by repeated inspections of the heart, evaluation of the level of pharmacologic support and IABP support, correction of coagulation defects, improved hemodynamic response and determination of the response to temporary reapproximation of the sternum. The DSC was routinely performed in the intensive care unit, thus avoiding the potential danger of transportation of the critically ill patient. Debridement of all non-viable tissue and meticulous cleaning with Betadine solution were performed. Bacterial cultures were taken from the chest wound. Two mediastinal drains as well as pleural drains, when necessary, were placed. The sternum was refixed with 4 Ethibond[1] sutures (figure of 8), followed by closure of the subcutaneous tissue and the skin in layers. Intravenous administration of antibiotics was continued until the final removal of the mediastinal drains.

All patient data for analysis was obtained from a computerized database (Digital)[4]. Perioperative death was defined as death for any reason occurring within 30 days after the operation. Sternal, neurologic, renal, respiratory, and infectious morbidity were tallied. Sternal morbidity was defined as bacteriologically confirmed superficial wound infection, mediastinitis, sternal dehiscence and need for refixation of grossly unstable sternum.

Postoperative follow-up was achieved through contact with the treating physicians to determine NYHA functional class, to complete survival analysis and to identify delayed sternal complications.

Statistics

Statistical analysis was carried out using paired and unpaired Student's *t*-test, chi-square tests, stepwise regression analysis and Kaplan-Meier survival analysis as appropriate. Significance levels were set at a probability value less than 0.05.

Results

The chest was closed definitively in 123 patients at a mean of 2.0 ± 1.4 days (ranging from 6 h to 8 days) after the initial cardiac procedures.

[1] Ethicon, Edinburgh, UK
[2] 3M, St. Paul, MN, USA
[3] Betadine, Purdue Frederick Co, Norwalk, CT, USA
[4] Digital Equipment Corp., Geneva, Switzerland

Table 4 Perioperative complications

	No.	%
Mortality	45	31.7
Respiratory[a]	28	19.7
Renal[b]	45	31.7
Neurologic[c]	6	4.2
Gastro-intestinal[d]	14	9.9
Septicemia	2	1.4
Multiple organ failure	11	7.8

[a] Ventilatory support >24 h
[b] S-Urea >9 mmol/l, S-Creatinine >125 µmol/l
[c] Any transient or permanent neurologic deficit occurring after the operative procedure
[d] Includes confirmed diagnosis of – upper or lower – gastro-intestinal hemorrhage, intestinal ischemia, acute cholecystitis and pancreatitis

Table 5 Mortality according to indication for open chest and delayed sternal closure

Low cardiac output	39/101	38.6%	
With IABP support	35/76		46.1%
			$P<0.01$
Without IABP support	4/25		16.0%
Hemodynamic breakdown	0/20	0.0%	
Diffuse bleeding	3/9	33.3%	
Arrhythmia	3/12	27.3%	

Mortality

The overall mortality rate was 31.7% (45/142). The incidences of major perioperative complications are presented in Table 4. Forty-five patients died: 19 before the DSC and 26 after this. When the indication for OC treatment was low postoperative cardiac output the mortality was 38.6%, untractable hemorrhage 33.3%, arrhythmias 27.3% and hemodynamic breakdown upon closure of the chest 0.0% (Table 5). Delayed sternal closure in patients without IABP support was more likely to be successful. The mortality rate in patients with IABP was 46.3% (35/76) compared to 16.0% (4/25) when IABP was not required, $P<0.01$. The primary cause of death was: low cardiac output due to perioperative myocardial infarction (10 patients), low cardiac output due to poor ventricular function without obvious reasons (11), gastro-intestinal complications (9), adult respiratory distress syndrome (5), bleeding (3), arrhythmias (3), neurologic complications (2) and septicemia (2).

In 121 patients requiring OC and DSC because of postoperative low cardiac output or hemodynamic breakdown on closure, the mean cardiac index was 1.6 ± 0.2 l/min per m^2. The central venous pressure (CVP) was 12 ± 2 mmHg. Prior to sternal closure 101 surviving patients had a mean cardiac index of 2.7 ± 0.2 l/min per m^2 and the CVP was

Table 6 Sternal related complications after DSC and control patients who had primary sternal closure, all surviving at least 10 days postoperatively

	Delayed closure [$n=123$]		Controls [$n=3178$]		
	No.	[%]	No.	[%]	
Sternal wound infection	2	1.6	58	1.8	n.s.
Mediastinitis	1	0.8	4	0.1	n.s.
Sternal dehiscence	3	2.4	80	2.5	n.s.
Refixation required	2	1.6	14	0.4	n.s.

Table 7 Incidence of redo surgery and urgency of the operation a comparison between patients with DSC and controls

	DSC $n=142$		Controls $n=3373$		P value
Reoperation	61	43.0%	460	13.6%	$P<0.001$
Emergency op.	9	6.3%	84	2.5%	$P<0.001$
Urgent op	22	15.5%	486	14.4%	n.s.
Elective op.	111	78.2%	2803	83.1%	n.s.

12±2 mmHg. No significant changes occurred after closure. Ninety-seven patients survived (97/123) 78.9% and were discharged from the hospital on an average of 11.6±5.2 days following the sternal closure.

Sternal morbidity

Sternum-related morbidity in 123 patients with DSC and in 3210 patients who had primary sternal closure after cardiac surgery and who survived at least 10 days, is summarized in Table 6. There were two patients with superficial sternal wound infections (1.6%) after DSC. They were all successfully treated with antibiotics and local debridement. Only one patient in the DSC group had mediastinitis and subsequently died. Various degrees of sternal instability were observed in three patients, two of whom required sternal refixation. Sternal wound cultures were found to be negative in 89 of 97 surviving patients in the DSC group. The positive cultures revealed *Staphylococcus aureus* in four, *S. epidermidis* in three and *Enterococcus* in one patient. Notably, no statistically significant differences could be calculated concerning sternal morbidity between the DSC group and control patients (primary closure) Table 6.

The average time of OC (time between operation and DSC) was significantly longer in patients that subsequently developed sternal wound infection, 80±16 h, and mediastinitis 108.0 h (only one case), compared to those who did not have any sternal complications, 48±33 h.

Risk factors

Reoperative cardiac surgery and emergency operations were significantly more frequent in patients treated with OC and DSC compared to patients with primary sternal closure (controls), Table 7. Other preoperative patient characteristics did not differ between the groups.

Follow-up

Follow-up was completed in 99% (96/97) of the patients surviving DSC, at an average of 32±4 months after discharge from the hospital (observation range 2–60 months). The average NYHA functional class at follow-up was 1.4±0.4 (NYHA class I 53, NYHA class II 22, NYHA class III 4 and NYHA class IV 0). During the follow-up 16 deaths occurred (16.8%). Thirteen of these deaths were cardiac-related (ventricular failure 10, sudden deaths 3), while one patient each died from a gastro-intestinal malignancy, a renal failure and a stroke. There was only one late sternal infection (sternal osteomyelitis) diagnosed 7 months postoperatively, requiring sternal revision and reosteosynthesis. Kaplan-Meier survival analysis was performed (Fig. 1) and demonstrated a 73.4% survival rate at 5 years.

Separate analysis

The 57 patients who had IABP inserted in the ascending aorta combined with OC and DSC were analyzed separately and this revealed that age and sex distribution as well as the incidence of preoperative risk factors were the same as for the entire series of DSC. Ninety-seven per cent of the patients were in NYHA functional class III or IV, 40% underwent emergency and urgent surgery and 50% of the operations were redos. All patients had 3-vessel coronary artery disease and the mean LVEF was 49.5±17.8, which is not significantly different from that of the total series. Aortic cross-clamping time and CPB time did not differ (81.6±29.6 min vs 76.6±29.8 min and 134.4±58.8 min vs 129.0±63.6 min).

Delayed sternal closure was carried out in 49 of the 57 patients in this group at a mean of 2.9±1.5 days (12 h–6 days) compared to 2.0±1.4 days for the entire series. Mortality was 39% (22/57 patients) compared to 27% (23) of the remaining 85 patients. There were no bleeding problems and no neurologic complications in this group. Furthermore there was no evidence of embolization on catheter removal, as there were no additional chest wound problems in this particular group. The causes of deaths were: low cardiac output with or without evidence of myocardial infarction in 16 patients, adult respiratory distress syn-

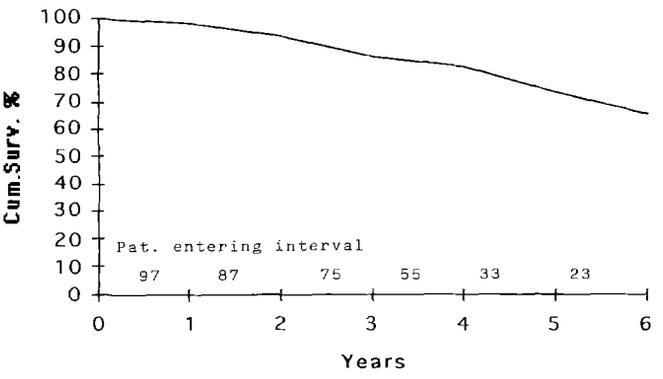

Fig. 1 Kaplan-Meier survival analysis of patients who were discharged from hospital after delayed sternal closure. Follow-up was completed in 99% (96/97) of the surviving patients at a mean of 32 ± 4 months (range 2–60 months). Survival is 73.4% at 5 years

drome in 2, gastro-intestinal complications in 3 patients (acute pancreatitis, 2, acute upper GI bleeding, 1) and septicemia in 1 patient. The 5-year survival rate (45 patients) did not differ from that calculatd for the entire group of patients with DSC, 75.1% vs. 73.4%.

Discussion

In the early days of cardiac surgery primary closure of the chest at the end of the operation was mandatory because of the fear of mediastinal infection. Recently several reports have appeared in the literature describing prolonged OC and subsequent DSC as a life-saving procedure in patients with uncontrollable hemorrhage, myocardial edema, low cardiac output and arrhythmias postoperatively [12, 13, 16, 20, 24]. However, most of these reports are either case reports or small series of patients, which do not allow for proper evaluation of the risks and benefits of this unorthodox approach. Restriction of diastolic filling is the main point at which there is a disproportion in the cardiac to mediastinal relationship, leading to compression or tamponade as described by Matsumoto [16]. Excessive myocardial edema can also lead to this complication. Severe pulmonary emphyema can compress the heart in a similar way.

Sternal closure has been shown to result in a significant decrease in cardiac output and diastolic filling, despite preserved velocity of fiber shortening, even in patients with good cardiac performance [16]. These effects are magnified in the presence of poor ventricular compliance secondary to ischemia, reperfusion and edema. Furnary et al. [13] have recently and elegantly demonstrated that low cardiac output can be improved by the opening of the sternum. After the sternal incision had been reopened there was a 59% increase in cardiac index and a 18% rise in systemic blood pressure, without significant change in cardiac filling pressures [13]. The hemodynamic data in our series regarding patients treated with OC and DSC because of postoperative low cardiac output and hemodynamic breakdown on closure corresponds well with those previously described by Furnary et al. [13].

The overall incidence (4.2%) of OC after cardiac operations at our institution is slightly higher than earlier reported, 1.7% [12, 13, 18]. The extraordinarily high proportion of high risk patients (redos, diffuse coronary artery disease and extremely poor preoparative left ventricular function) in our patient population may well explain the relatively high incidence of OC and DSC in this series. The myocardial protection employed did no change during the study period and has proven its efficiency since, for the 3231 patients not requiring OC treatment, the hospital mortality rate was 2.6% (84 patients) and the incidence of perioperative myocardial infarction was 1.1% (36 patients). However, the indications for OC treatment, in our series, are similar to those reported by others [12, 13, 15]. Our survival rates after OC treatment (68.4%) and DSC (81.7%) are similar or even better than published reports [12, 13, 19].

Patients who required OC treatment had a higher incidence of emergency or urgent operations, 21.8% and reoperative surgery (43%) as well as a moderately depressed LVEF, 46.2 ± 19.6%. After the operation, postoperative low cardiac output was evident in 71.1% of the patients, all requiring the use of inotrope pharmacologic support, and additional IABP in 75.3% of these patients. Mortality rate was also the highest in this group of patients. In patients where the IABP is required for postcardiotomy failing heart as an additional support, the mortality rate described in the literature corresponds to the mortality rate in our series, 30–56% [1, 7, 10, 21].

Severe bleeding at the termination of CPB, undue increase in heart size with resultant severe ventricular dysfunction and, relentless arrhythmias are potentially life-threatening complications of cardiac operations. They are often also associated with a prolonged perfusion time and poor myocardial preservation [12–14]. Treatment by OC in these cases allows time for recovery of the heart and for the bleeding to stop, while totally isolating the mediastinal structures from the outside environment. There is the added advantage of allowing the surgeon easy access to the mediastinum for evacuation of blood and clots after cardiac tamponade and for application of internal defibrillation and direct cardiac massage [15]. Relentless arrhythmia as an indication for OC has been reported by Furnary et al. [13]. The group of patients undergoing DSC are particularly at risk for infection, because they have predisposing factors such as: prolonged CPB time, low cardiac output, excessive bleeding and the need for multiple re-explorations of the chest [8]. It is therefore interesting to note that, in our series, the incidence of wound infections, med-

iastinitis and sternal dehiscence after OC and DSC was not significantly different from a control population that had primary sternal closure. The incidence of mediastinal infection after routine cardiac operations is reported to be greater than 1.5% [11]. Low incidence of sternal morbidity after DSC has also been reported by others [12, 13, 18, 19].

The effect of the time of OC treatment on sternal morbidity have not been addressed previously. In our series a longer time period before sternal closure was observed in those patients who subsequently developed sternal complications.

Many different techniques for the maintenance of OC have been described in the literature [2, 14, 16, 18]. However, we have applied the technique originally described by Applebaum et al. [2] using a wound zipper, and the effectiveness of this technique is reflected in the low sternal morbidity. In our series DSC could be performed in 123 patients (86.6%) on an average of 2.0 ± 1.4 days (ranging from 6 h to 8 days) which is in conformity with previous reports [12, 13, 16]. The average time of OC (time between operation and DSC) was longer in patients who subsequently developed sternal wound infection and mediastinitis, compared to those who did not have any sternal complications. Even though the postoperative mortality rate is rather high in this group of patients, the long-term follow-up results are encouraging: a 5-year survival rate of 73.4% and a low rate of late sternal complications. The average NYHA functional class at follow-up was significantly improved, 1.4 ± 0.4. These findings correspond well to a recent report on follow-up after DSC [13].

When sternal closure results in hypotension from significant cardiac compression, aggressive means to improve cardiac function should be instituted, including diuretics, inotrope agents etc. Consideration should be given to opening wide both pleural cavities (if not already done) and possibly resecting the pericardium. If such measures are unsuccessful, leaving the chest open may permit some degree of hemodynamic improvement. In situations of uncontrollable bleeding or relentless arrhythmias too, leaving the chest open for easy access should be considered. When IABP is required, in cases of postoperative low cardiac output, a transthoracic route of insertion may be preferred by the surgeon [26] and the chest wound might be left open. Continued support facilitates the reversal of cardiopulmonary dysfunction and hemostatic defects which in turn, permits successful DSC in most patients. Our study had demonstrated that this treatment modality can be used with a low sternal morbidity.

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