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Management of the Infected Median Sternotomy Wound with Muscle Flaps

The Emory 20-Year Experience

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Objective
The purpose of the study is to define those patient variables that contribute to morbidity and mortality of median sternotomy wound infection and the results of treatment by debridement and closure by muscle flaps.

Background
Infection of the median sternotomy wound after open heart surgery is a devastating complication associated with significant mortality. Twenty years ago, these wounds were treated with either open packing or antibiotic irrigation, with a mortality approaching 50% in some series. In 1975, the authors began treating these wounds with radical sternal debridement followed by closure using muscle or omental flaps. The mortality of sternal wound infection has dropped to <10%.

Methods
The authors' total experience with 409 patients treated over 20 years is described in relation to flap choices, hospital days after sternal wound closure, and incidence rates of morbidity and mortality. One hundred eighty-six patients treated since January 1988 were studied to determine which patient variables had impact on rates of flap closure complications, recurrent sternal wound infection, or death. Variables included obesity, history of smoking, hypertension, diabetes, poststernotomy septicemia, internal mammary artery harvest, use of intra-aortic balloon pump, and perioperative myocardial infarction and were analyzed using chi square tests, Fisher's exact tests, and multivariable logistic regression analysis.

Results
The mortality rate over 20 years was 8.1% (33/49). Additional procedures for recurrent sternal wound infection were necessary in 5.1% of patients. Thirty-one patients (7.6%) required treatment for hematoma, and 11 patients (2.7%) required hernia repair. Among patients treated since 1988, variables strongly associated with mortality were septicemia ($p < 0.00001$), perioperative myocardial infarction ($p = 0.006$), and intra-aortic balloon pump

(p = 0.0168). Factors associated with wound closure complications were intra-aortic balloon pump (p = 0.0287), hypertension (p = 0.0335), and history of smoking (p = 0.0741). Factors associated with recurrent infection were history of sternotomy (p = 0.008) and patients treated for sternal wound infection from 1988 to 1992 (p = 0.024). Mean hospital stay after sternal wound reconstruction declined from 18.6 days (1988–1992) to 12.4 days (1993–1996) (p = 0.005). To clarify management decisions of these difficult cases, a classification of sternal wound infection is presented.

Conclusions

Using the principles of sternal wound debridement and early flap coverage, the authors have achieved a significant reduction in mortality after sternal wound infection and have reduced the mean hospital stay after sternal wound closure of these critically ill patients. Further reductions in mortality will depend on earlier detection of mediastinitis, before onset of septicemia, and ongoing improvements in the critical care of patients with multisystem organ failure.

The median sternotomy incision was first described for use in cardiac surgery by Julian et al.[1] in 1957. Initial acceptance of this approach was hampered by reports of 5% infection rates, which invariably led to sternal dehiscence, often associated with cardiac exposure.[2] Infection with sternal dehiscence was associated with a 50% mortality in early series.[3] Early treatment protocols used open packing of the debrided wound and required months to achieve a healed wound if the patient did not die of cardiac or vein graft rupture in the interim. Subsequent treatment[2,4] focused on the use of debridement coupled with antibiotic irrigation administered through closed indwelling catheter systems. This technique, still in use, was a major advance and reduced the mortality to 20%.[5] Problems of bypass graft desiccation, even in this apparently moist environment, can lead to an unacceptably high incidence of graft rupture and death. Hospital stay and morbidity is inordinately prolonged, however, with some patients spending as long as 6 months receiving treatment.[6]

In 1976, Lee et al.[7] described the use of omentum to successfully close an open mediastinal defect. Our group introduced the concept of sternectomy followed by muscle flap or omental flap closure in 1975 and reported the first 12 patients treated with this technique in 1977, all of whom did not respond to debridement and closed catheter irrigation.[8,9] Nine (75%) of these 12 patients were salvaged with this technique. The ensuing years saw the introduction of numerous pedicled muscle flaps for the treatment of complex wounds, including pectoralis major, rectus abdominis, and latissimus dorsi. Use of these flaps found ready application as an alternative to omentum in the management of the infected sternal wound and continued the trend in mortality reduction.[9–11] The technique has proved effective in children as well as in heart transplant recipients.[12–14]

These procedures have formed the basis of our therapy for the salvage of median sternotomy wound infections over the past 20 years and have reduced substantially both hospital stay and mortality from this difficult problem.[10]

MATERIALS AND METHODS

Data on all patients who underwent sternal wound reconstruction with muscle or omentum flaps for the management of the infected median sternotomy at Emory University Hospital or Crawford W. Long Memorial Hospital from 1975 to 1996 were gathered from previous reports from our service[9,10] and chart review. These data describe flap choices, hospital days after sternal wound reconstruction, and incidence rates of complications, specifically hematoma, abdominal hernia, recurrent infection (*e.g.*, osteitis or osteochondritis), and death.

To evaluate the impact of specific patient variables on outcome, records of patients who underwent sternal wound reconstruction from January 1988 through June 1996 were reviewed precisely. Endpoints include the following:

1. Mortality: death from any cause within 30 days of flap reconstruction or at any interval if the death was related to sternal wound infection.
2. Flap closure complications: patients who experienced hematoma, partial flap loss, total flap loss, nonpurulent wound dehiscence, abdominal hernia, or re-exploration for wound necrosis.

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Table 1. FLAP CHOICES IN STERNAL WOUND RECONSTRUCTION: 1975–JUNE 1996 (409 PATIENTS)

	No.	%
Pectoralis major	440	65.2
Rectus abdominis	202	29.9
Omentum	16	2.4
Other	17	2.5

Table 2. MORTALITY AND MORBIDITY OVER 20 YEARS (409 PATIENTS)

	No.	%
Mortality	33/409	8.1
Hematoma	31/409	7.6
Hernia	11/409	2.7
Osteochondritis	21/409	5.1

3. Recurrent sternal wound infection: patients who required re-exploration to drain or debride septic foci for recurrent or residual infection.

Comparisons were made of length of hospital stay after sternal wound reconstruction. Risk factors considered in these analyses were age; gender; hypertension; chronic steroid use; insulin-dependent or noninsulin-dependent diabetes; chronic renal failure (on dialysis); obesity (25% or more over ideal body weight*); chronic obstructive pulmonary disease; history of smoking (20 or more pack years); previous median sternotomy; recent cerebrovascular accident (between median sternotomy and sternal wound reconstruction); perioperative acute myocardial infarction; harvest of either internal mammary artery (IMA) for coronary artery bypass grafting; placement of an intraaortic balloon pump (IABP); re-exploration of sternotomy wound for hemorrhage, for example; and septicemia before sternal wound reconstruction. Additional factors of interest in the detailed study group were whether the sternal wound reconstruction was performed earlier (1988–1992) or later (1993–1996) in the series, whether the infection was suprasternal or involved the sternum (''mediastinitis''), and whether the wound was treated by our service in one or two stages.

Sample means for hospital stay after sternal wound reconstruction among patients treated after 1987 were analyzed using Student's t test. Crude analyses for risk factors *versus* the three endpoints were performed using 2 $\times$ 2 contingency chi squares with Yates' correction for continuity. When the expected value in any cell was <5, Fisher's exact test was used.[15] Ninety-five percent confidence limits for the odds ratio were calculated for outcomes associated with a p value < 0.1. To further clarify independent factor association with outcome, multivariable backward stepwise logistic regression analyses were performed using the maximum likelihood estimation method (SPSS 6.1, SPSS Inc., Chicago, IL).[15,16]

* Ideal body weight defined as follows: men, 106 lbs for height of 5 ft (add 6 lbs for each inch above 5 ft); women, 100 lbs for height of 5 ft (add 5 lbs for each inch above 5 ft).

RESULTS

From January 1975 through June 1996, 409 patients underwent sternal wound reconstruction with various regional flaps; no cases required free-flap reconstruction. A total of 675 flaps were used (an average of 1.65 flaps per patient); pectoralis major flaps comprised 440 (65.2%) (Table 1). Thirty-one patients (7.8%) required re-exploration for hematoma, 11 (2.8%) had abdominal hernia develop, and 21 (5.6%) required re-exploration for recurrent sternal infection. The overall mortality rate for this 20-year series was 8.1% (Table 2).

Of the 186 patients treated from January 1988 through June 1996, 171 (91.9%) had mediastinitis, whereas 15 (8.1%) had suprasternal infections not communicating with the retrosternal space. When true mediastinitis with involved sternum occurred, the mortality was 9.9% (17 of 171 patients), whereas patients who were nonmediastinitis were predictably lower with a zero mortality. Overall mortality for this group was 9.1% (Table 3).

The pathogens responsible for infection were overwhelmingly gram positive (65%) *versus* gram negative (17.7%). Anaerobic infection occurred in only 1.2% of cases, whereas fungal infection (most commonly Aspergillus) accounted for 3.8% (Table 4). Most of our fungal

Table 3. EXTENT OF DEFECT AND ASSOCIATED MORTALITY: 1988–JUNE 1996 (186 PATIENTS)

	No.	%
Involved sternum	171	91.9
Mortality	17/171	9.9
Suprasternal	15	8.1
Mortality	0/15	—
Mortality/all cases	17/186	9.1

Table 4. PREDOMINANT PATHOGEN IN STERNAL WOUND RECONSTRUCTIONS: 1988–JUNE 1996 (186 PATIENTS)

	No.	%
Gram positive	121	65.1
Gram negative	33	17.7
Anaerobic	2	1.2
Fungal	7	3.8
Not recorded or necrosis only	15	8.1

infections were from an outside referral source in another state, where contamination of operating room equipment had occurred. Fifteen patients (8.1%) had no documented pathogen; some had negative cultures results (and may represent prior antibiotic administration), whereas others had sterile bony necrosis.

Table 5. RISK FACTORS AMONG PATIENTS: 1988–1996 (186 PATIENTS)

	No.	%
Age (yr) (mean, range)	61.9 (20–86)	—
Chronic steroids	12	6.5
COPD	58	31.2
CRF/on dialysis	6	3.2
CVA	14	7.5
Gender (male)	134	72
HTN	121	65.1
IABP	17	9.1
IDDM	36	19.4
NIDDM	37	19.9
IMA used	138	74.2
Obese	74	39.8
Perioperative AMI	43	23.1
Previous sternotomy	37	19.9
Rebleed/reexploration (poststernotomy)	32	17.2
Septicemia	51	27.4
Significant history of smoking (≥20 packs/yr)	109	58.6
SW operation/earlier in series (1988–1992)	87	46.8
SW operation/current (1993–1996)	99	53.2
Single stage SW reconstruction	162	87.1
Mediastinitis ("involved sternum")	171	91.9

COPD = chronic obstructive pulmonary disease; CRF = chronic renal failure; CVA = cerebrovascular accident; HTN = hypertension; IABP = intra-aortic balloon pump; IDDM = insulin-dependent diabetes mellitus; NIDDM = non-insulin-dependent diabetes mellitus; IMA = internal mammary artery; AMI = acute myocardial infarction; SW = sternal wound.

Table 6. INFERIOR MAMMARY ARTERY STATUS: 1988–1996 (186 PATIENTS)

	Suprasternal	Involved Sternum	All Cases
LIMA	13 (86.7)	114 (66.7)	127 (68.3)
RIMA	—	1 (0.6)	1 (0.5)
Bilateral IMAs	—	10 (5.8)	10 (5.4)
Any IMA	13 (86.7)	125 (73.1)	138 (74.2)
SVG only	1 (6.7)	21 (12.3)	22 (11.8)
Unclear or NA	1 (6.7)	24 (14)	25 (5.9)

Values are no. (%).
LIMA = left internal mammary artery; RIMA = right internal mammary artery; IMA = internal mammary artery; SVG = saphenous vein graph; NA = not applicable.

The most frequently observed risk factors among these patients were harvest of IMA (74.2%), hypertension (65.1%), and obesity (39.8%). Fifty-one patients (27.4%) had septicemia complicating their sternal wound management (Table 5). Further delineation of IMA status shows that 127 (68.3%) had revascularization with the left IMA, 1 (0.5%) had a right IMA, and 11 (6.4%) had bilateral harvest (Table 6). In 22 patients (11.8%), saphenous vein grafts alone were used, and in 25 cases (5.9%), records were incomplete (outside referrals) or patients underwent valve procedures, orthotopic heart transplants, or aortic arch repair.

Closure was achieved as either a single- or two-stage procedure in most cases. The trend in our practice since 1985 has been toward single-stage closure.[10] Between 1988 and 1996, 162 patients (87.1%) were closed as a single-stage procedure, whereas only 24 patients (12.9%) were closed in 2 stages (Table 7). This probably reflects a more radical approach to debridement, allowing closure of a totally excised wound.

Flap choices (Table 8) have remained fairly consistent throughout our experience,[10] although the past 4 years have seen a strong swing to almost exclusive use of the pectoralis major muscle flap as the flap of first choice, even for large inferior cavities toward the xiphisternum.

Table 7. NUMBER OF STAGES OF STERNAL WOUND PROCEDURES: 1988–1996 (186 PATIENTS)

No. of Stages	No.	%
1	162	87.1
2	24	12.9

Table 8. FLAP CHOICES: 1988–1996 (186 PATIENTS)

	Suprasternal	Involved Sternum	All Cases
Pectoralis major	12 (63.2)	201 (77.6)	213 (76.6)
Rectus abdominis	7 (36.8)	47 (18.1)	54 (19.4)
Omentum	—	6 (2.3)	6 (2.2)
Other	—	5 (1.9)	5 (1.8)
Total	19	259	278

Values are no. (%) of flaps.

Table 10. MORBIDITY FOLLOWING STERNAL WOUND RECONSTRUCTION: 1988–1996 (186 PATIENTS)

	No.	%
Flap closure complications	35/186	18.8
Hematoma	12	6.1
Partial flap loss	7	3.8
Wound dehiscence	12	6.1
Reexploration/wound necrosis	11	5.9
Abdominal hernia	4	2.2
Recurrent wound infection	12/186	6.5

Overall, the pectoralis major was used in 213 patients (76.6%), rectus abdominis in 54 patients (19.4%), omentum in 6 patients (2.2%), and other flaps such as the latissimus in 5 patients (1.8%). When compared with 223 patients treated between 1975 and 1987, the difference in flap selection becomes more apparent (Table 9). Among the earlier 397 flaps used, the pectoralis accounted for 57.2% and the rectus abdominis for 37.3%; use of the omentum and other flaps remained fairly consistent over 20 years.

Wound closure complications (Table 10) after these procedures occurred in 35 (18.8%) of 186 patients. Hematomas and wound dehiscence accounted for the highest number of problems (each 6.1%). No total flap losses occurred. Partial flap loss occurred in 3.8% of patients and abdominal hernias presented in 2.2% of patients (usually related to rectus harvest). Crude analysis showed that only IABP placement (41.2% *vs.* 16.7%, p = 0.0223, odds ratio, 3.5) was significantly associated with wound closure complications, whereas hypertension was marginally significant (23.1% *vs.* 10.8%, p = 0.063, odds ratio, 2.49) (all other factors not significant; data partially shown) (Table 11).

Four patients were eliminated from all multivariable logistic regression analyses because of missing data (they were referred from other institutions and their sternotomy records were incomplete), which left 182 patients for detailed factor analysis. The final regression model (p = 0.0043) for wound closure complications included IABP, hypertension, history of smoking, and septicemia (Table 12), although smoking and septicemia were only marginally significant (p = 0.0741 and 0.0885, respectively). All other risk factors were eliminated from the model.

Recurrent infection occurred in 12 (6.5%) of the 186 patients treated (Table 10). Incidence was numerically higher among patients who had a previous sternotomy (13.5% *vs.* 4.7%), IMA harvest (7.2% *vs.* 2.3%), earlier sternal wound reconstruction (9.2% *vs.* 4%), poststernotomy re-exploration (9.4% *vs.* 5.2%), or who were obese (9.5% *vs.* 4.5%), but because of the small number of patients who were affected, most of these differences did not reach significance using chi square or Fisher's exact tests (Table 13). History of sternotomy was a marginally significant factor (p = 0.065, odds ratio, 3.17) in the crude analysis. The final logistic regression model (p = 0.0076) included previous sternotomy and sternal wound reconstruction (1988–1992), plus IMA harvest as a marginally significant factor (p = 0.083) (Table 14). Again, all other risk factors were eliminated from the model.

Mortality among patients treated since 1988 was 9.1%. Twenty-five percent of patients who had septicemia at the time of diagnosis suffered death *versus* a 3% rate among patients who who did not have septicemia (p = 0.00001; odds ratio, 11.2) (Table 15). Perioperative myocardial infarction (20.9% *vs.* 5.6%, p = 0.0051; odds ratio, 4.4) and the use of an IABP (35.3% *vs.* 6.5%, p = 0.0016; odds ratio, 7.8) were both highly significant in the crude analysis and probably reflect the critically ill nature of these patients who are high risk. A history of chronic steroid use was marginally significant (25% *vs.* 8%, p = 0.083; odds ratio, 3.81). Mortality rates were numerically higher among patients who had a previous sternotomy (16.2% *vs.* 7.4%), cerebrovascular accident (21.4% *vs.* 8.1%), or poststernotomy re-exploration (12.5% *vs.*

Table 9. TRENDS IN FLAP CHOICES OVER 20 YEARS

	1975–1987 (397 flaps) (%)	1988–1996 (278 flaps) (%)
Pectoralis major	57.2	76.6
Rectus abdominis	37.3	19.4
Omentum	2.5	2.2
Other	3	1.8

Table 11. RISK FACTOR ASSOCIATION WITH WOUND CLOSURE COMPLICATIONS: 1988–1996 (186 PATIENTS)

Factor	Wound Closure Complications/Exposed	%	p Value	Odds Ratio	95% Confidence Limit
IABP	7/17	41.2	0.0223	3.5	1.23, 9.98
HTN	28/121	23.1	0.063	2.49	1.02, 6.08
Septicemia	14/51	27.5	0.10	2.05	0.95, 4.44 (NS)
CVA	5/14	35.7	0.145		NS
History of smoking	24/109	22	0.25		NS
COPD	14/58	24.1	0.295		NS
Obese	12/74	16.2	0.585		NS

IABP = intra-aortic balloon pump; HTN = hypertension; CVA = cerebrovascular accident; COPD = chronic obstructive pulmonary disease; NS = not significant.

8.5%), but these differences did not reach significance. The final logistic regression model ($p < 0.00001$) included septicemia, perioperative myocardial infarction, and IABP as major independent associated factors and cerebrovascular accident ($p = 0.091$) as a marginally associated factor (Table 16).

Hospital stay has been reduced significantly within the series as well as compared with other series reporting different techniques for management.[2,4,13,17,18] From 1975 through 1978, mean stay after sternal wound closure was 19 days (Table 17). Between 1979 and 1987, mean stay after sternal wound closure averaged 15.7 days, rising to 18.6 days between 1988 and 1992. Since 1992, a more radical approach to debridement and early closure in a single stage has evolved, leading to a reduction in mean stay after sternal wound closure to 12.4 days. Comparison of means between the 1987 to 1992 group and the 1993 to 1996 group was significant ($p = 0.005$). Median stay after sternal wound closure since 1988 was 10 days; the downward trend is displayed in Figure 1. Over the past 10 years, increasing use of home intravenous therapy for patients who require prolonged postoperative systemic antibiotics also has helped reduce hospital stay after sternal wound closure.

Table 12. FACTORS ASSOCIATED WITH WOUND CLOSURE COMPLICATIONS (182 PATIENTS): MULTIVARIABLE ANALYSIS/ LOGISTIC REGRESSION*

Risk Factors Included in the Model	β Coefficient (3 *df* T)	Likelihood Ratio Statistic (p value)
IABP	1.294	0.0287
HTN	0.951	0.0335
History of smoking	0.746	0.0741
Septicemia	0.72	0.0885

* Chi-square for the model (4 *df*) = 15.21; p = 0.0043.
IABP = intra-aortic balloon pump; HTN = hypertension.

DISCUSSION

Although a number of patients in the past 20 years have been referred from hospitals in other states, our overall incidence of sternal wound infection among patients who have median sternotomy at the Emory Clinic is 1%, which falls within the lower limits of the national average. Most patients are seen within 2 to 3 weeks after open heart surgery, because the cardiac surgeons are aware of the advantages of early referral before complications such as septic multiple organ failure can become established.

Patient Evaluation and Management

Initial evaluation includes a careful history and physical examination. History should include documentation of sternotomies and the use of the internal mammary arteries for cardiac revascularization. Risk factors such as diabetes, obesity, and chronic obstructive airway disease should be assessed. Although these factors appear to have little impact on outcome from our data, the number of patients who are exposed may be too small to detect significant differences. Clinical examination includes careful evaluation of the wound, wound drainage, wire exposure, and sternal instability, as well as potential communication with the pleural space. The latter is often associated with to-and-fro percolation of fluid within the wound cavity, linked to respiratory effort. Usually, the leukocyte count is elevated with a predominance of polymorphonuclear leukocytes. Renal function should be monitored closely because its deterioration may herald incipient multisystem organ failure. Plain chest radiographs may be valuable in

Table 13. RISK FACTOR ASSOCIATION WITH RECURRENT INFECTION*: 1988–1996 (186 PATIENTS)

Factor	Infection/ Exposed	%	p Value	Odds Ratio of Recurrent Infection	95% Confidence Limit
Previous sternotomy	5/37	13.5	0.065	3.17	0.95, 10.63 (NS)
Obese	7/74	9.5	0.147		NS
NIDDM	4/37	10.8	0.197		NS
IMA used	10/138	7.2	0.206		NS
SW OP 1988–1992	8/87	9.2	0.259		NS

* Required additional surgery; not cellulitis.
NIDDM = non-insulin-dependent diabetes mellitus; IMA = internal mammary artery; SW OP = sternal wound operation; NS = not significant.

assessing the presence of empyema and pleural effusions but provide little information on the state of the sternum and the degree of osteitis present. Bone scans are deemed of no value in this setting. Magnetic resonance imaging may be helpful to evaluate the presence of substernal fluid collections, and needle aspiration of collections can provide bacteriologic proof of deep infection in a superficial wound that is healing, with underlying sternal bone dehiscence. Overall assessment of the patient includes examination to exclude other causes of sepsis. Concomitant multisystem organ failure and abdominal sepsis arising from mesenteric infarction and empyema of the gall bladder have been seen in several of our patients at the time of presentation and may impact significantly on the final outcome.

Treatment in our series consists of early wound exploration with the patient under general anesthesia with complete reopening of the sternotomy wound. All wires are removed and wound cultures are taken. If sepsis is found, the sternal edges are debrided until healthy solid bone with briskly bleeding margins is found. If the bone is obviously necrotic, soft, and oozing pus, the entire sternum is resected. It is not our policy to resect the costal cartilages now unless they are obviously involved and necrotic. We have not seen an increase in sternal wound recurrent infection rates since this policy has evolved.

Table 14. FACTORS ASSOCIATED WITH RECURRENT INFECTION (182 PATIENTS): MULTIVARIABLE ANALYSIS/LOGISTIC REGRESSION*

Risk Factors Included in the Model	β Coefficient (3 *df*)	Likelihood Ratio Statistic (p value)
Previous sternotomy	1.942	0.008
SW OP 1988–1992	1.567	0.024
IMA used	1.614	0.083

* Chi-square for the model (3 *df*) = 11.94; p = 0.0076.
SW OP = sternal wound operation; IMA = internal mammary artery.

In the earlier phases of this study, debridement often was followed by packing with wet dressings and delayed closure at least 48 hours after the initial procedure.[9] This pattern has altered such that >87% of our wounds are now closed primarily. Muscle flap closure is preferred to omental closure in the first instance, thereby preventing the patient from having the added morbidity of a laparotomy. We favor the pectoralis major flap as the procedure of first choice with the rectus abdominis as our second preference. This is followed by the omentum and lastly the latissimus dorsi. However, the omentum remains an extraordinarily useful tissue source for these wounds because it is able to conform to the deepest recesses of the wound, but the donor site may rarely be morbid, with one case of intra-abdominal infection having been reported in the literature.[19] In patients in whom the omentum is not available and both internal mammary vessels have been harvested, a bipedicled flap of the pectoralis and rectus muscles may be raised on the thoracoacromial and deep inferior epigastric supplies, as noted by T. R. Hester (personal communication, 1988).[10] In 20 years of sternal wound management, we have never had to resort to free-flap reconstruction. All patients have drains placed to both the muscle donor sites and to the mediastinum. We do not use catheter irrigation as a primary source of therapy. Using these broad principles, we have achieved a significant reduction in mortality after sternal wound infection and have reduced the average hospital stay after sternal wound closure of these patients who are critically ill.[8–10]

Hospital Stay and Complications

In an age in which managed care has encroached dramatically and outcome studies are increasingly being de-

Table 15. RISK FACTOR ASSOCIATION WITH MORTALITY: 1988–1996 (186 PATIENTS)

Factor	Death/ Exposed	%	p Value	Odds Ratio of Death	95% Confidence Limit
Septicemia	13/51	25.5	0.00001	11.2	3.45, 36.38
IABP	6/17	35.3	0.0016	7.78	2.42, 25.02
Perioperative AMI	9/43	20.9	0.0051	4.43	1.59, 12.35
Chronic steroids	3/12	25	0.083	3.81	0.92, 15.7 (NS)
Previous sternotomy	6/37	16.2	0.112		NS
CVA	3/14	21.4	0.1225		NS
Prior reexploration	4/32	12.5	0.5		NS

IABP = intra-aortic balloon pump; AMI = acute myocardial infarction; CVA = cerebrovascular accident; NS = not significant.

manded, the reduction in mortality and the fall in the duration of hospital stay remain powerful incentives to use this technique. Conversion to a single-stage closure, when feasible, reduces operating room costs, with an average operating room time of 2 hours if bilateral pectoralis muscle flaps are raised at the time of debridement.

Further reduction in mortality may be difficult to achieve, because we are seeing an older and often sicker group of patients undergoing coronary artery bypass grafting in the 1990s than we did in the late 1970s. In addition, the trend toward immediate postinfarction revascularization has resulted in more patients with a perioperative infarct having to be operated on for infection than was the case 20 years ago. These patients may be more inherently unstable, requiring the use of IABP. Both perioperative myocardial infarction and the use of IABP correlated significantly with mortality from sternal wound sepsis. The association of mortality with septicemia at the time of diagnosis is not surprising, given the severity of the condition and the association with multisystem organ failure. This underscores the fundamental importance of early detection and treatment of sternal wound infections.

Table 16. FACTORS ASSOCIATED WITH MORTALITY (182 PATIENTS): MULTIVARIABLE ANALYSIS/LOGISTIC REGRESSION*

Risk Factors Included in the Model	β Coefficient (4 *df*)	Likelihood Ratio Statistic (p value)
Septicemia	2.434	<.0.00001
Perioperative AMI	1.728	0.006
IABP	1.834	0.0168
CVA	1.701	0.091

* Chi-square for the model (4 *df*) = 36.726; p < 0.00001.
AMI = acute myocardial infarction; IABP = intra-aortic balloon pump; CVA = cerebrovascular accident.

Complications reflect surgical technique as well as patients' risk factors. Hematoma is almost always a technique-driven complication and most often occurs as a consequence of bleeding from either the thoracoacromial pedicle or inadequately sutured distal stumps of the harvested muscles. Hematoma incidence is roughly equivalent between rectus abdominis and pectoralis major flaps. Occasionally, an internal mammary perforator may be a source of bleeding when a pectoral advancement flap is used. During the raising of the pectoralis turnover flap, it is crucial to visualize and carefully control the thoracoacromial pedicle, because these vessels may be substantial in size and can bleed vigorously.

Wound dehiscence has occurred most often in older patients with chronic obstructive airways disease and a history of smoking as well as in obese women with large pendulous breasts who undergo this procedure. It is now the authors' standard to provide suspensory tape support for these women in the early postoperative period in an effort to prevent mechanical disruption of the wound through lateral distraction. The most common site for dehiscence has been at the lower portion of the wound in the region of the xiphisternum. Tension is often high in this area, and yet undermining to facilitate closure may devascularize the skin, which has relatively few perforators entering from the internal mammary vessels as they exit beneath the costal margin to supply the rectus muscle. It is now the authors' policy not to undermine this skin if at all possible to optimize wound healing.

Sternal necrosis and invasive osteitis tend to be most severe in patients with gram-positive infections. In such cases, we tend to perform sternectomy rather than any attempt at rewriting of the sternum. If the sternum feels reasonably solid and is not exuding pus, we debride the bone

Table 17. TRENDS IN MEAN STAY AFTER STERNAL WOUND RECONSTRUCTION: 1975–1996 (409 PATIENTS)*

1975–1978	1979–1987	1988–1992	1993–1996
19 days	15.7 days	18.6 days	12.4 days

* Student's t test: p = 0.005.

edges with a sternal saw until stable, bleeding bone is obtained. This is not unlike the endpoint of debridement for osteitis in the lower extremity and follows conventional orthopedic teaching.[20] Bone cultures are taken from the cut ends, including deep bone biopsy specimens, which then may be used to assess the longevity and sensitivity of postoperative antibiotic therapy. Typically, if a partial sternectomy is performed, patients continue to receive intravenous antibiotics for 6 weeks, just as they would be for osteitis elsewhere in the body.[22] More common, osteitis is severe and the entire sternum is resected. If this is the case, there probably is less need to continue long-term antibiotic therapy because the infected source has been removed in its entirety together with debridement of the skin edges, and this effectively constitutes an exenteration of the abscess cavity apart from the contaminated surface of the heart and, on occasion, the lung. There are no prospective data to support this contention, however. With increased use of the Nugent pericardial flap on cardiac patients who were not operated on previously, we have seen a significant reduction in cardiac exposure associated with sternal wound sepsis. It is too early in our series to assess the true impact of the Nugent flap on survival, but one would expect that a procedure that excludes the heart from being bathed in pus could only improve a patient's chances of recovery. The advantage to leaving part of the lateral edge of the sternum during a partial sternectomy is that stability of the medial ends of the ribs and costal cartilages is maintained, reducing the incidence of early postoperative clicking and discomfort when these structures are allowed to float free of the constraining influence of the sternum after radical sternectomy. Using this approach to treat less severe forms of sepsis, we have not seen an increase in our long-term recurrence rates of infection requiring re-exploration.

Sternal Wound Classification

This subtle change in approach to sternal debridement has led the author (GJ) to propose a classification of sternal wound infection in an attempt to clarify management decisions when facing these complex wounds (Table 18). Sternotomy wound infections manifest as a continuum of

Table 18. CLASSIFICATION OF STERNAL WOUND INFECTION

Type	Depth	Description
1a	Superficial	Skin and subcutaneous tissue dehiscence
1b	Superficial	Exposure of sutured deep fascia
2a	Deep	Exposed bone, stable wired sternotomy
2b	Deep	Exposed bone, unstable wired sternotomy
3a	Deep	Exposed necrotic or fractured bone, unstable, heart exposed
3b	Deep	Types 2 or 3 with septicemia

clinical entities that may present with simple lesions such as a superficial suture abscess through to the severe case of life-threatening suppurative mediastinitis. Type 1a typifies the patient with a suture abscess or infected wound hematoma superficial to the deep fascia. Type 1b is similar with the exception that the deep fascial suture layer is exposed. These wounds are drained and left open to granulate closed with wound packing or may be secondarily closed when clean. At no point is sternal bone or wire seen in these wounds.

Type 2a constitutes a deeper process with exposed but stable sternotomy, whereas type 2b is associated with an unstable sternotomy. These wounds represent the most difficult judgment call. If the sternum is stable and an urgent gram stain of parasternal fluid is negative for bacteria, reclosure of the debrided skin wound may be safe and practicable. If the sternum is unstable and sterile and the sternal blood supply is bilaterally intact, rewiring is a resonable consideration. The sternal bone stock should be assessed carefully for strength; if there is any doubt about its ability to withstand rewiring, it is far safer to proceed with sternectomy and muscle flap closure without tension. We have examined a number of patients, many who are obese and have chronic lung disease, in whom sternal rewiring has been performed with internal mam-

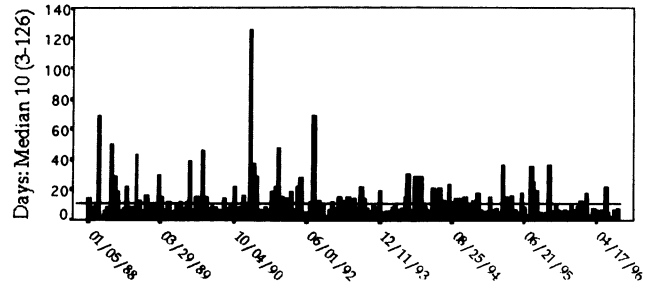

Figure 1. Hospital stay after sternal wound reconstruction 1988–1996.

mary grafting but whose bone strength has been unable to withstand the tremendous forces generated by the respiratory effort. Redehiscence in these patients is frequently accompanied by infection with potentially disasterous results. When patients who have had an IMA harvest develop sterile sternal dehiscence, they may be better treated with partial sternectomy and flap closure to minimize the risk for osteitis and suppurative mediastinitis.

Type 3a represents complete sternal disruption and suppurtive mediastinitis with exposure of the heart. Type 3b is charaterized by either Type 2a/b or 3a associated with septicemia. This scenario carries the worst potential for death as indicated by our current data. All Type 3 wounds should be radically debrided and may require delayed closure at 48 hours or even later if necessary, particularly when septicemia is present or when the patient is hemodynamically unstable. The greater the delay between debridement and final muscle flap closure, the greater the risk of desiccation and rupture of vital structures, particularly coronary grafts and the right ventricular wall, even in the face of daily wet dressing changes in the operating room. It should also be kept in mind that sudden changes in intrathoracic pressure induced by coughing may cause ventricular rupture and exsanguination if the venticle and adjacent tissues have become adherent to the posterior aspect of the ribs anteriorly, and the longer the chest is left open, the greater this risk becomes. Although early flap coverage will prevent drying of the tissues and attenuation of critical vascular structures, it may not prevent a blowout of an established area of attenuation produced by lengthy exposure to wet dressing changes. Localized thinning of a vein graft wall noted at the time of flap closure probably should be treated with a sleeve-like circumferential wrap of vein graft material to assist with obtaining a moist, secure seal around the vessel at risk.

This treatment algorithm is simple and is designed to accommodate the full spectrum of disease seen when these patients are referred by the cardiothoracic service. Any surgeon accustomed to managing these problems is only too familiar with how deceptive the surface appearance of the wound may be in a patient with sternal infection. A small draining sinus oozing seropurulent fluid often overlies severe mediastinitis with sternal disruption and osteitis, and appropriately aggressive intervention is mandatory when indicated. Use of the above classification brings a measure of objectivity to the management of these complex and dangerous wounds.

In conclusion, evaluation of our experience with sternal debridement and flap closure over a 20-year period supports our assertion that sternectomy and early muscle flap closure have reduced the mortality and morbidity of sternal wound infections. The increased use of single-stage debridement and closure has been appropriate in most cases without a rise in either mortality or morbidity.

Single-stage repair also has contributed to a significant reduction in mean hospital stay, which can only result in diminished hospital costs. This population of 409 patients treated at the Emory Clinic represents the largest reported series of patients treated in this manner, because this approach evolved at our center and was slow to be accepted elsewhere until it had been proved efficacious. The sustained reduction in mortality remains striking when compared with other treatment methods and is probably the most convincing reason to adopt this technique as the standard of care against which other techniques should be judged. A wound classification and treatment algorithm have been proposed in an effort to bring more objectivity to the clinical entity of sternal wound infection and suppurative mediastinitis.

Acknowledgments

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Discussion

DR. HARVEY W. BENDER, JR (Nashville, Tennessee): Thank you, Dr. Cameron, Dr. Copeland. I, too, would like to congratulate the program committee for the placement of this paper immediately following the two related scientific papers this morning. I think we need to be reminded constantly that the principles of surgery that Dr. Halsted laid down are important today, just as they were at the turn of the last century.

We have seen again the importance of bringing a blood supply to the wound and ridding the wound of devitalized tissue to lower the morbidity and mortality rate from what was a dreaded complication in cardiac surgery.

I have had the opportunity to review Dr. Jurkeiwicz's manuscript, and it has much detailed statistical information on the patient population they have been involved with at Emory. First, let me point out, as is pointed out in the manuscript, much of this material is referred to Emory and in no way reflects the incidence of wound problems in that institution. Their infection rate is, as you would expect, quite low.

It is a little difficult to draw much in the way of conclusions from the prominent factors in the patients that we have just heard about, because we don't know the denominator of patients with steroid therapy, chronic pulmonary disease, chronic renal disease, or those in which mammary arteries have been used in the original operative procedure.

I would make just a couple of comments about the clinical problem of infected sternal wounds. I think the same principles that Dr. Jurkeiwicz has pointed out as important in the management of the infected wound also are important in preventing the occurrence of this problem. It is vitally important to have a firm sternal closure. The operation does not end with the placement of bypass grafts or the placement of valves in the heart, but the operation still includes being certain that that sternal closure is intact.

It has been my experience that, in the absence of gross contamination, a sternal wound infection almost never occurs if there is not first a breakdown in the sternal closure and some instability of the sternum. I would point out that if it is recognized early and addressed early, the problem is less likely to occur.

Again, I'd like to thank the Association for the opportunity to comment.

DR. ALDEN H. HARKEN (Denver, Colorado): Dr. Cameron, Dr. Copeland, Members, and Guests. I appreciate the opportunity to comment on this paper. I recognize that the body of general surgery benefits tremendously when a plastic surgeon is not only going to participate in a comprehensive general surgical meeting like this one, but also when he sits up on the front row and attends all the sessions. When that plastic surgeon also is willing to make constructive criticisms of the way we accomplish our surgery, I believe we all benefit. I, again, witnessed that on the first day of this meeting at this glorious hotel when I watched Dr. Jurkeiwicz admonish the staff of this fine hotel about their lack of providing newspapers in each of the rooms. And I think that kind of constructive criticism is valuable.

I'd like to limit myself to two questions. First, the earlier we recognize a sternal infection, the better off we are and the better the patients do. Therefore, Dr. Jurkeiwicz, in reviewing this data, could you come up with the earliest signals? When most of us do these operations, it is very difficult for us to acknowledge that a patient has developed sternal dehiscence or mediastinitis. What is the earliest signal that we get in these patients? Is it fever? Is it a click? Is it a bacteremia? How can we pick this up at the earliest sign?

And, second, is there such a thing as a partial mediastinitis or partial infection? You indicated that you resected chondral cartilage when it was appropriate, but you also indicated that the more aggressive we are in dealing with these problems, the better off the patient is. Therefore, is the best possible therapy early aggressive complete sternectomy in removal of all the chondral cartilages and then, as Dr. Bender pointed out, replacement with viable vascularized myocutaneous flap? Isn't that the best possible therapy?

Again, thank you for raising this devastating complication to the level of constructive scientific comment.

DR. PHILLIP G. ARNOLD (Rochester, Minnesota): Dr. Cameron, Dr. Copeland, Colleagues. I thank you for the opportunity to comment on Dr. Jurkeiwicz's paper.

I became aware of the ability to move the pectoralis major muscles 20 years ago in Atlanta about a month before I left Dr. Jurkeiwicz's residency and moved north to Minnesota. I took the idea with me and have had an opportunity to do it on a number of occasions.

I have been working with Dr. Peter Pairolero, a member of