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Sternal Wound Infections following Cardiac Surgery: Risk Factor Analysis and Interdisciplinary Treatment

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ABSTRACT

Objective. Sternal wound infections are a serious complication after cardiac surgery. Although a variety of treatment algorithms has been published, the ideal operative treatment of complicated median sternotomy wounds is the subject of ongoing controversy.

Methods. In a retrospective review, 3016 consecutive open-heart surgery patients between January 2003 and June 2006 were evaluated: 65.6% underwent coronary artery bypass surgery (CABG), 16.3% cardiac valve replacement, 13.5% combined CABG and valve replacement, 2.8% aortic reconstruction or replacement, 0.6% artificial heart implantation, and 1.2% cardiac transplantation.

Results. Sixty-three patients (2.1%) developed sternal wound infections. Fifty-six wounds were treated with débridement, irrigation, and re-wiring. Thirty-four patients were treated using vacuum-assisted closure therapy. Nineteen of these patients eventually required plastic surgical coverage with either rectus abdominis or pectoralis major flaps. Diabetes mellitus, rethoracotomy, duration of operation and, interestingly, the time of operation (morning versus afternoon) presented significant risk factors for development of sternal wound infections ($P < .05$). Three patients developed partial flap necrosis and required a second flap. Eventually, all defects were successfully reconstructed and there was no recurrent ostemyelitis noticed over the entire observation period (follow-up, 23 ± 13 months).

Discussion. Patients at risk for development of sternal wound infections may be preferably operated in the morning at first position. Vaccuum-assisted closure therapy acts as a link between radical débridement and definitive plastic coverage. The type of flap is individually chosen based on location of the defect and availability of certain vascular axis. The presented interdisciplinary approach with radical surgical débridement, application of subatmospheric pressure dressings, and early involvement of the plastic surgical team allows efficient treatment of infected median sternotomy wounds.

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INTRODUCTION

Since its first description by Julian et al [1957] the median sternotomy, which provides optimum exposure of the heart and the great vessels, has been widely used in cardiac and vascular surgery [Farhat 2004; Ahumuda 2005]. The prices sometimes paid for this exposure are sternal wound infections and mediastinitis, which still represent serious complications with considerable morbidity and mortality. The incidence of such infections is, depending on the type of cardiac surgery and patient selection, between 0.4% to 5.0% [Sarr 1984]. The etiology is multifactorial. A large number of risk factors such as diabetes mellitus, age, obesity, use of internal mammary artery grafts, low ejection fraction, re-exploration of the mediastinum, use of blood products, chronic obstructive pulmonary disease (COPD), prolonged postoperative ventilation time, bone wax, and others have been described in several studies. However, results are still inconclusive and controversial [Milano 1995; Baskett 1999; Gummert 2002].

Several approaches of treating deep sternal wound infections have been reported [Jeevanandam 1990; Cowan 2005]. Extensive and radical surgical débridement should be performed as soon as possible [Nahai 1989; El Oakley 1996; Jones 1997]. While acute wound infections (El Oakley I and II) may be adequately treated by débridement and closed irrigation, chronic types of sternum osteomyelitis (El Oakley V) and complicated wound infections in presence of risk factors (El Oakley III and IV) require plastic surgical reconstruction [El Oakley 1996].

Subatmospheric pressure dressings (vaccuum-assisted closure [VAC] therapy) may be useful as a temporary wound care technique that prevents shear stress of the open sternum and helps to decrease wound edema and bacterial load. VAC therapy has also been used to optimize local wound conditions prior to plastic surgery reconstruction [Scholl 2004; Agarwal 2005].

Reconstructive techniques using muscle flaps have become the backbone of surgical treatment because the use of vascularized regional tissue improves wound healing withy increased blood flow and obliteration of dead space

[Francel 2001; Ascherman 2004]. A plethora of flaps have been described in the context of sternum osteomyelitis. The pedicled omentum flap has been used successfully for closure of mediastinal defects since 1976 [Lee 1976]. Unilateral or bilateral pectoralis major muscle or myocutaneous flaps (PEC) are considered the "workhorses" for treatment of sternum osteomyelitis [Pairolero 1991]. There is a variety of different modifications that allow transfer of the pectoralis muscle either supplied by its thoraco-acrominal vascular pedicle or based on perforators from the mammary artery [Hugo 1994; Wong 2006]. Another treatment modality for reconstruction of sternotomy wounds is the rectus abdominis flap either as muscle flap (RAM) or as myocutaneous flap with a vertically oriented skin island (VRAM) [Coleman 1989; Yamamoto 1994; Oh 2004; Fujiwara 2006].

In this article, we present a thorough risk factor analysis for development of sternum osteomyelitis and review our institutional experience using the VAC therapy in combination with PEC, RAM, and VRAM flaps to reconstruct large complex chest wall defects after median sternotomy in heart surgery patients.

PATIENTS AND METHODS

The present study is a retrospective review of 3016 consecutive open-heart surgery patients between January 2003 and June 2006 at the Center of Cardiac Surgery, University of Erlangen, Germany. Most of our patients had coronary artery bypass surgery (CABG) (1979 patients, 65.6%), cardiac valve replacement (491 patients, 16.3%), or combined CABG and valve replacement (408 patients, 13.5%). A minority of patients had aortic reconstruction or replacement (83 patients, 2.8%), artificial heart implantation (18 patients, 0.6%), or cardiac transplantation (37 patients, 1.2%). In 213 cases (7.1%), a rethoracotomy was performed due to diffuse bleeding, pericardial effusion, graft stenosis, or prosthetic dysfunction. In 1870 patients (78.3% from all CABG and combined CABG/valve replacement patients), the left internal mammary artery was used for revascularization.

El Oakley and Wright classified mediastinal wound infection into two large categories; superficial and deep (mediastinitis) sternal wound infection. They defined infection confined to subcutaneous tissue as "superficial" while infections involving the sternum (osteomyelitis), which may or may not be associated with involvement of retrosternal space, were defined as "deep" sternal wound infection. They further classified deep sternal infection into 4 subtypes based on the time of first presentation, previous results of attempted treatment, and patients' risk factors [El Oakley 1996]. According to this classification, all of the patients with mediastinal wound infections presented in this study had deep sternal infections. Superficial wound infections, which were successfully managed by conservative treatment, were not considered. Table 1 summarizes all data on patient demographics, cardiovascular risk factors, the time of operation time (ie, morning versus afternoon), the duration of operation, and the type of surgery. The EuroSCORE was used to assess the risk of early mortality in cardiac surgical candidates [Nashef 1999]. Sixty-three patients (2.1%) developed sternal wound infections. Wounds were defined as "infected" if purulent secretion was evident and positive culture results were available. Fifty-six wounds were treated with débridement, irrigation, and re-wiring. VAC therapy was initiated in 34 patients. Nineteen of these patients eventually required plastic surgical

Table 1. Demographic and Cardiac Surgery Data*

	All Patients, N = 3016	Deep Sternal Wound Infections, n = 63	PEC, RAM, VRAM, n = 19
Age, y	66.6 (16-98)	68.5 (29-83)	67.2 (29-75)
Male/female	71.0/29.0%	61.9/38.1%	47.4/52.6%
Body mass index	27.8 (15.8-45.8)	29.4 (19.5-44.2)	29.1 (18.8-40.4)
Diabetes mellitus	**28.4%**	**49.2%**	**52.6%**
Arterial hypertension	86.0%	90.5%	89.5%
Smokers	40.4%	27.0%	36.8%
Serum creatinine, mg/dL	1.3 (0.4-13.0)	1.3 (0.8-4.9)	1.2 (0.7-3.2)
Renal failure	14.3%	23.8%	5.3%
Chronic obstructive pulmonary disease	**8.6%**	**19.0%**	**26.3%**
Left ventricular function, ejection fraction %	54.9 (10-90)	54.0 (10-80)	51.1 (21-70)
Immunosuppression	1.2%	1.6%	5.3%
EuroSCORE	4.6 (0-23)	5.4 (0-15)	6.4 (2-15)
Use of left internal mammary artery graft	78.3%	77.4%	87.5%
Time of operation (morning:afternoon)	**48.2:51.8**	**38.1:61.9**	**36.8:63.2**
Bypass time, min	**82.9**	**110.4**	**139.3**
Total operation time, min	194.3	222.6	215.7
Duration of operation			
Short, % (0-150 min)	**20.1**	**7.9**	**0**
Medium, % (150-240 min)	64.7	61.9	68.4
Long, % (>240 min)	**15.2**	**30.2**	**31.6**
Blood products			
Erythrocyte concentrate	**2.5 (0-82)**	**8.4 (0-82)**	**9.6 (0-51)**
Fresh frozen plasma	2.0 (0-61)	4.6 (0-40)	5.5 (0-35)
Thrombocyte concentrate	**0.3 (0-22)**	**0.5 (0-12)**	**0.2 (0-2)**
Rethoracotomy	**7.0%**	**79.4%**	**78.9%**
Hospital mortality	**6.0%**	**12.7%**	**10.5%**
Type of surgery			
CABG	65.6%	65.1%	78.9%
Valve repair/ replacement	16.3%	7.9%	10.5%
Combined CABG and valve repair/replacement	13.5%	19.0%	5.3%
Cardiac transplantation	1.2%	1.6%	5.3%

*Demographic and cardiac surgery data for the 3016 consecutive open-heart surgery patients, the 63 patients with deep sternal wound infection and the 19 patients with muscle flap treatment. Significant differences between different groups ($P < .05$) were highlighted by bold typing. PEC indicates 6pectoralis major myocunataneous island flaps; RAM, rectus abdominis muscle flaps; VRAM, vertical rectus abdominis myocutaneous flaps; CABG, coronary artery bypass grafting.

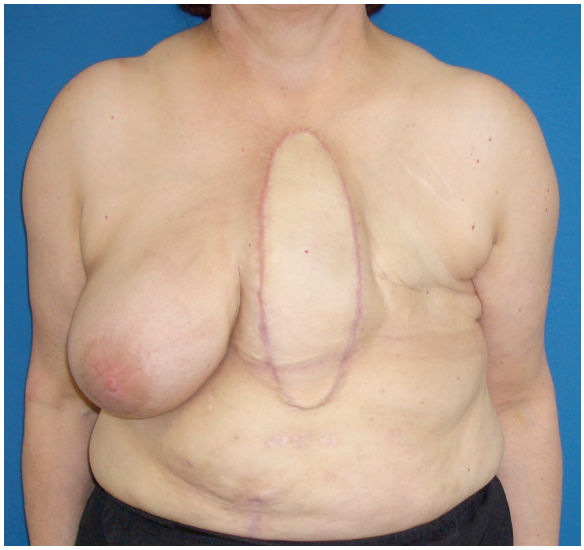

Figure 1. A 54-year-old female patient with a history of mamma carcinoma, mastectomy, and chest wall irradiation 10 years ago; 18 months following transfer of a vertical rectus abdominis myocutaneous flap due to sternum osteomyelitis following coronary artery bypass surgery.

coverage. Plastic surgical treatment of infected sternotomy wounds was initiated by radical and, if needed, repeated surgical débridement. This was followed by application of VAC therapy until definitive closure of the defect. In cases of uncertainty about patency of the mammary artery, angiography was performed prior to rectus abdominis flap transfer. The VRAM and RAM flaps were based on the superior epigastric vessels, but intercostal perforators were preserved in most of the patients. The VRAM flaps were harvested with a skin paddle located above the periumbilical perforators. The RAM flaps were harvested as isolated cranially based muscle flaps that were eventually covered with split-thickness skin grafts. The PEC flaps were raised as myocutaneous island flaps based on the thoracoacrominal vessels that were located with Doppler ultrasound prior to surgery. The skin island was positioned caudal to the nipple, including the perforating vessels in vicinity of the submammary fold. The insertion at the humerus was dissected if a wide arc of rotation was needed. Donor sites were closed primarily following minimal undermining of the skin.

Data and results are expressed as mean ± standard deviation. For statistical analysis, the chi-square test and the Student *t* test were used to compare patients with and without deep sternal wound infections. Significance was set at $P < .05$.

RESULTS

The incidence of deep sternal wound infection following medial sternotomy was 2.1% (63 from 3016 patients) in the last 3 years. Fifty-six patients underwent irrigation and rewiring, 34 patients received a VAC therapy and subsequently, 19 patients were referred to the plastic surgical team for consideration of PEC flap, RAM, or VRAM flap operation.

EuroSCORE was not significantly increased in patients suffering from deep sternal infection. Diabetes mellitus, chronic obstructive pulmonary disease, bypass time, duration of operation, and rethoracotomy (ie, reopening prior to the diagnosis of the sternal infection) were identified as independent risk factors for development of sternum ostemyelitis ($P < .05$). Interestingly, also the time of operation (ie, position in the operating schedule) presented a significant and independent risk factor for development of sternal wound infections. In this case we compared and analyzed all operations that started before 11:00 AM versus after 11:00 AM (morning versus afternoon). In the group of all patients, the operations were equally distributed (51.8 versus 48.2). However, the majority of patients who developed sternal infections (61.9 versus 38.1) and those who required plastic surgical coverage (63.2 versus 36.8) were operated in the afternoon ($P < .05$). The hospital mortality and the number of blood products (erythrocyte concentrate and fresh frozen plasma) were also significantly higher in the group of patients with wound infections and plastic surgical reconstruction. Table 1 summarizes cardiovascular risk factors and incidence of deep sternal wound infections.

The period between cardiac surgery and plastic surgical reconstruction was 85 ± 82 days. Total VAC treatment duration after irrigation and débridement of the wound was between 3 and 59 days. Total hospital stay (cardiac + plastic surgery) was 91 ± 37 days in patients who underwent plastic surgical reconstruction. Surgical closure was performed with RAM flap (4 patients), RAM and unilateral PEC flap (1 patient), VRAM flap (Figure 1) (7 patients), unilateral PEC (Figure 2) (5 patients), and bilateral myocutaneous PEC flap (Figure 3) (2 patients). In 3 of 7 patients undergoing VRAM

Figure 2. A 78-year-old male patient with a history of chronic sternum osteomyelitis following coronary artery bypass surgery in the cranial third with involvement of the sternoclavicular joint. After radical débridement including resection of the sternoclavicular joint and the cranial third of the sternum, a myocutaneous pectoralis major flap was transferred into the defect. Eight months postoperatively, the defect is sufficiently covered without any sign of recurrent osteomyelitis.

Figure 3. A 76-year-old male patient with a history of diabetes mellitus, peripheral occlusive arterial disease, open cholecystectomy, and chronic sternum osteomyelitis following coronary artery bypass surgery. The sternum defect (22 × 8 cm) was reconstructed using bilateral pectoralis major myocutaneous flap (5 months postoperatively).

transfer, a delay procedure was performed 7 to 14 days prior to flap closure. The skin island was incised and the inferior epigastric artery and veins were ligated. All patients were treated with VAC therapy prior to surgical reconstruction. Postoperatively, primary closure of both donor and recipient sites of the flap was achieved in all patients. In two patients, a hematoma at the donor site of the PEC flap was evacuated. There were no complete flap losses, vascular thromboses, fistulas, or donor-site complications. We did not observe hernia formation following RAM or VRAM transfer. In 5 patients (1 RAM, 2 VRAM, and 2 PEC), partial necrosis of the tip of the flap was successfully managed by débridement and conservative treatment (n = 2) and transfer of a second flap (2 PEC, 1 RAM, n = 3). Eventually all defects were successfully reconstructed and there was no recurrent ostemyelitis noticed over the entire observation period (follow-up, 23 ± 13 months). There were no statistically significant differences in total hospital stay and time from cardiac surgery until plastic surgical reconstruction between patients receiving different types of flaps. Detailed information regarding types of flaps and reoperations are given in Table 2.

DISCUSSION

The management of the chronically infected sternum remains a real challenge. Sternal wound infections can lead to significant morbidity, mortality, and hospital cost. There is a trend toward earlier referral for flap operation after the diagnosis of sternal wound infection in recent years [Coleman 1989; Yamamoto 1994; Oh 2004; Wong 2006]. The incidence of deep sternal wound infections in our hospital in the last 3 years was 2.1%. This is comparable to the reported worldwide incidence of 0.4% to 5.0% [Sarr 1984]. Several studies analyzed risk factors for sternal wound infections and mediastinitis; however, results are still inconclusive, and controversy remains about the predictive benefit of single factors identified. Diabetes mellitus, obesity, COPD, renal failure, use of internal mammary artery grafts, re-exploration, prolonged ventilation, use of blood products, and the duration of operation presented significant risk factors [Milano 1995; Baskett 1999; Gummert 2002]. Our study supports the relevance of diabetes, COPD, re-exploration, bypass time, and duration of the operation as risk factors for development of sternal wound infections. In addition, we were able to identify for the first time the time of operation (ie, the position in the operating schedule) as another relevant prognostic factor for the development of sternum osteomyelitis. A high number of patients who developed sternal infections and those who required plastic surgical coverage were operated on in the afternoon. This phenomenon might be explained by the increased air turbulence and concentration of pathogens and particles in the air of the operation room after a period of "activity." Although this finding needs to be confirmed in further studies including a larger number of cardiac surgery patients, we recommend based on the results of our study that patients with a number of specific risk factors such as COPD and diabetes who are scheduled for complex cardiac surgical procedures should be operated on in the morning rather than in the afternoon.

Adequate débridement of all infected and necrotic tissues, including skin, subcutaneous tissue, cartilage, and bone is still considered a prerequisite for successful management of infected sternal wounds. Some patients may benefit from closed irrigation and rewiring. It can accelerate early discharge, but wires can also act as nidus for further infections. Francel's group reported a failure rate of rewiring of 35% [Francel 2001]. In the last decade, VAC has been introduced by Morykwas and Argenta [Argenta 1997; Morykwas 1997]. Since their first report in 1997, VAC has been successfully applied for treatment of infected sternotomy wounds either solely or as an adjunctive therapy prior to flap coverage [Fleck 2002; Song 2003; Scholl 2004]. In our study, VAC

Table 2. Treatment Data*

Type of Flap	Total Number	Partial Loss	Second Flap	Defect Localization	Hospital Stay, d
PEC unilateral	5 (26%)	1		Cranial 1/3	77 ± 27
PEC bilateral	2 (10%)	1	1 RAM	Complete	92 ± 35
VRAM	7 (37%)	2	1 PEC	Complete (5), caudal 1/2 (2)	95 ± 53
RAM	4 (22%)	1	1 PEC	Caudal 1/2	99 ± 33
RAM + PEC	1 (5%)	0		Complete	105

*In total 19 patients were treated by transfer of unilateral or bilateral pectoralis major myocunataneous island flaps (PEC), vertical rectus abdominis myocutaneous flaps (VRAM), cranially based rectus abdominis muscle flaps + split thickness skin grafts (RAM), and combinations of different types of flaps. Defect localization in relation to the sternum is provided for each type of flap. Hospital stay is given as mean ± standard deviation.

therapy helped to reduce the number of painful dressing changes, improved wound conditions, and even allowed for complete wound closure without transfer of surgical flaps in a significant number of patients. In other patients who underwent plastic surgical reconstruction, it acted as a bridge between débridement and definitive closure. We did not observe any severe complication related to the use of VAC therapy in our patients.

In 5 of our patients, partial flap necrosis of the most distal proportion of the skin island occurred. While in two patients after initial local débridement the wounds healed uneventfully under conservative treatment regime, 3 patients required a second flap. In two of these patients, VRAM and RAM flaps were initially raised, and due to the extent of the sternum defect some of the cranial intercostal perforators have been sacrificed in order to achieve a larger arc of rotation. In the third patient, bilateral pectoralis major myocutaneous flaps were raised for reconstruction of an extended infected sternotomy wound. The most caudal part of the flap (ie, the most lateral proportion of the skin island prior to transfer) underwent necrosis. This demonstrates the limited reliability of myocutaneous pectoralis major island flaps for reconstruction of caudally located sternal wounds. All 3 patients had at least 2 vascular risk factors.

Pectoralis major island or advancement flaps and turnover flaps based on perforators originating from the mammary artery are excellent choices for reconstruction of the sternum [Ascherman 2004; Wong 2006]. However, the mammary artery perforator-based modification is contraindicated if patency of the mammary artery is not given [Lopez-Monjardin 1998]. Since the muscle proportion of the myocutaneous pectoralis major flap does not reach the inferior 1/3 of the sternum, only laterocaudal placement of the skin island [Jurkiewicz 1980], as demonstrated in Figure 3, allows reconstruction of this part of the sternum, but at the price of decreased reliability. Therefore we recommend, based on our personal experience and anatomical considerations, the PEC flap primarily for reconstruction of the upper 2/3 of the sternum.

The RAM flap is also an option for reconstruction of the presternal region if the superior epigastric artery is available [Coleman 1989; Iacobucci 1989; Fleischer 1993; Clarkson 2003]. The deep inferior epigastric system is the dominant pedicle of the rectus abdominis myocutaneous flap [Moon 1988]. Therefore, extremely caudal placement of the skin island bears a considerable risk of partial flap necrosis. Delay procedures that increase blood flow in the VRAM flap as demonstrated by angiography [Fujiwara 2006; Strecker 2006] have been performed in 3 of our patients.

Besides VRAM and PEC flaps, the omentum flap and the pedicled or free latissimus dorsi flap have also been used for treatment of mediastinitis [Banic 1995; Lopez-Monjardin 1998; Weinzweig 1995]. While the omentum flap requires a laparotomy, communicating a sterile cavity with a contaminated one, the latissimus dorsi flap does not provide enough tissue to completely fill out a post-sternectomy defect. Therefore we use these flaps in our institution only if no other first-line muscle flap is available for reconstruction.

In conclusion, the presented interdisciplinary joint approach allows safe and efficient treatment of patients who are at high risk for complications such as sternum osteomyelitis or wound dehiscence. Diabetes mellitus, COPD, rethoracotomy, duration of operation, and the time of the operation (morning versus afternoon) presented significant risk factors for development of sternal wound infections ($P < .05$). We suggest that patients who are at high risk for development of sternal wound infections should be operated on in the morning at first position rather than in the afternoon. VAC therapy acts as a link between radical débridement and definitive plastic coverage in prolonged sternal infections. We recommend based on our personal experience the use of PEC flaps as first-line procedure for cranial and central sternum defects while the RAM flap is primarily used for caudal defects. Complete sternal defects are in our institution reconstructed using delayed VRAM flaps, if a patent mammary artery is available.

REFERENCES

Agarwal JP, Ogilvie M, Wu LC, et al. 2005. Vacuum-assisted closure for sternal wounds: a first-line therapeutic management approach. Plast Reconstr Surg 116:1035-40; discussion 1041-3.

Ahumada LA, de la Torre JI, Ray PD, et al. 2005. Comorbidity trends in patients requiring sternectomy and reconstruction. Ann Plast Surg 54:264-8; discussion 267.

Argenta LC, Morykwas MJ. 1997. Vacuum-assisted closure: a new method for wound control and treatment: clinical experience. Ann Plast Surg 38:563-76; discussion 577.

Ascherman JA, Patel SM, Malhotra SM, Smith CR. 2004. Management of sternal wounds with bilateral pectoralis major myocutaneous advancement flaps in 114 consecutively treated patients: refinements in technique and outcomes analysis. Plast Reconstr Surg 114:676-83.

Banic A, Ris HB, Erni D, Striffeler H. 1995. Free latissimus dorsi flap for chest wall repair after complete resection of infected sternum. Ann Thorac Surg 60:1028-32.

Baskett RJ, MacDougall CE, Ross DB. 1999. Is mediastinitis a preventable complication? A 10-year review. Ann Thorac Surg 67:462-5.

Clarkson JH, Probst F, Niranjan NS, et al. 2003. Our experience using the vertical rectus abdominis muscle flap for reconstruction in 12 patients with dehiscence of a median sternotomy wound and mediastinitis. Scand J Plast Reconstr Surg Hand Surg 37:266-71.

Coleman JJ 3rd, Bostwick J. 1989. Rectus abdominis muscle-musculocutaneous flap in chest-wall reconstruction. Surg Clin North Am 69:1007-27.

Cowan KN, Teague L, Sue SC, Mahoney JL. 2005. Vacuum-assisted wound closure of deep sternal infections in high-risk patients after cardiac surgery. Ann Thorac Surg 80:2205-12.

El Oakley RM, Wright JE. 1996. Postoperative mediastinitis: classification and management. Ann Thorac Surg 61:1030-6.

Farhat F, Metton O, Jegaden O. 2004. Benefits and complications of total sternotomy and ministernotomy in cardiac surgery. Surg Technol Int 13:199-205.

Fleck TM, Fleck M, Moidl R, et al. 2002. The vacuum-assisted closure system for the treatment of deep sternal wound infections after cardiac surgery. Ann Thorac Surg 74:1596-600; discussion 1600.

Fleischer A. 1993. Closure of mediastinal wounds with deep ithelialized rectus abdominis musculocutaneous flaps. Ann Plast Surg 31:146-8.

Francel TJ, Kouchoukos NT. 2001. A rational approach to wound difficulties after sternotomy: reconstruction and long-term results. Ann Thorac Surg 72:1419-29.

Fujiwara M, Nakamura Y, Sano A, Nakayama E, Nagasawa M, Shindo T. 2006. Delayed vertical rectus abdominis myocutaneous flap for anterior chest wall reconstruction. Aesthetic Plast Surg 30:120-4.

Gummert JF, Barten MJ, Hans C, et al. 2002. Mediastinitis and cardiac surgery—an updated risk factor analysis in 10.373 consecutive adult patients. Thorac Cardiovasc Surg 50:87-91.

Hugo NE, Sultan MR, Ascherman JA, Patsis MC, Smith CR, Rose EA. 1994. Single-stage management of 74 consecutive sternal wound complications with pectoralis major myocutaneous advancement flaps. Plast Reconstr Surg 93:1433-41.

Iacobucci JJ, Stevenson TR, Hall JD, Deeb GM. 1989. Sternal osteomyelitis: treatment with rectus abdominis muscle. Br J Plast Surg 42:452-9.

Jeevanandam V, Smith CR, Rose EA, Malm JR, Hugo NE. 1990. Single-stage management of sternal wound infections. J Thorac Cardiovasc Surg 99:256-63.

Jones G, Jurkiewicz MJ, Bostwick J, et al. 1997. Management of the infected median sternotomy wound with muscle flaps. The Emory 20-year experience. Ann Surg 225:766-76.

Julian OC, Lopez-Belio M, Dye WS, Javid H, Grove WJ. 1957. The median sternal incision in intracardiac surgery with extracorporeal circulation; a general evaluation of its use in heart surgery. Surgery 42:753-61.

Jurkiewicz MJ, Bostwick J 3rd, Hester TR, Bishop JB, Craver J. 1980. Infected median sternotomy wound. Successful treatment by muscle flaps. Ann Surg 191:738-44.

Lee AB Jr, Schimert G, Shaktin S, Seigel JH. 1976. Total excision of the sternum and thoracic pedicle transposition of the greater omentum; useful stratagems in managing severe mediastinal infection following open heart surgery. Surgery 80:433-6.

Lopez-Monjardin H, de-la-Pena-Salcedo A, Mendoza-Munoz M, Lopez-Yanez-de-la-Pena A, Palacio-Lopez E, Lopez-Garcia A. 1998. Omentum flap versus pectoralis major flap in the treatment of mediastinitis. Plast Reconstr Surg 101:1481-5.

Milano CA, Kesler K, Archibald N, Sexton DJ, Jones RH. 1995. Mediastinitis after coronary artery bypass graft surgery. Risk factors and long-term survival. Circulation 92:2245-51.

Moon HK, Taylor GI. 1988. The vascular anatomy of rectus abdominis musculocutaneous flaps based on the deep superior epigastric system. Plast Reconstr Surg 82:815-32.

Morykwas MJ, Argenta LC, Shelton-Brown EI, McGuirt W. 1997. Vacuum-assisted closure: a new method for wound control and treatment: animal studies and basic foundation. Ann Plast Surg 38:553-62.

Nahai F, Rand RP, Hester TR, Bostwick J 3rd, Jurkiewicz MJ. 1989. Primary treatment of the infected sternotomy wound with muscle flaps: a review of 211 consecutive cases. Plast Reconstr Surg 84:434-41.

Nashef SA, Roques F, Michel P, Gauducheau E, Lemeshow S, Salamon R. 1999. European system for cardiac operative risk evaluation (EuroSCORE). Eur J Cardiothorac Surg 16:9-13.

Oh AK, Lechtman AN, Whetzel TP, Stevenson TR. 2004. The infected median sternotomy wound: management with the rectus abdominis musculocutaneous flap. Ann Plast Surg 52:367-70.

Pairolero PC, Arnold PG, Harris JB. 1991. Long-term results of pectoralis major muscle transposition for infected sternotomy wounds. Ann Surg 213:583-9.

Sarr MG, Gott VL, Townsend TR. 1984. Mediastinal infection after cardiac surgery. Ann Thorac Surg 38:415-23.

Scholl L, Chang E, Reitz B, Chang J. 2004. Sternal osteomyelitis: use of vacuum-assisted closure device as an adjunct to definitive closure with sternectomy and muscle flap reconstruction. J Card Surg 19:453-61.

Song DH, Wu LC, Lohman RF, Gottlieb LJ, Franczyk M. 2003. Vacuum assisted closure for the treatment of sternal wounds: the bridge between debridement and definitive closure. Plast Reconstr Surg 111:92-7.

Strecker T, Feyrer R, Horch RE, Weyand M, Kneser U. 2006. Simultaneous heart valve replacement and reconstruction of the radiation-damaged chest wall with a delayed vertical rectus abdominis myocutaneous flap. J Thorac Cardiovasc Surg 132:980-1.

Weinzweig N, Yetman R. 1995. Transposition of the greater omentum for recalcitrant median sternotomy wound infections. Ann Plast Surg 34:471-7.

Wong CH, Senewiratne S, Garlick B, Mullany D. 2006. Two-stage management of sternal wound infection using bilateral pectoralis major advancement flap. Eur J Cardiothorac Surg 30:148-52.

Yamamoto Y, Nohira K, Shintomi Y, Sugihara T, Ohura T. 1994. "Turbo charging" the vertical rectus abdominis myocutaneous (turbo-VRAM) flap for reconstruction of extensive chest wall defects. Br J Plast Surg 47:103-7.