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ORIGINAL PAPER

# A reconstructive algorithm for deep sternal wound coverage: the Cologne-Merheim approach

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**Abstract**
*Background* Several options are known for treatment of the sternal wounds. However, various wound diameters need various flaps.
*Patients and Methods* 135 patients with sternum osteomyelitis from 2006 to 2010 of our institution were analyzed in a retrospective study. After using various flaps from 2006 to 2009 we developed an algorithm based on wound width, using pectoralis muscle flaps or the latissimus dorsi muscle flap. Two groups from 2006 - 2009, and 2010 were analyzed. A matched pair analysis was done for groups with small (< 6 cm), medium (6 cm - 12 cm) and large wound width (> 12 cm). Endpoint for each analysis was wound dehiscence larger than 1cm. Factors influencing wound dehiscence were analyzed, such as infectious agents, applied flap for coverage, gender, co-morbidities, number of debridements before closure, ICU length of stay. Statistical analysis was done by Mann Whitney U-Test using the SPSS program.
*Results* 130 patients were included in the study and 48 in the match. No significant difference in patient population between the two groups was detected. Total number of wound dehiscence in the 2010 group was lesser, however without statistical significance. Groups with wound sizes lesser than 6 cm showed a significant difference in wound dehiscence when using our algorithm. However, significant lesser length of ICU and hospital stay for all groups treated according to our algorithm was seen.
*Conclusions* ICU and hospital length of stay can be significantly reduced when using our algorithm, reducing costs for treatment of deep sternal osteomyelitis.
Level of Evidence: Level IV, therapeutic study.

**Keywords** Sternal wound infection · Flap closure · Strategy · Latissimus dorsi flap · Pectoralis major flap

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## Introduction

Patients presenting with deep sternal wounds after having developed osteomyelitis require specialized therapy. This is especially true as the wound size varies widely and patients can present with wounds larger than 400 $cm^2$ that need differentiated coverage according to a concept. The primary therapeutic option widely applied by cardiothoracic surgeons is debridement and vacuum therapy, allowing for secondary sternal refixation [1]. However, secondary wound coverage sometimes fails [2–8]. The current concept for failed wound coverage includes several debridements and coverage using well-vascularized tissue [2–8]. Here, various flaps are described in the literature such as the pectoralis major flap, vertical rectus abdominis muscle (VRAM) or transverse rectus abdominis muscle (TRAM) flap, greater omental flap, or latissimus dorsi flap [3, 9–13]. Some flaps are described as being indicated especially for the coverage of infected wound tissue because these flaps facilitate wound healing [10, 11]. Although treatment with different vascularized flaps of sternal wounds for salvage wound closure after initial failed wound coverage is well described, only few concepts or algorithms for sternal wound coverage exist in the literature [3, 7, 10, 12]. We hypothesized that our treatment algorithm would reduce postoperative wound dehiscence and thereby reduce patient treatment costs. In the current study, we evaluated our hypothesis in a retrospective study, using matched-pair analysis between the groups treated in 2007–2009 and the group treated in 2010.

## Patients and methods

From 2006 to 2010, we have treated 135 patients transferred to our institution for deep sternal wounds. These patients were transferred from Cologne, Düsseldorf, and Duisburg, Germany, after having undergone coronary artery bypass grafting, valve replacement surgery, or both. All patients had developed sternal osteomyelitis with open sternal wounds. In all patients, complete sternotomy had been performed at our institution. From 2006 to 2009, we have applied several flaps and concepts described in the literature for sternal wound coverage such as the omental flap, the VRAM and TRAM flap, or the latissimus dorsi flap [3, 12]. However, sometimes, the flaps proved to be not sufficient for wound coverage, especially when large wounds were present. Therefore, we have developed an algorithm for wound coverage using the pectoralis major muscle flap and the latissimus dorsi muscle flap. The type of flap used is based on the width of the wound, as the sternum was resected in all cases and, therefore, the length of the wound varied only between 15 and 19 cm. For wounds up to 6 cm of width, classified as small, unilateral or bilateral myocutaneous pectoralis major flaps were used for coverage. Wounds sized between 7 and 12 cm, classified as middle, were covered using pedicled unilateral or bilateral pectoralis major flaps (Figs. 1, 2, and 3), and wounds larger than 12 cm, classified as large, were covered using a left side pedicled latissimus dorsi flap (Figs. 4 and 5).

We have evaluated two patient populations for wound dehiscence as end point: patients treated from 2006 to 2009 and patients treated using our concept in 2010. We developed the algorithm during our experience from 2006 to 2009. During this period, we used various flaps for different wound sizes. Based on evidence of wound healing/necrosis/dehiscence, we have developed our algorithm and tested this algorithm in 2010. Inclusion criteria were sternal wound infection type IVB or V (El Oakley classification [14]), previous wound debridements outside our institution, vacuum-assisted closure (VAC) device wound treatment at our institution, and secondary flap closure of the sternal defect at our institution. Exclusion criteria were age under 18 years and incomplete sternal resection. One hundred thirty-five patients with deep sternal wound infection as defined by the Center for Disease Control guidelines [15] were evaluated in this prospective observational study. The

**Fig. 1** Wound width 6 cm

patient data were taken from the Merheim sternum register of our department. Five patients were excluded because of incomplete sternal resection.

All patients were operated on by the same team of surgeons. Complete debridement of wounds always included removal of wires and cerclages. After each debridement, wounds were covered with polyurethane (PU) foam dressing using the negative pressure wound therapy (NPWT) device. The foam was fitted to the individual wound size, and the vacuum was set to 80 mmHg continuous negative pressure. To protect the precordial fat and the underlying heart, a sheet of Mepithel™ was placed between the fat and the PU foam (Fig. 6). Antibiotics were given only preoperatively and individually tailored to the antibiotic sensitivities of bacteria detected in the wound. Wounds were successively debrided with complete resection of the sternum, ribs, and bony sequesters until healthy bone was shown in the histopathological analysis and/or when the number of microorganisms in the wounds were close to none. Only then was flap coverage done and, if indicated, antibiotic therapy continued. This concept was used in both groups.

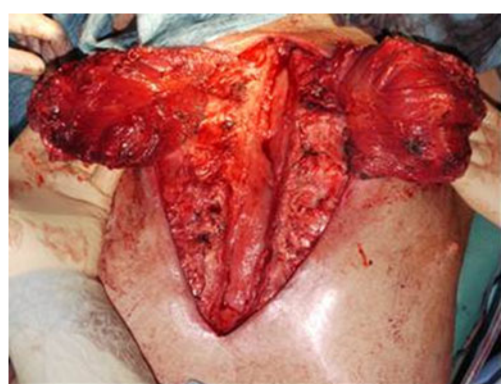

**Fig. 2** Bilateral pedicled pectoralis flaps before wound coverage

**Fig. 3** Complete wound coverage by the bilateral pedicled pectoralis flaps

Dissection of the myocutaneous pectoralis major flaps included elevation of the costosternal origin and freeing the muscle in the avascular plane above the pectoralis minor muscle. The muscles were advanced medially and sutured to each other into the sternal defect using mattress sutures. The soft tissue and skin were mobilized epifascially up to the areola and closed in a double-layered continuous fashion.

The pedicled pectoralis major flaps were dissected off the sternocostal origin and epifascially elevated above the pectoralis minor muscle. Just medial to the anterior axillary line, the fibers forming the humeral insertion were transected using monopolar diathermy. The clavicular origin was dissected from medial and lateral, isolating the pectoral branches of the thoracoacromial artery on which the flap is


**Fig. 4** Wound width 9 cm

**Fig. 5** Wound width 18 cm

based. Branches from the lateral thoracic artery were always divided to allow for a greater reach of the muscle, which was rotated into the defect.

In large defects, the muscle was elevated bilaterally and sutured to one another and the wound edges. The skin was then closed over the muscle in a double-layered fashion. In cases where the skin envelope was deficient, a split-

**Fig. 6** Wound coverage with left pedicled latissimus dorsi flap. A postoperative skin defect was covered with a split thickness skin graft

thickness skin graft was harvested and placed onto the muscle and secured by NPWT.

The latissimus dorsi muscle flap was elevated with a customized skin island to fit the defect and brought into place by creating a subcutaneous tunnel (Figs. 4 and 5). The muscle was secured to the contralateral deep wound edge. The customized skin island was sutured to the surrounding skin in a double-layered continuous fashion technique.

For all patients, an elastic pressure garment was fitted postoperatively to maintain a stable chest wall, and patients were instructed to wear them for 6 weeks. Wounds were inspected during daily dressing changes. Wound dehiscence or necrosis was defined as any small dehiscence or small necrosis of the wound of more than 1 cm during the hospital stay or up to 2 weeks after discharge.

In the matched-pair analysis, we have analyzed the result of our algorithm applied in 2010 (group 2) to the group treated from 2007 to 2009 (group 1). Inclusion criteria were treatment at our institution, age over 18 years, and deep sternal infection according to El Oakley classification IV and V [13]. Matching criteria were age, gender, wound size, and comorbidities. Three subgroups were compared, based on wound width: small wounds with a width lesser than 6 cm, medium wounds sized between 6 and 12 cm, and large wounds with a width larger than 12 cm (Figs. 2, 3, and 4). Factors analyzed for influencing wound dehiscence were age, gender, comorbidities such as smoking, obesity, diabetes, hyperlipoproteinemia, arterial hypertension, coronary artery bypass, aortic valve replacement, peripheral artery disease, cardiac insufficiency, coronary artery disease, renal insufficiency, and chronic obstructive pulmonary disease (COPD), steroid use, infectious agents, sepsis, and number of previous operations. Data were analyzed using the chi-square test, Fisher's exact test, and Mann–Whitney $U$ test and the SPSS program at the Institute for Research in Operative Medicine (IFOM). All dichotomous categorical variables were analyzed using Fisher's exact test, and continuous variables were evaluated with the Student's $t$ test. A $p$ value <0.05 was considered to be significant. Data are presented as the mean± standard deviation (SD).

## Results

One hundred thirty patients were included in our study after evaluation. From all included patients, 51 (39 %) patients were female and 79 (61 %) patients were male. The mean age was 69.1 years. Seventy (53.8 %) patients were transferred to the intensive care unit (ICU). Thirty-two (24.6 %) of these were transferred postoperatively for initial flap surveillance. Seventeen (13 %) died during the ICU stay; these were subsequently excluded from the study. The mean ICU stay was 37.2 days (SD, 34.7 days), where the patients had to be ventilated for 29.3 days (SD, 18.7 days) on average. Ninety (69 %) patients healed primarily without any signs of wound dehiscence and/or wound necrosis after flap coverage. They were discharged after a mean of 19.2 days (SD, 13.1 days).

Statistical evaluation between the 2006–2009 and the 2010 groups showed that, although the two groups were statistically significantly different in number of smokers and arterial hypertension, they did not differ significantly in age, mean wound width, number of previous operations, and other comorbidities (Table 1).

The subgroup characteristics are shown in Tables 2, 3, and 4. Evaluation of the subgroups showed significant differences in number of smokers and coronary artery disease in the small wounds, obesity, coronary artery disease, and arterial hypertension. Wound dehiscences were seen after defect coverage using four myocutaneous pectoralis flaps and two VRAM flaps in the 2006–2009 group and after five myocutaneous pectoralis major flaps in the 2010 group (Table 2). The group with middle-sized wounds showed significant differences in obesity, coronary artery disease, and arterial hypertension. The 2006–2009 group had wound dehiscence after four bilateral myocutaneous pectoralis major flaps, two VRAM flaps, and one latissimus dorsi flap, while the 2010 group had wound dehiscences after seven bilateral pedicled pectoralis major flaps (Table 3).

The group with large wounds had significant differences in the number of smokers, renal insufficiency, and coronary artery disease. Wound dehiscences occurred in the 2006–2009 group after one latissimus dorsi combined with pectoralis major flap and two latissimus dorsi flaps and in the 2010 group after three latissimus dorsi flaps (Table 4). There was a 7 % lesser wound dehiscence in the 2010 group noted than in the 2006–2009 group.

A total of 48 patients could be included into the match. Two of them were excluded because they did not completely fulfill the matching criteria. This left 15 male and 8 female patients in the 2 groups treated with or without algorithm. In the group of wound sizes lesser than 6 cm, there were 20 patients, 10 in each treatment group; 16 patients were male and 4 were female. The average age was 71 years in group 1 and 72 years in group 2, and the average wound width was 4.7 and 4.8 $cm^2$, respectively. In the group of wound sizes between 6 and 12 cm, there were 12 patients, 6 in each treatment group; 8 patients were male and 4 were female. The average age was 72.2 years in group 1 and 73.2 years in group 2, and the average wound width was 7.2 cm in group 1 and 6.9 cm in group 2. In the group of wound widths

**Table 1** Group characteristics

| Group | 1 | 2 | *p* value |
|---|---|---|---|
| Operating period | 2006–2009 | 2010 | |
| Number | 77 (59.23 %) | 53 (40.77 %) | 0.078 |
| Male/female | 55:22 | 33:20 | |
| Mean age (SD), years | 69.00 (9.70) | 69.96 (9.80) | 0.108 |
| Mean wound width (SD), cm | 7.66 (4.46) | 7.8 (4.85) | 0.098 |
| Previous operations | 2.23 | 2.12 | 0.099 |
| Smoker | 27 (35.06 %) | 28 (52.83 %) | 0.044* |
| Obesity | 55 (71.43 %) | 33 (62.26 %) | 0.087 |
| COPD | 15 (19.48 %) | 10 (18.86 %) | 0.077 |
| Kidney insufficiency | 30 (38.96 %) | 12 (22.64 %) | 0.065 |
| Coronary artery disease | 52 (67.53 %) | 34 (64.15 %) | 0.087 |
| Cardiac insufficiency | 19 (24.67 %) | 20 (37.73 %) | 0.077 |
| Peripheral arterial disease | 13 (16.88 %) | 12 (22.64 %) | 0.070 |
| Arterial hypertension | 46 (59.74 %) | 46 (86.79 %) | 0.042* |
| Hyperlipoproteinemia | 31 (40.25 %) | 23 (43.39 %) | 0.089 |
| ICU stay (SD), days | 38.23 (33.55) | 36.8 (32.24) | 0.083 |
| Total hospital stay (SD), days | 45.26 (30.52) | 44.40 (29.22) | 0.098 |

*SD* standard deviation

*$p<0.05$, significant difference

larger than 12 cm, there were 14 patients; 4 patients were male and 10 were female. The average age was 70 years in group 1 and 70.5 years in group 2, and the average wound size was 12.6 cm in group 1 and 11.3 cm in group 2. In the analysis using the chi-square test, the likelihood quotient, the Fisher exact test, and testing for a linear coherence, no significant difference was detected regarding age, wound size, steroid use, diabetes, smoking, obesity, COPD, renal insufficiency, coronary heart disease, cardiac insufficiency, peripheral arterial disease, hyperlipoproteinemia, aortic valve replacement, coronary artery bypass surgery, sepsis, number of infectious agents, or wound dehiscence (Table 5). The median number of operations before closure of the defect was 2.03 in group 1 and 2.02 in group 2. However, using the Mann–Whitney *U* test, a difference was found between total hospital stay, ICU length of stay, and ventilator days of all groups. Group 1 had a median of 35 days of total hospital stay (average, 45.5 days), while group 2 had a median of 28 days (average, 42.7 days); $p\leq0.8$, however, not statistically significant. Statistically significant differences were found between ICU length of stay and ventilator days. Group 1 had a median ICU length of stay of 3 days

**Table 2** Subgroup small width characteristics

| Subgroup | Group 1 | Group 2 | *p* value |
|---|---|---|---|
| Small (*n*) | 35 | 26 | 0.079 |
| Male/female | 29:06 | 21:05 | |
| Mean age (SD), years | 69.23 (9.47) | 71.15 (9.00) | 0.082 |
| Mean wound width (SD), cm | 4.40 (1.12) | 4.33 (1.62) | 0.109 |
| Previous operations | 1.97 | 2.12 | 0.086 |
| Smoker | 11 (31.42 %) | 15 (57.69 %) | 0.040* |
| Obesity | 22 (62.85 %) | 11 (42.30 %) | 0.062 |
| COPD | 9 (25.71 %) | 4 (15.38 %) | 0.051 |
| Renal insufficiency | 13 (37.14 %) | 4 (15.38 %) | 0.055 |
| Coronary artery disease | 34 (97.14 %) | 16 (61.53 %) | 0.038* |
| Cardiac insufficiency | 7 (20.00 %) | 8 (30.76 %) | 0.061 |
| Peripheral arterial disease | 4 (11.42 %) | 4 (15.38 %) | 0.081 |
| Arterial hypertension | 25 (71.42 %) | 22 (84.61 %) | 0.075 |
| Hyperlipoproteinemia | 14 (40.00 %) | 10 (38.46 %) | 0.088 |
| Wound dehiscence (*n*) | 6 (17.14 %) | 5 (19.23 %) | 0.086 |

*$p<0.05$, significant difference between the groups

**Table 3** Subgroup middle width characteristics

| Subgroup | Group 1 | Group 2 | $p$ value |
|---|---|---|---|
| Middle ($n$) | 35 | 21 | 0.078 |
| Male/female | 18:17 | 11:10 | |
| Mean age (SD), years | 67.41 (15.17) | 68.04 (10.81) | 0.083 |
| Mean wound width (SD), cm | 8.83 (1.69) | 9.04 (1.58) | 0.077 |
| Previous operations | 2.54 | 2.19 | 0.079 |
| Smoker | 13 (37.14 %) | 11 (52.38 %) | 0.068 |
| Obesity | 28 (80.00 %) | 8 (38.09 %) | 0.034* |
| COPD | 6 (17.14 %) | 2 (9.52 %) | 0.070 |
| Renal insufficiency | 14 (40.00 %) | 7 (33.33 %) | 0.074 |
| Coronary artery disease | 33 (94.28 %) | 15 (71.42 %) | 0.044* |
| Cardiac insufficiency | 9 (25.71 %) | 10 (47.61 %) | 0.054 |
| Peripheral arterial disease | 7 (20.00 %) | 6 (28.57 %) | 0.060 |
| Arterial hypertension | 17 (48.57 %) | 18 (85.71 %) | 0.038* |
| Hyperlipoproteinemia | 13 (37.14 %) | 10 (47.61 %) | 0.077 |
| Wound dehiscence ($n$) | 7 (20.00 %) | 4 (19.04 %) | 0.089 |

*$p<0.05$, significant difference between the groups

(average, 28.7 days), while group 2 had a median ICU length of stay of 0 days (average, 10.9 days); $p \leq 0.043$. Group 1 had an average of 16.6 ventilator days, while group 2 had an average of 5.91 days; $p \leq 0.031$ (Figs. 7 and 8).

## Discussion

Since poststernotomy mediastinitis is still a devastating complication and it implies a prolonged hospital stay and increased nursing care, it is also considered to have a substantial impact on the health care system economy. Sternal wire fixation was first described in 1897 and was made popular by Julian et al. in the 1950s [16]. After traditional median sternotomy incision, only a small percentage develops a bony instability with or without wound dehiscence or infection, described to be as high as 1–8 %. The vast majority of sternotomies result in osseous union whether sternal wiring or fixation plates are used [17–19].

The pathogenesis of sternal nonunion is multifactorial and includes patient factors, environmental factors, and operative techniques [20]. Risk factors for sternal nonunion are the same as for those of postoperative sternal dehiscence [21]. In addition, factors such as COPD, coughing, or strenuous physical exercises are described in the early postoperative

**Table 4** Subgroup large width characteristics

| Subgroup | Group 1 | Group 2 | $p$ value |
|---|---|---|---|
| Large ($n$) | 6 | 7 | 0.094 |
| Male/female | 1:5 | 2:5 | |
| Mean age (SD), years | 71.16 (7.69) | 71.28 (8.24) | 0.095 |
| Mean wound width (SD), cm | 19.83 (2.94) | 19.04 (5.43) | 0.089 |
| Previous operations | 2.00 | 2.71 | 0.091 |
| Smoker | 3 (50.00 %) | 2 (28.57 %) | 0.038* |
| Obesity | 5 (83.33 %) | 4 (57.14 %) | 0.063 |
| COPD | 0 (0.00 %) | 4 (57.14 %) | 0.0001* |
| Renal insufficiency | 3 (50.00 %) | 1 (14.28 %) | 0.028* |
| Coronary artery disease | 5 (83.33 %) | 3 (42.85 %) | 0.042* |
| Cardiac insufficiency | 3 (50.00 %) | 2 (28.57 %) | 0.052 |
| Peripheral arterial disease | 2 (33.33 %) | 2 (28.57 %) | 0.078 |
| Arterial hypertension | 4 (66.66 %) | 6 (85.71 %) | 0.074 |
| Hyperlipoproteinemia | 4 (66.66 %) | 3 (42.85 %) | 0.066 |
| Wound dehiscence ($n$) | 3 (50.00 %) | 3 (42.85 %) | 0.082 |

*$p<0.05$, significant difference between the groups

**Table 5** Group characteristics matching algorithm

| | Group 1 | Group 2 |
|---|---|---|
| Male/female | 15:08 | 15:08 |
| Diabetes | 23 | 23 |
| Smoker | 25 | 21 |
| Hyperlipoproteinemia | 13 | 10 |
| Obesity | 16 | 14 |
| COPD | 3 | 5 |
| Renal insufficiency | 9 | 5 |
| Aortic valve replacement | 6 | 6 |
| Coronary artery bypass | 19 | 20 |
| Sepsis | 10 | 8 |
| Wound necrosis | 6 | 6 |
| Hematoma | 1 | 3 |

course. Also, low bone mineral density is described as a contributing factor.

Following the use of the left internal mammary artery, relative avascularity of the sternum may result, leading to bone deterioration, fractures, or wire pull-through [20]. Coverage of open sternal wounds after deep sternum osteomyelitis still remains a challenge. The actual problem is the deep sternal wound infection, which is a serious complication after cardiac surgery. Frequently, this leads to instability of the chest, wound dehiscence, and chronic osteomyelitis [22]. Despite

**Fig. 7** The precordial fat is visible. Mepithel™ is placed over the precordial fat before inserting the PUV foam and applying the NPWT

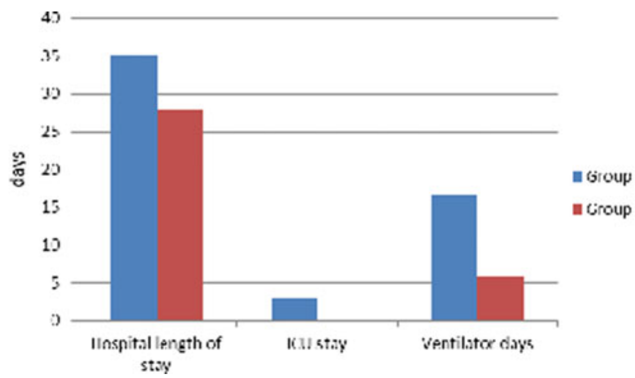


**Fig. 8** Mann–Whitney *U* test between the two groups; hospital length of stay, $p \leq 0.8$; ICU stay, $p \leq 0.043$; ventilator days, $p \leq 0.091$

debridements, application of VAC devices, antibiotic use, and rewiring as primary treatment, persisting wound dehiscence and sternal infections are described [16, 23–26]. Therefore, first and foremost, treatment is the eradication of the deep sternal osteomyelitis. At our institution, patients usually receive antibiotic treatment after the first debridement according to the sensitivities of bacteria detected in the wound preoperatively, before the following debridements, and final closure. However, antibiotic treatment is given only once preoperatively because the debridement cleans the wound of 70 % of bacterial load [26]. Antibiotic treatment supports the removal of only 20 % of the bacteria, stressing the importance of surgical wound debridement [26].

The management to cover these wounds is difficult because the wounds differ more in width than in length or depths. So far, there are only few concepts described in literature concentrating on open sternal wound coverage according to size. Nahai et al. have laid down treatment guidelines for sternotomy wounds, preferring a single muscle closure in a single-step procedure if possible [3]. In addition, they described the rectus abdominis muscle turnover flap after the use of bilateral internal mammary arteries, without change in physiologic abdominal function. Also, the pectoralis flap may be turned over to cover the open sternal defect; the flap will be perfused by the intercostal perforators. However, their treatment guidelines do not describe the use of specific muscles to cover the defect width. Similar treatment guidelines are described by Jones et al., Lee at al., and Erdmann et al. [7, 10, 12]. So far, there is no concept based on wound width after sternotomy.

The predominant concept is based on local flaps, such as the pectoralis major flap, the TRAM/VRAM flap, the omentum majus flap, or more seldom, the latissimus dorsi flap [7, 10, 12]. The drawback of all these descriptions is that they are not based on wound widths, but merely leaves the application of the flaps to the operating surgeon. Although there is some discussion about the resulting motoric dysfunction after the harvest of latissimus dorsi flaps and pectoralis major flaps, Scully et al. and Daigeler et al. have shown in their retrospective studies no difference in terms of upper extremity function and, in addition, final esthetic outcome [27, 28]. We present a wound management strategy based on the wound size and depth and the state of sternotomy that was performed. Statistical analysis did not show any difference between the compared groups. Although a 7 % lesser wound dehiscence was noted in the 2010 group with large wounds, the number of the group is small. A larger number is needed to test for a statistical significance.

During the years 2006–2009, we have used several flaps to cover small to large open sternal wounds. We experienced unwanted results such as wound dehiscence of 1 cm or higher or flap necrosis and have, therefore, developed our own strategy to treat presternal wounds, a reconstructive algorithm for the presternal wound.

Patients with deep sternal osteomyelitis with presternal wound dehiscence usually present with several comorbidities [7, 16, 29]. These comorbidities include

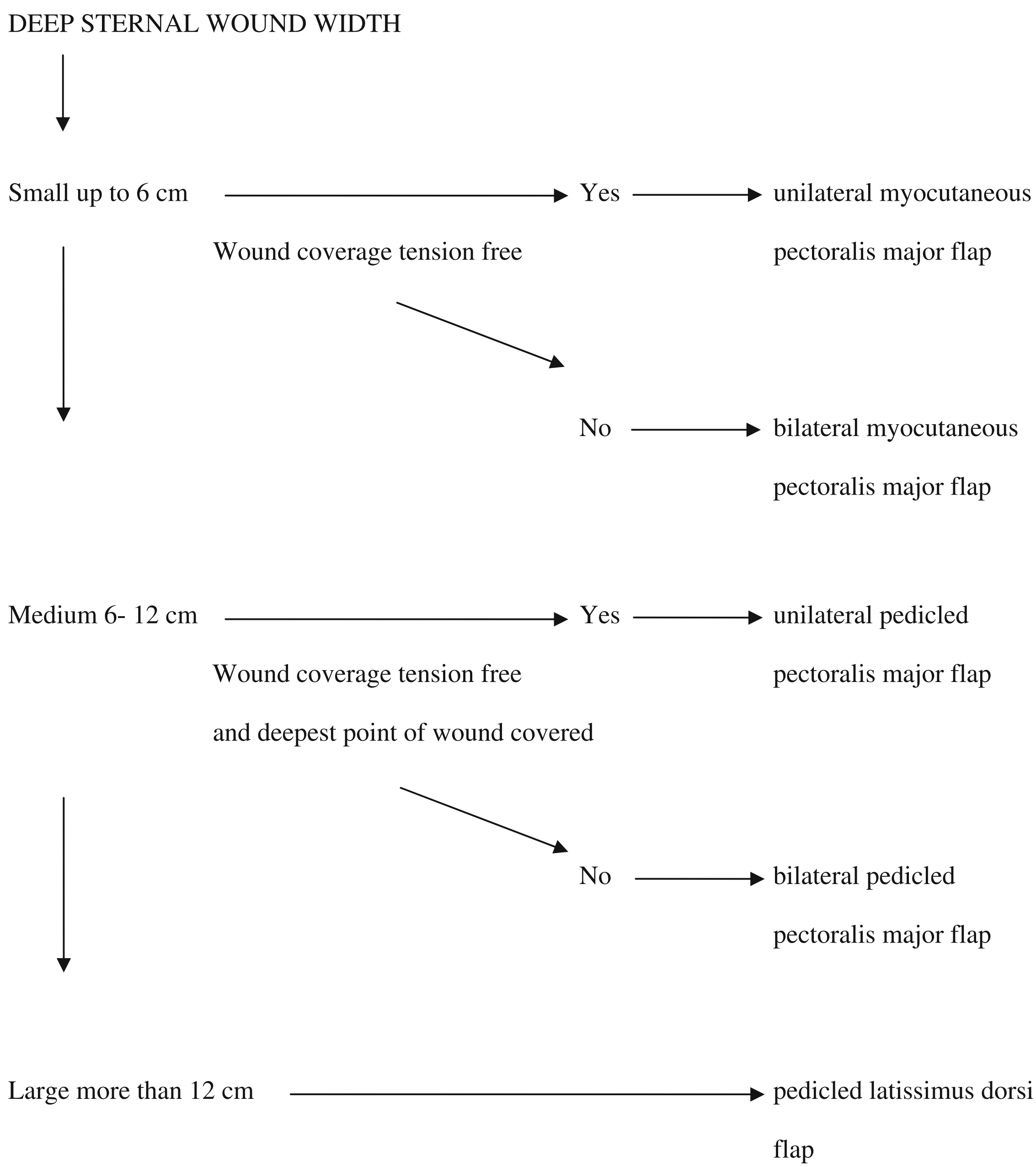


**Fig. 9** Reconstructive algorithm

obesity, arterial hypertension, hyperlipoproteinemia, peripheral arterial disease in various stages, COPD, renal failure in various stages, and many more. These comorbidities have been described to influence wound dehiscence [22, 30]. To eliminate these factors, we have performed a matched-pair analysis.

The combination of these comorbidities makes the preoperative, intraoperative, and postoperative management of these patients a challenge, often warranting postoperative ICU treatment [20, 22, 23]. However, treatment costs in any ICU are high and mortality of patients increases with length of stay [11, 31]; therefore, any reduction of length of stay in the ICU will reduce the costs and mortality. The average length of stay in our hospital in the ICU was 28.7 days in group 1. Using our treatment algorithm for sternal wound coverage, the length of stay was reduced to 10.9 days. This was statistically significant.

Reasons for shorter hospital stay in our study could be an increased learning curve for ICU treatment of these patients. Simek et al. described in their study mastering of their technique of debriding sternal wound infection [32]. This led finally to a shortened hospital stay. In our hospital, patients with sternal osteomyelitis are treated in the ICU in a combined approach with the department of anesthesia, internal medicine (cardiology), radiology, and if needed, the department of cardiothoracic surgery was involved. When applying this team approach, a learning curve results, leading to a better preoperative preparation of these patients and, in the end, a shorter hospital stay. Another reason is the reduction of the number of operations before defect coverage, as suggested in the literature [3, 32, 34]. Jeevanandam et al. even report on single-stage sternal wound coverage [32]. The average number of operations before closure of the defect was 2; no significant difference was found between the groups.

Another reason for the reduced hospital stay could be a more efficient operative technique and improved wound coverage, reducing operative time, thereby the length of stay in the ICU and postoperative complications were reduced [14, 31, 33]. However, we did not measure time for operations in our study.

Also, the number of treatments could influence the length of ICU stay [18, 29]. In a previous study, we have shown a positive correlation between number of treatments and increased length of stay in the ICU [29]. Nahai et al. have shown that early coverage of presternal wounds results in a decreased number of wound complications [3]. Morisaki et al. showed higher risk for mortality after prolonged ICU stay [35], stressing the need for ICU stays, which are as short as possible. This study also reveals a shorter total hospital stay, when the ICU stay was shorter [35]. In addition, complete sternal resection is suggested to reduce the treatment for osteomyelitis and the entire hospital stay [36]. Simek et al. found in their study that a reduced number of VAC treatments reduce the length of hospital stay [32]. However, we did not detect any significant difference between the two groups in our study in the number of previous operations, number of VAC changes, or number of operations at our institution.

ICU stays are expensive because of the continuous treatment of various comorbidities [31]. However, the exact costs are hard to calculate because of several comorbidities that need to be treated [31, 36]. Reduction of these costs could be achieved by reduction of length of stay in the ICU and reduction of ventilator days [37, 38]. Thereby, increased risks of transmission of ICU-related multidrug-resistant bacteria and ventilator-associated pneumonia could be reduced [25–27, 39] (Fig. 9).

The following was our concept of treatment. All wounds were measured prior to coverage. Small wounds with a width of 6 cm were covered by unilateral or bilateral myocutaneous pectoralis flaps, depending if the wound could be closed without tension. If the wounds were medium-sized, between 7 and 12 cm in width, unilateral pedicled pectoralis flaps were used for coverage. The bilateral pedicled pectoralis flaps were used if the deepest point of the wound could not be covered by a unilateral pedicled pectoralis major flap. For large wounds with a width of 13 cm and more, a left pedicled latissimus dorsi flap was used for coverage. This concept was applied to all patients admitted in 2010.

**Conflict of interest** None.

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