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ORIGINAL ARTICLE / ÖZGÜN MAKALE

Sternal wound types after median sternotomy and reconstruction using dead space-based approach

Median sternotomi sonrası sternal yara tipleri ve ölü boşluk bazlı yaklaşım ile rekonstrüksiyon

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ABSTRACT

Background: This study aims to classify wound complications after median sternotomy and provide an up-to-date reconstructive algorithm for multidisciplinary use.

Methods: A total of 15 patients (9 males, 6 females; mean age: 68±5 years; range, 60 to 75 years) who underwent sternal reconstruction for wound complications following median sternotomy between August 2020 and October 2023 were retrospectively analyzed. Wound complications requiring reconstruction were classified into three categories based on the extent of the dead space caused by sternal debridement. Type 1, 2, and 3 wounds presented with only skin defects and an intact sternum, with partial and total sternectomy, respectively. The time to consultation for plastic surgery and the duration of hospitalization were compared.

Results: Among the wounds, type 2 wounds were the most common type seen in 11 patients. Two patients each had type 1 and type 3 wounds. A superior epigastric artery perforator skin flap was used for type 1 wounds. Bilateral pectoral and split pectoral turnover muscle flaps from the side where the internal mammary artery was intact were used for type 2 wounds. A rectus abdominis muscle flap was used for type 3 wounds. Early consultation from plastic surgery reduced the length of hospital stay.

Conclusion: For type 1 wounds, skin flaps ensured sufficient coverage as they involved skin and subcutaneous fat, matching the defect. However, sternal excision required muscle flaps to fill the dead space, in which the vital organs were exposed.

Keywords: Dead space, median sternotomy, muscle flap, perforator skin flaps, sternal debridement.

ÖZ

Amaç: Bu çalışmada median sternotomi sonrasında yara komplikasyonları sınıflandırıldı ve multidisipliner kullanım için güncel bir rekonstrüktif algoritma sunuldu.

Çalışma planı: Ağustos 2020 - Ekim 2023 tarihleri arasında median sternotomi sonrası yara komplikasyonları nedeniyle sternal rekonstrüksiyon uygulanan 15 hasta (9 erkek, 6 kadın; ort. yaş: 68±5 yıl; dağılım, 60-75 yıl) retrospektif olarak incelendi. Rekonstrüksiyon gerektiren yara komplikasyonları sternal debridmanın neden olduğu ölü boşluk hacmine göre üç kategoride sınıflandırıldı. Tip 1 yaralarda yalnızca cilt defektleri olup, sternum intaktı; tip 2 yaralarda parsiyel sternal eksizyon ve tip 3 yaralarda total sternal eksizyon vardı. Plastik cerrahiye konsültasyon zamanı ve hastanede kalış süresi de karşılaştırıldı.

Bulgular: Yaralar arasında tip 2 yara 11 hastada en sık görülen yara tipi idi. İki hastanın her birinde tip 1 ve tip 3 yaralar mevcuttu. Tip 1 yaralar için superior epigastrik arter perforatör cilt flebi kullanıldı. Tip 2 yaralarda internal meme arterinin intakt olduğu taraftan alınan bilateral pektoral ve split pektoral turnover kas flepleri kullanıldı. Tip 3 yaralarda rektus abdominis kas flebi kullanıldı. Plastik cerrahiye erken konsültasyon, hastanede kalış süresini kısalttı.

Sonuç: Tip 1 yaralarda cilt flepleri defekti kapatarak cilt ve subkutan yağı da içine alacak şekilde yeterli bir kapatma sağladı. Ancak sternal eksizyonda yaşamsal organların da yer aldığı ölü boşluğu doldurmak için kas flepleri gerekti.

Anahtar sözcükler: Ölü boşluk, median sternotomi, kas flebi, perforatör cilt flebi, sternal debridman.

Median sternotomy which provides wide exposure to the surgeon is the most frequently used incision in cardiac surgery. However, complications after median sternotomy can be devastating due to thoracic instability and exposure of vital organs, such as the heart and lungs. Early reports estimated mortality rates at 50%; however, the use of reconstruction methods has reduced mortality rates to approximately 1%.[1]

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However, patients with wound complications experience longer hospital stays and a 2.8-fold higher cost of treatment compared to those without these complications.[2] Consequently, the management of wound complications after median sternotomy remains a significant challenge for plastic and cardiac surgeons.

Complications after a median sternotomy can result in various types of wounds. Some patients may exhibit superficial defects involving the skin and subcutaneous tissues only, whereas others may have extensive defects in which the sternotomy line separates and vital organs are exposed. The pre-, peri-, and postoperative risk factors for wound complications have been previously reported.[3-6] Identifying high-risk patients through cardiac surgeons' assessments and involving plastic surgeons early in the treatment may help to reduce mortality risks.[5,7,8]

Sternal wounds can be treated as a single entity despite their variable clinical presentation.[4,8] Treatment consists of three main steps until reconstructive operation: *(i)* managing the infection, *(ii)* debriding unhealthy tissues, and *(iii)* using vacuum-assisted closure (VAC) therapy as a bridge until definitive closure.

Wound type and reconstructive plan are determined at the end of these three steps, when wound becomes ready for reconstruction. Wounds are considered ready for reconstruction, when the infection has been eradicated and all unhealthy and nonviable tissues have been completely removed. Therefore, as soon as the diagnosis is made, serial debridement is performed at intervals of three to four days and microbiological samples are taken. Debridement requires collaboration with cardiovascular and plastic surgery team, particularly in cases requiring sternal excision, due to the close proximity of vital structures with the debridement area. After debridement, VAC therapy is initiated. Debridement is repeated with each VAC change. With serial debridement, VAC treatment and culture-specific antibiotic therapy, the wound typically becomes ready for reconstruction within approximately two weeks.[1,2,4] A wound type and reconstructive plan is determined at this stage, based on the components and size of the tissue defect formed after the final debridement.

Reconstruction methods include primary repair,[8] pectoral muscle flaps and modifications,[2,3,9] rectus abdominis flaps,[4,5,10] omental flaps,[11] latissimus dorsi flaps,[12] and perforator skin flaps.[13,14] To date, several methods for osseous reconstruction of the sternum have been described. If the sternal bone is healthy and well-vascularized, sternal rewiring[15] or rigid fixation with titanium plates[16] can be used for sternal fixation. In cases with sternal bone loss caused by sternal debridement, osteosynthesis methods,[6] the Robicsek procedure,[17] cementoplasty[18] and free fibula osseous flaps[19] have been described. However, necessity of rigid sternal fixation after sternal dehiscence is still controversial.[20,21] Previous studies have shown that muscle flaps can provide sternal stability without the need for rigid fixation.[22,23] Therefore, fixative osseous reconstruction methods are not widely accepted and routinely used in practice.

The diversity of wound types and numerous treatment options available have made it difficult to standardize the reconstructive method for each patient. Existing algorithms often lack reconstruction options and may not be suitable for multidisciplinary use. In the present study, we aimed to classify wound complications after median sternotomy and provide an up-to-date reconstructive algorithm for multidisciplinary use.

PATIENTS AND METHODS

This single-center, retrospective observational study was conducted at Balıkesir University Faculty of Medicine, Department of Cardiovascular Surgery between August 2020 and October 2023. A total of 15 patients (9 males, 6 females; mean age: 68±5 years; range, 60 to 75 years) who underwent reconstruction for wound complications following median sternotomy were included. Data on patient age, sex, comorbidities, and body mass index (BMI) were collected.

The patients were admitted to the Department of Cardiovascular Surgery throughout their hospitalization. Debridement was conducted in collaboration with cardiovascular surgeons.

All patients underwent VAC therapy after the initial debridement. The VAC changes were performed every three days in the operating room. During each VAC change, debridement was repeated, and tissue samples were obtained for microbiological examination.

The wound type was determined during the final debridement in clean wound after eradication of the infection. Median time for wound to be clean and ready for reconstruction was 10 days after plastic surgery consultation. Wounds were classified into three categories. Type 1 wounds were those in which dehiscence involved only the skin and subcutaneous tissues and the sternum remained

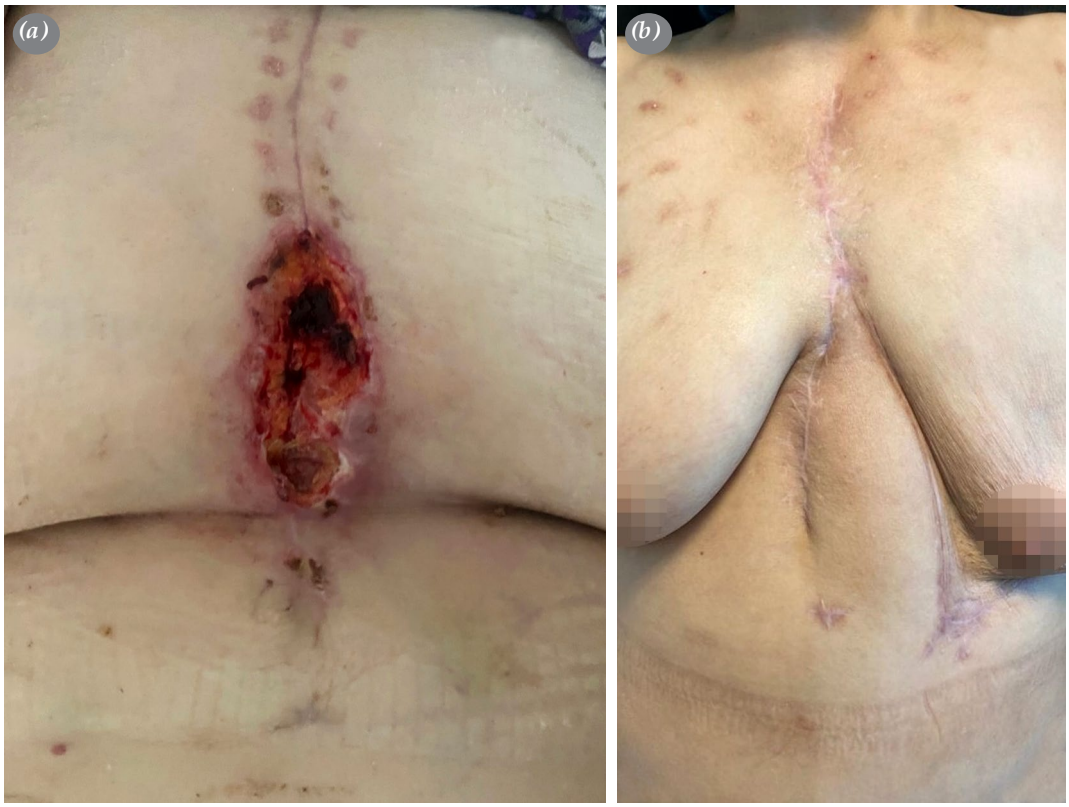

Figure 1. (a) Type 1 wound, defect includes only skin and subcutaneous tissues. **(b)** Type 1 wound reconstructed with superior epigastric artery perforator based skin flap.

stable (Figure 1). Sternal stability was evaluated during surgical debridement with inspection and sternal compression tests. The sternum was considered stable when it appeared vital, the wires remained in place, and the sternal edges did not separate upon compression. Type 2 wounds encompassed cases where sternal wires were removed and sternal edges were resected until healthy bone was obtained, resulting in a partial sternectomy (Figure 2). In type 3 wounds, the sternum was completely excised (Figure 3). In type 2 and type 3 wounds, vital organs were exposed.

For type 1 wounds, a superior epigastric artery perforator skin flap was used. For type 2 wounds, bilateral pectoral muscle flaps and a split pectoral turnover muscle flap, obtained from the side where the internal mammary artery (IMA) was intact, were used. For type 3 wounds, the rectus abdominis muscle flap was used. In type 2 and type 3 wounds with bone defects, no fixation methods were used for osseous reconstruction.

In addition, the patients were divided into two groups: those who received plastic surgery consultations within the first 15 days (n=5) and those who received this consultation later (n=10). The duration of hospitalization was compared between the two groups.

Statistical analysis

Statistical analysis was performed using the SPSS version 25.0 software (IBM Corp., Armonk, NY, USA). The Shapiro-Wilk and Levene tests were used to investigate whether the assumptions of normal distribution and homogeneity of variance were met. Continuous variables were expressed in mean ± standard deviation (SD) or median (min-max), while categorical variables were expressed in number and frequencies. The Spearman rank-order correlation coefficient was calculated to determine the relationship between the cumulative duration of hospital stay and the time to plastic surgery consultation. The Mann-Whitney U or Kruskal-Wallis test was used to evaluate continuous variables, whereas the Fisher-Freeman-Halton test was used to analyze categorical variables. A p value of <0.05 was considered statistically significant.

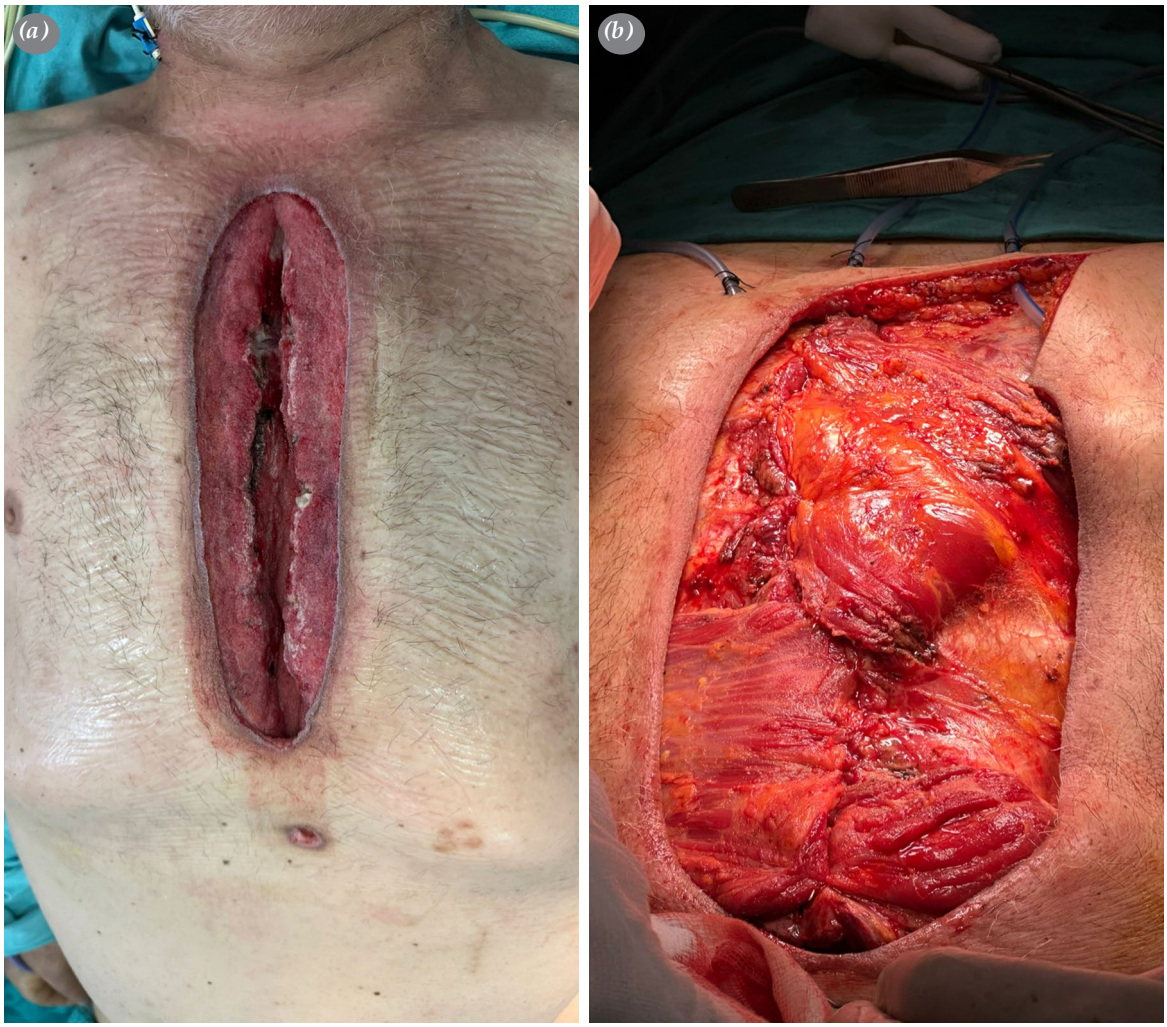

Figure 2. (a) Type 2 wound, defect resulted with partial sternectomy. **(b)** Type 2 wound reconstructed with bilateral pectoral advancement flap and split pectoral turnover flap.

RESULTS

All patients had at least one comorbidity, the most common being diabetes mellitus. The mean BMI of the patients was 28±4 (range, 21.5 to 35.3) kg/m^2 (Table 1).

Type 2 was the most common wound type in all wounds which was seen in 11 patients (Table 2). Four patients had complications. All complications occurred in patients with wound types 2 and 3 reconstructed using muscle flaps (Table 2). One patient who underwent repair using a rectus muscle flap experienced skin dehiscence in the donor area. Two patients who underwent repair with bilateral pectoral muscle flaps developed hematomas, and one patient developed skin necrosis. The patient with skin necrosis was treated with VAC therapy for two weeks after debridement, followed by skin graft placement onto the intact pectoral flap (Figure 4a, b).

The median length of hospital stay was 28 (range, 19 to 52) days. Patients who received a plastic surgery consultation within 15 days (median: 24 days; range, 19 to 27 days) had significantly shorter hospital stays than those who received this consultation later (median: 33 days; range, 21 to 52 days) (Figure 5).

The median follow-up was 12 (range, 3 to 30) months. None of the patients showed signs of infection recurrence or clinical pulmonary symptoms related to thoracic instability.

DISCUSSION

Sternal reconstruction algorithms developed to date consider factors such as the timing of sternal wound presentation 15, width of the wound 12, anatomical localization 10, and infection status 8. However, we propose that sternal integrity is the most crucial

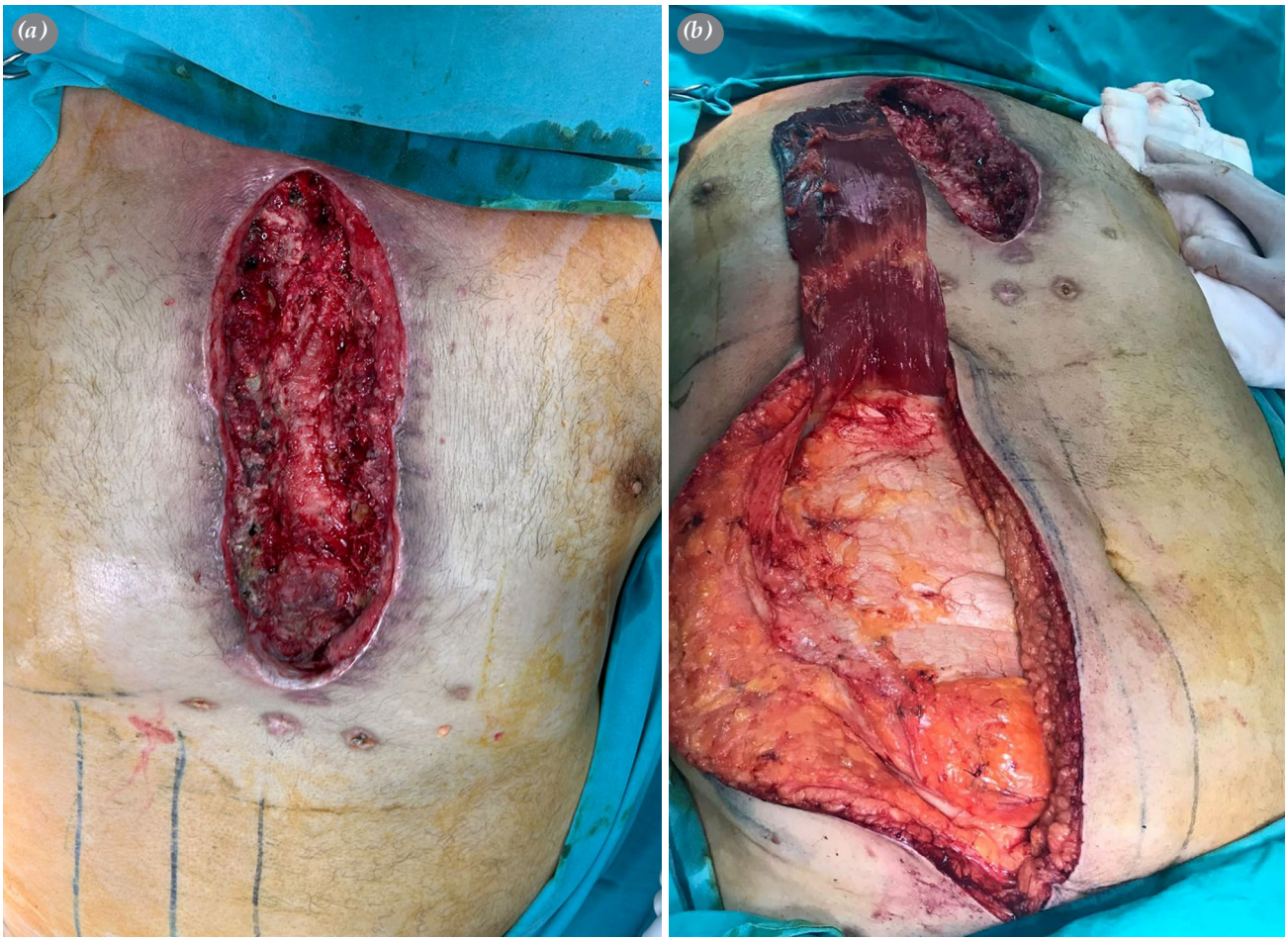

Figure 3. (a) Type 3 wound, resulted total sternectomy. **(b)** Type 3 wound reconstructed with rectus abdominis muscle flap, flap before tunnelization.

Table 1. Demographic characteristics of patients

	n	Mean±SD	Range
Age (year)	15	68±5	60-75
Sex			
Male	9		
Female	6		
Comorbidity			
Diabetes mellitus	14		
Hypertension	11		
Coronary artery disease	11		
Asthma	2		
Other	2		
Body mass index (kg/m^2)		28±4	21.5-35.3

SD: Standard deviation.

parameter for planning sternal reconstruction. Partial or total excision of the sternum leads to sternal instability and creates dead space proportional to the excised sternal volume. The primary goals of reconstruction are to fill the dead space, close the wound, and ensure sternal stability.

Not all complications arising from sternal wounds following a median sternotomy require reconstruction. Pairolero[24] defined these cases as sterile sternal dehiscence, characterized by serous discharge within postoperative three days. Sterile sternal dehiscence occurs due to the loosening of sternal wires due to chronic cough, osteoporosis, or incorrect wiring. When diagnosed within the first three days, it can be treated with sternal rewiring and primary closure.[5,25] This patient group is primarily managed by cardiac surgeons and does not require a multidisciplinary approach. However, sterile sternal dehiscence may present with vague symptoms such as pain or delayed postoperative recovery.[4] Failure to diagnose sterile sternal dehiscence can result in secondary infection of mobile sternal edges.[4,5,8] Therefore, cardiac surgeons

Table 2. Clinical features of patients (n=15)

	n	Median	Min-Max
Type of wound			
1	2		
2	11		
3	2		
Number of debridement		2	1-6
Type of flap used			
BPA flap + SPT flap	11		
Rectus abdominis muscle flap	2		
SEAP flap	2		
Complication	4		
Time to reconstruction (day)		10	4-22
Time to plastic surgery consultation (day)		21	12-34
Total hospitalization (day)		28	19-52
Total follow-up time (month)		12	3-30

BPA: Bilateral pectoral advancement: SPT: Split pectoral turnover; SEAP: Superior epigastric artery perforator.

should identify patients at high risk in the early postoperative period and routinely test for the presence of sternal dehiscence using a sternal compression test. Early rewiring of the sterile sternal dehiscence before secondary infection occurs can reduce the need for reconstruction.

In our practice, we categorize wounds into three types. Wounds in which only the skin and subcutaneous tissues are affected are classified as type 1 wounds. Factors such as obesity and macromastia may contribute to skin breakdown in this group. Consistent with previous studies, this subgroup is minority among to the all wound types.[5,26] Schiraldi et al.[5] reported that sternal wound breakdown rarely resulted from skin-related factors. Therefore, in this patient group, it was essential to definitively demonstrate

Figure 4. (a) Patient with skin necrosis after reconstructive surgery. **(b)** After debridement of the necrotic skin, wound reconstructed with skin graft on top of the intact pectoral flap.

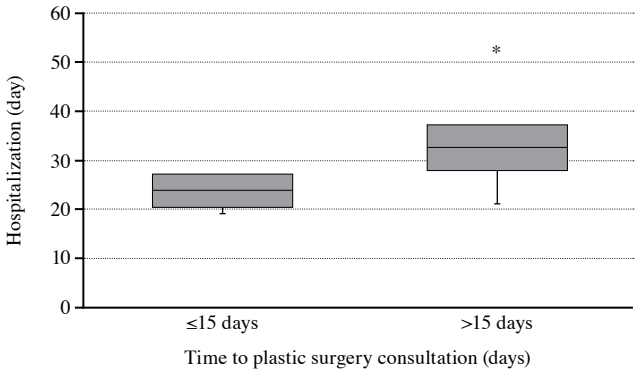

Figure 5. Comparison between groups in terms of timing of plastic surgery consultation and hospitalization.
* The asterix represents extreme cases.

that wound breakdown arose solely from the skin and subcutaneous tissues and not from any underlying sternal osseous dehiscence. We performed debridement in collaboration with cardiac surgeons for all patients and assessed sternal stability based on the clinical findings during debridement. Wounds in which the wires did not loosen and separation was not observed at the sternal edges under sternal compression were classified as pure skin defects. In these cases, the defect involved only the skin and subcutaneous fat, with no dead space present. We preferred closure with a superior epigastric artery perforator skin flap in these patients. As perforator flaps are a recent development in sternal reconstruction, they are rarely included in reconstruction algorithms presented.

Perforator skin flaps via IMA perforators and superior epigastric artery perforators have been described to treat various sternal defects. Minimal donor site morbidity and short operation times are among the advantages of perforator flaps; however, their ability to fill dead spaces remains controversial. Bertheuil et al.[13] suggested that perforator skin flaps were sufficient for closure, even in cases of total sternal excision, whereas Kannan[14] suggested the use of a perforator skin flap with muscle while dealing with extensive dead space. In our view, perforator skin flaps should only be used in patients with skin-only defects without sternal excision (type 1 wounds). The primary reason for this is that the dead space-filling effect of perforator skin flaps depends on the thickness of the patient's subcutaneous fat and cannot be standardized. Another reason is the poor vascularization of fat tissue, which fills the dead space and covers vital organs. Studies with perforator flaps have shown high complication rates owing to the nature of the venous congestion of these flaps.[13,14] Delicate flap monitoring and leech therapy may be required; nevertheless, partial flap losses may leave vital organs exposed.[13]

In cases involving sternal excision with exposure of the heart and lungs, we believe that well-vascularized muscle tissues may provide more reliable coverage than skin flaps. Patients who underwent partial sternal excision were classified as having type 2 wounds. Consistent with previous studies, our study found that type 2 wounds were the most frequent in sternal wound complications.[5,8,9] In these cases, the cause of wound tension is greater in the distal sternum, and dead space tends to be larger in the lower third part of the sternum.[3,10] However, the pectoralis major flap, when used in a standard fashion, may not provide sufficient coverage of the lower third of the sternum. Modifications of the pectoralis major flap extending to the lower third of the sternum have been described previously.[7,9] In our practice, we achieved adequate closure of the lower third of the sternum using a pectoralis split-turnover flap planned from the side where the IMA is intact. When planned as a turnover flap, the dead-space filling effect is greater than that of a standard advancement flap.[7] However, as the turnover flap is supplied by the IMA perforators, harvesting the IMA bilaterally by a cardiac surgeon poses some risks. Therefore, cardiac surgeon input is essential for reconstruction planning.

Patients who underwent total sternal excision were classified as having type 3 wounds. The rectus abdominis flap is more effective than the pectoral flap in terms of filling dead space, owing to its greater muscle mass.[4,5,27] In the present study, a unilateral rectus abdominis muscle flap was sufficient to cover the entire sternal defect. Opinions differ on the necessity of an intact IMA for rectus muscle flaps. Greig et al.[10] suggested that the rectus muscle flap could only be used when the IMA was intact, whereas other studies indicated that rich collateral circulation allowed the rectus muscle flap to be elevated without relying on the IMA.[4,27,28] We preferred to plan the rectus muscle flap from the side where the IMA was not harvested during the cardiac operation. For patients who underwent major cardiac surgery and experienced fatal complications such as sternal dehiscence, reliable and safe options should be prioritized.

The management of sternal wound complications requires multidisciplinary collaboration between cardiac and plastic surgeons. Cardiac surgeons should diagnose and treat sterile sternal dehiscence that becomes apparent within the first few days of a cardiac operation. Cases that arise may, then, require reconstruction, necessitating the early involvement

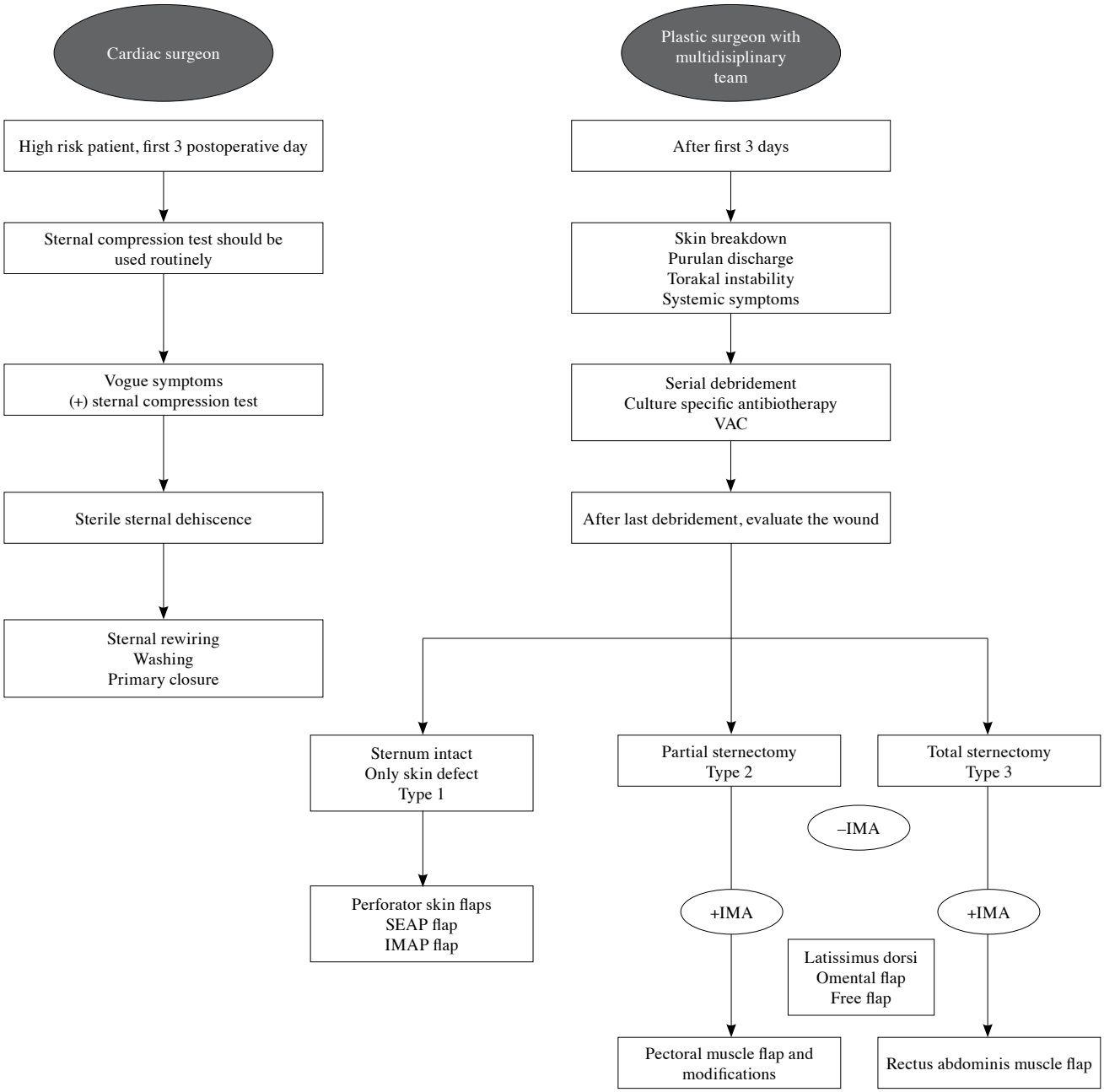

Figure 6. Algorithm for wound complications following median sternotomy.
VAC: Vacuum assisted closure; SEAP: Superior epigastric artery perforator; IMAP: Internal mammary artery perforator; IMA: Internal mammary artery.

of plastic surgeons. Studies have shown that early involvement of plastic surgeons in treatment may help to reduce the length of hospital stay and mortality rates.[5,7,8,29] In our study, patients who received plastic surgery consultations within the first 15 days had more favorable outcomes compared to those who received it after 15 days.

Nonetheless, there are some limitations to this study. First, this is retrospective observational study, and the small sample size does not allow for comparisons between the groups. Second, the effect of the transferred tissue on sternal stability was unable to be addressed; only its effectiveness in closing dead spaces was discussed. Previous studies

have shown that pectoral muscle flap can ensure sternal stability when used bilaterally and sutured in the midline.[22,23] However, there is no study comparing the effects of different muscle flaps and skin flaps on sternal stability. We speculate that the long-term fibrosis of the muscle transferred over the sternal bone defect may contribute to sternal stabilization. Therefore, in type 2 and type 3 wounds where sternum is partially or totally excised, skin flaps may not ensure sternal stability when used without sternal fixation methods. However, further studies are required to address this topic.

In conclusion, sterile sternal dehiscence if diagnosed in first three days can be treated with sternal rewiring by cardiac surgeons. After three days, sternal dehiscence should be treated multidisciplinary with cardiac and plastic surgery teams. After eradication of infection, final wound can be classified based on the dead space caused by sternal excision and reconstructive plan should be based on the wound type (Figure 6).

Ethics Committee Approval: The study protocol was approved by the Balıkesir University Faculty of Medicine Ethics Committee (date: 14.08.2023, no: 2023/97). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Conception, design, supervision, data collection, materials, data processing, literature review, writer, critical review: B.C.; Materials, data collection, writer reviewer: Y.F.K.; Materials, data collection, writer, critical review: H.D.; Writer, critical review, data processing: Y.Ç.G.; Writer, critical review, data collection, supervision: A.D.

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