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# Free Flap Reconstruction of Sternal Defects after Cardiac Surgery: An Algorithmic Approach for Dealing with Sparse Recipient Vessels

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**Background:** Sparsity of recipient vessels poses a challenge for microsurgical free flap reconstruction of sternal defects following deep sternal wound infection after cardiac surgery.
**Methods:** From January 2013, a standardized algorithm for dealing with sparse recipient vessels was strictly followed. In this retrospective study including 75 patients, we compared operative details, surgical complications, and reconstructive outcomes of patients treated according to this algorithm (group A: January 2013–May 2021; n = 46) with a historical control group (group B: January 2000–December 2012, n = 29).
**Results:** The left internal mammary artery had been harvested for arterial bypass grafting in 40 of 46 cases (87%) in group A and in all cases in group B. The right internal mammary artery (RIMA) and right internal mammary vein (RIMV) were the first choice as recipient vessels. In case of unsuitability of the RIMV, a right cephalic vein (CV) turndown was used for venous outflow. If both RIMA and RIMV proved insufficient, a single-stage arterio-venous loop (AVL) between the CV and subclavian artery (CV–SA AVL), CV and thoracoacromial artery (CV–TA AVL), or subclavian artery and subclavian vein (SA–SV AVL) was established. The algorithmic approach significantly reduced partial flap necrosis [group A: n = 3 (7%) versus group b: n = 7 (24%); $P = 0.04$], and overall operation time [group A: 360 ± 88 min versus group B: 415 ± 80 min; $P = 0.01$].
**Conclusions:** Standardized approaches improve clinical outcomes in microsurgical free flap sternal reconstruction after cardiac surgery. *(Plast Reconstr Surg Glob Open 2024; 12:e5722; doi: 10.1097/GOX.0000000000005722; Published online 9 April 2024.)*

## INTRODUCTION

Deep sternal wound infection (DSWI) after cardiac surgery is a rare yet severe complication associated with devastating mortality rates.[1–3] Radical surgical debridement; antibiotic therapy; and finally, early defect reconstruction with well-perfused tissue is crucial for the successful treatment of DSWI.[4–6] When the entire sternal region is affected, locoregional flaps might not suffice for coverage, thus necessitating the combination of locoregional and pedicled flaps with increasing periprocedural morbidity.[7,8] Introduced in the early 1990s, microsurgical free flap reconstruction of sternal defects can be an attractive alternative.[7,9–11] In this context, adequate recipient vessels are of paramount importance. This often renders sternal free flap reconstruction in the context of DSWI particularly challenging for two main reasons: (1) absence of mammary vessels due to uni- or bilateral use of the internal mammary artery (IMA) as cardiac bypass grafts; (2) extensive scarring of the sternocostal region with involvement of the internal mammary vessels, which usually renders them unsuitable for microsurgical anastomosis. In these patients,

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additional vascular reconstruction is mandatory to guarantee an adequate vascular access for free flap transfer. Despite several publications on the matter, evidence-based recommendations and algorithmic guidelines are still lacking. To address this knowledge gap, we present our two-decades single-center experience on 75 free flap sternal reconstructions and propose an algorithmic approach in the setting of absent or inadequate recipient vessels.

## PATIENTS AND METHODS

From January 2013 a standardized perioperative algorithm for dealing with sparse recipient vessels in the setting of microsurgical free flap sternal reconstruction was implemented at our institution and strictly followed (Fig. 1). The retrospective single-center study (IRB approval: 2021-15577) included 46 patients (group A, January 2013–May 2021), who underwent free flap sternal reconstruction for DSWI in accordance with the mentioned algorithm. All included patients presented an extensive defect affecting all three thirds of the sternum. To evaluate the surgical algorithm, we compared operative details and reconstructive outcomes with a historical control group of 29 patients (group B, January 2000–December 2012). Operative details; flap reexploration because of microvascular compromise or hematoma; and surgical complications of the donor and recipient site, including wound complications and partial (necrosis >5% of the flap) and total flap necrosis, were compared between both groups. “Major” complications were defined as postoperative surgical complications requiring additional surgical intervention. Furthermore, all medical complications such as respiratory failure, cardiovascular instability, or death during hospital stay were evaluated. The diagnosis of sternal osteomyelitis was confirmed in all 75 patients through clinical and histopathological aspect of bone morphology, contrast-enhanced computed tomography (CECT), and microbiological specimens. DSWI was rated in accordance to the El Oakley and Wright classification.[12] Sternal osteomyelitis was treated with radical surgical debridement of soft and bony tissue, consecutive antibiotic therapy for at least 6 weeks according to the antimicrobial resistance, and early defect reconstruction. The mean follow-up period after discharge was 9 months.

### Dissection of the Subclavian Artery and Vein

In case of a cephalic vein (CA)–subclavian artery (SA) arterio-venous loop (AVL), CV dissection is continued through the deltopectoral groove. Then the pectoralis major muscle is split in the direction of its fibers and the CV can be followed entering the subclavian vein (SV). Subsequently, the SA and SV are exposed and can be separated for performing the anastomoses. In case of an SA–SV AVL, an infraclavicular slightly curved skin incision following the deltopectoral groove is performed. The plane between the deltoid and pectoralis major muscle is used for dissection. Then, the pectoralis major muscle is split in the direction of its fibers. Subsequently, the SA and SV are exposed for performing the anastomoses. Care is given to the infraclavicular brachial plexus nerves in this region.

> **Takeaways**
>
> **Question:** Evidence-based recommendations and algorithmic guidelines are lacking in the context of free flap sternal reconstructions and vessel-depleted situations.
>
> **Findings:** A perioperative algorithm for dealing with sparse recipient vessels in the setting of microsurgical sternal reconstruction was implemented. The algorithmic approach reduced operative time as well as the incidence of further major surgical complications.
>
> **Meaning:** Standardized approaches improve clinical outcome in free flap sternal defect reconstruction.

### Postoperative Anticoagulation

Intraoperatively, 500 IU of heparin was applied before reperfusion of the flap. In case of arterio-venous loop (AVL) creation, 2000–3000 IU of heparin was applied before cross-clamping of the SA, and a second heparin bolus of 1000 IU was applied before cross-clamping of the AVL. Postoperatively, all patients received subcutaneous application of low-molecular-weight heparin in therapeutic or prophylactic dose based on their respective comorbidities.

### Statistics

Statistics were calculated with SPSS, version 20.0 (IBM, Inc., Armonk, N.Y.) and GraphPad Prism 8.0 (GraphPad Software, Inc., San Diego, Calif.). The differences between both groups were analyzed with the unpaired two-sided *t* test or two-sided Mann-Whitney U test for continuous- and the two-sided Fisher exact test for dichotomous variables. A *P* value of less than 0.05 was considered statistically significant.

## RESULTS

From January 2000 to May 2021, 75 patients (27 women, 48 men) with a mean age of 67 years (range: 38–85 years) underwent free flap sternal reconstruction with the tensor fasciae latae (TFL, n = 62; 83%), musculocutaneous vastus lateralis (VL, n = 7; 9%), musculocutaneous vertical rectus abdominis (VRAM, n = 5; 7%), and latissimus dorsi (LD, n = 1; 1%) flap. Table 1 summarizes all relevant patient characteristics.

### Algorithm for Dealing with Sparse Recipient Vessels

From January 2013 to May 2021 (group A), before free flap surgery, the recipient vessel situation was evaluated based on the type of previous cardiac surgery [eg, coronary artery bypass grafting (CABG) using the internal mammary arteries and/or saphenous vein grafts] and CECT in every patient. In addition, the availability and quality of the CV and greater saphenous veins (GSVs) were examined via Doppler sonography. Intraoperatively, flap harvesting and sternal recipient vessel dissection was performed simultaneously in a two-team approach. A graphic illustration of the algorithm is shown in Figure 1. The left internal mammary artery (LIMA) had been harvested for arterial bypass grafting in 40 of 46 patients (87%) in group A and in all 29 patients (100%) in group

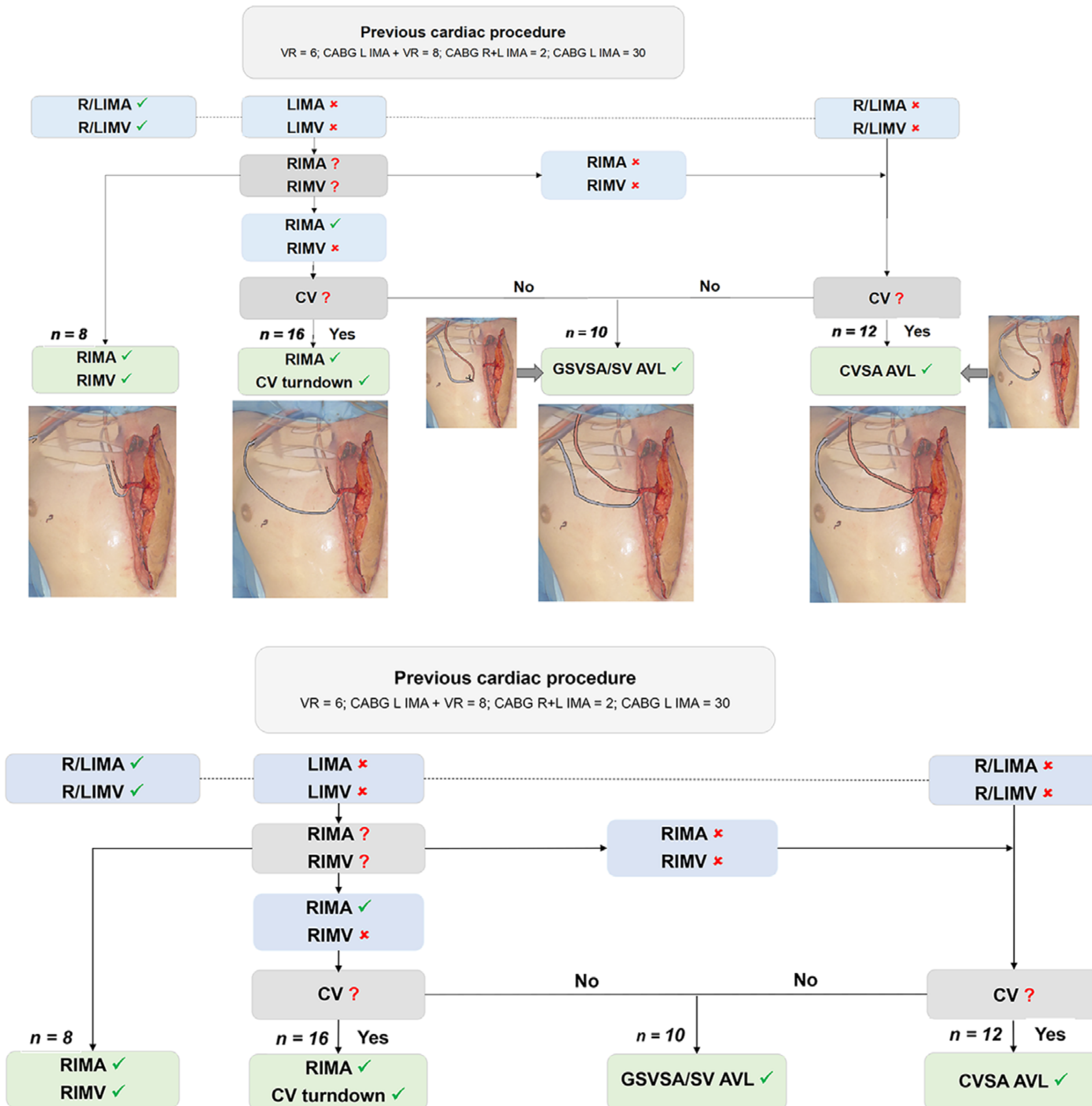


**Fig. 1.** Algorithm for dealing with sparse recipient vessels for free flap sternal reconstruction. The RIMA and RIMV were the first choice. In case of unavailability or absence of the RIMV, right CV turndown was used for venous outflow. If both RIMA and RIMV proved insufficient, a single-stage CV–SA AVL was established. In rare cases of insufficiency or absence of the CV, a single-stage SA–SV AVL using a GSV graft was established. VR, valve replacement; LIMV, left internal mammary vein.

B, and thus, was not an option for flap anastomosis. The right internal mammary artery (RIMA) had been harvested in only two patients in both groups. Thus, the RIMA and right internal mammary vein (RIMV) were our first choice as recipient vessels for flap anastomosis, if CECT confirmed availability and patency. Based on the suitability of the RIMA and RIMV, the need for vascular back-up options was evaluated and the decision in favor or against vascular reconstruction was made. Facing recipient vessel sparsity, the right CV proved a versatile and reliable back-up option for safe venous drainage. If the RIMA was suitable for arterial anastomosis, but the RIMV was insufficient or lacking, we propose performing a right CV turndown for venous outflow (Fig. 2). In case of lacking RIMA and RIMV, a CV–SA AVL was created via end-to-side anastomosis (Fig. 3). In the rare case of an insufficient CV, a GSV graft was harvested to create an SA–SV AVL (Figs. 4 and 5). In the control (group B), either IMA/IMV or CV and thoracoacromial artery (TA) AVL were used as recipient vessels.

**Table 1. Patient Characteristics, Distribution of Comorbidities, and Previous Cardiac Surgery**

| Patients | Total n (%) | Group A (%) | Group B (%) | P |
|---|---|---|---|---|
| No. patients | 75 | 46 | 29 | — |
| Mean age (y) ± SD | 67 ± 11 | 67 ± 12 | 68 ± 9 | 0.90 |
| Median ASA (range) | 3 (2–4) | 3 (2–4) | 3 (3–4) | 0.90 |
| Sex (female/male) | 27/48 | 15/31 | 12/17 | — |
| **Previous Cardiothoracic Surgery** | | | | |
| CABG-LIMA | 54 (72%) | 30 (65%) | 24 (83%) | — |
| CABG-LIMA and RIMA | 4 (5%) | 2 (4%) | 2 (7%) | — |
| VR | 6 (8%) | 6 (13%) | — | — |
| CABG-LIMA and VR | 11 (15%) | 8 (18%) | 3 (10%) | — |
| **Distribution of Comorbidities** | | | | |
| Arterial hypertension | 69 (92%) | 43 (94%) | 26 (90%) | 0.67 |
| Coronary heart disease | 65 (87%) | 40 (87%) | 25 (86%) | 0.90 |
| Heart insufficiency | 49 (65%) | 28 (61%) | 21 (72%) | 0.33 |
| Peripheral artery disease | 28 (37%) | 17 (37%) | 11 (37%) | 0.90 |
| COPD | 29 (39%) | 17 (37%) | 12 (41%) | 0.81 |
| Chronic kidney disease | 36 (48%) | 22 (48%) | 14 (48%) | 0.90 |
| Diabetes mellitus | 47 (62%) | 29 (63%) | 18 (62%) | 0.90 |
| NIDDM | 11 (15%) | 7 (15%) | 4 (14%) | 0.90 |
| IDDM | 36 (48%) | 22 (48%) | 14 (48%) | 0.90 |
| Active smoker at the time of surgery | 23 (31%) | 14 (30%) | 9 (31%) | 0.61 |
| BMI ($kg/m^2$) | 29.3 ± 5.6 | 29.7 ± 6.1 | 28.6 ± 4.8 | 0.39 |
| Obesity (BMI ≥30 $kg/m^2$) | 31 (41%) | 19 (41%) | 12 (41%) | 0.90 |
| **El Oakley and Wright Classification** | | | | |
| I | — | — | — | — |
| II | — | — | — | — |
| IIIA | 16 (21%) | 9 (19%) | 7 (22%) | — |
| IIIB | 15 (20%) | 10 (22%) | 5 (16% | — |
| IVA | 5 (7%) | 3 (7%) | 2 (6%) | — |
| IVB | 6 (8%) | 1 (2%) | 5 (16%) | — |
| V | 33 (44%) | 23 (50%) | 10 (41%) | — |

ASA, American Society of Anesthesiologists; OT, operation time; N/IDDM, non/insulin-dependent diabetes mellitus; BMI, body mass index; VR, valve replacement.

**Comparative Analysis of Reconstructions**

From January 2000 to December 2012 (group B), 29 free flap sternal reconstructions were performed using the TFL (n = 23; 79%), VRAM (n = 4; 14%), and VL (n = 2; 7%) flap. As described before, the LIMA had been harvested for arterial bypass grafting in all patients. In eight cases (28%), the RIMA and RIMV were suitable for end-to-end anastomosis. In 21 cases (72%), a single-stage CV–TA AVL was created for flap anastomosis.

From January 2013 to May 2021, 46 patients (group A) underwent free flap sternal reconstruction with a TFL (n = 39; 85%), VL (n = 5; 11%), VRAM (n = 1; 2%), and LD (n = 1; 2%) flap according to the proposed algorithm (Fig. 1). The LIMA had been harvested for arterial bypass grafting in 40 patients (87%). In 24 cases (52%), the RIMA was used as arterial recipient vessel, whereas venous outflow was achieved either through the RIMV in eight patients (18%) or via CV turndown in 16 cases (35%). In 22 cases, CECT demonstrated insufficient morphology or absence of the RIMA, whereas in two patients both LIMA and RIMA had been used for CABG. To achieve vascular access, single-stage CV–SA AVL (12 patients, 26%) or SA–SV AVL interposing the GSV (10 patients, 22%) were established.

**Comparison of Intra- and Postoperative Surgical Complications**

The incidence of intraoperative vascular complications was lower in group A (n = 1; 2%) when compared with group B (n = 3; 10%); however, this difference was not significant [odds ratio (OR): 5.2; confidence interaval (CI): 0.7–68.7; $P = 0.29$]. In group A, intraoperative venous thrombosis occurred in one patient after flap anastomosis to the RIMV followed by immediate thrombectomy and reanastomosis to the CV via turndown. In group B, intraoperative arterial thrombosis occurred after flap anastomosis to the RIMA in two cases. Arterial thrombectomy of the RIMA was performed via a Fogarty catheter. However, it was decided to anastomose the flap via CV–TA AVL. One patient developed thrombosis of the arterial portion of the CV–TA AVL. The thrombotic segment was resected, and AVL was reanastomosed. Intraoperatively, all flaps could be salvaged. Postoperative microvascular complications occurred in three patients (7%) in group A and in four patients (14%) in group B (OR: 2.3; CI, 0.57–9.6; $P = 0.42$). In group A, three TFL flaps were successfully salvaged for acute arterial occlusion of the CV–SA AVL (n = 1; 2%), SA–SV AVL (n = 1; 2%), or venous thrombosis of the RIMV (n = 1; 2%) within 48 hours after surgery. In group B, four TFL flaps were successfully revised for acute arterial (n = 2; 7%) or venous thrombosis (n = 2; 7%) of the CV–TA AVL within 48 hours after surgery. In all cases, immediate flap reexploration with anastomotic revision was performed, whereas all flaps could be salvaged. The occurrence of postoperative vascular complications was statistically equal when CV–SA


**Fig. 2.** CV turndown. A, A 48-year-old man presented with DSWI after surgical treatment of sternal osteomyelitis following aortic valve replacement. The resulting sternal defect measured 24 × 8 cm. B, Defect reconstruction was achieved using a free TFL flap from the left thigh. The RIMV was not suitable. Therefore, the CV was dissected from the deltopectoral groove over a length of 30 cm and was tunneled into the defect. The venous anastomosis was created in an end-to-end fashion to the CV, and the arterial anastomosis was performed end-to-end to the right IMA. C, The postoperative course was uneventful. D, The patient was discharged from hospital 13 days after surgery.

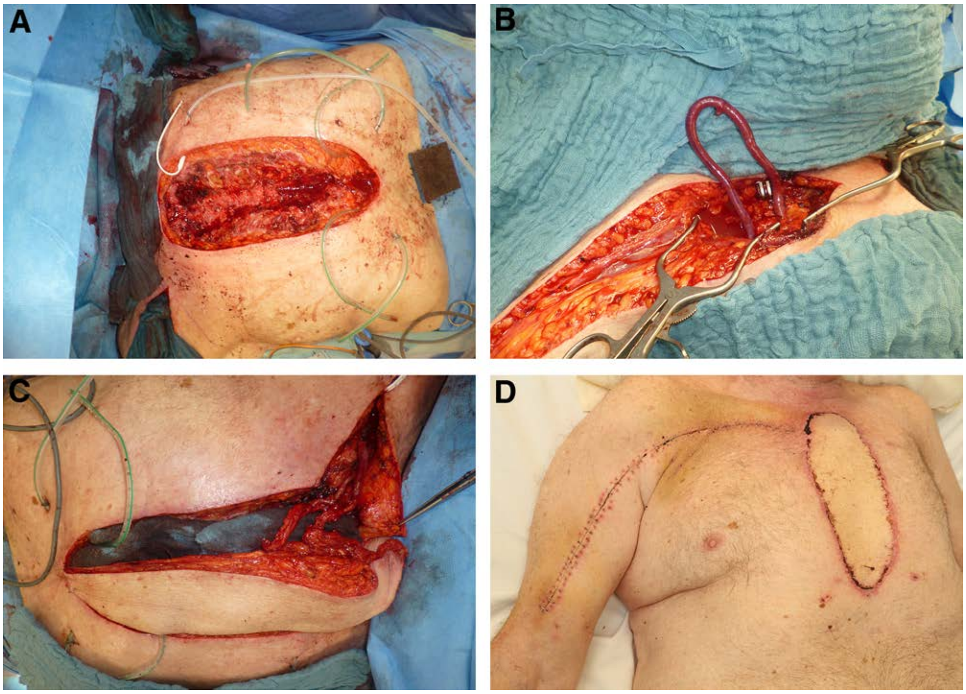

**Fig. 3.** CV–SA AVL. A, A 73-year-old man developed a sternal wound dehiscence with sternal osteomyelitis after emergency myocardial revascularization. After debridement with subtotal sternectomy, the defect measured 24 × 9 cm. B, A free TFL flap from the left thigh was used for defect reconstruction. The CV was dissected form the deltopectoral groove to the middle of the upper arm. After dissection of the SA, an AVL was created between the CV and the SA through an end-to-side anastomosis. Subsequently, The AVL was divided in the middle, and arterial and venous end-to-end anastomoses were performed. C, Flap healing was uneventful. D, The patient was discharged from hospital 16 days after surgery.

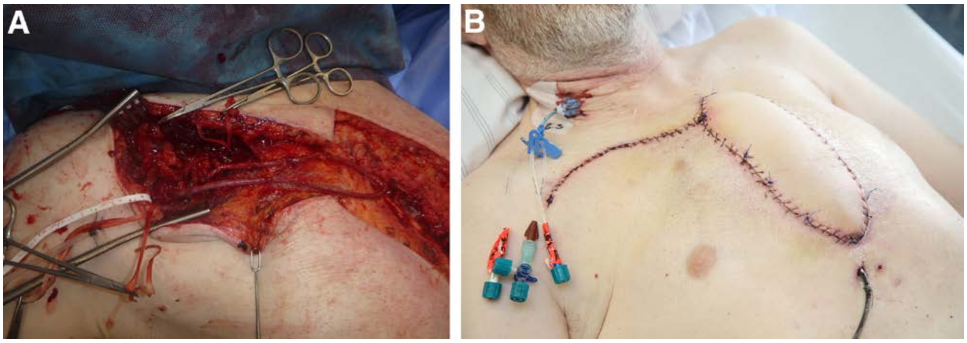

**Fig. 4.** SA–SV–AVL. A, A 62-year-old man presented with DSWI after debridement of sternal osteomyelitis after combined CABG and aortic valve replacement. A defect of 21 × 10 cm was the result after multiple debridement, including sternal resection. Defect reconstruction was performed with a free TFL flap from the left thigh. Ultrasound mapping before surgery demonstrated an insufficient CV, whereas the right GSV proved to be sufficient. Subsequently, the right GSV vein was harvested and used for creation of an AVL between the SA and SV. B, The AVL was divided, and arterial and venous end-to-end anastomoses were carried out.

and SA–SV AVLs (group A, n = 22) were compared with CV–TA AVLs (group B, n = 21) (group A: n = 2 versus group B: n = 4; OR: 2.4; CI, 0.48–13.3; $P$ = 0.41). After implementation of the algorithm, overall occurrence of major complications was significantly lower (group A: n = 11 versus group B: n = 14; OR: 3.0; CI, 1.1–7.6; $P$ = 0.04). The incidence of partial flap necrosis was significantly lower (group A: n = 3 versus group B: n = 7; OR: 4.6; CI, 1.1–17.1; $P$ = 0.04). In group A, necrosis of the distal flap portion of three TFL flaps (5%) was reconstructed through a pedicled VRAM flap, an intercostal artery perforator propeller flap, and two local rotation flaps, respectively. In group B, partial necrosis of six TFL flaps (7%) and one VL flap (3%) required additional reconstruction with a pedicled VRAM flap (n = 2), a combined pedicled VRAM and bilateral pectoralis major flap

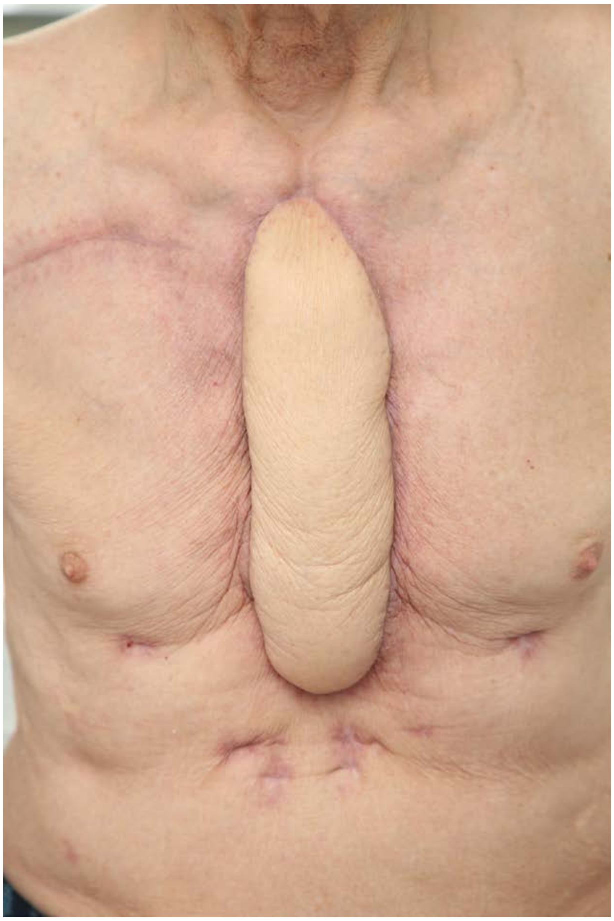

**Fig. 5.** The postoperative course was uneventful with stable defect reconstruction at hospital discharge on postoperative day 14.

(n = 1), or local advancement flaps (n = 4), which was combined with split-thickness skin grafting in three cases. In addition, overall operation time (group A: 360 ± 88 min versus group B: 415 ± 80 min; $P = 0.01$) and flap ischemia (group A: 59 ± 15 min versus group B: 67 ± 12 min; $P = 0.02$) were significantly shorter after implementation of the algorithm. A subgroup analysis of group A revealed an equal incidence of postoperative flap pedicle thrombosis (RIMA: n = 1 versus AVL: n = 2; OR: 2.3; CI, 0.25–34.6; $P = 0.60$) and partial flap necrosis (RIMA: n = 1 versus AVL: n = 2; OR: 2.3; CI, 0.25–34.6; $P = 0.60$) for flaps that were anastomosed to the RIMA (n = 24) and an AVL (n = 22). Operation-related characteristics and distribution of surgical complications are depicted in Tables 2 and 3.

### Comparison of Medical Complications and Postoperative Course

A total of 53 patients (71%) were postoperatively admitted to the intensive care unit (OR: 2.9, group A: n = 38 versus group B: n = 18; $P = 0.06$). Patients in group B required more tracheotomies (group A: n = 5 versus group B: n = 8; OR: 3.2; CI, 1.0–9.7; $P = 0.12$) and showed prolonged postoperative ventilation (>24 h post flap surgery; group A: n = 9 versus group B: n = 12; OR: 2.9; CI, 1.0–8.3; $P = 0.06$). However, these differences were not statically significant. An overview of medical complications in given in Table 4.

## DISCUSSION

Microsurgical free flap sternal reconstruction is technically demanding due to the diminished physical reserves of these critically ill patients, and the lack of recipient vessels.[13] Hereby a standardized and reliable algorithm of reconstruction can be helpful to make the procedure as safe as possible. This is the first study to introduce a perioperative treatment algorithm for extensive sternal defect reconstruction with focus on sparse recipient vessels. Our major finding was that implementation of the algorithmic approach reduced operative and flap ischemia time as well as the incidence of further major surgical complications.

Regarding the current literature, the vast majority of flap options for sternal reconstruction is composed of

**Table 2. Distribution and Comparison of Recipient- and Donor-site Surgical Complications**

| Intra- and Postoperative Complications, n (%) | | | | |
|---|---|---|---|---|
| **Intraoperative Microvascular Complications** | **Total** | **Group A** | **Group B** | ***P*** |
| Venous thrombosis | 1 (1%) | 1 (2%) | — | 0.90 |
| Arterial thrombosis | 3 (4%) | — | 3 (10%) | 0.06 |
| Total rate of intraoperative microvascular complications | 4 (5%) | 1 (2%) | 3 (10%) | 0.29 |
| **Postoperative Microvascular Complications** | | | | |
| Venous thrombosis | 3 (4%) | 1 (2%) | 2 (7%) | 0.30 |
| Arterial thrombosis | 4 (5%) | 2 (4%) | 2 (7%) | 0.64 |
| Total rate of postoperative microvascular complications | 7 (9%) | 3 (7%) | 4 (14%) | 0.42 |
| **Postoperative Major Surgical Complications** | | | | |
| Partial flap necrosis | 10 (13%) | 3 (7%) | 7 (24%) | 0.04 |
| Wound dehiscence | 6 (8%) | 3 (7%) | 3 (10%) | 0.67 |
| Hematoma | 9 (12%) | 5 (11%) | 4 (14%) | 0.73 |
| Total rate of major complications | 25 (33%) | 11 (24%) | 14 (48%) | 0.04 |
| Reconstructive failure | 5 (7%) | 2 (4%) | 3 (10%) | 0.37 |
| **Donor-site Complications** | | | | |
| Wound dehiscence | 5 (7%) | 3 (7%) | 2 (7%) | 0.90 |
| Infection | 1 (1%) | 1 (2%) | — | 0.90 |
| Total rate of donor-site revision | 6 (8%) | 4 (9%) | 2 (7%) | 0.90 |

**Table 3. Operation-related Characteristics**

| Operative Details | Total | Group A | Group B | *P* |
|---|---|---|---|---|
| First debridement after cardiac surgery (d) | 51 ± 73 | 58 ± 80 | 40 ± 62 | 0.24 |
| Mean OT ± SD (min) | 381 ± 88 | 360 ± 88 | 415 ± 80 | 0.01 |
| Mean sternal defect length ± SD (cm) | 22.8 ± 2.7 | 22.7 ± 2.8 | 23.0 ± 2.6 | 0.58 |
| Mean sternal defect width ± SD (cm) | 8.6 ± 1.3 | 8.5 ± 1.1 | 8.8 ± 1.5 | 0.28 |
| Mean sternal defect size ($cm^2$) ± SD | 197.5 ± 43.2 | 193.3 ± 41.4 | 204.2 ± 47.7 | 0.31 |
| Mean flap ischemia time ± SD (min) | 63 ± 15 | 59 ± 15 | 67 ± 12 | 0.02 |
| Mean flap size ± SD ($cm^2$) | 203.6 ± 38.1 | 200.7 ± 35.8 | 209.8 ± 41.8 | 0.28 |

OT, operation time.

**Table 4. Overview of Medical Complications and Postoperative Course between Both Groups**

| Medical Complications | Total | Group A | Group B | *P* |
|---|---|---|---|---|
| Global respiratory failure | 6 (8%) | 2 (4%) | 4 (14%) | 0.20 |
| Acute respiratory insufficiency | 2 (3%) | 1 (2%) | 1 (3%) | 0.90 |
| Cognitive impairment | 1 (1%) | 1 (2%) | — | 0.90 |
| Cardiovascular instability | 4 (5%) | 2 (4%) | 2 (7%) | 0.64 |
| Septic shock | — | — | — | — |
| Paralytic ileus | 1 (1%) | 1 (2%) | — | 0.90 |
| Total rate | 14 (19%) | 7 (15%) | 7 (24%) | 0.37 |
| 30-days mortality | 6 (8%) | 2 (4%) | 4 (14%) | 0.20 |
| **Postoperative Course** | | | | |
| Tracheotomy | 13 (17%) | 5 (11%) | 8 (28%) | 0.12 |
| Prolonged postoperative ventilation | 21 (28%) | 9 (20%) | 12 (41%) | 0.06 |
| Ventilation (h) ± SD | 289 ± 337 | 306 ± 380 | 276 ± 337 | 0.86 |
| Mean LOIS (d) ± SD | 8 ± 11 | 7 ± 12 | 10 ± 8 | 0.23 |
| Mean LOHS (d) ± SD | 37 ± 20 | 37 ± 16 | 38 ± 25 | 0.92 |
| Mean PLOHS (d) ± SD | 28 ± 23 | 27 ± 22 | 28 ± 24 | 0.90 |

PLOHS/LOHS, postoperative/overall length of hospital stay; LOIS, length of intensive-care-unit stay.

pedicled LD, pectoralis major, or rectus abdominis flaps. However, we share the experience that the pedicled bilateral pectoralis major flap is well suited for reconstruction of the upper sternum, whereas the pedicled VRAM flap allows for a reliable reconstruction of the lower sternum.[14–16] We further experienced that an increasing defect size significantly raises the incidence of partial necrosis of pedicled flaps when compared with free flaps.[11] In addition, harvesting the LD, pectoralis, or rectus muscle as a large auxiliary respiratory muscle may impair pulmonary function, which could translate into higher medical complication rates.[5,17,18] Furthermore, the pedicled LD flap needs to be operated on in lateral position and may sometimes require patients' intraoperative repositioning. This can cause respiratory insufficiency due to the patients' unstable chest. In our opinion, these are strong arguments in favor of free flap reconstructions harvested from distant regions.

Banic et al reported on the first successful free flap sternal defect reconstruction in 1995. They used the IMA or carotid artery and external jugular vein as well as the superior thyroid artery and vein as recipient vessels to transfer seven free LD flaps.[9] In comparison, Brown and associates mainly used the free rectus abdominis muscle flap and introduced a single-stage AVL procedure to achieve reliable recipient vessels. In detail, they harvested a GSV graft and created an AVL between the superior thyroid artery and internal jugular vein. Intraoperative vascular occlusion occurred in one flap, which could be salvaged. Another flap was lost due to an unrecognized venous thrombosis.[19] These findings demonstrate that cervical vessels can be used for free flap transfer to the sternal region. Nevertheless, the distance between the recipient vessels and the defect may make the flap pedicle prone to kinking, compression, or distortion. In addition, lengthening the vascular pedicle of the flap may render an adequate flap design. Dornseifer and colleagues retrospectively reported on 12 patients with lacking internal mammary arteries due to previous CABG surgery undergoing free flap sternal reconstruction (eight gracilis and four ALT flaps) after DSWI. They harvested the gastroepiploic vessels with either laparotomy or a laparoscopic technique and transferred them through a tunnel from the abdominal cavity to the sternal defect. There was no flap loss or revision surgery, but there was one case of incisional hernia after laparotomy.[20] However, with specific emphasis on donor-site morbidity and outcome, harvesting the gastroepiploic vessels may not be the preferred procedure to provide appropriate vessels to cover sternal defects. Despite their promising results, a two-cavity procedure may further raise the risk of transferring infection into a sterile area or damaging the diaphragm, raising the risk of internal herniation or incarceration, as known from the experience of harvesting a greater omentum flap.[21] In 2007, Heitmann and Engel were the first to describe the use of a CV–TA AVL as recipient vessels for free flap sternal reconstruction. AVL creation and free flap coverage were performed in a single step.

Overall flap loss was none; revision of the arterial anastomosis was necessary in two cases constituting a vascular compromise of 12%.[22] It was clearly demonstrated that it is possible to handle such vessel-depleted and critically ill patients who have previously been considered unsuitable for free flap reconstruction.[10] Although subgroup analysis did not demonstrate significant differences in vascular complications between CV–TA AVLs and CV–SA AVLs, the applicability of the TA is sometimes limited by its inconsistent course and caliber. Therefore, we established the CV–SA AVL as a straightforward alternative procedure. Taeger et al proposed AVL creation 10 days before free flap surgery.[7] They concluded that a two-stage procedure may reduce the risk of postoperative thrombosis and ensures a sufficient in- and outflow for free flap anastomosis.[7] However, we performed only single-stage reconstructions with simultaneous AVL creation, which resulted in successful healing. Previously, in a series of 103 AVL free flaps, we were able to demonstrate that single-stage reconstruction results were comparable with two-stage reconstructions.[23] In patients with cardiac comorbidities, hemodynamic consequences of AVL with a significant shunt volume may present an additional risk. Recently, we demonstrated elevated NT-proBNP serum levels in patients with AVL and cardiac comorbidities. We therefore clearly recommend single-stage AVL creation for free flap sternal reconstruction.[24] Our results indicate that microsurgical free flap reconstruction of sternal wounds due to DSWI led to successful healing even under complex and challenging conditions. The patient collective represents a negative selection because all patients presented with a significant bony and soft tissue defect. Several patients presented a sparse of recipient vessels. Pursuing the main objective of minimizing treatment time and complication rates to an absolute minimum through keeping the operation time as short as possible, we implemented a treatment algorithm. The outcomes were compared with those of a historical control group. Our major findings are that in a patient cohort with comparable risk factors and defect sizes, patients treated according to the proposed algorithm had a significantly lower incidence of major complications as well as reduced operative and flap ischemia times. After the routine implementation of CECT as well as cephalic- and saphenous vein mapping with ultrasound before surgery, we found that this straightforward approach provided reliable recipient vessels and saved operation time. Based on this experience, we deliberately proceeded to AVL creation, if mammary vessels were not applicable. Furthermore, as described before, we chose the easily accessible free TFL or VL flap, thus eliminating the need for lengthy intraoperative repositioning of the patient.[25] Further benefits are their highly vascularized muscle bulk, low donor-site morbidity, and the reliable diameters of their vascular pedicles, allowing for safe anastomosis, even in combination with AVLs.[5,26] In addition, loss of important auxiliary breathing muscles (ie, LD or rectus abdominis muscle) can be avoided in these already morbid patients.[11,17] We harvest flaps and dissect the recipient vessels with or without AVL creation simultaneously in a two-team approach. We would like to emphasize that neither age nor higher ASA status or El Oakley classification compromised the surgical or medical outcome in our series. Prolonged operation time may increase the risk for secondary bleeding or postoperative hematoma formation.[27,28] Moreover, a relationship between prolonged operation time and higher general complication rates (such as wound breakdown, pneumonia, sepsis, deep vein thrombosis) and flap-specific complications (such as partial flap loss and free flap failure) are reported.[27,28] This is underlined by the implementation of our algorithm. We conclude that a reduced operative and flap ischemia time decreased the incidence of major surgical complications such as partial flap loss. In addition, the learning curve over time and different levels of microsurgical experience may also reduce the incidence of partial flap loss. Interestingly, patients treated according to the algorithm also had fewer tracheotomies, a reduced ICU stay, and reduced ventilation time.

Despite these preliminary data providing new insights on the management of microsurgical sternal reconstruction, our findings should be interpreted in the context of the study's limitations. First, the monocentric retrospective structure of the study and the relatively small number of patients per group makes it prone to numerous biases. Therefore, a larger cohort of patients undergoing free flap sternal reconstruction following our algorithm and a longer period of follow-up would be necessary to gain more certainty about the presented reconstructive approach. Second, by including a two-decades consecutive series of reconstructive procedures, the involvement of several surgeons at different level of microsurgical experience performing the flap surgery and their different preferences of reconstruction may limit the evaluation. In addition, patient-specific factors, an institutional learning curve, change in anticoagulation regimens, and achievements in anesthesiology and critical care medicine might represent significant confounders.

## CONCLUSIONS

Our results indicate that microsurgical free flap sternal reconstruction in patients with unsuitable or absent mammary vessels consistently resulted in successful and stable healing. The proposed algorithm led to lower complication rates and shorter operation times.

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## DISCLOSURE

*The authors have no financial interest to declare in relation to the content of this article.*

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