

# Pectoralis Muscle Flap Repair Reduces Paradoxical Motion of the Chest Wall in Complex Sternal Wound Dehiscence

Jacob Zeitani, M.D.<sup>1</sup>, Marco Russo, M.D.<sup>2</sup>, Eugenio Pompeo, M.D.<sup>3</sup>,  
Gian Luigi Sergiacomi, M.D.<sup>4</sup>, Luigi Chiariello, M.D.<sup>1</sup>

<sup>1</sup>Cardiac Surgery Unit, Clinica Mediterranea, Departments of <sup>2</sup>Cardiac Surgery,  
<sup>3</sup>Thoracic Surgery, and <sup>4</sup>Diagnostic Images, Policlinic of Tor Vergata University

**Background:** The aim of the study was to test the hypothesis that in patients with chronic complex sternum dehiscence, the use of muscle flap repair minimizes the occurrence of paradoxical motion of the chest wall (CWPM) when compared to sternal rewiring, eventually leading to better respiratory function and clinical outcomes during follow-up. **Methods:** In a propensity score matching analysis, out of 94 patients who underwent sternal reconstruction, 20 patients were selected: 10 patients underwent sternal reconstruction with bilateral pectoralis muscle flaps (group 1) and 10 underwent sternal rewiring (group 2). Eligibility criteria included the presence of hemisternum diastases associated with multiple ( $\geq 3$ ) bone fractures and radiologic evidence of synchronous chest wall motion (CWSM). We compared radiologically assessed (volumetric computed tomography) ventilatory mechanic indices such as single lung and global vital capacity (VC), diaphragm excursion, synchronous and paradoxical chest wall motion. **Results:** Follow-up was 100% complete (mean  $85 \pm 24$  months). CWPM was inversely correlated with single lung VC (Spearman  $R = -0.72$ ,  $p = 0.0003$ ), global VC ( $R = -0.51$ ,  $p = 0.02$ ) and diaphragm excursion ( $R = -0.80$ ,  $p = 0.0003$ ), whereas it proved directly correlated with dyspnea grade (Spearman  $R = 0.51$ ,  $p = 0.02$ ) and pain ( $R = 0.59$ ,  $p = 0.005$ ). Mean CWPM and single lung VC were both better in group 1, whereas there was no difference in CWSM, diaphragm excursion and global VC. **Conclusion:** Our study suggests that in patients with complex chronic sternal dehiscence, pectoralis muscle flap reconstruction guarantees lower CWPM and greater single-lung VC when compared with sternal rewiring and it is associated with better clinical outcomes with less pain and dyspnea.

**Key words:** 1. Sternum  
2. Wound dehiscence  
3. Cardiac surgical procedures, adverse event

## Introduction

Sternal wound dehiscence occurs in approximately 0.4% to 5.1% of patients undergoing cardiac surgery [1]. The typical profile of patients undergoing cardiac surgery procedures nowadays explains the persistence of wound healing problems. Patients are older,

and they usually present more risk factors, such as diabetes and obesity, that involve a high risk for wound complications. Several surgical techniques have been proposed to treat sternal dehiscence, including rewiring, titanium plates, and sternum reconstruction by means of muscles or omental flaps [2-6]. When multiple bone fractures occur, a simple rewiring of-

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Corresponding author: Marco Russo, Cardiac Surgery Division, Tor Vergata University of Rome, Policlinico Tor Vergata, Viale Oxford 81, 00133 Rome, Italy  
(Tel) 39-3282528248 (Fax) 39-0620903868 (E-mail) [mar.russo1987@gmail.com](mailto:mar.russo1987@gmail.com)

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ten is not sufficient and sternal reinforcement as proposed by Robicsek et al. [7], or other reinforcement techniques, are required to stabilize the surgical site. The muscle flap procedure is an alternative method for treating wound complications. In a recent series, we have reported that muscle flap reconstruction guarantees better early and long-term results in terms of reduced mortality, procedure failure, and respiratory function with higher lung volumes and lower New York Heart Association (NYHA) class at follow-up (FU) [8].

In complex sternal wound dehiscence, the presence of multiple rib fractures might induce paradoxical chest motion, which might negatively affect both healing of the sternum and ventilatory mechanics [7-9]. A flail segment of the chest wall will have several effects on the respiratory system: inefficient ventilation/negative pressure during inspiration creates a paradoxical movement, but generally, total ventilation is maintained. However, asymmetric motion of the hemisternum can slow wound healing [10]. The role of different surgical approaches in complex sternal dehiscences and in particular the relationship of paradoxical motion of the chest wall and respiratory outcome are poorly investigated in the literature.

In this study we tested the hypothesis that in patients with chronic complex sternum dehiscence, the use of muscle flap repair minimizes the occurrence of paradoxical motion of the chest wall (CWPM) when compared to sternal rewiring, eventually leading to better respiratory function and clinical outcomes.

**Methods**

**1) Demographic features and study design**

From January 1st, 2002 to December 31st, 2006 at the Cardiac Surgery Unit of Rome Tor Vergata University, 94 patients (2.1%) had sternal complications requiring surgical management. Table 1 summarizes the main features of the whole cohort.

Twenty-eight patients were treated with muscle flap reconstruction (group 1) and 66 patients with rewiring (group 2). Infection of the surgical site with positive samples was present in 45 cases (47%). The two groups constituting the whole cohort were similar in term of risk factors like diabetes, chronic obstructive pulmonary disease (COPD), and obesity distribution.

**Table 1.** The characteristics of patients who experienced sternal dehiscence (N=94)

Characteristic	Value
Age (yr)	68.3±6.1
Age >75 yr	58 (55)
Male sex	60 (57)
Chronic obstructive pulmonary disease	49 (52)
Hypertension	61 (65)
Diabetes mellitus	5 (27)
Peripheral vascular disease	11 (12)
Renal dysfunction <sup>a)</sup>	9 (9.5)
Obesity <sup>b)</sup>	39 (42)
Weight >80 kg	60 (57)
Smoke habits	38 (40)
Preoperative atrial fibrillation	28 (30)
<b>Primary surgical procedure</b>	
Isolated coronary artery bypass grafting	61 (65)
Bilateral internal thoracic artery	28 (30)
Blood transfusions <sup>c)</sup>	62 (66)
<b>Positive cultures</b>	
<i>Staphylococcus aureus</i>	55
<i>Staphylococcus epidermidis</i>	40
Others	5
Transverse fractures of sternum (at least one)	94 (100)
≥3 sternal fractures	53 (56)

Values are presented as mean±standard deviation, number (%), or %. <sup>a)</sup>Serum creatinin >1,5 mg/dL. <sup>b)</sup>Obesity defined as body mass index >30 kg/m<sup>2</sup>. <sup>c)</sup>One or more units.

For the purpose of this study, using a propensity score matching analysis, we selected a cohort of 20 patients to assess comprehensive results.

In this propensity score (1:1) matching analysis, performed by a greedy 5-to-1 digit matching algorithm, we compared radiologically assessed ventilatory mechanic indices after muscle flap reconstruction (group 1, 10 patients) or sternal rewiring (group 2, 10 patients) in patients with complex chronic dehiscence of the sternum. Eligibility criteria included the presence of hemisternum diastases associated with multiple (≥3) bone fractures and radiologic evidence of synchronous chest wall motion (CWSM) with intact overlying skin and no evidence of active infection. Fig. 1 summarizes the process before the propensity score analysis.

To describe respiratory function at FU, all matched patients underwent volumetric computed tomography (CT) with a 64-row multidetector CT scanner (GE LightSpeed-64 row; GE Healthcare, Milwaukee, WI,

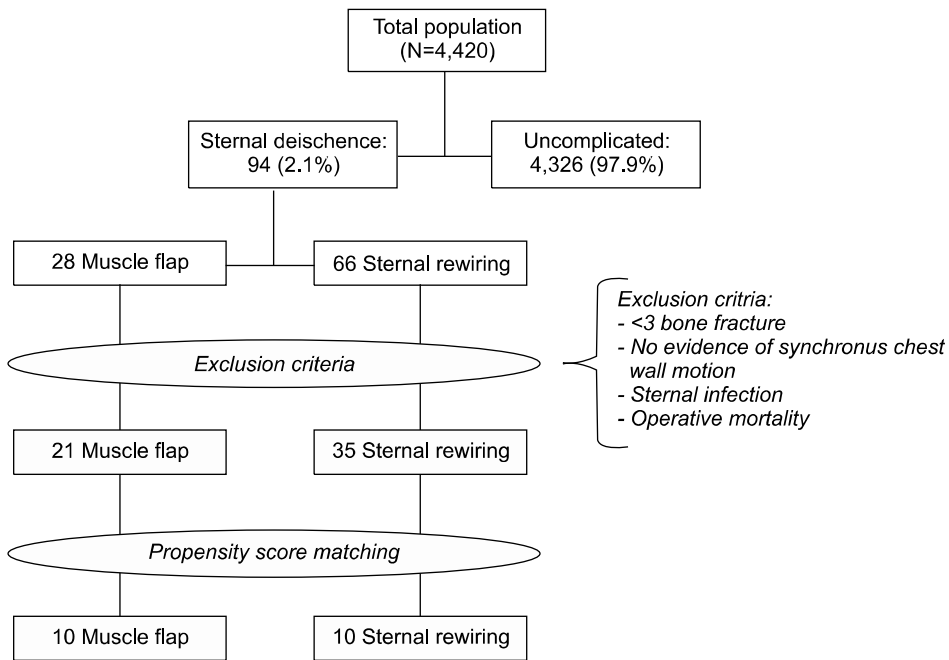


Fig. 1. Flow chart of patient selection and propensity score matching analysis construction.

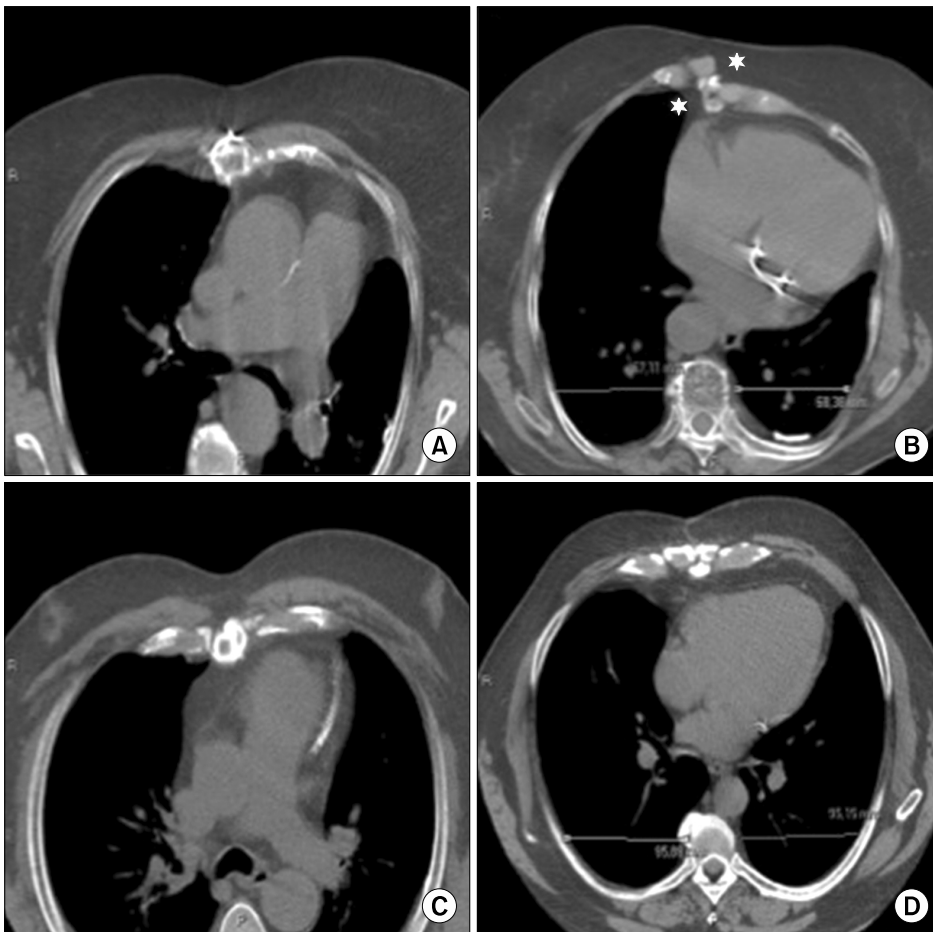


Fig. 2. (A,C,D) A 64-row multidetector computed tomography scanner using a 3-dimensional reconstruction algorithm for assessment of chest wall motion and lung volumes changes during ventilation. (B) Dynamic study with a cine-scan mode in axial view, during normal breath, on an operated patient, showing the asymmetric movement of the chest and the sternum (star).

USA) in the helical mode without intravascular administration of contrast medium using a 3-dimensional (3D) reconstruction algorithm for assessment of chest wall motion and lung volume changes during ventilation [3].

In particular, single lung and global vital capacity (VC), CWSM, CWPM, and diaphragm excursion were measured radiologically during coached breath-holds. We defined CWPM as the presence of paradoxical, inspiratory, inward motion of any visible anterior chest wall segment. CWSM was defined as the measure of the maximal, inspiratory-to-expiratory, non-paradoxical chest wall excursion. Fig. 2 describes the 3D reconstruction algorithm used for the assessment of chest wall motion and lung volume changes during ventilation; a dynamic study with a cine-scan mode analysis was performed by an experienced radiologist to describe sternum stability, evaluating altered motion. Anterior-to-posterior rib cage excursion was used for the measure of chest mechanical elasticity. An evaluation of the diaphragm dynamic was performed, calculating the dome excursion during a deep breath as an evaluation of thoracic expandibility. In the assessment of lung dynamics, the lung volume calculated at end-inspiration was considered to reflect total lung capacity (TLC), whereas that calculated at end-expiration was deemed to reflect the residual volume. VC was thus estimated radiologically as well by subtracting the residual volume from the TLC.

### **2) Data collection**

All patients in hospital files were reviewed. Data were retrieved from an institutional database. The diagnosis of deep and superficial wound complication was made according to the Guidelines for Prevention of Surgical Site Infection [10]. Operative mortality included deaths occurring during hospitalization or within 30 days after sternal reconstruction.

Patients were followed for  $85 \pm 24$  months (range, 60 to 118 months). No patients were lost at FU. During clinical FU chest pain was assessed by visual analog scale (VAS) and dyspnea evaluated according to NYHA classification.

### **3) Ethic statement**

The study design was approved by the institutional review boards and ethics committees of Tor Vergata University. The study was conducted according to the

principles expressed in the Declaration of Helsinki. For the retrospective database, we reviewed the medical records of all consecutive patients with sternal wound complication who were treated in our unit. For the FU and computerized tomography studies, written informed consent was obtained from each patient.

### **4) Surgical technique**

The surgical procedure has been completely described in our preceding published series [8]. Briefly, a primary cardiac surgical procedure was performed after skin disinfection with 10% povidone-iodine and intravenous antibiotic prophylaxis with 2 g of ceftizoxime; a sternotomy was performed with an oscillating saw. Internal thoracic artery (ITA) conduits were harvested in a skeletonized fashion. Re-approximation of the sternum was then achieved by means of 6–10 (approximately 1 for each 10 kg of patient weight) single interrupted stainless steel wires, 2–3 through the manubrium and the others in peristernal position at the intercostal spaces. Fascia, subcutaneous tissue and skin were closed according to current methods.

During the secondary procedure in both study groups, wound reconstruction consisted of the resection of all devascularized and necrotic cutaneous and subcutaneous tissue, bone, and cartilage, followed by cleaning and rinsing with hydrogen peroxide, 10% povidone-iodine, and saline water. If muscle flaps were performed, the pectoralis major muscles were sectioned from their insertion to the sternum margins using electrocautery, in which case the internal mammary artery perforator branches should be isolated and clipped. Then, dissection of the muscle was performed from the subcutaneous layer in the relatively avascular plane and from the chest wall until the mid-clavicle line so that the flap can be advanced to the mid sternum without significant tension. The two muscles flaps are then advanced to the midline and the free margins are attached by means of interrupted absorbable 0 polyglycolic acid suture lines. Two drains are placed in each hemisternum, one under the muscle flap and one under the subcutaneous layer. Another drain is placed between the hemisterna. During the rewiring procedure, adhesions between the chest wall and the heart are dissected. Six patients needed sternum re-

**Table 2.** Preoperative risk factor data in the whole cohort and in the study cohort after PS matching

Variable	Whole cohort			PS-matched cohort		
	Group 1 (N=28)	Group 2 (N=66)	p-value	Group 1 (N=10)	Group 2 (N=10)	p-value
Age (yr)	66±9	71±6	0.04	66±9	67±9	0.7
Male gender	17	55	0.03	9	8	1.0
≥3 sternal fractures	20	33	0.08	10	10	1.0
Active sternal infection	10	22	0.2	-	-	-
Body mass index (kg/m <sup>2</sup> )	28±3.8	26.9±4.2	0.08	28.4±6.0	29±3.5	0.8
Left ventricular ejection fraction (mean value)	0.47±0.1	0.49±0.1	0.8	0.50±0.1	0.52±0.1	0.7
New York Heart Association (class)	1.8±0.9	2.2±1.3	0.7	1.8±0.9	2.0±0.9	0.8
Diabetes	10	15	0.1	5	4	1.0
Chronic obstructive pulmonary disease	19	40	0.8	8	8	1.0

Values are presented as mean±standard deviation or number. Between-group comparison was performed with the Mann-Whitney (means) or two-tailed test. Fisher exact test (categorical data).

PS, propensity score.

**Table 3.** In-hospital results

Variable	Group 1 (N=10)	Group 2 (N=10)	p-value
Window to revision (day)	70±127	52±92	0.06
Operative time (min)	54±28	57±24	0.5
Postoperative blood transfusion (unit/patient)	1.8±1.5	2.3±3.5	0.2
Procedure failure	0	0	NS
Postoperative stay (day)	6.3±6.8	11.3±11.2	0.03
In-hospital mortality	0	0	NS

Values are presented as mean±standard deviation or number (%). NS, not significant.

inforcement according to the Robicsek technique because of multiple bone fractures.

The choice of one of the two different techniques depended on the surgeon's own decision: in general, flap repair was selected in patients with a more extensive dehiscence, with more material to remove, and was the approach of choice in the more recent period. In patients with positive cultures, we usually positioned VAC therapy on the wound, waiting for negativity, and then approached surgical correction.

In all patient groups, direct closure of the subcutaneous and superficial layers was achieved by interrupted unabsorbable number 2 silk sutures. Intravenous antibiotic prophylaxis with 2 g daily of ceftizoxime for 48 hours, or specific antibiotics based on the antibiogram, were given and administered for a 4-to-6-week course postoperatively.

### 5) Statistical analysis

Statistical analysis was performed using the Stat-View ver. 4.5 software package (Abacus Concepts, Berkeley, CA, USA). Categorical variables were presented as frequencies and percentages, and continuous variables were expressed as means with standard deviations or medians with ranges. For the purpose of the study, the inclusion criteria were the presence of at least 3 transverse bone fractures, radiologic evidence of CWSM, and no operative failure. To reduce the effect of treatment selection bias and potential confounding factors, we performed adjustments for the differences in the baseline characteristics by use of propensity score matching. Eight covariates including age, gender, COPD, body mass index, diabetes, preoperative left ventricular ejection fraction, infection, and type of primary surgical procedure were used to generate propensity score matching.

The propensity scores were estimated with multiple logistic regression analysis. For the development of the propensity score-matched pairs (a 1:1 match), a greedy 5-to-1 digit matching algorithm was used.

After propensity score matching, the data of the two groups were compared with a paired t-test or the Wilcoxon signed rank test for continuous variables. In the propensity score-matched cohort model, the odds ratios of clinical outcomes were calculated after matching using conditional logistic regression analysis. Probability values of 0.05 were considered statistically significant.

Propensity score matching yielded 10 matched pairs

**Table 4.** Postoperative dynamic computed tomography and clinical data in the study cohort

Outcome measures	Group 1	Group 2	Mann-Whitney p-value
<b>Radiological</b>			
CWPM	2	7	0.06
CWPM (mm)	0.3±0.2	11,3±1.4	0.04
Chest wall synchronous motion (mm)	12±1.8	12±1.5	0.97
Diaphragm excursion (mm)	43±8	32±13	0.06
Radiologic VC <sub>single-lung</sub> <sup>a)</sup> (mL)	1,735±144	1,594±126	0.02
Radiologic VC <sub>global</sub> (mL)	3,712±240	3,563±357	0.27
<b>Clinical</b>			
Dyspnea (modified Medical Research Council dyspnea score)	0.9±0.7	1.9±1.0	0.02
Pain visual analogue pain scale (score)	0.5±0.7	2.4±1.6	0.01

Values are presented as number or mean±standard deviation.

CWPM, chest wall paradoxical motion; VC, vital capacity.

<sup>a)</sup>On side with CWPM.

of patients in which there were no significant differences in baseline characteristics between the muscle flap group and sternum rewiring group. Variables were presented as mean±1 standard deviation. Differences were considered significant at values of  $p < 0.05$ .

## Results

The main preoperative data before and after propensity score matching are detailed in Table 2. In-hospital results for the 2 matched groups are summarized in Table 3. Mean duration from open-heart surgery to muscle flap or rewiring in these patients (window to revision) was similar in the 2 groups (52 vs. 72 days,  $p=0.06$ ), whereas the postoperative durations of stay are lower in the muscle flap group. Before revision, 60% of patients were symptomatic for dyspnea and 45% had persistent temperature, while 35% had fluid impairment.

The results of volumetric CT assessment are reported in Table 4. Mean PMCW and single lung VC were both better in group 1, while there were no differences in CWSM, diaphragm excursion, and global VC. Six months after treatment, dyspnea and chronic pain assessed by VAS were significantly better in the muscle flap group (Table 4). Spearman correlation analysis showed that, overall, CWPM was inversely correlated with single lung VC (Spearman  $R = -0.72$ ,  $p=0.0003$ ), global VC ( $R = -0.51$ ,  $p=0.02$ ), and diaphragm excursion ( $R = -0.80$ ,  $p=0.0003$ ), whereas it proved directly correlated with dyspnea grade (Spearman  $R = 0.51$ ,  $p=0.02$ ) and VAS ( $R = 0.59$ ,  $p=0.005$ ).

## Discussion

Sternal wound complication following median sternotomy is a rare complication that involves 0.4% to 5.1% of patients who underwent cardiac surgery [1]. Different studies reported an incidence of 1.1% to 6.7% for superficial problems and of 0.1% to 3.7% for wound complications [11,12]. Several studies focused on the influence of concomitant conditions and surgery-related factors on wound healing; advanced cardiac disease, diabetes, peripheral vascular disease, smoking, and bilateral ITA harvesting are known risk factors [8]. Moreover factors that increase forces acting on the sternum such as patient obesity, COPD, and prolonged postoperative mechanical ventilation have been related to an increased risk of sternal complication. Recent redo procedures and emergency surgery have been described as the most important risk factors in contemporary cardiac surgery [13]. Successful management of the dehiscence requires an identification of the underlying causes, especially when an infection has occurred.

In complicated cases, multiple bone fractures and wound contamination frequently occur. When a series of adjacent ribs are fractured in 2 distinct sites, the chest wall segment may lose its mechanical continuity with the rest of the thorax. As a result, the flail segment moves paradoxically inward during spontaneous inspiration, interfering in a variable manner with ventilation, and in gas exchange with a flail chest the continuity of the chest wall is disrupted, and the physiological action of the ribs is altered [11].

The optimal treatment, for these clinical situations, especially for more complicated cases, is still unclear, and several techniques have been reported. Among these, muscle flap reconstruction and sternal rewiring are the most commonly used. In a precedent series from our institution, we demonstrated how a pectoralis muscle flap presents several advantages in comparison to the rewiring technique in terms of reduced mortality, procedure failure, and hemisternum stability, resulting in higher lung volumes and fewer symptoms for dyspnea at FU. The impact of different surgical approaches to the repair of sternal dehiscence on respiratory function and chest motion has been, unfortunately, poorly investigated in the literature.

In this study, we have found that pectoralis muscle flap repair resulted in lower mean CWPM and greater single lung VC than sternum rewiring. In addition, CWPM correlated with dyspnea and VAS, suggesting that even in the absence of a real flail chest, CWPM affected ventilatory mechanics and clinical outcome in a negative fashion. There were no differences in diaphragm excursion that could estimate thoracic expandability. As a result, assessment of split lung volumes by volumetric CT reconstruction algorithms might help disclose regional inequality in ventilation and lung mechanics, which could not be detected by standard spirometry [14]. Moreover, it could be very interesting in another series to better analyze the results with spirometry.

Assessment of the clinical impact of such a finding requires a larger cohort, although in the current series the dyspnea grade and pain VAS were both significantly lower in the muscle flap group.

Successful management of the dehisced sternum requires precise assessment of the underlying causes and ascertainment of the bone integrity, especially if multiple sternum fractures have occurred. In these instances, standard sternum rewiring can result in suboptimal outcomes. In fact, poor bone quality due to osteoporosis as well as previous paramedian sternotomy may both negatively affect sternum stability as well as the success of rewiring repair [8,15].

We believe that the advantages of pectoralis muscle flaps include avoidance of adhesions, dissection with no risk of damage to vital structures, and achievement of better stability of the sternum. The theoretical higher rigidity of the chest resulting from a muscle flap repair did not occur in our series, as

shown by the better results in radiologically assessed ventilatory mechanic indices that suggest maintenance of adequate elastic properties of the chest wall by this method.

Superior chest wall stability and the avoidance of bone friction due to the positioning of the muscle flap in the gap between the hemisterna may have contributed to better outcomes. The hypothetical disadvantages of muscle flap include the para-physiologic displacement of the pectoralis muscles and a less appealing cosmetic result, which, however, may be counterbalanced by a better quality of life in terms of physical functioning [8].

Compared to spirometric data, quantitative radiologic assessment of VC performed by a computerized algorithm tended to slightly underestimate spirometry results, but avoided the potential bias of inter-observer disagreement and allowed the performance of a comparative analysis even in patients who underwent TC but not spirometry, preoperatively.

This study presents some limitations, including a small cohort and retrospective data collection; however, to limit the bias, a 1:1 propensity match score was used to select the patient groups. This method of selection guaranteed homogeneous preoperative characteristics, but reduced the sample size. Nevertheless, in our analysis, we have found significant differences in several outcome measures, which suggest a superior efficacy of muscle flap repair in comparison with the rewiring method. In a subsequent series, comparison with more detailed spirometry data will be necessary to clarify clinical and respiratory outcomes and to better define a tailored approach to each patient.

In conclusion, postoperative wound complications after open-heart surgery are still one of the major causes of morbidity and mortality and remain a challenge for cardiac surgeons with severe implications for both the patient and the health care system. Our results suggest that in patients with complex, chronic sternal dehiscence, use of pectoralis muscle flap reconstruction resulted in lower CWPM and greater single-lung VC when compared with sternal rewiring, eventually leading to better clinical outcomes. The clinical impact of such novel findings remains to be better elucidated by further detailed investigation, even if at this point muscle flap repair seems to guarantee better results.

### Conflict of interest

No potential conflict of interest relevant to this article was reported.

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