Sternal reconstruction with titanium plates in complicated sternal dehiscence

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Abstract

Objective: Sternal dehiscence after median sternotomy can be a challenging problem in case of multiple fractures or infection. The use of titanium plates is a promising approach for sternal reconstruction. Methods: Titanium plate fixation was used in 15 patients (67 ± 5.9 years, 171 ± 8.2 cm, 93.6 ± 14.9 kg, body mass index 32 ± 5 kg/m²) with unstable thorax after failed attempts of sternal closure and patients in whom failure of conventional rewiring would be expected due to one or more serious risk factors (e.g. multiple fractures or loss of sternum, excessive overweight). In six patients, one of whom had an infection, the Synthes® Titanium Sternal Fixation System was used as transverse plate fixation (series 1). In nine other patients, longitudinal titanium plating of the sternum was performed with 2.4 mm Synthes locking reconstruction plates, which were cross-connected by wires (series 2). In six of these patients the cross-connection was reinforced by additional short transverse plates.

Results: Mean operation time was 133 ± 21 min (series 1) and 110 ± 12 min (series 2). Transverse plating required more extensive mobilization of pectoral muscle. All patients had an uneventful early postoperative course and were extubated 5.1 ± 5.9 h (median 4 h) after surgery. Postoperatively, patients had a stable thorax, but in the long-term three patients from series 1 complained of plate-related pain during breathing, with the subsequent need of plate removal. One multi morbid patient from series 1 died on the 31st postoperative day. The cause of death was not related to the sternal plate refixation. Conclusion: Titanium plate fixation is an effective method to stabilize complicated sternal dehiscence. The longitudinal plating technique is easier to apply and seems to be associated with fewer complications.

Keywords: Sternal dehiscence; Rigid plate fixation; Osteosynthesis

1. Introduction

Median sternotomy, with its broad exposure of the heart, has been the incision of choice for most cardiac operations, since its introduction into clinical practice by Julian et al. in 1957 [1]. The closure of median sternotomy is usually done by wiring with stainless steel wires [2] in simple interrupted or figure-of-eight fashion. In general it is a safe approach with few complications. However, sternal dehiscence with or without infection is one major cause of morbidity and mortality, with an incidence of 0.5—5.0% [3]. The risk of sternal complications is increased by obesity, osteoporosis, and chronic obstructive pulmonary disease as well as by factors related to wound healing in general, e.g., diabetes or intake of corticosteroids.

In addition to these patient-related factors, operative details play a role. Technical mistakes in sternotomy or sternal closure, break in sterility, bilateral internal mammary removal or prolonged operative time can contribute to wound infection and/or sternal non-union. Postoperatively, prolonged ventilation, symptomatic transitory psychotic syndrome or the need of cardiac massage have been reported to increase the risk of sternal complications. In the presence of poststernotomy complications, the length of hospitalization is increased, and hospital costs are significantly higher [4].

In general sternal non-union can successfully be treated by simple rewiring after wound debridement. However, in cases of poor quality of bone, multiple transverse sternal fractures or inability to reduce risk factors that results in instability, steel wires or bands often fail to prevent excessive motion, leading to insufficient bone healing [5]. To treat such patients, the principles of rigid plate and screw osteosynthesis gained from craniomaxillofacial and orthopedic surgery have been recommended by several authors for sternal refixation [6—9]. We present our experience with...
rigid sternal fixation, using transverse and/or longitudinal titanium plates to manage complicated sternal dehiscence after median sternotomy.

2. Materials and methods

2.1. Plate system

Sternal reconstruction was performed with titanium plates. For large transverse thoracic stabilization we used the new Titanium Sternal Fixation System\(^\text{TM}\) (Synthes\(\text{TM}\), Switzerland, Fig. 1). It consists of titanium self-tapping unilock screws (Fig. 2) with a diameter of 3.0 mm (length: 8–18 mm) and 2.4 mm thickness titanium plates available in different lengths (12 hole plate, 104.5 mm; 20 hole plate, 168.5 mm; and 30 hole plate, 248.5 mm). For short transverse fixation, e.g. the manubrium, star-shaped or H-shaped plates with 6–12 holes are available. All plates consist of two parts joined by U-shaped release pins permitting a quick and easy sternal re-entry in cardiac emergencies. For longitudinal reconstruction we used additional 2.4 mm Synthes osteosynthesis titanium plates without emergency pin lock (not part of the Titanium Sternal Fixation System\(^\text{TM}\)). The system contained a bending template, bending pliers and a plate cutter (shortcut\(\text{TM}\)) for individual fitting of the reconstruction plates. Additionally, a depth gauge, a drill guide and drill bits with stop served for the right choice and placement of the screws.

2.2. Patients

From 12/2005 to 12/2006 we performed sternal plate refixation in 15 patients (height: 171 ± 8.2 cm; weight: 93.6 ± 14.9 kg) with sternal non-union. The average age was 66.7 ± 5.9 years, ranging from 57 to 79 years. There were 14 male patients and 1 female patient. Prior sternotomy had been performed because of coronary artery bypass (CABG, \(n = 8\)), aortic valve replacement (AVR, \(n = 4\)), CABG and AVR (\(n = 1\)), Bentall operation (\(n = 1\)) or replacement of ascending aorta and aortic arch (\(n = 1\)), with sternal wire placement in all patients. The initial heart operation had been performed 8–2037 days (median 60 days) before sternal plate reconstruction. With the exception of one patient all primary procedures had been performed at our institution. Four patients had undergone one or more unsuccessful previous attempts (\(n = 2 \pm 1.2\)) of conventional sternal wire fixation. All patients had comorbid factors (Table 1). The clinical diagnosis of sternal non-union was confirmed by a thoracic computed tomographic (CT) scan. In four patients the sternal non-union was associated with a deep sternal wound infection, confirmed by bacteria isolated from the culture of sternal purulent exudates.

Patients with sternal non-union after median sternotomy were only considered for rigid plate fixation if:

1. Standard rewiring failed before

and

2. Failure of standard rewiring was expected due to one or more serious risk factors (e.g.: nearly complete loss of sternal bone \(n = 2\), multiply fractured sternum \(n = 13\), excessive overweight \(n = 10\), insulin-dependent diabetes mellitus \(n = 7\)).

Clinical examination was done 3–12 months postoperatively with additional CT examination (Figs. 3 and 4).

2.3. Operative technique

The operations were performed under general anesthesia. The prior median sternotomy incision was opened and the
steel wires were removed. The degree of sternal separation, bone vitality and the presence of fractures and infection were assessed. After irrigation with polyvidone–iodine solution the edges of the sternal bone were mobilized and cut with an oscillating saw until bleeding from the bone marrow was visible. In two patients (one in each series) the debridement was associated with a nearly complete loss of sternal bone. In case of infection, swabs were taken and patients were additionally treated as follow: a systematic wound debridement was performed with excision of all wound edges, including skin, subcutaneous tissue and any necrotic-appearing tissue until healthy bleeding tissue was visible. Then the wound was pulse-jet lavaged with 3 l of warm sodium chloride solution, followed by placement of a visible. Then the wound was pulse-jet lavaged with 3 l of warm sodium chloride solution, followed by placement of a vacuum assisted closure (VAC) device. The antibiotic therapy was made according to the bacterial sensitivity. Sternal plating was applied once the wound was germ-free, which was achieved after a median of 13 days. Without regarding the pathology of sternal non-union, the first six patients were treated with a transverse rigid plate fixation (series 1), and the following nine patients were treated with a longitudinal plating with (n = 6) or without (n = 3) small transverse connection plates (series 2).

Operative technique in series 1 (Fig. 5): The major pectoral muscle was elevated bilaterally, from the insertion along the medial aspects of the ribs to the mid-clavicle line until it was sufficiently mobile for transverse plate placement and for later approximation. The left and right side of the remaining sternum were approximated by using surgical steel wires. In areas of lost sternal bone, the sternal part of the ribs was approximated with the same technique. After counterdrilling Synthes titanium plates to the best fitting shape, they were fixed transversely on the 2nd to 6th rib level with locking screws. For stable plate fixation 3–5 screws were necessary on each side. The emergency release pin was centered to the midline of the sternum. If necessary, an additional H-shaped or star-shaped plate was fixed on the manubrium or the caudal part of the sternal body. The holes for the screws were drilled with the aid of a drill guide. The right length of each screw was identified by measurement of the bone diameter with a depth gauge. The necessary screw lengths to achieve bicortical placement varied from 12 to 18 mm. To avoid perforation of mediastinal or pleural structures we used only drill bits with stop of the proper length as determined before.

Operative technique in series 2 (Fig. 6): The pectoralis muscle was mobilized until the sternum was just visible. In case of previous sternectomy the sternal parts of the ribs were delivered from overlaying pectoral muscles. A larger pectoral muscle preparation was only done if it was necessary for strainless wound closure. Two 2.4 mm fixation plates (14–22 holes) were fitted individually to the complete sternal halves in a longitudinal fashion. The plates were positioned in such a way that they rested as much as possible on the area of solid sternum or if necessary on a solid part of the ribs. Every plate was fixed with 5–10 screws, placed in solid osseous areas, using the same technique as described in series 1. The thorax was closed by normal rewiring, whereas 6–8 sternal cerclages were placed very closely around the titanium plates. In one patient we used titanium wires, in the other patients normal steel wires. In case of excess of weight (n = 6) one or two additional short transverse plates were placed for better reinforcement.

In all patients the pectoralis muscles were approximated at the midline and the wound was closed in layers after placing 12 mm redon drains through small stab incisions under each pectoralis muscle flap.

2.4. Statistical analysis

Results are presented as median or mean ± 1 standard deviation. For comparisons between dichotomous variables Fisher’s exact test, and for comparisons of continuous variables by means the t-test was used. A p value of less than 0.05 was regarded statistically significant. All statistical analyses were performed using the SPSS 15 software (SPSS, Chicago, Illinois).

3. Results

The mean operation time was 133 ± 21 min in series 1 and 110 ± 12 min in series 2. Nine patients (60%) could be extubated within the first 4 h postoperatively, four of them immediately after surgery. The longest intubation time was

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Table 1
Preoperative patient data

<table>
<thead>
<tr>
<th>Patient characteristics</th>
<th>All patients (n = 15)</th>
<th>Patients series 1 (n = 6)</th>
<th>Patients series 2 (n = 9)</th>
<th>p value (series 1 vs 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>66.7 ± 5.9</td>
<td>65.8 ± 7.1</td>
<td>67.3 ± 7.1</td>
<td>0.629</td>
</tr>
<tr>
<td>LVEF (mean, %)</td>
<td>50.2 ± 14.8</td>
<td>48.8 ± 16.0</td>
<td>51.8 ± 14.3</td>
<td>0.792</td>
</tr>
<tr>
<td>Time from original heart operation to sternum plate refixation (days) (median)</td>
<td>265.0 ± 556.0 (60.0)</td>
<td>430.0 ± 789.0 (135.0)</td>
<td>155 ± 345 (30.0)</td>
<td>0.451</td>
</tr>
<tr>
<td>Body mass index (kg/m²) (median)</td>
<td>32.0 ± 5.0 (31.5)</td>
<td>31.4 ± 1.4 (31.2)</td>
<td>32.4 ± 6.4 (34.5)</td>
<td>0.666</td>
</tr>
<tr>
<td>Hypertension (%)</td>
<td>86.6</td>
<td>83.0</td>
<td>88.8</td>
<td>0.657</td>
</tr>
<tr>
<td>Insulin-dependent diabetes mellitus (%)</td>
<td>46.6</td>
<td>50.0</td>
<td>44.4</td>
<td>0.612</td>
</tr>
<tr>
<td>COPD (%)</td>
<td>20.0</td>
<td>16.7</td>
<td>22.2</td>
<td>0.659</td>
</tr>
<tr>
<td>Dyslipidemia (%)</td>
<td>80.0</td>
<td>66.6</td>
<td>88.8</td>
<td>0.341</td>
</tr>
<tr>
<td>Multiple sternal fracture (%)</td>
<td>86.6</td>
<td>83.3</td>
<td>88.8</td>
<td>0.657</td>
</tr>
<tr>
<td>Nearly complete sternectomy after previous debridement (%)</td>
<td>13.3</td>
<td>16.6</td>
<td>11.1</td>
<td>0.657</td>
</tr>
<tr>
<td>Sternal wound infection (%) (pathogenic germ)</td>
<td>26.6%</td>
<td>16.6 (1 × MRSA)</td>
<td>33.3 (2 × CNS, 1 × MRSE)</td>
<td>0.659</td>
</tr>
</tbody>
</table>

*Preoperative patient data presented as mean values ± standard deviation, unless otherwise indicated. LVEF: left ventricular ejection fraction; COPD: chronic obstructive pulmonary disease; CNS: coagulase-negative Staphylococcus; MRSA: methicillin-resistant Staphylococcus aureus; MRSE: methicillin-resistant Staphylococcus epidermidis.*
23 h in a patient (series 1) with congestive heart failure (LVEF 18%) and severe neurological impairment after stroke history. Prior to plate reconstruction he had had a 60-day ICU stay after CABG due to severe respiratory insufficiency. After sternal plate refixation the patient’s condition improved initially, but finally he died on the 30th postoperative day as consequence of heart failure.

A subpectoral seroma formation was seen in the first patient of series 1 after redon drain removal. He was treated by a percutaneous drain (Pleuracut®).

In another patient (series 2) with nearly complete sternal resection, a monstrously presternal hematoma suddenly occurred 4 weeks after thoracic plate fixation. The operative revision revealed an arterial bypass bleeding in the area of a bony gap of the residual sternum. The application of a
surgical stitch to stop the bleeding was impossible due to the fragility of the tissue after previous infection. The bleeding was immediately stopped by applying tissue fleece in combination with tissue glue, without removal of the fixation plates. The location of bleeding was far away from plates or screws. The examination of the plate reconstruction revealed an absolutely stable thorax, despite the need of external cardiac massage 2 weeks previously, after accidental aspiration during eating. This patient had the longest hospital stay (45 days).

The median length of postoperative ICU stay of the surviving patients (n = 14) was 1 day, with a range from 1 to 5 days and a mean of 1.7 days. The median time from operation to hospital discharge was 6 days, with a range from 2 to 45 days and a mean of 9.2 days.

Postoperative chest pain disappeared in the majority of patients with only minor discomfort in the long-term. However, in three patients with transverse thoracic plate reconstruction (series 1) the thoracic pain persisted, despite clinical stability of the sternum, which was confirmed by CT scan. The thoracic pain correlated with breathing excursions. Compared to the other patients, the preoperative risk factors of these patients were equal or even lower (e.g.: age 65 ± 7 years, body mass index 31.3 ± 2.5 kg/m², insulin-dependent diabetes mellitus 33.3% and no previous infection). In these patients plate removal was done on the 60th, 100th and 150th postoperative day. In all patients we found a loosening of the lateral costal screw-fixation of the transverse titanium plates with intact fixation in the middle part. One patient, on the 60th postoperative day, had a coagulase-negative staphylococcus-associated osteomyelitis with the need of further VAC therapy. In two of the three patients chest pain disappeared immediately after plate removal, whereas in one patient the pain persisted, despite a solid sternum and the absence of infection.

The postoperative controls with a median follow-up time of 250 days revealed thoracic stability in all patients. Until now the 1-year follow-up is complete in seven patients. The postoperative data are summarized in Table 2.

4. Discussion

Sternal dehiscence with or without infection is a rare but serious complication of median sternotomy. In case of reduced bone vitality, efforts of sternal refixation can be a challenging problem. If a reunion by simple rewiring is impossible, muscle flaps or mesh grafts can be used to close the sternal defect [10]. However, in the long-term many patients complain of chronic pain from the sternal separation [11]. It is generally accepted in the orthopedic literature that limiting relative motion between broken segments of bone is beneficial for rapid bony healing [12]. Moreover, approximating the sternal edges is mandatory to reduce tension on a pectoral muscular flap reconstruction, thus facilitating healing. Therefore, a solid thoracic refixation is preferable. Technical modification of rewiring like described by Robicsek et al. [13] or the use of sternal bands help to reinforce the sternal closure. In our experience sternal plate refixation is the most stable kind of osteosynthesis, especially when the sternal bone is multiply fractured or largely resented.

Fig. 6. (A) Longitudinal reinforcement of the sternal halves. (B) Thoracic closure is done by rewiring with additional placement of two short transverse plates.
However, so far there are no randomized clinical trials supporting this opinion. Recent in vitro or animal studies comparing the stability of rigid plate fixation vs wire fixation, proved the significant superiority of rigid plates \([14,15]\).

Despite these findings, until now the clinical use of plates in heart surgery is rare and the most effective placement of the plates has not been defined.

In our patients we used two basic plate orientations: transverse and longitudinal placement. With both techniques we achieved a constant thoracic stabilization. However, postoperatively we had to remove 50% of the transverse placed plates, due to persisting pain. Cicilioni et al. \([6]\), a plastic surgeon, described plate removal in 8% of a group of 50 patients treated with transverse plate fixation. Hallock and Szydłowski \([16]\) had to remove the transverse plates in one of four patients (25%). This complication was not seen in patients with longitudinally placed plates. One reason for these findings could be that the rigid transverse plates block the mobility of the ribs. The more lateral, the more motion is at the rib. Laterally placed costal screws may possibly loosen in the long-term. Based on this consideration it is preferable to choose the transverse plates as short as possible.

The formation of seromas was also seen by Cicilioni et al. with an incidence of 10%. It is difficult, however, to conclude that seromas were caused by the presence of metal plates. In comparison, Hugo et al. reported a 24% rate of seroma formation in their series of 74 sternal wound reconstructions using pectoralis muscle flaps only \([17]\). It is more likely that seromas are directly related to pectoral muscle dissection, which has to be more extensive for transverse plate fixation. We faced this problem already in the first case. Since then, we have left the subpectoral drains in place until the daily secretion suspended. We have not seen any seroma formation since.

Bleeding in one of our patients was not related to plates or screws. Cicilioni described bleedings in 4% of the patients, originating from an intercostal and a pectoral vessel and thus also not plate-related. Nevertheless, drilling and screwing for plate fixation involves the danger of damaging blood vessels or other mediastinal or pleural structures. Especially in transverse plate fixation it is difficult to measure the proper depth of the ribs. This area, however, is crucial, because a bicortical screw placement is preferable to provide stability. By drilling too deep or choosing too long screws there is the risk of lung or internal mammary artery injury. In contrast, longitudinal plate orientation gives the possibility to place the screws under direct visual and digital control. Therefore, the residual sternum or the sternal parts of the ribs have to be delivered. On principle sternal plate fixation is also possible without adhesiolysis of the substernal area \([18]\) and without the use of wires. In this case the sternal halves have to be approximated by two forceps before transverse plating. We avoid using forceps because of the risk of injury as described above \([16]\). As part of our standard technique in sternal refixation, we are used to dissecting the sternal border to remove any fibrous tissue and thus to promote firm healing of the bone. With the use of wires it is possible to adapt the thorax halves with uniformly distributed forces prior to transverse plate fixation.

Most patents suffered from a multiply fractured sternal bone. Sternal stability was restored to its former condition by longitudinal plating. In case of widely resected or lost sternal bone, the longitudinal plates connected to the residual sternum or the ribs served as a kind of ‘neo-sternum’. In this case the thoracic closure by wires mimics the principles of standard closure of median sternotomy. Only in overweight patients additional transverse plating served as an additional locking feature. To avoid bone destruction we tried to minimize the number of screws. Only in case of pure bone quality up to 10 screws were needed to provide secure longitudinal plate fixation. Nevertheless, with this technique no plate mobilization was seen, even in patients with less sternal bone mass or plate fixation directly to the ribs.

The mixture of stainless steel and titanium can create an electromagnetic current or battery effect. Theoretically, this could result in a local tissue reaction or inflammation. Even after 1 year of follow-up we have not seen any signs indicating such a reaction. In fact, the contact area between the different metals is very small and probably not sufficient to create a relevant electromagnetic effect. Mitra et al. \([8]\), using a similar mix-technique, did not see any reaction, either. Nevertheless, to avoid the risk of electromagnetic effects, we have started the use of titanium wires.

Our results confirm that rigid plate fixation is an applicable technique for stabilization of sternal non-union after median sternotomy, even in complicated cases \([19]\). In our series with transverse or longitudinal plate placement, complete thoracic stabilization was achieved in 100% of the patient’s. However, compared to the longitudinal plate placement, the large transverse plate placement has the need for a more invasive access and seems to be associated with more complications in the long-term. Therefore, we recommend longitudinal plate placement with rewiring whenever possible. Additional short transverse plate connections could be helpful for thoracic stabilization in overweight patients. Larger transverse plate fixation may play a role in patients where sternal or rib adaptation is not possible or would lead to severe compression of the lung. In these cases the plates should be selected as short as possible.

Table 2
Postoperative data

<table>
<thead>
<tr>
<th></th>
<th>All patients ((n = 15))</th>
<th>Patients series 1 ((n = 6))</th>
<th>Patients series 2 ((n = 9))</th>
<th>(p) value (series 1 vs 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time of intubation (h) (median)</td>
<td>5.1 ± 5.9 (4)</td>
<td>5.5 ± 8.7 (2.5)</td>
<td>4.8 ± 3.6 (5)</td>
<td>0.876</td>
</tr>
<tr>
<td>Stay on intensive care unit (days)* (median)</td>
<td>1.7 ± 1.3 (1)</td>
<td>1.6 ± 0.8 (1)</td>
<td>1.7 ± 1.5 (1)</td>
<td>0.791</td>
</tr>
<tr>
<td>Hospital discharge (days after OP)* (median)</td>
<td>9.2 ± 10.7 (6)</td>
<td>7.0 ± 4.2 (5)</td>
<td>10.5 ± 13.1 (7)</td>
<td>0.472</td>
</tr>
<tr>
<td>Need of hardware removal (n) (%)</td>
<td>3 (20.0)</td>
<td>3 (50.0)</td>
<td>0 (0.0)</td>
<td>0.044</td>
</tr>
<tr>
<td>Subpectoral seroma/hematoma (n) (%)</td>
<td>2 (13.3)</td>
<td>1 (16.6)</td>
<td>1 (11.1)</td>
<td>0.657</td>
</tr>
</tbody>
</table>

Postoperative data presented as mean values ± standard deviation, unless otherwise indicated.

* Only surviving patients (\(n = 14\)).
References