Chest-wall reconstruction in case of infection of the operative site: is there any interest in titanium rib osteosynthesis?†

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Abstract

OBJECTIVES: To describe the management of thoracic reconstructions in the presence of primary chest-wall infection (PCWI) or secondary deep chest-wall infection (SCWI), focussing on local tolerance of a titanium rib osteosynthesis system.

METHODS: PCWI included infected chest wall tumours (CWT), infected T3 non-small-cell lung carcinoma (NSCLC) and open flail chest. SCWI was defined by deep infection of previous thoracic-wall reconstructions. Infection was identified by preoperative bacterial analysis of the tumour or surgical site. In PCWI, a one-step procedure combined extensive resection of infected tissues and rigid reconstruction of the defect; skeletal rigidity was achieved using titanium implants. In SCWI, we removed all synthetic material except titanium implants. In both groups, the surgical field was thoroughly cleaned and implants were wrapped or covered by flaps.

RESULTS: From January 2005 to December 2011, 11 patients (54 ± 10.2 years) with either PCWI (3 CWT, 3 T3 NSCLC, 1 open flail chest) or SCWI (3 CWT, 1 funnel chest) were treated. Infection was polymicrobial in all but 1 case. Bacteria observed in PCWI patients were multidrug resistant. In PCWI, we resected 4.2 ± 0.6 ribs en bloc with the lung (n = 5), the skin and the pectoralis major and then used mesh and 2.1 ± 1.2 titanium implants for reconstruction (n = 6). The mean defect was 1154.4 ± 318 cm². Surgical SCWI management removed polytetrafluoroethylene-mesh and preserved the titanium implants. A Vicryl mesh (n = 3) and greater omentum flap (n = 3) were added. One of the 2 postoperative deaths in the PCWI group was related to infection recurrence. No other patient had infection at the 6-month follow-up with leucocyte-labelled scintigraphy.

CONCLUSION: Titanium rib osteosynthesis is reliable in two complex and life-threatening situations: PCWIs and SCWIs. In combination with a flap, this allows rapid, reliable, rigid reconstruction of infected full-thickness chest-wall defects in a single-step procedure.

Keywords: Chest wall • Chest-wall infection • Chest wall prosthesis • Primary tumours • Lung cancer

INTRODUCTION

Thoracic-wall reconstructions are commonly indicated for a variety of conditions, such as trauma or malformation pathology, and after resection of large primary or secondary chest wall tumours (CWT) and T3/T4 non-small-cell lung carcinoma (NSCLC). Numerous synthetic and autogenous materials have been used in chest-wall reconstruction. The choice of material usually depends on the location and extent of the defect, together with the experience of the surgical team. The goal of skeletal reconstruction is to prevent paradoxical chest-wall motion and protect the lungs, heart and major vessels from injury, and secondarily to maintain scapula function and cosmetic integrity.

Independent of the material selected, complications after chest-wall reconstruction are common, with incidence rates ranging from 16 to 69% [1]. The reported incidence of infections is 0 [2]-22% [3] after rigid reconstruction of the chest wall and 10% for hardware infections after sternum osteosynthesis [4].

Two situations are particularly challenging for thoracic surgeons: rigid chest-wall reconstruction in the presence of surgical-site infection [primary chest-wall infection (PCWI)] and deep infection of a previous rigid reconstruction of the chest wall [secondary chest-wall infection (SCWI)]. Both situations can result in significant morbidity and mortality, ranging from 9 to 47% [5].

PCWI and SCWI have several common issues: the need for rigid stabilization, the possibility of one-step surgery, the use of synthetic material, the association of a musculocutaneous flap and the monitoring of these patients. In PCWI, the general
consensus is to avoid the use of synthetic material; in SCWI, traditional management requires the removal of infected hardware. However, when the chest-wall defect is large, early hardware removal places patients at high risk of major lung function impairment, deformity and chronic pain. Some recent data suggest that infected and exposed osteosynthetic hardware throughout the body can be preserved under certain circumstances and that the use of an osteosynthesis system might be appropriate in infected surgical areas [6–8].

We review below our experience in the management of thoracic-wall reconstruction in 11 patients with PCWI and SCWI, highlighting the available management options for these complicated situations, the material used and its local integration.

MATERIALS AND METHODS

Patient population

From the patient records of rigid reconstruction for large chest-wall defects in our two thoracic surgery departments, both in university hospitals (Montpellier and Saint-Etienne), we selected all cases with PCWI or SCWI from January 2005 to December 2011. Patients with superficial wound infection solely involving the skin, subcutaneous tissues or muscular superficial fascias were not included. All patients initially operated on in our thoracic surgery departments received oral and written information before consenting to chest-wall reconstruction with titanium implants. Both hospitals had implemented a therapeutic and operative strategy of performing or maintaining titanium rib osteosynthesis despite deep local infection.

The diagnosis was based on clinical examination and CT scan with intravenous contrast to delineate the extent and characteristics of the infectious process. Microbiological samplings were performed preoperatively, by protected bronchial samples and/or direct biopsy of granulomatous infected tissues in PCWI and by radio-guided puncture in case of deep fluid collections in contact with osteosynthesis material in SCWI. Multiple samples were taken at the beginning of surgery. Using the Center for Disease Control and Prevention definition [9], a deep chest-wall infection diagnosis involved at least one of the following criteria: (i) a pathogen organism isolated from culture of deep chest-wall tissues or fluid samples, or purulent drainage from deep parietal chest wall tubes; (ii) an evidence of deep chest-wall infection seen during the operation or initial clinical examination; (iii) deep fluid collection on the CT scan in the presence of either unusual strong chest pain or its recurrence after a symptom-free period and fever (>38°C), swelling in contact with the implants and (iv) deep wound dehiscence with exposed osteosynthesis hardware. No one biological parameter specifically indicates a prosthesis infection. Therefore, CRP values and white blood cell count were only used for the postoperative follow-up, and were not included in the surgical decision.

PCWI cases included infected CWT, infected T3 NSCLC and open flail chest causing effraction of the muscular planes and ribs with or without affecting the skin and subcutaneous tissues. SCWI cases were defined by deep infection of previous thoracic-wall reconstruction. Postoperative infection was classified as ‘early’ when it occurred during the first month, ‘delayed’ in months 2–6, and ‘late’ after the sixth month, according to the specific recommendations for bone and joint prosthetic device infection in clinical practice [8].

Surgical technique

In both PCWI and SCWI, we proceeded with surgery in a clinically stable patient after bacteriological samples were analysed and effective intravenous antibiotics had been started. In PCWI, neoadjuvant therapy was the only reason to postpone surgery, ending treatment at least 1 month before surgery. In our practice, the key principle of chest-wall infection management is to preserve respiratory function. To this end, we combined resection and rigid reconstruction in a one-step surgical procedure in PCWI patients. In SCWI patients, the titanium osteosynthesis material already in place was preserved. This decision resulted from reviewing the reports on the management of infected sternal dehiscence after cardiac surgery [7] and the poor outcome of Patient 3, from whom all synthetic material, including titanium hardware, was secondarily removed.

In PCWI, we performed a large resection of all infected or necrotized tissues to reach healthy, well-vascularized tissue. In the case of neoplasty, we followed the conventional rules of en bloc chest-wall resection [1]. After resection, we employed a pulse-jet lavage of the wound with 3 l of polyvidone-iodine solution. As described previously for aseptic lesions, the reconstruction includes the re-establishment of thoracic wall continuity and rigidity. We used titanium plates to bridge the defect, along with a mesh on the inner side sewn to the plates and ribs under maximum tension. A muscular or greater omentum (GO) flap was systematically used to cover the synthetic hardware. The titanium implants were either Stratos [Strasbourg thoracic osteosynthesis system (MedXpert GmbH, Heitersheim, Germany)] or MatrixRib Fixation System (DePuySynthes, West Chester, PA, USA). Stratos implants were placed as previously described [1] and MatrixRib as described by Voss et al. [10].

In SCWI, the surgical procedure included radical debridement of the thoracic wall with complete excision of tissue necrosis, meticulous pulse-jet lavage and in some cases, decortication. All synthetic material implanted during the initial reconstruction was systematically removed, except for the titanium implants. To restore the continuity of the chest wall, a Vicryl mesh [(polyglactin 910)] by Ethicon, Inc., Somerville, NJ, USA) was usually used. The framework was wrapped or at least covered in a muscular or GO flap. Extended resections of the thoracic wall as well as the patient’s medical history (radiotherapy, mastectomy and arteriosclerosis) often compromised the main blood supply of the musculocutaneous flaps, which guided the choice of the most appropriate flap. In SCWI, the GO flap was the preferred choice.

At least four large-bore chest tubes (Argyle 24, 28 or 32; Sherwood Medical Company, St. Louis, MO, USA) were placed in the thoracic wall, in front of, and behind, the mesh and flap to avoid seroma, and two in the thoracic cavity. The duration of drainage depended on the clinical and the biological follow-up and the results of the postoperative thoracic CT scan.

Antibiotherapy: follow-up

The prescription of antibiotherapy followed current guidelines for bone and joint infections at the prosthetic device [8]. Briefly, in case of sepsis, antibiotherapy was initiated probabilistically after collecting microbiological samples. Infection was treated with a combined antibiotherapy course of at least 12 weeks, intravenously for 15 days and then via per os administration, using molecules with good bone distribution.
A control thoracic CT scan was performed before discharge and at 6 months postoperatively. Leucocyte-labelled scintigraphy was performed at 6 months postoperatively.

Surgical data were obtained from operating room notes, microbiology reports and postoperative care reports. No patient was lost to the follow-up. Preoperative, perioperative and postoperative data were collected prospectively in the surgical database by trained personnel during the study period, including demographic characteristics, operative variables and in-hospital complications. Early mortality was defined as any death during the hospital stay or within 30 days post-surgery.

RESULTS

Pathology status: previous therapy

From January 2005 to December 2011, 11 patients (54 ± 10.2 years, 5 women) were included, 7 with PCWI (3 CWT, 3 T3 NSCLC, 1 open flail chest) and 4 with SCWI (3 reconstructions for CWT, 1 for funnel chest). Of all major chest-wall reconstructions using titanium, PCWI occurred in 6.3% and SCWI in 5.1%. All patients except 1 were treated surgically.

Primary chest-wall infection. Pathology status, previous therapy and resection characteristics are presented in Table 1. Patient 4 was included in the PCWI group due to an infected local recurrence 17 months after resection of a T3 NSCLC initially reconstructed with a combination of DualMesh ([polytetrafluoroethylene], W. L. Gore & Associates, Inc., Flagstaff, AZ, USA) and Stratos implants. In this group, 71% had received chemotherapy and thoracic radiotherapy. In Patients 3 and 4, this was part of the multimodal therapy of an extended NSCLC. Three patients had been treated for breast cancer. Patient 1 had been gored by a bull (anterior open chest trauma). This patient was admitted with extensive, multiple, and extremely dirty soft tissue injuries; 6 bifocal and 9 monofocal rib fractures with loss of bone substance (Gustilo classification for open fractures). Grade IIIA and anterior flail chest. Three days after the chest trauma and prompt debridement of soft tissue lesions and internal pneumatic stabilization attempts in a secondary hospital, the patient was transferred to a thoracic department because of poor evolution of the wounds, worsening of the respiratory condition, bilateral pleural effusion and sepsis despite broad-spectrum antibiotherapy.

Secondary chest-wall infection. The initial surgery was indicated for sarcoma in 3 cases and funnel chest in 1. Four to 6 ribs were resected (bilaterally in 1 case); the resection was extended to the sternum, pectoralis major and the skin in all cases, and to the lung (n = 2), pericardium (n = 2) and innominate vein (n = 2). The chest-wall defect was initially reconstructed by a combination of DualMesh and titanium implants in 2 patients and MMM sandwich and kirshner pins in another. There were 3 early and 1 delayed SCWI (Patient 11). The mean interval between initial surgery and diagnosis of early SCWI was 7.3 days. A 71-year old man (Patient 11) underwent anterior chest-wall reconstruction combining 3 Stratos plates and a DualMesh implant and was discharged on postoperative day 10 in good condition with a stable anterior chest wall. On Day 143, the patient was readmitted with pain recurrence, a loose titanium plate on chest X-ray, and cutaneous fistula defining a delayed SCWI.

Microbiology data

Bacteria were identified in all but Patient 1, who had a previous broad-spectrum antibiotic intake (Table 2). In the 7 patients treated for PCWI, the infection was generally polymicrobial (71%). In case of initial skin and soft tissue necrosis, the isolated bacteria were always multidrug resistant. After PCWI treatment, Patient 3 developed a recurrent chest-wall infection involving Acinetobacter baumannii, Klebsiella oxytoca, Candida glabrata, which was the same as the initial infection. This suggests the persistence of the infectious process despite aggressive initial

<table>
<thead>
<tr>
<th>Patient</th>
<th>Topography of the thoracic wall defect</th>
<th>Lung resection</th>
<th>Number of affected or resected ribs</th>
<th>Sternal resection</th>
<th>Muscle or skin resection</th>
<th>Others</th>
<th>Volume (cm³)</th>
<th>Area (cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ant/Lat</td>
<td>WR</td>
<td>6 bifocal fracture and 9 monofocal fracture</td>
<td>Bifocal fracture</td>
<td>Local muscles and skin resection</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>2</td>
<td>Ant/Lat</td>
<td>WR</td>
<td>5</td>
<td>Partial resection</td>
<td>PM + skin</td>
<td>Pericardium</td>
<td>1500</td>
<td>290</td>
</tr>
<tr>
<td>3</td>
<td>Ant/Lat</td>
<td>P</td>
<td>5</td>
<td>Partial resection</td>
<td>—</td>
<td>SCA, SCV</td>
<td>1050</td>
<td>150</td>
</tr>
<tr>
<td>4</td>
<td>Ant/Lat/Post</td>
<td>Completion pneumonectomy</td>
<td>4</td>
<td>—</td>
<td>PV + skin</td>
<td>VB</td>
<td>1462</td>
<td>210</td>
</tr>
<tr>
<td>5</td>
<td>Ant/Lat</td>
<td>WR</td>
<td>4</td>
<td>Total resection</td>
<td>PM + skin</td>
<td>Pericardium</td>
<td>1220</td>
<td>280</td>
</tr>
<tr>
<td>6</td>
<td>Ant/Lat</td>
<td>Lingulectomy</td>
<td>4</td>
<td>Partial resection</td>
<td>PM + skin</td>
<td>Pericardium</td>
<td>1120</td>
<td>220</td>
</tr>
<tr>
<td>7</td>
<td>Ant/Lat</td>
<td>RUL</td>
<td>3</td>
<td>Partial resection</td>
<td>PM + SC</td>
<td>SCV (right)</td>
<td>540</td>
<td>108</td>
</tr>
</tbody>
</table>

Ant: anterior; D: diaphragm; L: lateral; LD: latissimus dorsi; LUL: left upper lobectomy; P: pneumonectomy; PV: paravertebral muscles; PM: pectoralis major; Post: posterior; RUL: right upper lobectomy; SC: scalen muscle; SCA: subclavian artery; SCV: sub clavian vein; VB: vertebral body; WR: wedge resection.
management. **Staphylococcus epidermidis** was the most frequently reported pathogen, identified in all SCWI cases and isolated in at least two preoperative and intraoperative samples; possible skin flora contamination was discarded.

### Surgical management

**Primary chest-wall infection.** In 5 patients with PCWI, we performed *en bloc* chest-wall resection, 4.2 ± 0.6 ribs, with the lung resection (2 pneumonectomies, 1 lobectomy, 1 segmentectomy and 2 wedge resections), and partial or total resection of the sternum (Fig. 1 and Table 2). The mean size of the resection was 1154.4 ± 318 cm³. Skin and muscles, with or without pericardium, were resected in 6 cases. Reconstruction was achieved using the combination of a mesh (Vicryl: *n* = 4, DualMesh: *n* = 1, XCM: *n* = 1) and horizontal titanium osteosynthesis system (2.1 ± 1.2 implants) to insure stability and continuity of the chest wall during a one-step procedure.

The recurrence of infection and a poor outcome in Patient 3 prompted us to review our therapeutic approach regarding the mesh [1]. Patient 7 had a large, infected T3-NSCLC invading the chest wall; we used the XCM biological tissue matrix to avoid surgical-site infection. Due to delayed seroma with DualMesh despite aggressive drainage of the thoracic wall, we adopted an absorbable double layer of Vicryl mesh, without reported complications. In Patient 2, we used the Matrix rib system as an osteosynthesis device to stiffen the parietal reconstruction because the Stratos device could not be secured to a healthy rib.

- **Table 2: Reconstruction procedure and early follow-up**

<table>
<thead>
<tr>
<th>Patient</th>
<th>Type of reconstruction</th>
<th>Pre- or Postoperative surgical site necrosis or infection</th>
<th>Material infection or rupture</th>
<th>Material removal</th>
<th>Identified bacteria:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>–3 Stratos and 4 Stracos</td>
<td>Preoperative laceration of the skin</td>
<td>–</td>
<td>–</td>
<td>1. Extremely dirty wound</td>
</tr>
<tr>
<td>PCWI</td>
<td>–</td>
<td>Postoperative: uneventful</td>
<td>–</td>
<td>–</td>
<td>2. No bacteria</td>
</tr>
<tr>
<td>2</td>
<td>Vicryl/3 Matrix</td>
<td>Preoperative local infection and necrosis (9/4 cm)</td>
<td>–</td>
<td>–</td>
<td>1. Staphylococcus aureus</td>
</tr>
<tr>
<td>PCWI</td>
<td>LD mobilization</td>
<td>Postoperative skin necrosis (1/1 cm)</td>
<td>–</td>
<td>–</td>
<td>2. No bacteria</td>
</tr>
<tr>
<td>3</td>
<td>Dual mesh/1 Stratos</td>
<td>Preoperative pulmonary and chest-wall infection</td>
<td>Infection and rupture</td>
<td>DM and Stratos removal</td>
<td>1. Acinetobacter baumannii, Candida glabrata</td>
</tr>
<tr>
<td>PCWI</td>
<td>PM mobilization + GO</td>
<td>Postoperative site infection</td>
<td>–</td>
<td>–</td>
<td>2. Acinetobacter baumannii, Klebsiella oxytoca</td>
</tr>
<tr>
<td>4</td>
<td>Vicryl (DM removal)/1 Stratos (hardware replacement)</td>
<td>Preoperative pulmonary and chest-wall infection</td>
<td>–</td>
<td>–</td>
<td>1. Staphylococcus aureus</td>
</tr>
<tr>
<td>PCWI</td>
<td>LD mobilization</td>
<td>Postoperative: uneventful</td>
<td>–</td>
<td>–</td>
<td>2. Streplococcus alpha-haemolyticus</td>
</tr>
<tr>
<td>5</td>
<td>Vicryl/1 Stratos</td>
<td>Preoperative site infection</td>
<td>–</td>
<td>–</td>
<td>1. Staphylococcus aureus</td>
</tr>
<tr>
<td>PCWI</td>
<td>LM mobilization</td>
<td>Postoperative skin necrosis</td>
<td>–</td>
<td>–</td>
<td>2. No bacteria</td>
</tr>
<tr>
<td>6</td>
<td>Vicryl/4 Stratos</td>
<td>Preoperative infection and necrosis (11/7 cm)</td>
<td>–</td>
<td>–</td>
<td>1. Escherichia coli, Proteus mirabilis</td>
</tr>
<tr>
<td>PCWI</td>
<td>RA</td>
<td>Postoperative: uneventful</td>
<td>–</td>
<td>–</td>
<td>2. No bacteria</td>
</tr>
<tr>
<td>7</td>
<td>XCM/1 Stratos</td>
<td>Postoperative pulmonary infection</td>
<td>–</td>
<td>–</td>
<td>1. No bacteria</td>
</tr>
<tr>
<td>PCWI</td>
<td>–</td>
<td>Postoperative: uneventful</td>
<td>–</td>
<td>–</td>
<td>2. Escherichia coli</td>
</tr>
<tr>
<td>8</td>
<td>/Preservation of the hardware</td>
<td>Preoperative wound dehiscence and necrosis</td>
<td>Infection</td>
<td>DM removal</td>
<td>1. Staphylococcus epidermidis</td>
</tr>
<tr>
<td>SCWI</td>
<td>(2 Stratos) PM mobilization + GO</td>
<td>Anterior mediastinal fluid collection</td>
<td>–</td>
<td>–</td>
<td>2. No bacteria</td>
</tr>
<tr>
<td>9</td>
<td>/Preservation of the hardware</td>
<td>Postoperative wound infection</td>
<td>–</td>
<td>–</td>
<td>1. Staphylococcus epidermidis</td>
</tr>
<tr>
<td>SCWI</td>
<td>LD mobilization + GO</td>
<td>Externalization of the hardware</td>
<td>–</td>
<td>–</td>
<td>2. No bacteria</td>
</tr>
<tr>
<td>11</td>
<td>Vicryl/Preservation of the hardware (3 Stratos)</td>
<td>Preoperative wound dehiscence and necrosis</td>
<td>Rupture</td>
<td>1 barre replacement</td>
<td>1. Staphylococcus epidermidis, Escherichia coli</td>
</tr>
<tr>
<td>SCWI</td>
<td>PM mobilization + GO</td>
<td>Postoperative uneventful</td>
<td>–</td>
<td>–</td>
<td>2. No bacteria</td>
</tr>
</tbody>
</table>

DM: DualMesh (2 mm thickness); GO: great omentum; LD: latissimus dorsi; PM: pectoralis major; RA: rectus abdominis; STRATOS: Strasbourg Thoracic Osteosynthesis System; Vicryl: Vicryl mesh; XCM: XCM biological tissue matrix.
implantation of 3 Stratos bars and 4 Stracos. We covered the synthetic framework with a pedicled musculocutaneous flap in 2 cases (1 rectus abdominis, 1 latissimus dorsi combined with an abdominal advancement flap), or by rotating the pectoralis major or the latissimus dorsi.

Secondary chest-wall infection. The titanium osteosynthesis system was left in place in all cases. In case 10 (Figs 2, 3 and 4), in a single-step procedure, we removed the methylmethacrylate sandwich (polymethyl methacrylate, Stryker Howmedica Osteonics, Mahwah, NJ, USA) reinforced with Kirshner pins and the chest-wall

Figure 1: Patient 6, PCWI. (A) Large musculocutaneous necrosis (from the axilla to mid chest line) related to a radioinduced sarcoma invading ribs. (B) Large full-thickness chest wall defect; chest wall continuity restoration and visceral protection using double layer of Vicryl mesh. (C) Chest wall rigidity restoration using titanium implants. (D) Musculocutaneous coverage with rectus abdomini flap.

Figure 2: Patient 10, SCWI: views of the chest wall before reconstruction. (A) Preoperative multiple and extensive musculocutaneous infection and necrosis, externalization of the hardware. (B) Removal of all ‘non-titanium’ hardware (methylmetacrylat armed with Kirshner pins).
reconstruction using two Stratos plates. A GO flap was used in 3 cases, combined with pectoralis major or latissimus dorsi mobilization. Patient 9, the only non-surgical case, had early SCWI after a sternochondroplasty (reinforced with 2 Stratos bars) performed for a profound funnel chest. Considering the absence of chest-wall defects, the risks of reoperation and the early diagnosis of infection, we chose a conservative treatment: CT-guided puncture of a deep fluid collection, intravenous

Figure 3: Patient 10, SCWI: views of the chest wall during reconstruction and the follow-up. (A and B) One-step, full-thickness reconstruction of the chest wall combining rigid reconstruction made of two transversal titanium osteosynthesis devices, GO flap wrapped around the osteosynthesis system, and musculocutaneous coverage using latissimus dorsi. (C) Final result, 9 months postoperatively.

Figure 4: Patient 11, SCWI: infection and necrosis spread to contiguous cartilages in the lower sixth to ninth ribs and enlargement of the resection was required, with the excision of the entire fused costal cartilaginous arch to eradicate infection, generating a very large defect. (A and B) Wrapping of the titanium implants (conservative surgical treatment with preservation of the hardware) with the GO split into two flaps. (C and D) Postoperative CT scan (6 months), with hardware fully integrated, no mediastinal fluid collection and late abdomino-mediastinal hernia.
antibiotics and local care. After 12 weeks of antibiotic therapy (2 weeks intravenously and orally thereafter), the patient had an uneventful postoperative course.

**Follow-up**

Nine patients were discharged from the hospital without major sequels (Table 2). Two patients died (18% early death rate): Patient 8 of massive pulmonary embolism and Patient 3 after 68 days in the intensive care unit due to late postoperative extensive bacterial pneumonia. Only 1 death was directly related to the persistence of an active infection, bringing the ‘infection-related mortality rate’ to 9% (PCWI 14% and SCWI 0%). In the 9 surviving patients, the follow-up ranged from 10 months to 8 years (mean, 3.4 years) and control thoracic CT scan was normal, with standard soft-tissue density and no persistence of chest-wall abscess. In SCWI, delayed leucocyte-labelled scintigraphy showed no pathological activity around the chest-wall reconstruction. There was no flap loss in our series but 2 patients required additional debridement of necrotic skin and subsequent skin grafting. The other patients had primary healing with restored function of the chest wall. Nine patients had an uneventful recovery, with immediate extubation after surgery, no tracheostomy and no repeated bronchial toilet by bronchoscopy. No patient presented postoperatively with clinically evident paradoxical motion of the reconstruction.

**DISCUSSION**

Very few case reports or subchapters of articles dealing with chest-wall reconstructions in thoracic surgery are available concerning patients with PCWI and SCWI, life-threatening conditions that are complicated to treat. Conventional treatment is based on the removal or non-use of prosthetic material as soon as an infection is identified. This therapeutic approach might place the patient in a critical respiratory situation and often leads to long-term major functional after-effects. The availability of a rib osteosynthesis system made of titanium has modified our surgical management, which is based on the preservation or use of these implants in a one-step surgical procedure despite deep infection in the operative site. This approach has achieved 81% rapid healing without major functional sequela in patients with deep and extensive infection of the chest wall.

**Epidemiology**

**Incidence.** With multiple pathological entities, PCWI incidence is difficult to define, but has been reported to range from 3 to 40% after open rib fractures [8]; regardless of size, defect topography and material used, the reported SCWI incidence is between 0 [2] and 22% [3]. Recently, Fabre et al. [11] reported a 4% SCWI rate, considering this low rate as related to the technical specifications of the titanium implants. In our experience (large anterior and lateral defects), the PCWI rate was 6.3% and SCWI was 5.1%.

**Mortality.** As in similar studies, we reported a substantial 18% global mortality rate, including 9% infection-related post-operative mortality in 11 patients treated for complex full-thickness chest-wall defects (4.2 ± 0.6 ribs including sternum in 5 cases). A review of deep sternal-wound infection after cardiac surgery [12] reported a specific mortality rate of 10 to 47% [5, 6]. In PCWI, Koppert et al. [3] reported 12.5% mortality with 50% of local complications. Postoperative deaths were due to severe sepsis and complete failure of the chest-wall reconstruction [3].

Comparing the historical series [13] with recent publications, the SCWI incidence has not changed much over the past 25 years despite the use of titanium implants. However, combining this approach with flaps seems to improve the management of chest-wall infections and morbimortality rates.

**Surgical procedure**

In PCWI, the initial width of the defect indicates the rigidity of the reconstruction. In SCWI, most authors [10, 14] agree on the necessity of extensive debridement and removal of all synthetic materials in order to leave a healthy implantation base. Costal cartilages are known to be exceedingly vulnerable to infection, and bone removal is traditionally continued until punctuate bleeding appears [12, 13]. Thus, satisfactory debridement in SCWI always leads to a larger parietal defect than initially indicated for primary reconstruction. In Patient 11, the secondary infection spread to contiguous cartilages in the lower sixth to ninth ribs, requiring the complementary excision of the entire fused costal cartilaginous arch.

**Rigid reconstruction.** Performing a ‘surface-only’ chest-wall repair after removing all synthetic materials (Patient 3) failed to manage infection recurrence. In a review of necrotizing chest-wall infections, Urschel et al. [15] underlined that, due to loss of standard pulmonary mechanisms, the genuine problem to be considered in post-debridement reconstruction of defects is physiological. Larson and McMurtrey [14] used a musculocutaneous flap in PCWI and reported morbid paradoxical respiratory movements in the early postoperative period. A large chest-wall defect without any rigid reconstruction results in respiratory complications, often incompatible with tracheal extubation. Maintaining a rigid structure in the chest wall appears to be a surgical imperative.

Fearing that foreign-body material would sustain infection, Arnold and Pairolero [13] did not recommend rigid tissue reconstruction with mesh or other prosthetic material in case of PCWI or SCWI. However, it is difficult to recommend the use of a myocutaneous flap alone because it has been reported to provide inadequate rigidity within 2 postoperative months [10, 16]. Makboul and Salama Ayyad [16] used this approach to reconstruct infected chest-wall osteoradionecrosis; they achieved rigid reconstruction in this specific condition because fibrosis of the parietal pleura supports the myocutaneous flap. Advocating the sufficiency of myocutaneous flaps, McKenna et al. [17] reported routine post operative day 1 extubation with no additional prosthetic supportive material in 26 patients with PCWI. Surprisingly, in the same series, the Marlex/MMPS combination was used for reconstruction in non-infected patients. To address the lack of flap rigidity without adding synthetic material, the reinforcement of myocutaneous flaps using latissimus dorsi strengthened by deep aponevrosis and fascia has been proposed [18]. In our opinion, the use of titanium implants to perform
rigid reconstruction in debilitated patients avoids an additional lengthy procedure and potential donor-site morbidity.

**Conservative treatment.** Instability of the reconstruction after large chest-wall resection initiates the infectious process or recurrences [19]. Furthermore, the use of titanium implants in PCWI allows rigid reconstruction in a single-step procedure. Conservative surgical management could be proposed for SCWI. Some reports [4, 7, 10] suggest that titanium hardware preservation may be an acceptable approach to treat PCWI and SCWI. Gaudreau et al. [4] reported the largest series of infected sternal hardware with a 9.7% rate of infection recurrence among 92 patients treated with transverse sternal plate. The author used transversal titanium rigid fixation. Guided by the rules of conservative treatment of prosthetic infections in orthopaedic and vascular surgery, we considered the optimal circumstances for conservative treatment of SCWI to be the following:

(i) Significant medical comorbidities (risk for redo of open surgery),
(ii) major chest-wall defect and
(iii) indolent Gram-positive organisms; considering the treatment of aortic graft infection, many Gram-negative bacteria are not ideal for conservative therapy because of their propensity to invade adjacent tissues; *Staphylococcus epidermidis* is known to be among the most indolent bacteria [20].

**Mesh and flap.** During surgery, we had two priorities: maintaining the rigidity and interrupting the continuity of the chest wall in order to prevent a perfect reconstruction seal. DualMesh was always removed in SCWI and we avoided its use in PCWI. Our experience, along with others [11], leads us to limit the use of DualMesh because it may induce seroma. Its complete compartmentalization between the thoracic cavity and overlying soft tissues is inadequate in case of infection and we increasingly use resorbable (Vicryl) or integrable (XCM) mesh.

The selection of the most appropriate flap is primarily dictated by the location and size of the defect. Tissue availability or surgeon’s preference can also influence the decision. We always use GO along with titanium implants in PCWI or SCWI; other authors use it when no other option is available. We advocate its use, pedicled on the right or left gastroepiploic vessels. Cohen and Ramasastry [21] reported on the qualities of GO in 75 complex anterolateral chest-wall reconstructions with a local and general complications rate <5%. These include its supplé texture (Fig. 4A) that easily fills the residual chest-wall cavity (Fig. 4B) and its rich lymphatic plexus that greatly assists infection control. In our experience, a partial abdominothoracic hernia (Case 11, Fig. 4D) was noticed and easily treated during follow-up.

**Microbiological data and titanium implant characteristics**

Stainless steel, titanium and titanium alloys are the most commonly used materials for osteosynthesis implants. Of the 3, stainless-steel implants have been associated with significantly greater infection rates in experimental studies [22]. In current clinical practice, Marie Lannelongue Hospital [11] described a 7% decrease in infectious complications with use of titanium implants. As in orthopaedic surgery, the choice of pure or alloy titanium with a bar shape or a plate shape appears to be associated with lesser infection. The Ley prosthesis used in the sternal reconstruction was not associated with any deep infection in patients with SCWI [23]. A possible explanation is that soft tissue adheres firmly to titanium-implant surfaces, whereas a biologically active layer is formed on steel implants. This layer is composed of a complex mixture of fibrinogen that not only supports host cells, but also bacteria that spread freely in this unvascularized substratum. As in our series, *Staphylococcus epidermidis* is the coagulase-negative *staphylococci* most frequently isolated from implant-associated infections. It is characterized by its ability to colonize a polymer surface and form a thick biofilm [24]. This biofilm (slime) is poorly penetrated by most antibiotics, supporting the approach of removing all infected implants, whatever the characteristics of the material. Titanium is known to make the surface of the biomaterial less interactive because of its specific surface/interface design. For example, infection rates in implantation of tibial devices (secondarily inoculated) in rabbits were significantly lower (*P* = 0.05) in titanium (35%) vs steel (75%) [22]. According to experimental studies, better resistance to infection would likely be obtained by modifying the polish of the metal surface or the surface chemistry of biomaterial, or by using antimicrobial coating [22, 24].

**CONCLUSION**

The use of titanium implants in combination with GO and/or myocutaneous flap during a one-step surgery allows rapid and reliable rigid chest-wall reconstruction in PCWI or SCWI, two complex and life-threatening situations.

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