The combination of polytetrafluoroethylene mesh and titanium rib implants: an innovative process for reconstructing large full thickness chest wall defects†

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Abstract

OBJECTIVES: The reconstruction of large full thickness chest wall defect after resection of T3/T4 non-small cell lung cancer (NSCLC) or primary chest wall tumours presents a technical challenge for thoracic surgeons and is a critical factor in determining post-operative outcome. When the defect is large, complications are common with a 27% mean rate of respiratory morbidity.

METHODS: Since 2006, 31 patients underwent reconstruction for wide chest wall defects using titanium implants and strong mesh. The reconstruction was achieved using a layer of polytetrafluoroethylene or a XCM biologic tissue mesh shaped to match the defect and sutured under maximum tension to re-establish the skeletal continuity. The mesh was placed close to the lung and was fixed onto the bony framework and onto the titanium plate. In one case, we used XCM biologic tissue because of a large infected T3 NSCLC. A horizontal titanium rib osteosynthesis system was used to reestablish the rigidity of the thoracic wall by bridging the defect except for one case in which we use a vertical rib osteosynthesis system.

RESULTS: Twenty-six patients underwent a complete R0 resection with the removal of a mean of 4.67 ± 1.5 [3–9] ribs, including the sternum in 14 cases. The mean defect area was 198 ± 91.2 [95–400] cm². Reconstruction required a mean of 2.06 ± 1.1 [1–4] titanium plates. There were two cases of deep wound infection that required surgical removal of the osteosynthesis system in one patient. Only one patient developed a major complication in the form of respiratory failure. There were two postoperative deaths neither of which was directly related to the surgical procedure.

CONCLUSIONS: Our experience and initial results show that titanium rib osteosynthesis in combination with strong biologic or synthetic mesh can easily and safely be used in a one-stage procedure for the reconstruction of major chest wall defects.

Keywords: Rib prosthesis • Chest wall tumor • Lung cancer • Chest wall reconstruction

INTRODUCTION

The reconstruction of large full thickness chest wall defects remains controversial and challenging for thoracic surgeons. Postoperative outcome depends largely on the modality of reconstruction. When the defect is large, complications after chest wall reconstruction are common and range between 46 and 69% [1, 2], a rate that includes 27% respiratory morbidity [1]. Primary or secondary chest wall tumours (CWT), T3/T4 non-small cell lung cancer (NSCLC) are the main indications for large chest wall resections. There are two major stages in the conventional management of large full thickness chest wall lesions: first, the surgical resection with disease-free margins (with or without ‘En-Bloc’ resection of the lung, soft tissue and skin) and second, the bone reconstruction, with or without musculocutaneous coverage. It is this second aspect that we address here.

Numerous synthetic materials have been applied in chest wall reconstruction to ensure thoracic wall stability and mechanical organ protection, prevent ventilatory impairment, avoid incarceration of the tip of the scapula and maintain acceptable cosmetic integrity. The most commonly used implants are synthetic (polytetrafluoroethylene (PTFE), polypropylene with or without methylmethacrylat (MM)) or autogenous materials (such as muscle flaps and bone grafts). It is mainly the habit of the operating team which will determine the choice of the material used, however, rules are imposed according to the extension and location of the defect. The drawbacks of usual materials are well known. Methyl metacrylate sandwich (MMS) is associated with many local complications including fractures, seromas, wound
hematomas and infections. Moreover MMS provides a rigid base which does not permit the complete range of respiratory movements especially when the defect is large. The exclusive use of muscle flap may be inadequate since they require about 2 months to achieve final firmness. The major drawback common to all these materials is their unsuitability for three-dimensional reconstruction of the chest wall.

Here we review our experience in the combined use of titanium plates and strong synthetic or biologic mesh in chest wall reconstructions following very large chest wall resections with a special analysis on local integration. As a synthetic mesh we used PTFE (ePTFE Dualmesh 2 mm, Gore-Tex, W. L. Gore & Assoc., Flagstaff, AZ, USA) except for one case where we used XCM mesh (XCM Biologic Tissue Matrix, Synthes GmbH, Oberdorf, Suisse). The titanium implants were STRATOS (Strasbourg Thoracic Osteosyntheses System; MedXpert GmbH, Heitersheim, Germany) for horizontal osteosynthesis and the VEPTR system (Vertical Expandable Prosthetic Titanium Rib, Synthes Spine Company of West Chester, Pennsylvania, USA) for vertical osteosynthesis (Fig. 1).

**MATERIALS AND METHODS**

This study was approved by our ethics committee and individual consent was obtained in each cases. The patients were operated in two French surgical centres [(i) Department of Thoracic Surgery, University Hospital Arnaud de Villeneuve, Montpellier and (ii) Department of Thoracic Surgery, University Hospital, Strasbourg] both of which approved a similar therapeutic and operative strategy. To plan the therapeutic approach for T3–T4 NSCLC or CWT, a multidisciplinary approach involving respiratory oncology physicians, radiologists, radiotherapists, thoracic surgeons, spinal surgeons and plastic surgeons was employed. Computed tomography (CT) of the chest, abdomen and brain was routinely carried out in all patients before resection and showed that none of the patients had extrathoracic metastases at the time of assessment. For posterior tumours, magnetic resonance imaging of the entire spine was performed to verify the absence of any abnormalities in the spinal cord. In all patients, samples from the tumour region were taken preoperatively for bacterial analysis if there were ulcerations. Bacterial analyses of bronchial and sputum samples were also systematically made prior to operation. In case of postoperative sepsis, we ensured that numerous protected bronchial samples and samples at the level of the surgical site were taken.

From October 2006 to February 2011, 31 patients underwent a large chest wall resection. We chose the combination of strong mesh (biologic or synthetic) and titanium implants as an elective procedure for large thoracic wall defect reconstructions. Large chest wall defects were defined as any resection involving more than two ribs or a combined resection of two ribs (at least) and the sternum. Resections of less than three ribs and those located in the posterior chest wall beneath the scapula were managed by ribs approximation and soft-tissue coverage and were not included in this study. Anterior chest wall defects were defined as being located between the sternum and the anterior axillary line, lateral defects were those between the anterior and posterior axillary lines and posterior defects were those between the spin and the posterior axillary line. Chest wall resection included the ribs, parietal muscles and, when required, one or more of the following items: sternum, clavicles, vertebral body.
subclavian vessels, superior vena cava, lung (wedge, lobectomy or pneumonectomy), diaphragm, pericardium, soft tissues and skin (Fig. 2A). The resection of the tumour, the chest-wall and adjacent invaded organs was always performed by the thoracic surgeon sometimes with the assistance of an orthopaedic surgeon experienced in spinal surgery. The surgical approach depended on both the chest wall parts involved and the associated resections required. When the tumour was posterior, the level of the inverted J-shape approach depended on the associated vertebral resection required. A combined anterior and posterior approach was used to resect anteroposterior tumours with posterior extensions. Ectopic tumours were resected through a direct anterior approach. The disease-free resection margins were established during the operation on the basis of frozen tissue section analysis.

We reconstructed the chest wall as follows:

- The first step involved using a layer of strong synthetic or biologic mesh to restore the continuity of the chest wall. The mesh was shaped to match the defect and was sutured under maximum tension. It was fixed onto the bony framework of the chest wall and onto the titanium plates (Fig. 1A) before being fully anchored to the inner corners and edges of the defect thus separating the remaining lung and the mediastinum from the superficial tissues. In all cases except one, we used a PTFE mesh, the Dualmesh (ePTFE, Dualmesh 2 mm, Gore-Tex, W. L. Gore & Assoc., Flagstaff, AZ, USA) and standard PTFE soft tissue patch (W. L. Gore & Assoc., Flagstaff, AZ, USA), chosen for its high strength with high suppleness. The smooth side of the Dualmesh was placed close to the lung. The matrix XCM, a biologic mesh, was used in patient number 23 (Fig. 1D).

- The second step involved re-establishing the rigidity of the chest wall using titanium implants to bridge the defect. In all cases except one, we used the STRATOS which consists of titanium rib clips available in different angles and of low profile connecting bars available in different lengths which can be moulded to match the shape of the defect. One complete implant consists of two rib clips and one connecting bar. It is important to underline that stability was obtained without the need to rebuild each rib level and that the implantation of the STRATOS required a sufficient segment of disease-free rib located laterally to the margins of the resection (Fig. 1B). Two situations required an unconventional use of the STRATOS: first, the bars were inserted onto the opposite ribs in cases involving associated sternal resection or where the disease-free ribs were too short; second, angled rib clips were used to perform a horizontal osteosynthesis without taking into account the level of posterior and anterior segments of the ribs. In one case (no. 19) involving very large posterior defects without the opportunity to lock the STRATOS clip posteriorly, we performed a vertical rib osteosynthesis with a VEPTR device (Fig. 1C). The VEPTR device is an expandable curved metal rod placed in a vertical position between the disease-free ribs. To ensure a three-dimensional (3D) reconstruction of the chest and maintain a proper volume of the thoracic cavity, we hung the ePTFE from the titanium bars with multiple non-absorbable sutures. Subsequently, absorbable sutures were used for soft tissue reconstruction, and in cases of full-thickness resection, flaps of skin, muscle (rectus abdominis, latissimus dorsi, pectoralis major) or the greater omentum were used (Fig. 2C).

The surgical and oncological data were obtained from the operation notes, the pathological reports and the postoperative care reports. Data concerning aesthetic and functional results,
mortality and hospital stay, were also collected. No patient was
lost in the follow-up. Clinical (TNM) and pathological (pTNM)
were assigned in agreement with the new International System
for Staging Lung Cancer, as developed by the American Joint
Committee on Cancer and the Union Internationale Contre le
Cancer.

RESULTS

Between 2006 and 2010, 31 patients (15 women) with a median
age of 59 ± 8.5 years [34–84] with chest wall invasion from either
primary (13), or secondary (5) CWT tumours or T3/T4 NSCLC
(13) were treated at our two institutions. Histology, neoadjuvant
therapy, resection quality and tumour classification are reported
in Table 1. There were 13 NSCLC cases, 12 of whom underwent
neoadjuvant chemotherapy and preoperative radiation therapy.
Patient 23 had a very large infected necrotizing NSCLC for which
neoadjuvant treatment was rejected. In this patient, bronchial
and sputum samples showed an infection of the large tumour
cavity (multiresistant Escherichia coli) despite appropriate anti-
biotic treatment. The resection status was complete (R0) in

83.9% of the patients. Patients with R1 resections were numbers
3, 17, 22, 26 and 28, who showed microscopic invasion of the
margins, the tunica adventitia of the subclavian artery, the cer-
vical soft tissue, the pericardium, the diaphragm and the para-
vertebral muscles, respectively.

Bone resections

Table 2 summarizes the type of chest wall resection. An average
number of 4.67 ± 1.5 [3–9] ribs were resected along with the
sternum in 14 cases. The mean defect zone was 198 ± 91.2 [95–
400] cm² and the mean volume of the En-Bloc resection was
1096 ± 662.6 [190–3150] cm³, calculated using data from the
pathologist to approximate the size of the tumour. The vertebral
bodies were involved in five patients and required anterior and
posterior fixation of the vertebral column in four.

Chest wall reconstruction

Implants (Dualmesh or XCM) measured 2 cm larger than the
defect found in each patient. A Dualmesh was used in 25 cases,
standard 2 mm thickness GoreTex mesh in 5 and an XCM
Biologic Tissue Matrix was implanted in patient no. 23 following
the same principles of insertion as the synthetic mesh (Fig. 1).

As a horizontal rib osteosynthesis device to stiffen the parietal
reconstruction, a mean of 2.06 ± 1.1 [1–4] titanium plates were
implanted (Table 2). In our experience, one plate was sufficient
for the reconstruction to provide a rigid enough reconstruction
of 2.26 rib levels. In cases 1 and 18, the bars crossed the
resected portion of the sternum and were positioned so as to
bypass it since there was no way of attaching them to its sides.
The distal implantation onto the contralateral ribs without enlar-
ging the thoracic approach was possible in these two cases
thanks to the use of the moulded plates and angulated tools.

In case 19, there was no posterior segment of a healthy rib in
any of the five resected rib levels sufficient to lock a STRATOS
implant. We therefore performed a vertical osteosynthesis using a
VEPTR that locked onto the middle of the second and
eighth ribs.

A muscular flap was added in 18 cases by rotating either the
tectoralis major or the latissimus dorsi (Table 3) (Fig. 2C). In one
case (no. 21), we used the rectus abdominis because the pector-
alis major had been resected due to tumour invasion and the lat-
issimus dorsi muscle had been used to reconstruct the breast
20 years earlier (Fig. 2D). A flap of greater omentum was used in
two patients owing to insufficient soft tissue cover and in a third
patient as a result of local infection (Fig. 3C and D).

Complications and infections

Twenty-six patients experienced no major complications and we
observed no intraoperative complication. A delayed rupture of
the titanium rib clips (STRATOS) at the joint was experienced by
four patients (patients 3, 4, 27 and 30) equating to a rate of
6.5%. In patient 4, the ruptured bar was removed at 6 months to
avoid it migrating into the soft tissues or mediastinum (Table 3).

Three patients (3, 17 and 18) did developed infections in the
surgical site. The bacteria identified within the surgical site were
Acinetobacter baumanii and Candida glabrata in one case,
**Table 2:** Type and size of resection

<table>
<thead>
<tr>
<th>Patient</th>
<th>Topography of the defect</th>
<th>Lung resection</th>
<th>Number of resected ribs</th>
<th>Sternum resection</th>
<th>Muscle or skin resection</th>
<th>Others</th>
<th>Volume, cm³</th>
<th>Area, cm²</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Ant.</td>
<td>LUL</td>
<td>3</td>
<td>Subtotal</td>
<td>–</td>
<td>SCV, SCV</td>
<td>520</td>
<td>130</td>
</tr>
<tr>
<td>2</td>
<td>Ant./lat.</td>
<td>RUL</td>
<td>4</td>
<td>–</td>
<td>PM</td>
<td>SCV</td>
<td>910</td>
<td>130</td>
</tr>
<tr>
<td>3</td>
<td>Ant./lat.</td>
<td>P</td>
<td>5</td>
<td>Partial</td>
<td>–</td>
<td>SCV, SCV</td>
<td>1050</td>
<td>150</td>
</tr>
<tr>
<td>4</td>
<td>Post./lat.</td>
<td>RUL</td>
<td>5</td>
<td>–</td>
<td>–</td>
<td>VB</td>
<td>572</td>
<td>143</td>
</tr>
<tr>
<td>5</td>
<td>Post.</td>
<td>WR</td>
<td>6</td>
<td>–</td>
<td>–</td>
<td>VB</td>
<td>572</td>
<td>115</td>
</tr>
<tr>
<td>6</td>
<td>Ant.</td>
<td>WR</td>
<td>4</td>
<td>Subtotal</td>
<td>PM + skin</td>
<td>–</td>
<td>585</td>
<td>120</td>
</tr>
<tr>
<td>7</td>
<td>Post./lat.</td>
<td>WR</td>
<td>3</td>
<td>–</td>
<td>D</td>
<td>–</td>
<td>1638</td>
<td>350</td>
</tr>
<tr>
<td>8</td>
<td>Ant./lat./post.</td>
<td>RUL</td>
<td>4</td>
<td>–</td>
<td>Sc &amp; PM + skin</td>
<td>VB</td>
<td>1462</td>
<td>210</td>
</tr>
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<td>9</td>
<td>Post./lat.</td>
<td>RUL</td>
<td>4</td>
<td>–</td>
<td>–</td>
<td>VB</td>
<td>1638</td>
<td>350</td>
</tr>
<tr>
<td>10</td>
<td>Ant./lat.</td>
<td>RUL</td>
<td>4</td>
<td>–</td>
<td>LD + skin</td>
<td>Surr. nectomy</td>
<td>975</td>
<td>300</td>
</tr>
<tr>
<td>11</td>
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<td>LUL</td>
<td>3</td>
<td>–</td>
<td>–</td>
<td>Sc</td>
<td>450</td>
<td>95</td>
</tr>
<tr>
<td>12</td>
<td>Ant./lat./post.</td>
<td>–</td>
<td>9</td>
<td>–</td>
<td>LD</td>
<td>–</td>
<td>2800</td>
<td>280</td>
</tr>
<tr>
<td>13</td>
<td>Post./lat.</td>
<td>RUL</td>
<td>4</td>
<td>–</td>
<td>Sc</td>
<td>VB</td>
<td>964</td>
<td>108</td>
</tr>
<tr>
<td>14</td>
<td>Ant.</td>
<td>WR</td>
<td>4</td>
<td>Partial</td>
<td>D &amp; PM + skin</td>
<td>Pericardium</td>
<td>1575</td>
<td>225</td>
</tr>
<tr>
<td>15</td>
<td>Ant.</td>
<td>WR</td>
<td>7</td>
<td>Total</td>
<td>Skin</td>
<td>Pericardium</td>
<td>1000</td>
<td>200</td>
</tr>
<tr>
<td>16</td>
<td>Post./lat. Completion</td>
<td>6</td>
<td>–</td>
<td>–</td>
<td>LD</td>
<td>Osophogeal</td>
<td>1008</td>
<td>126</td>
</tr>
</tbody>
</table>

Ant: anterior; D: siaphragm; Lat: 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.

*Staphylococcus epidermidis* and *Enterococcus* in the other two. Patient 3 was highly symptomatic and suffered from a very large necrotic tumour that became infected during neoadjuvant chemotherapy. In this patient, temporary removal of the STRATOS bar and the Dualmesh was required at postoperative day 10. After intensive cleaning of the surgical area, a STRATOS bar was reinserted to stabilize the thoracic wall. This titanium bar was implanted together with a Vicryl mesh and was covered using a patch of the great omentum. The other two patients were treated by ablation of the Dualmesh while keeping in place the titanium bars. This procedure was combined with covering using a great omentum flap in one case (patient 17) (Fig. 3A–E). The postoperative course was uneventful and polynuclear scintigraphy no evidence of infection around the surgical area 6 months after the second surgical procedure. One patient (patient 18) had partial skin necrosis and infection that required prompt debridement and primary closure. Follow-up was then uneventful. In this patient, the initial coverage of the thoracic osteosynthesis material was performed using a large skin flap because the local muscle flaps were no longer fit for use.

An infection of the operative area was identified in five cases before the reconstruction of the thoracic wall which included three infected CWT with skin necrosis (patients 8, 21 and 22) and two large infected excavated T3 NSCLC (patients 3 and 23).

In cases of soft tissue infection, the microbial flora was multiple and was resistant to the standard antibiotics in two patients. In these patients (8, 21 and 22), chest reconstruction was carried out using titanium bars and Dualmesh once intensive cleaning of the surgical area had been preformed. Reconstruction involved the use of a titanium bar in association with XCM for patient 23 because of the purulent nature of the surgical site. In addition, the poor outcome of patient no. 3 has encouraged us to use biological material for all such patients. The use of myocutaneous or great omentum flap was not feasible because of the history of this patient (bilateral breast prosthesis, diabetes, multiple laparotomies).

We observed two early deaths neither of which was directly related to the surgical procedure: one patient died as a result of a massive pulmonary embolism (patient 7) and the other patient died as the result of a fatal heart rhythm disorder (patient 21). One patient died (patient 3) after 68 days in the intensive care unit because of a late post-operative bacterial pneumonia, followed by respiratory failure. This patient underwent a redo surgery because of a local wound infection. After excluding...
patients 3, 7 and 21 (early post-operative death, POD 7 and POD 10 and an intensive care unit stay of over 30 days), median in-hospital stay was 11.6 (7–22) days, including a median stay of 3.6 days in intensive care. No chest wall deformity was observed in any patient.

**DISCUSSION**

The main objective of surgical resection of CWT or T3/T4 N0 NSCLC is to achieve an En-Bloc resection of the chest wall and the adjacent structures (if necessary lung, pericardium, phrenic muscle, superior vena cava, subclavian vein, subclavian artery and vertebral body) with disease-free margins (R0). When the required surgical resection is radical, it represents the essential element of treatment. Downey et al. [3] demonstrated that incomplete resection (R1 or R2) is of no interest in treating a T3 or T4 CBNCP. An R0 resection is also mandatory for a CWT [4].

Other prognostic items are essential including the mediastinal nodal involvement in the treatment of T3/T4 NSCLC and the pathological grade in the treatment of primary CWT.

In our series dealing with large CWT (4.67 ± 1.5 [3–9] ribs resected), the resection status was complete (R0) in 83.9%. Confident in our methods of chest wall reconstruction, we chose a radical and aggressive method of bone resection complemented by a systematic intra-operative analysis of the resection

<table>
<thead>
<tr>
<th>Patient</th>
<th>Mesh</th>
<th>Number of STRATOS or VEPTR bars</th>
<th>Muscle flap</th>
<th>Pre- or Postoperative surgical site necrosis or infection</th>
<th>Material infection or rupture</th>
<th>Material removal</th>
<th>Identified bacteria: (i) wound samples, (ii) bronchiolo-alveolar samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DM</td>
<td>2 STRATOS</td>
<td>PM mobilization</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>(i) Acinetobacter baumanii, candida glabrata, (ii) Acinetobacter baumanii, Klebsiella oxytoca</td>
</tr>
<tr>
<td>2</td>
<td>DM</td>
<td>1 STRATOS</td>
<td>PM mobilization</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>DM</td>
<td>1 STRATOS</td>
<td>PM mobilization + GO</td>
<td>Preoperative pulmonary infection Postoperative site infection</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>DM</td>
<td>1 STRATOS</td>
<td>-</td>
<td>Postoperative site infection, postoperative skin necrosis (2/3 cm)</td>
<td>-</td>
<td>-</td>
<td>(i) Staphylococcus aureus, (ii) Streptococcus alpha-haemolyticus</td>
</tr>
<tr>
<td>5</td>
<td>DM</td>
<td>1 STRATOS</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>DM</td>
<td>1 STRATOS</td>
<td>PM mobilization</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>DM</td>
<td>1 STRATOS</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>DM</td>
<td>1 STRATOS</td>
<td>PM mobilization</td>
<td>Preoperative site infection postoperative skin necrosis (2/3 cm)</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>DM</td>
<td>2 STRATOS</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>DM + V</td>
<td>2 STRATOS</td>
<td>GO</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>11</td>
<td>DM</td>
<td>1 STRATOS</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td></td>
</tr>
<tr>
<td>12</td>
<td>DM</td>
<td>4 STRATOS</td>
<td>LD mobilization</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>13</td>
<td>DM</td>
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<td>14</td>
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</tr>
<tr>
<td>15</td>
<td>DM + V</td>
<td>3 STRATOS</td>
<td>PM mobilization</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>16</td>
<td>DM + V</td>
<td>3 STRATOS</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>17</td>
<td>DM</td>
<td>1 STRATOS</td>
<td>PM mobilization + GO</td>
<td>Postoperative infection, postoperative skin necrosis (2/1 cm) and infection</td>
<td>-</td>
<td>-</td>
<td>(i) Staphylococcus epidermidis methy-R, (ii) no bacteria, (iii) Staphylococcus epidermidis, Enterococcus, (ii) no bacteria</td>
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<tr>
<td>18</td>
<td>DM + V</td>
<td>2 STRATOS</td>
<td>Skin advancement</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
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<td>LD mobilization</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>DM</td>
<td>3 STRATOS</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>DM</td>
<td>4 STRATOS</td>
<td>RA</td>
<td>Preoperative local infection and necrosis (9/4 cm), postoperative skin necrosis (1/1 cm)</td>
<td>-</td>
<td>-</td>
<td>(i) Proteus mirabilis, Klebsiella oxytoca, Streptococcus mili, Corynebacterium, (ii) no bacteria</td>
</tr>
<tr>
<td>22</td>
<td>DM</td>
<td>4 STRATOS</td>
<td>LD</td>
<td>Preoperative infection and necrosis (11/7 cm)</td>
<td>-</td>
<td>-</td>
<td>(i) Escherichia coli, proteus mirabilis</td>
</tr>
<tr>
<td>23</td>
<td>XCM</td>
<td>1 STRATOS</td>
<td>-</td>
<td>Preoperative pulmonary infection</td>
<td>-</td>
<td>-</td>
<td>(i) No bacteria, (ii) Escherichia coli</td>
</tr>
<tr>
<td>24</td>
<td>DM</td>
<td>1 STRATOS</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>GT</td>
<td>2 STRATOS</td>
<td>PM mobilization</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>GT</td>
<td>2 STRATOS</td>
<td>LD + serratus</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>GT</td>
<td>3 STRATOS</td>
<td>PM mobilization</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>GT</td>
<td>3 STRATOS</td>
<td>LD</td>
<td>Late rupture</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>DM + V</td>
<td>4 STRATOS</td>
<td>PM mobilization</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>DM</td>
<td>2 STRATOS</td>
<td>LD</td>
<td>Late rupture</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>GT</td>
<td>1 STRATOS</td>
<td>PM mobilization</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
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</table>

DM: Dualmesh 2 mm thickness; GO: great omentum; GT: classical gore tex; LD: latisimus dorsi; PM: pectoralis major; RA: rectus abdominis; STRATOS: Strasbourg Thoracic Osteosynthesis System; V: vicryl mesh; VEPTR: vertical expandable prosthetic titanium rib; XCM: XCM biologic tissue matrix.
margins. We decided to respect a 3 cm limit of macroscopic healthy tissue wherever possible for bone resection. The intercostal spaces located above and below the macroscopic limits of the disease were always removed. Resection of tumours localized in the costovertebral gutter involved the systematic resection of the transverse process and the vertebral insertion of the ribs. A larger vertebral resection was carried out in cases where RMN showed obvious signs of invasion of the vertebral column. This surgical strategy has led us to perform numerous wide resections of the chest wall. Weyant et al. [1] presented the results of chest wall resection and reconstruction from a large series reporting a 3.8% operative mortality rate and a 3.1% rate of respiratory failure. The median defect size was 80 cm² and the median number of resected ribs was 3 [1–8]. According to a multivariate analysis, the size of the chest wall defect was the most significant predictor of complications in this series.

The main physiological explanations for respiratory failure after major chest wall resection is based on the Thoracic Insufficiency Syndrome (TIS) usually described in adolescents or children with severe scoliosis. The musculoskeletal thorax is a 3D structure that expands the lungs through increasing the volume of the thorax by contracting the diaphragm and expanding the rib cage. When this respiratory musculoskeletal pump cannot provide passive circumferential support for the lungs then TIS develops [5]. It follows that very large chest wall resections, with or without lung resection, can cause an acute restrictive lung disease because the thoracic mechanism of respiration may be compromised in the early postoperative period. The importance of the reconstruction of the thoracic wall is emphasized by the lack of any significant difference observed by comparing the lung function failure rates after large chest wall resection with and without pulmonary resection [6]. The quality of the chest wall reconstruction is thus a strong determining factor in the events occurring in the postoperative period. According to Lardinois et al. [7], the reconstruction must be performed in a ‘one-step procedure’ at the same time as the tumour resection to favour an early extubation of the patient. Several authors [1, 2] have stressed the mortality risk related to the combination of a chest wall resection and pneumonectomy. Wahi et al. [8] reported the specific type of surgical resection as an independent risk factor for mortality. A 3-fold increase in mortality was noticed when comparing standard pneumonectomy and pneumonectomy associated with chest wall resection. Weyant et al. [1] reported a small number of patients undergoing pneumonectomy combined with chest wall resection (n = 9) with a mortality rate of 44% compared with the global mortality rate of 3.8% in this series of 262 patients. In our series, three patients (3, 16 and 24) underwent pneumonectomy combined with chest wall resection including one case of completion pneumonectomy. Patient 3 was the only patient within our study who experienced an early fatal respiratory failure and the two others required a prolonged stay in the intensive care unit. Weyant et al. concluded that pneumonectomy plus chest wall resection should be performed only in highly selected patients. These findings are concordant with our study.

One of the key principles of the chest reconstruction is the restitution of a thoracic volume sufficient to ensure an early proper lung expansion [9]. The general rules of reconstruction of the chest wall are consensual [10]; however, it is important to note that several other factors should be considered: the level of the defect, the number of ribs resected (more than the length of the resection), the degree of sternal resection, the resection of surrounding tissues (lung, main vessels, vertebral body, and

Figure 3: Infection in the surgical site. As an example: patient 17. (A) Chondrosarcoma of the sternum. (B) The patient experienced an infection in the surgical site: fluid collections around the Dualmesh and the Stratos bars. (C) Operative view of the infected implants. There is obvious pus on the Dualmesh and in contact with the Stratos bars. (D) The patient was treated by ablation of the Dualmesh keeping in place the titanium bars. This procedure was combined with a great omentum flap after an intensive cleaning of the surgical area in a one-step procedure. (E) The postoperative course was uneventful, and the CT scan shows the greater omentum flap in place surrounding the Stratos bars. Fluid collections and gas bubbles have disappeared. Polynuclear scintigraphy showed no evidence of infection around the surgical area 6 months after the second surgical procedure.
diaphragm) and any associated disease (heart failure, contralateral lung disease).

There is a consensus that there is no indication in reconstructing the defects of less than 5 cm regardless of topography and that posterior defects are reconstructed only when they are larger than 10 cm. Deschamps et al. [2] found no correlation between the choice of prosthetic material, generally related to habits of a surgical team, and the complication rate. Debate continues regarding the non-rigid or rigid nature of the skeletal reconstruction. The general consensus, however, is that a two-rib segmental chest wall resection requires soft tissue coverage alone and a non-rigid prosthesis may be sufficient to reconstruct subtotal sternectomies and posterior defects [11]. In contrast, large anterolateral chest wall defects and complete sternectomies require rigid reconstruction. Our experience is not fully in agreement with Arnold and Pairolero [12] who suggested that most patients can tolerate sternectomy or resection of four to six ribs without rigid reconstruction and without experiencing respiratory insufficiency. Historically [13], the technique that satisfied the requirements for rigidity, protection and chest wall shaping was a sandwich consisting of two sheets of marlex mesh and containing a thick layer of MM. Many reports [14] underline the drawbacks of the MM sandwich citing technical difficulties, time-consuming surgery, need for experienced hands and numerous postoperative local complications (dead parietal space, early fractures, infection, extrusion). The availability of new materials combined with such complications relating to the use of the MM sandwich has changed the common indications for chest wall reconstruction.

In a previous report [15], we described TIS in 26% of patients operated on from 1995 to 2006 because the use of single PTFE mesh combined with muscle flap in very large chest wall defects requiring rigid reconstruction only provided 2D reconstruction. Since 2006, we have been using titanium bars combined with strong mesh as modern rigid implants to reconstruct full thickness chest wall defects. While metal plates are reported to be responsible for lung injury [16], their association with a strong mesh that is placed under the titanium plates ensures the protection of the lungs and tissue affinity. Dualmesh is made up entirely of ePTFE and has two distinct surfaces: the smoother surface is designed for minimal tissue attachment, and the indented surface to facilitate a high degree of adhesion with the surrounding tissues. The most common problem encountered after reconstruction using synthetic implants is the development of a seroma. Deschamps et al. [2] demonstrated that the use of PTFE to reconstruct the chest wall did not reduce the rate of local complications such as seroma or infection. In our study, we used numerous large chest drains with negative pressure to prevent fluid collection. Although our study is a limited retrospective study, we have made a favourable assessment of the biocompatibility of the Dualmesh combined with titanium plates. We used Dualmesh in 25 cases and standard GoreTex mesh in 5 others. We observed no significant difference in the local wound outcome between these two groups.

The use of titanium bars has been previously described for sternal reconstruction after sternectomy [17] or dehiscence of the sternum. Compared with other implants, titanium is corrosion-free, chemically inert and quickly and precisely adaptable to the shape of the thoracic wall. Titanium can be imaged safely with both CT-scan and magnetic resonance imaging, and therefore it does not affect the oncological follow-up. We encountered no difficulty to adapt STRATOS to many anatomical situations, and the shape of the pliers allowed us to minimize the skin incision. A rupture of the thoracic osteosynthesis system can occur (four cases in our series) at the junction between the native rib, which can bow along with the motion of the thoracic wall, and the rigid materials which are under strong loads throughout respiration. In our study, the rupture rate was low probably because of the flexibility and the strength of titanium. In addition, the use of multiple implants in cases of large chest wall defects (one implant to replace 2.26 ribs) and the association of a strong mesh may harmoniously divide and distribute the forces of the respiratory movements across the chest wall.

We treated a case of large posterolateral full thickness defect associated with four vertebral body resections by the implantation of a titanium vertical thoracic osteosynthesis system (VEPTR) [18]. Stable thoracic wall repair was possible thanks to the VEPTR, however, according to the Campbell et al. [5], several clinical situations are not compatible with VEPTR implantation: absence of disease-free ribs for proximal attachment, body weight below the 25th percentile and active pulmonary infection.

Chest wall reconstruction in the presence of infected CWT or NSCLC is a potentially complex devastating situation as is the postoperative infection of the surgical wound and implanted devices after major chest wall reconstruction. This last complication is described as occurring in 5–10% of patients in the literature [2]. Traditional surgical teaching advocates the removal of all the potential sources of infection (removal of all synthetic materials) and the stabilization of the chest wall in cases of deep wound infection after chest wall reconstruction. In the case of chest wall reconstruction in contaminated fields (infected CWT or NSCLC), it is recommended to reconstruct the thoracic wall using only biological material. However, the stabilization of the chest wall may not be only achieved by the use of biological material in the event of wide chest wall defects.

In our study, we performed three chest wall reconstructions despite the presence of active local soft tissue infection (patients 8, 21 and 22) (Fig. 2B and D), all cases of primary or secondary infected CWT. None of the three patients experienced a postoperative infection of the thoracic wound. We also performed two reconstructions in the presence of a large necrotic and infected NSCLC (patients 3 and 23). Patient 3 suffered a deep infection of the thoracic reconstruction.

Among the 31 patients, we noted four local complications, three of which were infection during the postoperative period. A limited cutaneous necrosis was treated by local wound care as well as a case of superficial infection. Both cases of deep operative wound infections were treated by a systematic wound debridement and excision of all wound edges, including skin, subcutaneous tissue and any necrotic appearing tissue until healthy bleeding tissue was visible. Concerning the mesh and the osteosynthesis system, we removed the Dualmesh in both cases of deep operative wound infection and we removed the STRATOS in one out of the two.

The titanium bar was removed in one case and put back in place secondarily. The patient died after 68 days in the intensive care unit because of a late respiratory failure. Such prompt removal of the entire synthetic material was recommended by Voss et al. [19] in four cases of sternal non-union associated with a confirmed deep wound infection. Once the wound was germ free (after a median of 13 days), the author did perform sternal titanium osteosynthesis. During follow-up, they noticed a stable and non-infected sternum 8 months postoperatively. In our experience, the situation was different since the removal of the osteosynthesis material involves great difficulties in weaning
the patient off mechanical ventilation because of the size of the chest wall defect.

In the second case, we decided to restabilize the chest wall in a one-step procedure to prevent respiratory distress by using a flap of greater omentum and preserving the titanium osteosynthesis system (Fig. 3A–E). The postoperative course was uneventful and polymeric scintigraphy showed no evidence of infection around the surgical area 6 months after the reoperation. According to Gaudreau et al. [20], one-step titanium sternal osteosynthesis in the treatment of deep sternal wound infection allows early extubation, a decrease in sternal pain and a decreased incidence of paradoxical chest-wall breathing. In one review, Van Wingerden et al. [21] stress the value of a greater omentum flap in deep sternal infections compared with the muscle flap since in cases of infection, while the muscle flaps are able to fill the dead space where bacterial contamination might take place, their properties of neo-vascularization and absorbing exudates, which the omentum has, have not been sufficiently proven. Contrary to Contant et al. [22], we believe that pedicled omentoplasty combined with non-absorbable implants (i.e. titanium implants) can successfully be used for chest wall reconstruction in an infected area.

Finally, in our experience, thoracic immediate titanium rib osteosynthesis in patients for whom the presence of a contaminated field was found prior to surgery (for which careful cleaning of the surgical area and multiple drainage was performed) allowed a satisfactory postoperative course. We have also shown that removal of the titanium bars does not seem to be mandatory in cases of infection after chest wall reconstruction. The generally accepted notion that ‘deep infection of thoracic reconstruction requires hardware removal’ should perhaps be re-examined when titanium has been used.

The surgical site of infection in case 3 prompted us to change our therapeutic approach in the management of another patient (patient 23) who had a large infected T3-NSCLC invading the chest wall. Several materials with properties of rapid integration into surrounding tissues and resistance to infection are available. To prevent surgical site infection, we used XCM biologic tissue matrix as a mesh. This is a strong biologic implant of consistent thickness and without any orientation that is usually applied in plastic surgery and abdominal reconstructive procedures [23]. Experimental studies have shown good levels of integration with the surrounding tissue at 6 weeks.

CONCLUSION

Our experience and initial results indicate that horizontal titanium rib osteosynthesis combined with strong mesh simplifies reconstruction when compared with previous reconstruction techniques that involve rigid reconstruction. This type of one-step rigid reconstruction of the chest wall could be performed safely with low morbidity rates but is not indicated after large posterior resections. Our clinical experience indicates the reliability of the titanium rib osteosynthesis after resection of an infected CWT or T3/T4 NSCLC or in cases of secondary infection of the chest wall reconstruction. The synthetic or biological material to use in combination with titanium in these indications remains undetermined.

Conflict of interest: none declared.

REFERENCES

APPENDIX. CONFERENCE DISCUSSION

Dr K. Papagiannopoulos (Leeds, UK): Do you find any difference in the symptomatology of these patients when you do large defects of the lateral chest wall compared to the anterior part of the chest? Because I have found myself that when you resect large defects on the lateral chest wall, people tolerate them better, while if you take their anterior chest plate away and you put a lot of metalwork on, they sometimes do have a heavy feeling in the chest.

Dr Berthet: We don’t find any great difference between the anterior and the lateral chest wall defects. I think the main problem is the size of the chest wall defects. We had so many paradoxical motions of the chest wall in the first period when we only used Gore-Tex mesh in the anterior chest wall and the lateral chest wall defects. I think the main difference is in the anterolateral defects compared with posterior defects.

Dr A. Chapelier (Suresnes, France): So, Jean-Philippe Berthet, may I ask you to give more details on the two cases of wound infections you observed in this quite large experience?

Dr Berthet: Well, we had two infectious processes which required extraction of the thoracic osteosynthesis system in one case. In both cases we extracted the PTFE mesh, but in one patient we also extracted the titanium plates on the tenth postoperative day. And in these patients, after the cleaning of the large chest wall anterior defects, we performed another osteosynthesis using titanium combined with a large omental flap. In the other case, we only removed the PTFE mesh and we kept the titanium plates in place. With antibiotics and the current ICU management, we have a good follow-up, a good outcome in these two patients.

Dr K. Diemel (Hamburg, Germany): I have just one comment, also regarding the infection problem. Our experience is that in some patients, too, with a PTFE membrane we had to remove it, and have now completely changed to bovine pericardium, which in most cases does not require removal of the material in infections. And my question concerns your drainage management. Do you place tubes above and under the PTFE membrane to prevent seromas, which might be an infectious source?

Dr Berthet: We use many chest tubes in the thoracic cavity and above and under the PTFE mesh to avoid a seroma. And you are right, finding a seroma during the early follow-up is a problem. This is the beginning of the infectious process. So we insert four chest tubes at least, two in the thoracic cavity and two for the chest wall reconstruction.

Dr Chapelier: A last comment. You mentioned difficulty in fixing the STRATOS at the back part of the rib when the field concerned is a costal transverse process. Do you think there is a need for reconstruction in this posterior part of the chest wall?

Dr Berthet: Well, that is a problem and it is controversial, I think. In our experience, we fix and we will reconstruct posterior defects when they are very large. We are concerned about the incarceration of the tip of the scapula. We did discuss that, and some surgical teams usually cut the tip of the scapula to avoid its imprisonment in the chest cavity. In one slide, I showed incarceration of the entire scapula in the thorax, inducing a restrictive process, a restrictive insufficiency syndrome. So, yes, we will reconstruct large defects of the posterior chest wall.

And when we had two cases of large posterior chest wall defects in which we could not choose the horizontal titanium osteosynthesis system, on one occasion we used another device, which is a vertical osteosynthesis system, usually used for children in thoracic insufficiency syndrome. This is a VEPTR, which is a vertical osteosynthesis, and is locked on the rib above and under the defect.