Experience with titanium devices for rib fixation and coverage of chest wall defects

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Abstract

OBJECTIVES: To describe our experience with two new titanium-based devices for chest wall reconstruction and stabilization.

METHODS: A retrospective analysis of 18 consecutive patients (multiple rib fractures n = 9, iatrogenic rib fracture n = 2, lung herniation n = 2, chest wall tumour n = 5) who underwent surgery for rib fractures or chest wall tumours requiring chest wall resection and reconstruction between October 2010 and March 2012 was conducted. Chest wall defects and rib fractures were fixed with titanium clips and bars or titanium plates and screws through a posterolateral thoracotomy.

RESULTS: There were 12 males, and the median age was 61 years. There were no postoperative deaths. The only postoperative complication observed was a pleural effusion requiring drainage in one patient who had titanium clips for the fixation of multiple traumatic rib fractures. Median length of stay of the drain and median length of hospital stay were 3 days (range 1–6) and 4 days (range 2–42 days), respectively. The average follow-up period of operatively managed patients was 6 months, (range 2–14 months). Two cases of hardware failure occurred in two patients treated for a lung hernia with large chest wall defects involving the anterior costal margin with either devices.

CONCLUSIONS: Titanium devices (clips and bars; screws and plates) are effective and safe for repair of rib fractures and large chest wall defect reconstruction with minimal complications and good long-term results.

Keywords: Chest wall tumour • Chest wall trauma • Chest wall fixation • Chest wall reconstruction

INTRODUCTION

The integrity of the chest wall musculoskeletal structure is important for normal physiological respiratory function. In the setting of trauma, rib fractures and lung contusion are often the cause of acute respiratory insufficiency [1]. Flail segments from multiple rib fractures compound the problem and are responsible for significant morbidity and mortality. Mal-union of old rib fractures is a painful condition that can be adequately addressed by rib fixation.

Large chest wall defects from resection of primary or secondary chest wall tumours can be challenging to reconstruct. Various skeletal reconstructive materials have been described with or without soft tissue coverage. They are all based on using a combination of a rigid structure (bars, screws and plates, methylmethacrylate cement) and a patch [expanded polytetrafluoroethylene (PTFE), polypropylene, acellular collagen matrix or autologous soft tissue] [2–7].

The use of titanium bars, plates and screws has increased recently in the fixation of rib fractures as well as the reconstruction of chest wall defects following the resection of tumours involving the chest wall [2–4, 7]. The Strasbourg thoracic osteosynthesis system, Stratos (MedXpert GmbH, Germany) is based on titanium clips and bars and the vertical expandable prosthetic titanium rib system. Synthes® (Solothurn, Switzerland) is a system based on titanium plates and screws.

The aim of this study was to describe our preliminary experience with these two new titanium devices with Veritas acellular collagen matrix (Veritas® Collagen Matrix, Synovis Surgical Innovations, St Paul, MN, USA) where appropriate for chest wall reconstruction and rib stabilization and to discuss our indications, our postoperative complications and long-term complications.

MATERIALS AND METHODS

This is a retrospective series of 18 consecutive patients who underwent rib fixation or chest wall reconstruction with new titanium fixation system (Stratos and Synthes) between October 2010 and March 2012. A combination of the titanium device and the Veritas patch was used to reconstruct large chest wall defects following the resection of three or more ribs.

All patients had a chest computed tomography (CT) scan to ascertain the extent of the trauma and the chest wall invasion in case of cancer. Patients with chest wall tumours in addition had...
a CT abdomen and pelvis, as well as positron emission tomography/CT scan to screen for regional and distal metastases. All patients had a full preoperative evaluation including a thorough history, physical examination and routine haematological and biochemical blood tests. Individual patient consent was obtained for each of the cases.

All operations were performed under general anaesthesia. The surgical access was a posterolateral thoracotomy; the extension and the location varied according to the locations of the tumour or the rib fractures. We avoided the use of accessory thoracotomies in order to minimize surgical trauma and pain. In patients with trauma, all the fractured ribs were stabilized, and the pleural cavity was always opened to check for any bleeding and to remove the fluid or the clots. If no effusion was present on preoperative imaging or perioperatively, a small redivac drain was used. In case of effusion or lung injury, a 28Fr inter-costal drain was inserted.

The titanium device in the Stratos system consists of clips that are crimped onto the edges of the resected ribs anteriorly and posteriorly using special pliers. It is very important that the clips are adherent for all their surfaces to the ribs. A connecting bar measured and cut to the length of the defect is then inserted to the medial ends of the clips and crimped firmly to re-establish chest wall rigidity (Figs 1a and 2). The bars can be bent and moulded according to the thoracic shape. The Synthes system consists of titanium screws and plates that we only used to fix rib fractures (Figs 1b and c). The appropriately sized plate is selected during the operation such that there are at least two screws on either side of the fracture (Fig. 3c and d). Any excess callous is filed down or resected, and the periosteum is elevated before the plate is placed on the rib and secured with screws. To achieve adequate stability, the titanium devices are fixed on the ribs for at least 3–5 cm on either side of the defect or fracture. Both titanium systems can only work when attached to ribs and are therefore not suitable for posterior defects involving the spine. Also, Stratos clips only come in one size and are not suitable for very small or very large ribs. A Veritas patch is used to protect intrathoracic structures underneath the titanium devices. The soft tissue covering the defect is completed by reattaching divided muscle and fat layers with absorbable sutures. One chest drain was inserted in the pleural space.

The indications for the intraoperative utilization of these devices were: chest trauma with multiple rib fractures and flail chest that required stabilization (n = 6), mal-union of rib fractures and chronic persistent pain (n = 3), lung herniation (n = 2), iatrogenic rib fractures during thoracotomy (n = 2) and chest wall primary or secondary tumours that required extensive chest wall resection and reconstruction (n = 5) (≥3 ribs). Surgery for rib fractures was undertaken after failed conservative management with persistent pain, mobile rib fractures and alteration of normal anatomy of thoracic cavity in three patients, concomitant hemothorax in two patients and flail chest with failed weaning off the ventilator in one patient.

Rib fixation for fractures sustained at thoracotomy was undertaken for double fractures with a ‘flail’ fragment of rib that was unattached and could not be adequately immobilized with peri-costal sutures. All fractured ribs were fixed in order to improve the stability of the chest wall and re-establish the normal breathing mechanism.

In patients who underwent chest wall resection for a tumour, all the resected ribs were substituted with the titanium device. The defect was covered with a Veritas patch.

Lung herniation was managed with the titanium device and patch in order to minimize the size of the gap in the chest wall, hence reducing the risk of recurrence of the hernia. Both Synthes and Stratos were used in the management of lung hernias, which were caused by defects in the chest wall involving the anterior costal margin.

![Figure 1: Stratos system. (a) Titanium bars and clips. (b and c) The titanium plates and it shows the final result with the plate in place and stabilized with the screws.](https://academic.oup.com/icvts/article-abstract/15/4/588/650450)
Chest wall tumours were resected with a margin of at least 5 cm and the chest wall was reconstructed using a Veritas patch and titanium device. A Veritas patch was used with Titanium bars when the defect in the chest wall was larger than 6 cm or ≥3 ribs were resected. The patch was fashioned to fit the defect in the chest wall and then anchored onto the edges of the defect with multiple interrupted non-absorbable pericostal sutures under tension.

In one case of rib fracture with malunion and a large chest wall defect, we used a Gore-tex patch (GORE-TEX® Soft Tissue Patch, W. L. Gore & Associates, Newark, DE) due to the tension and absence of adequate muscular soft tissue coverage (Fig. 3a and b).

Individual patient data were obtained from case notes and operation notes as well as a prospectively collected surgical database. Continuous data are reported with medians and ranges.
while categorical data are reported with counts and percentages. Patient characteristics are reported in Table 1.

**RESULTS**

Between October 2010 and March 2012, a total of 18 patients underwent chest wall reconstruction or rib stabilization and were included in this study. The two groups were homogeneous in terms of demographic characteristics. The characteristics of the two groups are summarized in Table 1.

Table 2 summarizes the operative indications and postoperative course of all patients. Two patients were operated on for lung herniation after spontaneous rib fracture from severe bouts of cough (Fig. 4a and b). One patient presented with a right-sided anterior chest wall defect and the other with a left-sided chest wall defect. One lung hernia was repaired using Stratos clips to fix the fracture and the anterior costal margin and a Veritas patch to close the gap between the ribs. The other was repaired using a Synthes plate to repair the rib fractures and a Veritas patch to close the gap between the ribs. Both patients did not experience any postoperative complications and were discharged after 3 days. The patient treated with Stratos experienced a recurrence 4 months later, and the chest wall was repaired with Stratos and gore-tex mesh to reinforce the defect again. After the second repair, he has not experienced any further recurrence 1 year after the procedure and remains asymptomatic. The other patient with a hernia repaired with Synthes experienced a recurrence after 2 months. Unfortunately, he developed an unrelated myocardial infarction before reoperation, and his surgery was postponed because he was still on double platelet antiaggregation treatment.

Nine patients were operated on for a chest trauma with multiple rib fractures. Four patients were operated on with Stratos and five with Synthes (Figs 4c and d).

In the Stratos group, the rib fractures were fixed using clips only in two patients and clips and bars in the other two. Three patients experienced chest trauma with multiple rib fractures (n = 6, n = 5 and n = 3, respectively) that required a fixation. One patient experienced the trauma more than 1 year before being referred. On the chest CT scan, there was a single mal-united fracture with a defect of the anterior chest wall (Fig. 4c and d). In this patient, the mal-united segment of the rib was resected and stabilized using two clips and a bar, and the defect of the chest wall was corrected using a gore-tex mesh and a wire to stabilize the anterior costal margin (Fig. 3a and b). One patient experienced a contralateral effusion that required a simple drainage. She had suffered chest trauma with multiple rib fractures and flail chest on the right side with bilateral contusion and atelectasis. Rib fixation facilitated subsequent weaning of the patient off the ventilator. She also had multiple other injuries and fractures that were fixed by the orthopaedics team and was discharged after 42 days. The other three patients were discharged home after 4, 4 and 7 days, respectively, without complications. At the follow-up, all patients were clinically stable, with no pain and all of them went back to normal physical activity post-trauma in 2 months.

In the Synthes group, all five patients suffered thoracic trauma. Two patients required the fixation of three broken ribs, and three of one rib. Two of them presented after 2 months with chronic pain, which required the use of modified-release morphine twice a day and chest wall shape alteration. The pain was affecting their work and recreational activities. None of the patients experienced postoperative complications. The median hospital stay was 3 days (1–6 days). Following surgery, four patients were weaned off morphine within a month of the operation and were able to resume work. During the follow-up, one of the patients still had significant pain, which affected his normal activity and required morphine medication (20–40 mg a day) 7 months after surgery.

### Table 1: Characteristics of the study population (n = 18)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Synthes (n = 6)</th>
<th>Stratos (n = 12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (M:F)</td>
<td>3:3</td>
<td>9:3</td>
</tr>
<tr>
<td>Age (years) [median (range)]</td>
<td>58 (21–72)</td>
<td>67.5 (35–79)</td>
</tr>
<tr>
<td>Side (R:L)</td>
<td>2.4</td>
<td>7.4</td>
</tr>
<tr>
<td>Length of stay of the drain [days] [median (range)]</td>
<td>2 (1–3)</td>
<td>2 (0–21)</td>
</tr>
<tr>
<td>Length of hospital stay [days] [median (range)]</td>
<td>3 (1–6)</td>
<td>4 (2–42)</td>
</tr>
<tr>
<td>Follow-up (months) [median (range)]</td>
<td>4.2 (2–7.5)</td>
<td>5.4 (2.2–14)</td>
</tr>
<tr>
<td>Complication</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

### Table 2: Summary of indications for surgery with intraoperative and postoperative details

<table>
<thead>
<tr>
<th>Indication</th>
<th>Operating time min (range)</th>
<th>Blood loss ml</th>
<th>Length of drainage median (range)</th>
<th>Length of hospital stay</th>
<th>Postoperative complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest trauma</td>
<td>120–160</td>
<td>600*</td>
<td>2 (0–8)</td>
<td>4 (1–42)</td>
<td>Contralateral pleural effusion*</td>
</tr>
<tr>
<td>Tumour involving chest wall</td>
<td>140–190</td>
<td>200</td>
<td>2 (1–14)*</td>
<td>4 (2–10)</td>
<td>Surgical emphysema*</td>
</tr>
<tr>
<td>Lung herniation</td>
<td>110</td>
<td>100</td>
<td>1.5</td>
<td>3</td>
<td>No</td>
</tr>
<tr>
<td>Iatrogenic trauma*</td>
<td>10*</td>
<td>50</td>
<td>18</td>
<td>14–31</td>
<td>No</td>
</tr>
</tbody>
</table>

*Two patients had haemothorax with 1 and 1.5 litres of blood already present at the time of the operation.  
*Patient with bilateral chest trauma and bilateral lung contusion.  
*Patient with persistent air leakage after lobectomy and chest wall resection.  
*Patient managed conservatively.  
*The fixation required an extra 10 min. Both patients developed complications related to their underlying condition, mesothelioma and lung cancer, in order to minimize the pain and improve their recovery and mobilization, both had rib fractures fixed.
Two patients had Stratos clips to fix iatrogenic rib fractures during surgery. The first patient had a rib fracture during a pleurectomy decortication for mesothelioma. The second patient experienced a rib fracture during a posterolateral thoracotomy and lower lobectomy for non-small-cell lung cancer. Both patients presented with intraoperative complications: bleeding
during decortication and respiratory failure in the lung cancer patient. In order to improve their recovery, we fixed the rib fractures using Stratos devices. The first patient was discharged home after 10 days with a drain in situ for a persistent air leakage without pain. The drain was removed a week later and he is now receiving radiotherapy and chemotherapy and is pain free. The second patient developed postoperative respiratory failure requiring intubation and prolonged ventilation. He was discharged after 30 days, having come off morphine 6 days after the operation. He is pain-free and only takes paracetamol occasionally.

The last group of patients consists of those who underwent a chest wall resection for a primary chest wall tumour or for a tumour involving the chest wall. All five patients were treated with Stratos. One patient had a neuroendocrine tumour infiltrating the manubrium, which was resected and reconstructed using a titanium Stratos bar and a Veritas patch. This patient had the manubrium resected and the defect bridged with Stratos clips fixed on the second and third ribs bilaterally and connecting bars. Another patient had a resection of the third rib for a single osteolytic lesion; the final histopathology was a mastocytoma of the third rib; in this patient no mesh was used, because only one rib was resected. The other three patients had a chondrosarcoma grade II involving the 8th, 9th and 10th ribs, a single chest wall metastasis from a renal cancer previously completely resected involving the 5th, 6th and 7th ribs (Fig. 6a and b), and a right upper lobe non-small-cell lung cancer involving the 3rd and 4th ribs, respectively (Fig. 6c and d). All these four patients had a Veritas patch. The median length of stay of the drain was 2 days (range 1–10) and the hospital stay 4 days (range 2–10). The patient with the third rib resected developed surgical emphysema post-drain removal, which was managed conservatively; it was completely resolved after 1 week. After right upper lobectomy and chest wall resection, one patient was discharged home with the drain for a persistent air leakage. The drain was removed in the clinic 4 days later. A repeat chest CT at 1 month in these patients did not show any collection around the chest wall reconstruction.

**DISCUSSION**

The fixation of rib fractures is indicated in case of flail chest, concomitant lung lesion, serious alteration of the chest shape and persistent and chronic pain that affects normal life.

The resection of chest wall tumours necessitates clear margins to ensure complete resection. In cases where this involves more than three ribs or ~5 cm, there is consensus that reconstruction is needed to cover the defect [2, 8]. The main purpose of chest wall reconstruction is 2-fold. Firstly, to re-establish a rigid structure to protect intrathoracic and mediastinal structures from damage and/or herniation. Secondly, to restore chest wall mechanics and avoid paradoxical movement during breathing, which is essential for normal respiratory function [2, 9, 10]. Since their advent in the 1980s, the use of prosthetic materials such as PTFE, polypropylene mesh (PPM) and PPM–methylmethacrylate composites for chest wall reconstruction has been described in large series with good results [9–11]. Whereas these materials provide adequate coverage of the defects in the resected chest wall, they are often not able to restore the anatomical contouring of the chest wall because of the difficulty in moulding them precisely. In addition, they do not provide mechanical rib continuity to preserve the mechanics of breathing by active co-ordinated chest wall motion. This often results in loss of intrathoracic volume, impaired expansion of the chest and impingement of the rigid mesh–methylmethacrylate sandwich into soft tissue with resultant pain [2, 3].

In our experience, titanium prosthetic devices—be they Stratos clips and bars, or Synthes plates and screws—provide a lightweight but strong rigid support for rib fixation and chest wall

![Figure 6: Chest wall resection for cancer. (a) Preoperative chest CT shows a single metastasis of renal cancer involving the chest wall. (b) Postoperative chest X-ray shows the Stratos device in place. (c) Preoperative chest CT shows a non-small-cell lung cancer invading the chest wall (pT3N0). (d) Postoperative chest X-ray shows good lung re-expansion after upper lobectomy and correction of the chest wall defect.](https://academic.oup.com/icvts/article-abstract/15/4/588/650450)
reconstruction. The advantages of these systems relate firstly to the properties of the titanium material, which has a high strength-to-weight ratio, can integrate with bone, which further strengthens the reconstruction with time, resistance to infection and low interference with CT [12]. Secondly, these titanium devices closely ‘mimic’ the anatomic contour of the ribs that they replace, thus maintaining the shape of the chest wall. Moreover, the dynamic movements of Stratos bars have been shown to be synchronous to normal ribs [12]. The use of titanium Stratos bars in combination with biological (or other) patches, as previously reported by our group, is technically straightforward and well tolerated. Whether this offers any benefit over older techniques is unproven, but we believe that restoring mechanical rib continuity best preserves the mechanics of breathing, avoids the use of large semirigid polymer/cement prostheses, and is more comfortable in the long term.

For the reconstruction of large defects, we used a novel acellular collagen matrix (Veritas). Preparation of this matrix results in low levels of extractable DNA, but with a degree of immunogenicity that allows for host cell infiltration and remodelling [13]. This ensures that it provides good fascial support to surrounding autologous tissue and resists infections. Its use in abdominal surgery is established [13]. These properties were pivotal in persuading us to use it for coverage of the chest wall defects under-neath the titanium devices with good results. This matrix is substituted entirely by homologous fibrotic tissue, reducing the risk of infection mainly in patients at risk of neutropenia like cancer patients. The recurrence of lung herniation in the two patients treated with the Veritas patch perhaps reflects the significant tension from the defects involving the costal margin without adequate anchorage of the patch, making the latter unsuitable for this particular indication.

We believe that an extended thoracotomy is sufficient to fix and reconstruct the chest wall and have not needed to use accessory thoracotomies.

In our series, the Synthes system was used mainly for the fixation of rib fractures. In case of rib fractures, the excision of segments of mal-union ensured the removal of excess callous, which facilitates the fixation of the titanium plates flush with the rib surface with both devices. In case of trauma, the main indication to use either Synthes or Stratos was dictated by the dimension of the rib. At the moment, the Stratos clips only come in one size, and in broad ribs, they are very difficult to securely fix to the rib segments. In these cases, we opted for the Synthes bar, which can be adapted more easily in case of broad ribs.

In case of chest wall resection for cancer, we used Stratos because they can be moulded more precisely to the chest wall shape, and the clips have different angles, which facilitates the re-establishment of the chest wall shape and better cosmetic results.

With either device, the key technical point is ensuring that the fixation device is firmly held flush with the rib during fixation, using ratcheted clamps.

We did not experience any postoperative complications related to the use of these systems; we specifically did not have any infections of the prosthetic materials, or seroma. Reducing the risk of infection of the prosthetic material is very important in order to reduce the rate of reoperation and improve the quality of life after these operations.

In our series, only one patient, treated with Synthes, complained of chronic persistent chest pain that requires morphine tablets (20 mg twice a day) after 6 months and still affects his physical activity.

Fractures of titanium prostheses were experienced with both systems in lung herniation repair. These patients had large anterior chest wall defects involving the costal margin. The muscle coverage of this area is very poor. We believe that these devices are still a good option to fix anterior chest wall defects, but they need to be associated with other devices to reduce the tension and increase the stability of the area, like Gore-TEX mesh and wires.

This is a preliminary report on the cases in which one can use these systems with good long-term results. There is no published comparative study between Stratos and Synthes, and our data are too few for such a comparison. However, in our preliminary experience, either system seems effective. The authors believe that the reduced pericostal dissection required for the Synthes system may represent an advantage in trauma patients, although the technique required is a little more demanding.

In conclusion, we present here our initial experience with a novel system of chest wall reconstruction based on anatomically equivalent titanium-based devices with a biological matrix in a heterogeneous group of patients, which is a testament to the versatility of these devices. In our experience, there is evidence that these devices are safe, with an acceptable hospital morbidity and mortality. Further studies will need to be done with more patients to evaluate the long-term efficacy of these promising systems.

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Conflict of interest: none declared.

REFERENCES

options include implantation of vertical expandable prosthetic titanium rib (VEPTR) devices and serial lengthening of the sliding device to allow thoracic wall expansion [2-3].

First described in 1989, expansion thoracoplasty using a VEPTR device was applied in children with congenital scoliosis. Subsequently, the VEPTR device was successfully implanted in children with congenital chest wall defects, and was affixed to healthy ribs above and below the defect [3]. The VEPTR device was introduced to Europe in 2002 with excellent long-term results [4]. The advantage of this system is its ability to deal with the challenges of a growing child, other treatment modalities for paediatric chest wall defect such as methyl methacrylate have successfully fix the chest wall and yield good results in the short-term, however this leads to long-term chest wall asymmetry, growth failure and scoliosis.

In addition to the VEPTR device, some types of patch material are required to cover the large congenital defects of the chest cage. Initially, polytetrafluoroethylene was used, but this proved to be restrictive in the follow-up and required removal. Thus, a non-synthetic biodegradable patch material derived from porcine small intestinal submucosa was applied (Surgisis, Cook, Bloomington, IN) and showed to be a superior alternative to others synthetic patches [5].

The main drawbacks and hazards of complex chest wall reconstruction are the vast amount of hardware with its liability to untoward reactions, infection, and the difficulty of going back to the chest structures for any future surgical procedures. According to the literature [2-5], expansion thoracoplasty and VEPTR implantation are safe and efficient methods for the treatment of thoracic insufficiency syndrome in children.

Conflict of interest: none declared

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