European Journal of Cardio-thoracic Surgery 38 (2010) 39—45

EUROPEAN JOURNAL OF CARDIO-THORACIC SURGERY

www.elsevier.com/locate/ejcts

Malignant primary chest-wall tumours: techniques of reconstruction and survival☆

Alessandro Gonfiotti [a,*], Paolo Ferruccio Santini [a], Domenico Campanacci [b], Marco Innocenti [c], Sante Ferrarello [d], Adele Caldarella [e], Alberto Janni [a]

[a] Thoracic Surgery Unit, University Hospital Careggi, Viale Morgagni 1, Florence 50139, Italy
[b] Orthopaedic Oncology, University Hospital Careggi, Florence, Italy
[c] Plastic Surgery, University Hospital Careggi, Florence, Italy
[d] Service of Thoracic Anaesthesiology, University Hospital Careggi, Florence, Italy
[e] Department of Human Pathology and Oncology, University Hospital Careggi, Florence, Italy

Received 30 September 2009; received in revised form 4 December 2009; accepted 17 December 2009; Available online 24 February 2010

Abstract

Objectives: We analysed our experience in primary malignant chest-wall tumours (PMCWTs) with an emphasis on a new reconstruction technique and on survival. **Methods:** From 1998 to 2008, 41 patients (23 (56%) male, mean age 48 years) with PMCWT were operated in our unit: chondrosarcoma *n* = 25; osteosarcoma *n* = 8; Ewing's sarcoma *n* = 2; other *n* = 6. We performed nine sternectomies and 32 lateral chest-wall resections (median number of ribs resected = 3.5). Resections were extended to the lung (*n* = 2), diaphragm (*n* = 3), vertebral body (*n* = 3), scapula (*n* = 1) and upper limb (*n* = 1). Stability was obtained by a prosthetic material, rigid and non-rigid and a muscular flap. As non-rigid material, we mostly used a polytetrafluoroethylene patch (*n* = 24). In the past 2 years, two patients (one total sternectomy and one wide anterior chest-wall resection) were reconstructed with a rigid system composed of mouldable titanium connecting bars and rib clips (Strasbourg Thoracic Osteosyntheses System — STRATOS, MedXpert GMbH, Heitersheim, Germany). A muscular flap was added in 12 patients (29.3%). **Results:** There was no perioperative mortality or significant morbidity and all patients were extubated within first 24 h. At a mean follow-up of 60.5 months (range 4—130 months), the overall 5- and 10-year survival was 61% and 47%, respectively. In the chondrosarcoma group, 5- and 10-year survival was 80%. **Conclusions:** Wide resection with tumour-free margins is necessary in PMCWT to minimise local recurrence and to contribute to long-term survival. The STRATOS system, developed for chest-wall replacement, allows a firm reconstruction, simple to handle and to fix, avoiding instability or paradoxical movement also in wide chest-wall resections.

Keywords: Chest wall; Primary tumours; Chest-wall primary tumours; Surgery

1. Introduction

Primary malignant chest-wall tumours (PMCWTs) are a heterogeneous group of tumours developing in the bones and soft tissues of the thoracic cage. They are usually considered as a group because the diagnostic and therapeutic problems they pose are similar [1]. We retrospectively reviewed their pathological findings, surgical treatment and survival in our past 10 years' experience. We also show and discuss the role of a new rigid system for chest-wall reconstruction, consisting in mouldable titanium bars and rib clips (Strasbourg Thoracic Osteosyntheses System — STRATOS; MedXpert GmbH, Heitersheim, Germany).

2. Materials and methods

During the period 1998—2008, 41 patients (23 (56%) males and 18 (44%) females, ranging from 9 to 75 years, mean age 48 years) with PMCWT were diagnosed and treated by Thoracic Surgery Unit of the University Hospital Careggi in Florence. Diagnostic work-up included a standard chest X-ray and a thoracic computed tomography (CT) scan in all cases, to delineate the extent of the bone, soft tissue, pleural and mediastinal involvement. When appropriate, magnetic resonance (MR) was used (suspicion of spinal cord, mediastinal or thoracic outlet involvement). A complete work-up was undertaken in all cases to eliminate a disseminated disease. Where the histological diagnosis was not present at the time of our observation, we performed a core-needle aspiration or an excisional biopsy; fine-needle aspiration was not included in our diagnostic work-up. Most of our operations were planned and performed by a team composed of a thoracic surgeon, an orthopaedic oncologist and a plastic surgeon. Our

☆ Presented at the 23rd Annual Meeting of the European Association for Cardio-thoracic Surgery, Vienna, Austria, October 18—21, 2009.

* Corresponding author. Tel.: +39 0 55 7947935; fax: +39 0 55 7947935.
E-mail address: agonfiotti@hotmail.com (A. Gonfiotti).

1010-7940/$ — see front matter © 2010 European Association for Cardio-Thoracic Surgery. Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.ejcts.2009.12.046

surgical policy in treating PMCWT was, in general, as follows: skin incision included the site of the previous biopsy, the invaded skin or previously irradiated tissues; wide resection of a lateral PMCWT included the affected ribs with at least 3-cm free margin proximally and distally to the tumour and the adjacent portions of one normal rib above and below the lesion; the extent of surgery in sternal PMCWT (partial sternectomy, subtotal sternectomy or complete sternectomy) depended on the dimension and the location of the tumour and, in all cases, resection included the adjacent sternocostal cartilages on each side; tumour extension into the chest cavity was evaluated and any other structure involved in the tumour was also excised. Resection and reconstruction were performed as a one-stage procedure in all cases. Every effort was made to wean patients rapidly from the ventilator. The need to perform induction chemotherapy or postoperative chemotherapy and radiotherapy in the case of high-grade sarcomas was discussed and planned with the medical oncologist and the radiotherapist in an oncological multidisciplinary group: as result of this, induction chemotherapy was performed in five patients (12%), adjuvant chemotherapy in 10 patients (24%) and radiation therapy was given to five (12%). Survival was calculated from the date of operation to death or date of last follow-up for those patients who survived, and estimated by the Kaplan—Meier product-limit method.

2.1. Extent of resection

We performed 32 lateral chest-wall resections (78%) with a mean number of 3.5 ribs resected (range 1—6) and nine sternectomies (22%). Partial sternectomy (defined as resection less than 90% of longitudinal diameter) was performed in five cases: lesions at the middle third underwent resection of the body and preservation of the manubrium and the xiphoid process ($n = 3$); lesions of the upper third were treated with resection of the manubrium, the medial ends of the clavicles and portion of the sternal body ($n = 2$); one of these was a radio-induced sarcoma (RIS) and the associated invasion of the thoracic outlet required a transcervical thoracic approach. A subtotal sternectomy, defined as resection $\geq$90% of the longitudinal diameter of the sternum, was performed in three cases for large lesions of the sternal body: in one case, sparing the uppermost 1 cm of the manubrium and clavicles, and in two cases sparing the xiphoid and the lower 1 cm of the sternal body. One total sternectomy was performed in a 65-year-old woman with a wide chondrosarcoma of the sternal body that also infiltrated the manubrium. Resections were extended to the lung in two patients, the diaphragm in three, the vertebral body in three, the scapula in one and the upper limb in one. In every case, care was paid during resection to spare unaffected muscles such as the latissimus dorsi (LD) and the lateral part of the pectoralis major (PM), both commonly used for reconstruction.

2.2. Chest-wall reconstruction

Chest-wall reconstruction was carried out with prosthetic material in 29 patients (71%): non-rigid $n = 26$ (90%) and rigid $n = 3$ (10%). As non-rigid prostheses in 24 cases, we used a 2-mm expanded polytetrafluoroethylene (ePTFE) patch (Gore Dualmesh Plus, W.L. Gore & Associates, Flagstaff, AZ, USA), a prosthetic biomaterial combined with two antimicrobial preservative agents (chlorhexidine diacetate and silver carbonate, both active against Gram-positive and Gram-negative organisms) and also provided of a smooth visceral surface to minimise adhesions and a textured external surface for tissue ingrowth; in two patients, performed at the beginning of this series, we used a Marlex mesh (Bard Inc., Murray Hill, NJ, USA). Rigid reconstruction was carried out in one case with Marlex mesh-methylmethacrylate sandwich (MMM) while in two cases, of the past 2 years, with the STRATOS. This new system consists of titanium rib clips available in different angles (straight 45° or 22.5° left and right) and connecting bars also available in three lengths (15, 19 and 23 cm) and its assembly is very simple and quick: once the ribs are isolated laterally to the margin of resection, the rib clips and the connecting bars can be bent to shape (by means of special bending instruments, rib clip fixation and cutting pliers) and fitted individually to reconstruct the chest defect (Fig. 1). A muscular flap was added in 12 patients (29%): PM, $n = 8$; LD, $n = 4$.

2.2.1. Sternal reconstruction

In four partial sternectomies (44%) and two subtotal sternectomies (22%), the reconstruction of sternal defects was carried out using ePTFE and a PM muscle flap with skin advancement (bilateral: $n = 5$; monolateral: $n = 1$); one case (11%) of RIS of the manubrium involving the left sterno-clavicular joint was reconstructed using ePTFE and an LD muscular flap, because the omolateral PM was previously irradiated (Fig. 2). Rigid reconstruction was performed in two patients in this group (22%), in one case after a subtotal sternectomy with MMM and in one case after a complete sternectomy with STRATOS. The reconstruction technique adopted after complete sternectomy (including the entire sternum together with the previous site of biopsy, costochondral arches and internal third of clavicles) was as

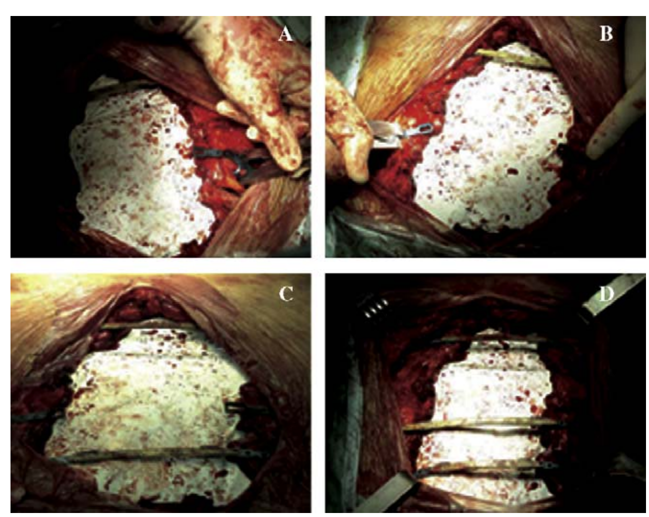

Fig. 1. Reconstruction of the sternum with the STRATOS: various steps of the assembly. (A) The rib clips are fixed bilaterally and (B) angled with special pliers. (C) The clips placed in the right direction for the positioning of the bar. (D) The bar positioned between the two clips.

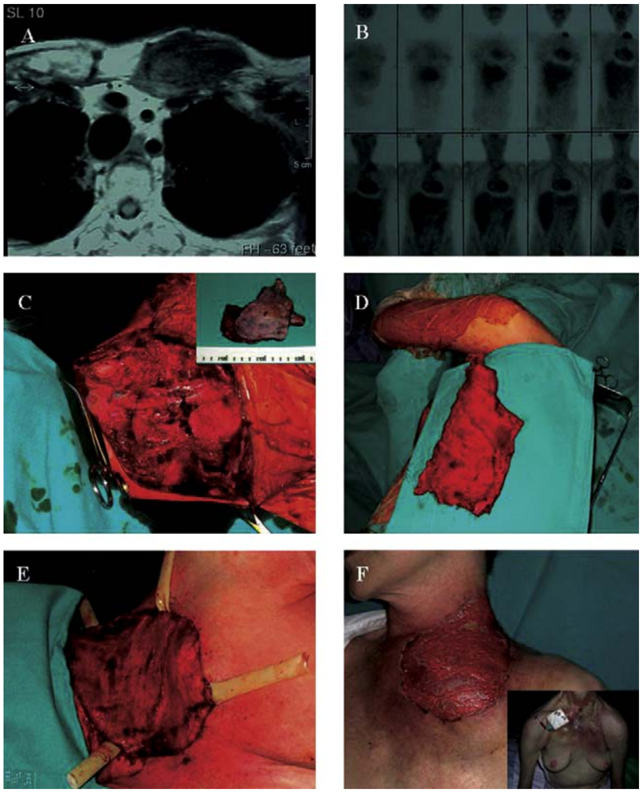

Fig. 2. Radio-induced sarcoma of the left sterno-calivicular joint (55-year-old woman with previous primary Hodgkin's disease). (A) Magnetic resonance in transverse section. (B) PET scan. (C) Trans cervical approach including a L-shaped cervicotomy extended into the deltopectoral groove with resection of the internal half of the clavicle (surgical specimen in the box). (D) LD muscular flap prepared and (E) transferred. (F) Final result before and after (box) the skin grafting.

follows: an expanded PTFE patch 0.1-mm thick (Peritoneal; W.L. Gore & Associates, Flagstaff, AZ, USA) was anchored to the inner edges of the defect with non-absorbable sutures to separate the mediastinum from the superficial layers, without sterno-clavicular joint reconstruction; then, a rigid sternal reconstruction was performed with titanium plates: for transverse reconstruction we used the STRATOS (Fig. 1), and for longitudinal reconstruction we used a multi-perforated titanium plate (commonly employed in orthopaedic implants, not part of the STRATOS) placed at right angles to the bars and wired into each bar by separated stitches with non-absorbable suture passed through the holes of the plate (Fig. 3). Finally, we covered the implant with a bilateral PM muscular flap. The technique used in this case has been extensively detailed elsewhere [2].

2.2.2. *Lateral chest-wall reconstruction*

Reconstruction of the lateral chest-wall defect was performed using a non-rigid prosthetic material in 19 out of 32 patients (59%); in two of these cases, we added an omolateral LD muscle transposition. Rigid reconstruction was performed in one case (3%) — after a wide antero-lateral resection in a 14-year-old patient with Ewing's sarcoma of the anterior chest wall infiltrating the left upper lobe (Fig. 4(A)); after induction chemotherapy (Fig. 4(B)), he underwent a wide antero-lateral chest-wall resection that extended to the lung (left upper-lobe atypical resection) and subsequent reconstruction with the STRATOS (Figs. 4(C)—(D)): two bars were fixed posteriorly on the ribs with the special clips whereas because the sternocostal cartilage was removed and we could not use the apposite rib clip anteriorly, the bars were fixed on the edges of the sternum with metal wires passed in the sternal body through the hole available on the extremity of the bars (Fig. 4(C) — arrow); we preferred this option to others such as pushing the bars into the spongious layer of the sternum or fixing the bars with their own clips onto the corresponding controlateral ribs (enlarging the wound till the other side of the sternum). The pleural cavity was then separated from the chest wall using a 0.1-mm-thick ePTFE patch (Peritoneal; W.L. Gore & Associates, Flagstaff, AZ, USA) and the whole implant was covered with

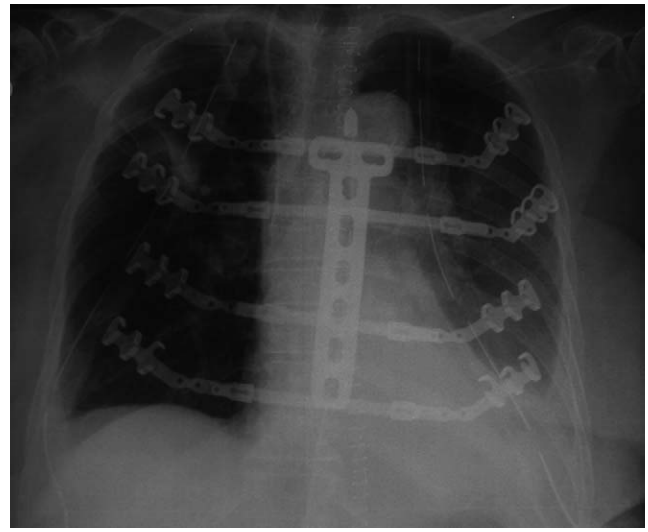

Fig. 3. Postoperative chest X-ray of STRATOS sternal replacement.

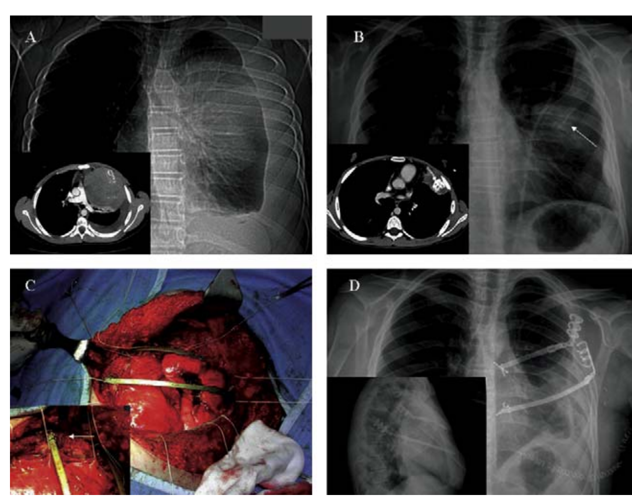

Fig. 4. Ewing sarcoma of the anterior chest wall. (A) Chest X-ray and CT scan before induction chemotherapy. (B) Chest X-ray and CT scan after induction chemotherapy. (C) Chest-wall reconstruction with the STRATOS; in the box is evidenced a particular of the bar fixed to the sternum with a stitch steel (arrow). (D) Postoperative radiological appearance of the reconstruction.

Table 1
Histopathological findings.

Histological type	*N*	%
Chondrosarcoma	25	61
Grade I	12	48
Grade II	10	40
Grade III	3	12
Osteosarcoma	8	20
Ewing sarcoma	2	5
Radio-induced sarcoma	2	5
Solitary plasmocytoma	2	5
Desmoid tumour	1	2
Fibrosarcoma	1	2

an omolateral LD muscular flap. The other 12 patients (37%) in this group did not require any reconstruction.

3. Results

The histological types are depicted in Table 1. Thirty-nine patients (95%) were extubated at the end of surgery; two patients (one complete sternectomy and one subtotal sternectomy) were extubated in the intensive care unit within the first 24 h. There was no perioperative mortality. Neither major septic complication nor flap-related complication occurred: two patients developed a seroma ($n = 1$: MMM after subtotal sternectomy; $n = 1$: lateral chest-wall non-rigid reconstruction) and were treated conservatively without consequences. Postoperative hospital stay averaged 8.6 days (range 5—14 days). We experienced a partial paradoxical movement in three cases (11%) in patients with non-rigid reconstruction, but without respiratory complications linked to chest-wall instability. We had a local recurrence in two patients (5%) 15 months and 26 months after surgery, performed for a desmoids tumour and a high-grade chondrosarcoma, respectively. Both patients underwent a new resection and a subsequent radiotherapy; the chondrosarcoma patient developed a disseminated disease and despite a systemic treatment, ultimately died of disease 14 months after recurrence. With a mean follow-up time of 60.5 months (range 4—130 months), the overall 5- and 10-year survival in PMCWTs was 61% and 47%, respectively (Fig. 5A). In the chondrosarcoma group ($n = 25$), 5- and 10-year survival was 80% while the 5-year survival in patient with primary osteosarcoma ($n = 8$) was 21% (Fig. 5(B)). No difference in survival was observed between the three grades of chondrosarcoma. In the osteosarcoma group, all patients received a combined treatment with induction ($n = 3$) and/or adjuvant ($n = 7$) chemotherapy; even if we did not experience local recurrence in this group, five patients developed disseminated disease within 2 years of surgery and finally died of the disease. All patients with Ewing's sarcoma were treated with induction chemotherapy and surgery; of the two patients in this group, a 14-year-old boy is still alive and disease free after 13 months, while a 9-year-old patient died after 10 months of surgery with metastases. The two patients with solitary plasmocytoma died after 28 and 14 months, respectively, of multiple myeloma. One patient out of two with an RIS developed malignant pleural effusion after 12 months and died of disseminated disease.

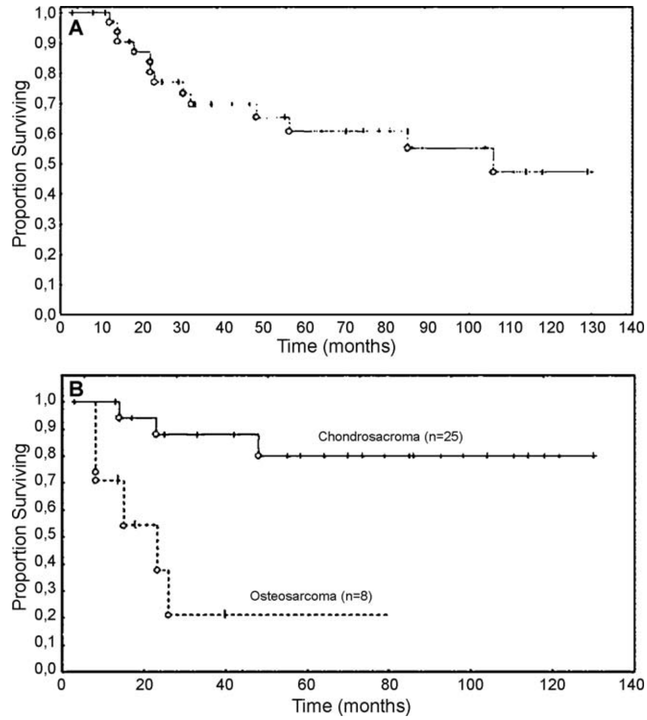

Fig. 5. (A) Overall survival in PMCWT. (B) Overall survival in chondrosarcoma and osteosarcoma.

4. Discussion

PMCWTs are rare, accounting for less than 1% of all primary tumours [3]. The most common origin of PMCWT is bone or cartilage, as in our series, even if some authors report a prevalence or an equal distribution between bone, cartilage and soft tissues [1,4]; ribs are a more frequent location of PMCWT than the sternum [1—4], as confirmed in our study (32 (78%) vs 9 (22%), respectively). Surgery represents the cornerstone in the treatment of PMCWT; tenets of chest-wall resections and reconstructions are well known and can thus be summarised: an adequate radical resection associated with the maintenance of chest stability, lung function and an acceptable cosmetic result [5]. Consequently, a critical point, in general in anterior chest-wall resections, is a suitable prosthetic replacement, able to restore the rigidity of the chest and to prevent paradoxical motion, and a healthy soft-tissue coverage able to seal the pleural space, to protect the viscera and great vessels and to prevent infection [5—7]. The importance of radical surgery in PMCWT is well known and has been demonstrated by several authors [7—9]: in our series, we always checked the margins on soft tissues with intra-operative examination, while on the bone we tried to respect the limit of 3 cm of healthy tissue; as a result, all the operations were margin free, minimising the incidence of local recurrence (5% in our series). As a wide resection of the chest wall often threatens stability, reconstruction plays a crucial role in determining postoperative morbidity and mortality [5,6,7,10]. Even if the importance of chest-wall reconstruction has been described by historical and more recent reports, there are still controversies as to which chest-wall lesions should be reconstructed [6,7,11]. The rule generally followed, as also we have applied, is not to reconstruct defects smaller than 5 cm in size in any location and those up to 10 cm in size posteriorly, while larger defects, most anterior defects or defects in proximity to the tip of the scapula must be reconstructed. As non-rigid prosthetic materials, the most commonly used are Prolene or Marlex mesh and PTFE [5—7,11,12]: the choice of prosthetic material is usually based on the surgeon's preference and Deschamps and associates have shown no significant difference in the postoperative outcome or in complication rate as a consequence of this choice [11]. The authors opted in most part of cases for ePTFE (24/26; 92%) with a low rate of complications and excellent final results; our choice was based on the product features (malleability, inertness and resistance to infection) but actually also on the confidence acquired using this material. In our experience, in the case of subtotal sternectomy, when a small part of the manubrium (with the sterno-clavicular joint) or a part of the lower sternal body are conserved, a rigid reconstruction is not necessary; further, these defects can be replaced by non-rigid prostheses. In the case of large antero-lateral chest-wall defects or in the case of a complete sternectomy, a reconstruction with rigid material is often mandatory to restore chest-wall stability and to maintain the geometry of the thoracic cage [13,14]. Rigid prosthetic reconstruction commonly consists of methylmethacrylate spread between two layers of Prolene or Marlex mesh, tailored to the size and contour of the chest-wall defect [6,15]; however, the intra-operative preparation of the MMM requires time and it is not very easy to handle and to adapt to the shape of the patient's chest and to set directly onto bony structures, particularly in non-experienced hands. Moreover, even if the methylmethacrylate sandwich provides excellent chest-wall stability and a low risk of respiratory complications, it is associated with a great number of wound complications; further, fracture, tilting or extrusion of the implant are reported [5,6,11,13,16]. In this series, the authors used a new rigid material composed of mouldable titanium bars and rib clips (STRATOS) in one case after a total sternectomy and in another case after a wide antero-lateral chest-wall resection in a paediatric patient. The utility of titanium bars for sternal reconstruction has been previously described in cases of complicated sternal dehiscence after cardiac surgery, whereas their use has only been occasionally reported after subtotal sternectomy for primary tumours [17,18]. In our experience, STRATOS, realised for chest-wall replacement, allows a firm reconstruction, and is more simple to handle and to attach to the resected edges of the ribs, so that the bars are not easily dislodged. Furthermore, by exploiting the flexibility of the bars and rib clips, the surgeon can model the reconstruction to the specific shape of the chest and of the defect without dead parietal spaces, which are reported in the methylmethacrylate sandwich; in the same way, if, postoperatively, the thoracic cage shrinks to some extent or changes dimension as it happens in a young patient, the implant has a good margin for adapting progressively to the new shape, because of the flexibility of the titanium bars. This rigid reconstruction makes the chest wall immediately stable, allowing the physiological respiratory motion since the early postoperative period and minimises the risk of any other wound complications, with excellent final cosmetic results; titanium also can be imaged safely with CT and MR and therefore does not affect the follow-up of these patients. In our opinion, STRATOS should be considered as an option for reconstruction after a wide chest-wall resection. Once the chest wall has been stabilised, a soft-tissue coverage can be used to complete the reconstruction to control infection, obliterate dead space, cover and separate the synthetic material. Since Jurkiewicz and Arnold in 1977 rediscovered the musculocutaneous flap for chest-wall surgery [19], autogenous replacement became the mainstay for thoracic reconstruction; a variety of muscles or musculocutaneous flaps have been introduced over the years. In this series, the soft tissue transfer was always performed in close interaction with a plastic surgeon, involved in the preoperative selection of the flap as well as in the surgical procedure. PM is the most frequently selected muscle for sternectomy, because of its proximity, reliability and versatility and it can be used unilaterally or bilaterally, with skin advancement or as a musculocutaneous flap [13,14]; we used an omolateral LD muscular flap for sternal reconstruction only in one case of PM that was unavailable because of previous irradiation. We reconstructed preferentially the antero-lateral chest-wall defects with an LD muscle flap associated with skin advancement; the LD flap is easily transposed on thoraco-dorsal vessels and its length and bulk provide extensive coverage [5—7,11,12,16]. We associated the LD muscular flap with a skin graft in one patient having a large skin defect at the recipient site. The importance of a multidisciplinary approach in the treatment of PMCWTs is widely accepted and this need arises from the complexity of surgery (resection and subsequent reconstruction) as well as from the local and systemic aggressiveness of some histological types of PMCWTs. In our series, every procedure was planned and performed with contributions from the plastic surgeon and, in some cases, also of the orthopaedic oncologist; in the same way, the indications to induction or adjuvant therapy were discussed and planned, together with the medical oncologist and the radiotherapist; as result of this co-operation, 12% and 37% of patients in this series underwent induction and adjuvant therapy, respectively. For PMCWTs, a 5-year survival range of 46—66% has been reported, with a wide difference between the various histologic types [8,9,20]; according to this range, after a median follow-up of 60.5 months, we observed a 5-year survival of 61%. However, in our opinion, it is beside the point to consider the survival of PMCWTs as a single group; actually, also in our experience, the 5-year survival ranges very widely from 80% for chondrosarcomas to 21% for osteosarcomas. Chondrosarcoma is the most common PMCWT and the grade of the tumour has been reported as the most important prognostic factor, together with an adequate resection [4,8,9,16] (as also reported by the recent series of the Scandinavian Sarcoma Group), with a 10-year survival of 92% in patients operated with wide margins compared with 47% for those with intralesional resections [21]; the first observation was not confirmed in our series, probably because of the low number of cases. Osteosarcomas are usually high-grade tumours and combined treatment is required; in spite of this, they often metastatise and survival is significantly lower as compared to other subgroups of PMCWTs [8,9]. Ewing's sarcomas of the chest wall are rare and usually considered as a systemic disease necessitating local as well as systemic therapy; despite this aggressive treatment, up to 40% of patients with localised disease succumb to the illness [8,9,20]; in this series, one patient out of two with Ewing's sarcoma had disseminated disease and died few months after surgery. Desmoid tumour is considered a low-grade fibrosarcoma, but it should be resected with wide margins to avoid recurrence, as all other PMCWTs; radiation therapy represents a proven and effective alternative or supplementary treatment [1,8,9]. Localised solitary plasmocytoma is a rare disease and surgery followed by adjuvant chemotherapy is generally effective [1,8,9]; however, the most important factor affecting survival is the subsequent development of a systemic disease: in this series, both patients died after developing multiple myeloma. RIS is an uncommon but increasing group of PMCWT; it develops commonly in patients previously irradiated for breast cancer or Hodgkin's disease and frequently arise or involve the thoracic outlet (one patient out of two in our series). Radical resection with adjuvant chemotherapy is advocated; however, despite aggressive management, local and systemic recurrence rates are higher than other sarcomas of the chest wall [22].

5. Conclusions

Wide resection with tumour-free margins is necessary in PMCWT to minimise local recurrence and to contribute to long-term survival. Consequently, to achieve a satisfactory surgical management, the coordinated effort of a multidisciplinary surgical team is mandatory. The numerous advance over the years made available various prosthetic materials and free or pedicled muscle flaps for chest-wall replacement; the new STRATOS allows a firm reconstruction, simple to handle and to fix and, in our opinion, represents a new option in the scenario of rigid reconstruction. Despite the progress in multimodality treatment, survival in PMCWTs is closely tumour dependent and high long-term survival can be obtained only in the case of chondrosarcoma.

References

[1] Athanassiadi K, Kalavrouziotis G, Rondogianni D, Loutsidis A, Hatzimichalis A, Bellenis I. Primary chest wall tumors: early and long-term results of surgical treatment. Eur J Cardiothorac Surg 2001;19:589—93.
[2] Gonfiotti A, Santini PF, Campanacci D, Innocenti M, Ferrarello S, Janni A. Use of moldable titanium bars and rib clips for total sternal replacement: a new composite technique. J Thorac Cardiovasc Surg 2009;138:1248—50.
[3] Pass HI. Primary and metastatic chest wall tumors. In: Roth JA, Ruckdeschel JC, Weisenburger TH, editors. Thoracic oncology. 2nd ed., Philadelphia, PA: W.B. Saunders; 1995. p. 519—37.
[4] Burt M. Primary malignant tumors of the chest wall: the Memorial Sloan—Kettering Cancer Center experience. Chest Surg Clin N Am 1994;49:363—9.
[5] Mansour KA, Thourani VH, Losken A, Reeves JG, Miller Jr JI, Carlson GW, Jones GE. Chest wall resection and reconstruction: a 25-year experience. Ann Thorac Surg 2002;73:1720—5.
[6] Weyant M, Bains M, Venkatraman E, Downey R, Park B, Flores R, Rizk N, Rusch V. Results of chest wall resection and reconstruction with and without rigid prosthesis. Ann Thorac Surg 2006;81:279—85.
[7] Chapelier A, Macchiarini P, Rietjens M, Lenot B, Margulis A, Petit JY, Dartevelle P. Chest wall reconstruction following resection of large primary malignant tumors. Eur J Cardiothorac Surg 1994;8:351—7.
[8] Incarbone M, Pastorino U. Surgical treatment of chest wall tumors. World J Surg 2001;25:218—30.
[9] Martini N, Huvos A, Burt M, Heelan R, Bains M, MeCormack P, Rusch V, Weber M, Downey R, Ginsberg R. Predictors of survival in malignant tumors of the sternum. J Thorac Cardiovasc Surg 1996;111:96—106.
[10] Lardinois D, Muller M, Furrer M, Banic A, Gugger M, Krueger T, Ris HB. Functional assessment of chest wall integrity after methylmethacrylate reconstruction. Ann Thorac Surg 2000;69:919—23.
[11] Deschamps C, Tirnaksiz BM, Darbandi R, Trastek VF, Allen MS, Miller DL, Arnold PG, Pairolero PC. Early and long-term results of prosthetic chest wall reconstruction. J Thorac Cardiovasc Surg 1999;117:588—91.
[12] Novoa N, Benito P, Jimenez MF, de Juan A, Luis Aranda J, Varela G. Reconstruction of chest wall defects after resection of large neoplasms: ten-year experience. Interact CardioVasc Thorac Surg 2005;4:250—5.
[13] Chapelier AR, Missana MC, Couturaud B, Fadel E, Fabre D, Mussot S, Pouillart P, Dartevelle PG. Sternal resection and reconstruction for primary malignant tumors. Ann Thorac Surg 2004;77:1001—7.
[14] Soysal O, Walsh GL, Nesbitt JC, McMurtrey MJ, Roth JA, Putnam Jr JB. Resection of sternal tumors: extent, reconstruction, and survival. Ann Thorac Surg 1995;60:1353—8.
[15] McCormack P, Bains MS, Beattie Jr EJ, Martini N. New trends in skeletal reconstruction after resection of chest wall tumors. Ann Thorac Surg 1981;31:45—52.
[16] Arnold PG, Pairolero PC. Chest wall reconstruction: an account of 500 consecutive patients. Plast Reconstr Surg 1996;98:804—10.
[17] Voss B, Bauernschmitt R, Will A, Krane M, Kröss R, Brockmann G, Libera P, Lange R. Sternal reconstruction with titanium plates in complicated sternal dehiscence. Eur J Cardiothorac Surg 2008;34:139—45.
[18] Briccoli A, Manfrini M, Rocca M, Lari S, Giacomini S, Mercuri M. Sternal reconstruction with synthetic mesh and metallic plates for high grade tumours of the chest wall. Eur J Surg 2002;168:494—9.
[19] Jurkiewicz MJ, Arnold PG. The omentum: an account of its use in the reconstruction of the chest wall. Ann Surg 1977;185:548—54.
[20] Warzelhan J, Stoelben E, Imdahl A, Hasse J. Results in surgery for primary and metastatic chest wall tumors. Eur J Cardiothorac Surg 2001;19: 584—8.
[21] Widhe B, Bauer HC, Scandinavian Sarcoma Group. Surgical treatment is decisive for outcome in chondrosarcoma of the chest wall: a population-based Scandinavian Sarcoma Group study of 106 patients. J Thorac Cardiovasc Surg 2009;137:610—4.
[22] Chapelier AR, Bacha EA, de Montpreville VT, Dulmet EM, Rietjens M, Margulis A, Macchiarini P, Dartevelle PG. Radical resection of radiation-induced sarcoma of the chest wall: report of 15 cases. Ann Thorac Surg 1997;63:214—9.

Appendix A. Conference discussion

Dr D. Miller (*Atlanta, Georgia, USA*): I would like to congratulate you and your colleagues on an excellent long-term survival in a very complex group of patients. As we learned Saturday at the Techno College, the STRATOS support system is becoming more popular in Europe for chest-wall reconstruction, and I'd like to applaud you for using it in these complex cases.

My first question is in regard to your PTFE reconstruction of the sternum. The majority of surgeons in the U.S. would use a methyl methacrylate sandwich for the anterior reconstructions to prevent paradoxical motion and respiratory issues. In your series you only had one case of methyl methacrylate reconstruction, but in your results section, you had no respiratory complications. I wish you would comment further on respiratory concerns in regard to your reconstruction method for the anterior resections.

Dr Gonfiotti: We have a little experience with methyl methacrylate. We used it also in another case of sternal reconstruction for resection after breast cancer recurrence, and we experienced no major complications, no big trouble, but we had a lot of problems during the operation in the preparation of the methyl methacrylate and adaptation of the methyl methacrylate to the shape of the defect. At our first meeting with STRATOS 2 years ago, it was something like love at first sight. We used it for the first time and it was very simple and quick, and also easy to understand how it works; the tools of the system are easy to use too and its assembly doesn't require any enlargement of the skin incision. So we started to use it and we were so satisfied with the result that in the next cases we continued to use this system.

Dr Miller: I'd like for you to comment on that one case where you used the longitudinal bar. I've never seen that used before, especially in a total sternectomy. How did you attach to the chest wall and why did you use it?

Dr Gonfiotti: Because when we finished adapting the transverse bars, we saw the independent movement of the transverse bars. It was something like a flail chest. So we were not sure if, without a link between the bars, the chest would have been stable, and we added a transverse bar to obtain a real sternal replacement and to stabilise the transverse bars.

Dr Miller: Has anybody else in the audience used a longitudinal bar? I'm not accustomed to that technique.

My last question, 5 of your PTFE patients had radiation post-resection. Did the patients develop a late seroma or a complication from their patch? Sometimes when patients have been reconstructed with PTFE and receive postoperative radiation, they can develop complications related to the patch, such as seroma formation. Did your patients happen to experience any associated patch complications.

Dr Gonfiotti: No, I have not noticed complications from the radiation therapy with these patients.

Dr A. Chapelier (*Suresnes, France*): Clearly today you have again endorsed the option of the bars for rigid reconstruction.

I have a short question. You mentioned in your series two plasmacytomas. Could you tell us if in the follow-up there was still solitary plasmacytoma, or did these patients develop general disease, as it has been published?

Dr Gonfiotti: These patients died from systemic disease after developing multiple myeloma, yes.

Dr Chapelier: Both of them?

Dr Gonfiotti: Both of the patients, one 14 months and the other 28 months after the procedure.

Dr S. Yang (*Baltimore, Maryland*): In my practice, we get a lot of outside referrals of patients who have had a lot of radiation and a picture similar to what you had shown with ulceration. How does that change your management? I assume you still put in a prosthetic bar. I'd like to hear your comments about using some of these other bioprostheses, like AlloDerm and these other biologic agents for chest-wall reconstruction.

Dr Gonfiotti: I didn't get your question.

Dr Yang: When you have a patient who has had a lot of radiation, say 60 Gy, or when you have ulceration, like the picture you've shown, does that change your approach? You would still use a bar for those patients?

Dr Gonfiotti: Actually, we were never approached with this problem because we treated the patients with radio-induced sarcoma before the introduction of the titanium bars in our practice and we managed these kind of operations together with the plastic surgeon. So maybe if in the future we have new cases of radio-induced sarcomas, before using the STRATOS, we will call Dr Wihlm for some suggestions.

Dr J.-M. Wihlm (*Strasbourg, France*): Just a little tip. I was worried about your wires on the sternum. The solution is very simple. You could have seen it in the Techno College: you just crimp a regular rib clip on the healthy cartilage on the other side of the sternum and it works.