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ORIGINAL PAPER

A general algorithm for chest wall reconstruction based on a retrospective review

Ee Hsiang Jonah Kua · Hui Ling Chia · Terence L. H. Goh · Chong Hee Lim · Siew Weng Ng · Bien-Keem Tan

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Abstract
Background Many chest wall reconstruction algorithms have been proposed, but there is still no general consensus. The purpose of this study is to review our single institutional experience in chest wall reconstruction and identify a working algorithm based on our retrospective analysis.
Methods This is a retrospective analysis of 54 patients who underwent chest wall reconstruction in our department from 1996 to 2011.
Results The mean follow-up was 38 months. Central chest wall defects were the most common, while infection and tumour resection were the two most common indications. The pedicled latissimus dorsi flap was a versatile flap, used as a single or combination flap for anterolateral, lateral and posterior defects. The pectoralis major flap was suitable for central and anterolateral defects and the rectus abdominis flap for lower central defects. Omentum flaps were useful in radiation-damage skin or in patients with recurrent infection.
Conclusions Locoregional flaps are the mainstay of chest wall reconstruction. Most skeletal reconstruction, when required, is safely accomplished with the use of prosthetic materials. Free flaps are usually only indicated for large defects or when regional flaps are unavailable.
Level of Evidence: Level IV, therapeutic study.

Keywords Chest wall reconstruction · Flaps · Anterior · Lateral and posterior chest wall defects · Full thickness chest wall defects

E. H. J. Kua · H. L. Chia · T. L. H. Goh · S. W. Ng · B.-K. Tan (✉)
Department of Plastic, Reconstructive and Aesthetic Surgery, Singapore General Hospital, Outram Road, Singapore 169608, Singapore
e-mail: tan.bien.keem@sgh.com.sg

C. H. Lim
Department of Cardiothoracic Surgery, National Heart Centre Singapore, 5 Hospital Drive, Singapore 169609, Singapore

Introduction

Despite recent surgical advances, chest wall reconstruction remains a challenging problem for the reconstructive surgeon. Increasingly aggressive surgical extirpation of chest wall disease has resulted in a variety of large defects with unique and variable problems. While some defects only require soft tissue coverage of vital structures, others may involve reconstruction of the diaphragm, pleural seal or skeletal stability to preserve physiological pulmonary function. Over the years, many authors have reviewed their experiences and expounded the use of workhorse flaps such as the pectoralis major (PM), latissimus dorsi (LD), rectus, omentum and anterolateral thigh (ALT) flaps [1–3]. Arnold and Pairolero reviewed their experience in pedicled musculocutaneous flaps in chest wall reconstruction and concluded that these flaps were safe, durable and associated with long-term survival [1]. However, the role that each flap plays in chest wall reconstruction has not been clearly defined. There is also no general consensus

on an overall management algorithm. The purpose of this study is to review our single institutional experience in chest wall reconstruction for over a decade and identify an effective working algorithm. We will also describe our experience on the reconstruction of massive chest wall defects, involving combination flaps, biomaterials and diaphragmatic reconstruction.

Patients and methods

This study was conducted according to the guidelines of the Institutional Review Board of our hospital. All patients who underwent flap reconstruction of chest wall defects from 1996 to 2011 were included in the study. Their medical charts were retrospectively reviewed. The pathological diagnosis, location of defect, method of reconstruction and surgical outcomes were examined. In measuring outcomes, major and minor operative complications were recorded. The patients were then grouped accorded to the location of chest wall defect, and the type of flap used was reviewed.

Results

Fifty-four patients underwent chest wall reconstruction in our institution between January 1996 and January 2011. The mean follow-up was 38 months, with a range from 23 to 196 months. Infection was the most common indication (55.6 %) for chest wall reconstruction, followed by tumour extirpation (31.5 %) and bronchopleural fistula (7.4 %) (Table 1). Desmoid tumours and chondrosarcomas are the most common tumours in our series (Table 2). The most common flap used is the latissimus dorsi flap (21/61; 34.4 %), followed by the pectoralis major flap (16/61; 26.2 %) and rectus abdominis flap (7/61; 11.5 %). Pedicled muscle or musculocutaneous flaps were effectively used in the majority of patients (92.6 %; 50/54) and only 7.4 % (4/54) of patients required a free flap. Chest wall skeletal repair with prosthetic materials was performed in only six cases (11.1 %; 6/54).

Table 1 Indications for chest wall reconstruction

Indication for surgery	*n*
Infection	30 (55.6 %)
Tumour	17 (31.5 %)
Bronchopleural fistula	4 (7.4 %)
Others	3 (5.6 %)

Table 2 Types of chest wall tumours

Types of tumour	*n*
Osteosarcoma	3
Chondrosarcoma	3
Desmoid tumour	4
Histiocytosis	1
SCC	1
Cystosarcoma phyllodes	2
Advanced breast Ca	2
Primitive neuroectodermal tumour	1

The most common defect locations were central (37.0 %) and anterolateral (37.0 %), followed by lateral (18.5 %) and posterior (7.4 %). The LD was noted to be most versatile and well-suited for anterolateral, lateral and posterior defects. The PM was well suited for central and anterolateral defects. The rectus was also well suited for central defects, especially the lower central defects (Table 3). Omentum flaps were useful in patients with radiation-damaged skin and recurrent infection. Common post-operative complications such as partial flap necrosis, infection and wound dehiscence are detailed in Table 4. Infection occurred in eight patients (13.1 %) and six patients (9.8 %) had wound dehiscence. Only two patients (3.2 %) had partial flap necrosis. Based on these results, we propose our algorithm (Fig. 4).

Case 1

A 38-year-old patient presented with dyspnoea secondary to an intrathoracic malignant spindle cell sarcoma. Computed tomographic (CT) scan of the thorax showed a right pleural effusion with an intrathoracic mass (Fig. 1a). Video-assisted thoracic surgery and biopsy of the mass confirmed that it was a malignant spindle cell sarcoma. Oncological resection resulted in a 19×14 cm full-thickness chest wall defect with five ribs resected (Fig. 1b) An inlay prolene mesh was sutured to the ends of the rib to provide semi-rigid skeletal support, and LD muscle flap was used to cover the mesh and provide a pleural seal (Fig. 1c–f).

Table 3 Defect location in relation to flap use

Defect location	Subjects (*n*)	Total no. of flaps	No. of flaps used				
			Pectoralis major	Latissimus dorsi	Rectus	Omentum	Other flaps
Central	20	23	11 (47.8 %)	2 (8.7 %)	6 (26.1 %)	4 (17.4 %)	0
Anterolateral	20	23	4 (17.4 %)	11 (47.8 %)	1 (4.4 %)	2 (8.7 %)	5[a] (21.7 %)
Lateral	10	11	1 (9.1 %)	5 (45.5 %)	0	0	5[b] (45.5 %)
Posterior	4	4	0	3 (75 %)	0	0	1[c] (25 %)
Total flaps :	54	61	16	21	7	6	11

[a] TRAM (1), deltopectoral flap (1), rotation flap (1), transposition flap (1), free ALT flap

[b] Serratus anterior flap (1), free rectus flap (1), free ALT(1), transposition flap (2)

[c] Free vastus lateralis flap (1)

Case 2

A 58-year-old lady had multiple dermatofibrosarcoma protuberans of the left anterior chest (Fig. 2a). A right pedicled latissimus dorsi muscle flap muscle flap was used to reconstruct the chest defect 8 years ago (Fig. 2b). She developed a recurrence 5 years later. Oncological resection involved a segment of the left

Table 4 Rate of complications associated with each region and flap

Defect location	Total no. of flaps (*n*)	Infection	Necrosis	Dehiscence
Central	23			
Pectoralis major	11	3 (4.9 %)	0	2 (3.2 %)
Latissimus dorsi	2	1 (1.6 %)	0	1 (1.6 %)
Rectus	6	0	0	1 (1.6 %)
Omentum	4	0	0	0
Other flaps	0	0	0	0
Anterolateral	23			
Pectoralis major	4	0	0	0
Latissimus dorsi	11	2 (3.2 %)	1 (1.6 %)	1 (1.6 %)
Rectus	1	0	0	0
Omentum	2	0	0	0
Other flaps	5	1 (1.6 %)	1 (1.6 %)	1 (1.6 %)
Lateral	11			
Pectoralis major	1	0	0	0
Latissimus dorsi	5	0	0	0
Rectus	0	0	0	0
Omentum	0	0	0	0
Other flaps	5	1 (1.6 %)	0	0
Posterior	4			
Pectoralis major	0	0	0	0
Latissimus dorsi	3	0	0	0
Rectus	0	0	0	0
Omentum	0	0	0	0
Other flaps	1	0	0	0
	61	8 (13.1 %)	2 (3.2 %)	6 (9.8 %)

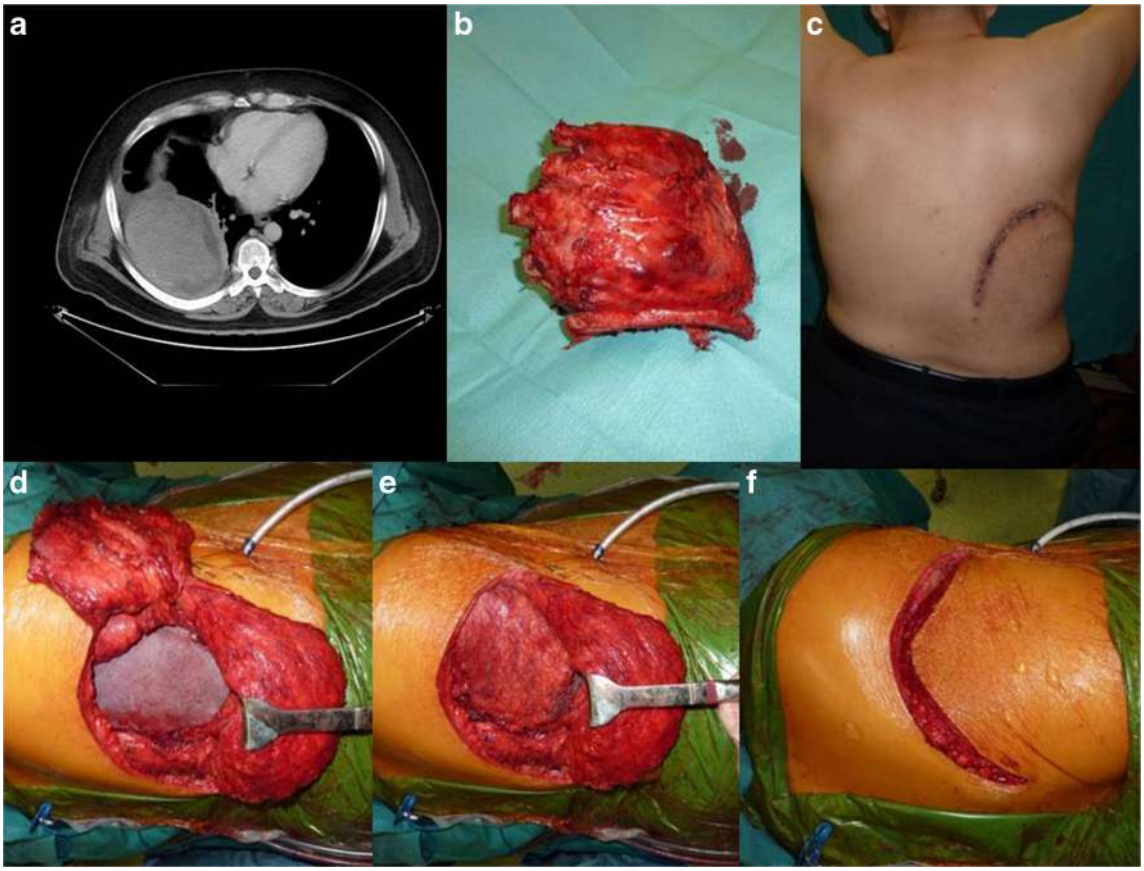


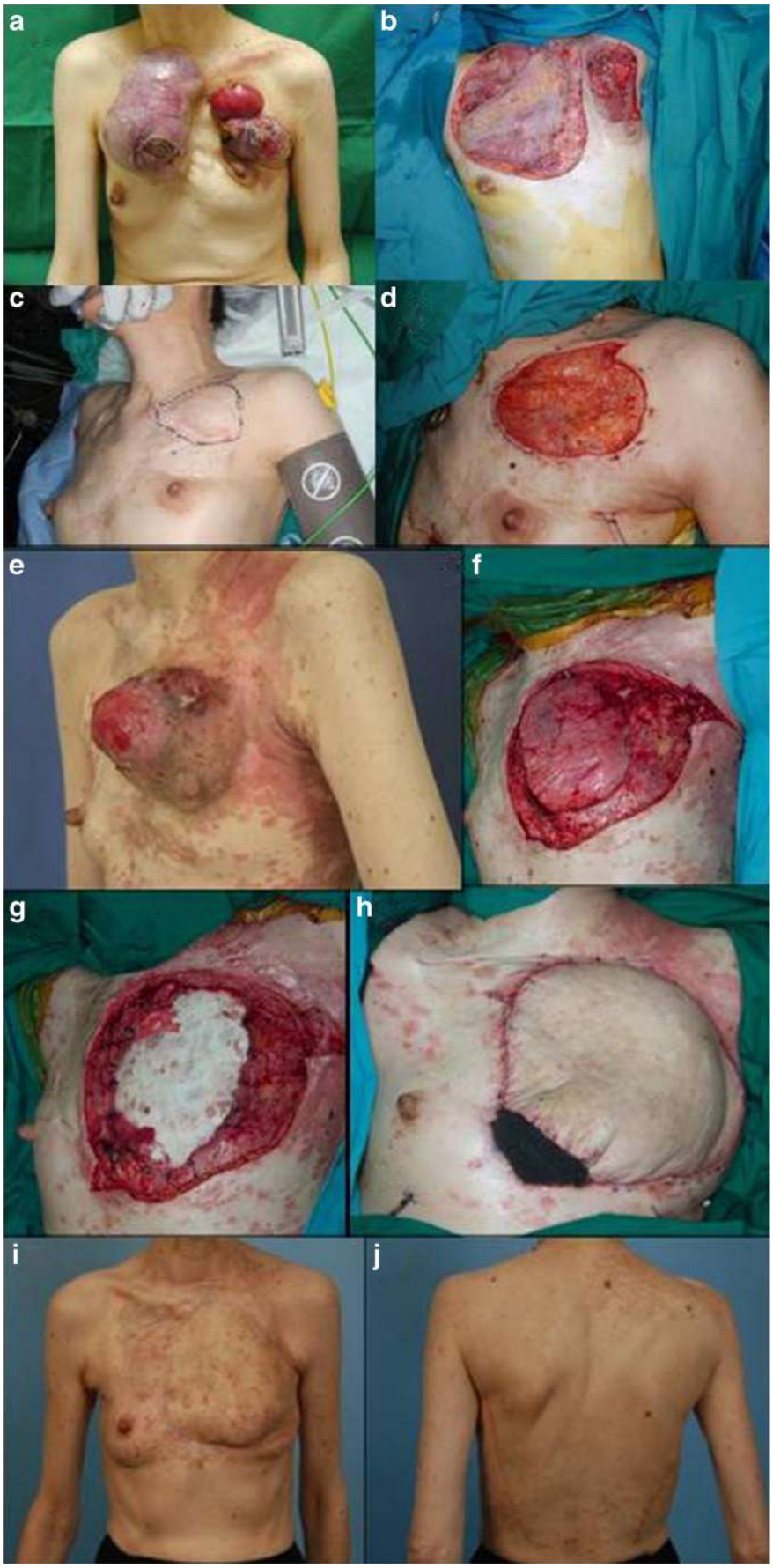
Fig. 1 **a** This patient was diagnosed with an intrathoracic malignant spindle cell sarcoma. **b** Oncological resection resulted in a 19×14 cm full-thickness chest wall defect with five ribs resected. **c**, **d**, **e**, **f** An inlay prolene mesh was sutured to the ends of the rib to provide semi-rigid skeletal support, and LD muscle flap was used to cover over the mesh to provide a pleural seal

clavicle and the fist rib, revealing a full-thickness chest defect with exposed lung and left subclavian vein. A left pedicled latissimus dorsi muscle flap was used to reconstruct the left side of the chest following re-excision (Fig. 2d). Unfortunately, she developed another recurrence at the same site (Fig. 2e). Surgical extirpation of the recurrent tumour involved a complete excision of the manubrium, partial stenectomy involving the 2nd to 5th costal cartilage and excision of the 2nd and 3rd left rib (Fig. 2f). Reconstruction of the defect was achieved with a prolene mesh–methylmethacrylate cement sandwich and a free anterolateral thigh flap as there was no locoregional alternatives available (Fig. 2g, h).

Case 3

A 77-year-old lady presented with a right anterolateral chest mass which developed over 4 months (Fig. 3a). She had a history of right breast cancer and had undergone a simple mastectomy and axillary clearance 17 years ago. This was followed by adjuvant chemotherapy and radiotherapy. A computed tomography scan revealed a right 8×7×6 cm anterolateral chest wall mass with destruction of the right 8th and 9th ribs and diaphragmatic involvement. Core biopsy showed malignant cells with spindled and epithelioid morphology. She underwent a wide resection of the mass which included four ribs and the lateral part of the diaphragmatic dome,

Fig. 2 **a** This 58-year-old lady had multiple recurrent dermatofibrosarcoma protuberans of the left anterior chest. **b** A right latissimus dorsi flap was used to cover over the right anterior chest defect but she developed a recurrence at the left clavicular region. **c**, **d** The recurrent tumour was excised and a left latissimus dorsi flap was used to provide coverage. **e** She developed a 2nd recurrence at the left infraclavicular region. **f** Complete excision of the manubrium and partial stenectomy involving the 2nd to 5th costal cartilage, and excision of the 2nd and 3rd left rib was peformed. **g**, **h** As regional flap options were exhausted, reconstruction of the defect was achieved with a prolene mesh–methylmethacrylate cement sandwich and a free anterolateral thigh flap. **i**, **j** The flap healed well and these were the postoperative results 1 year later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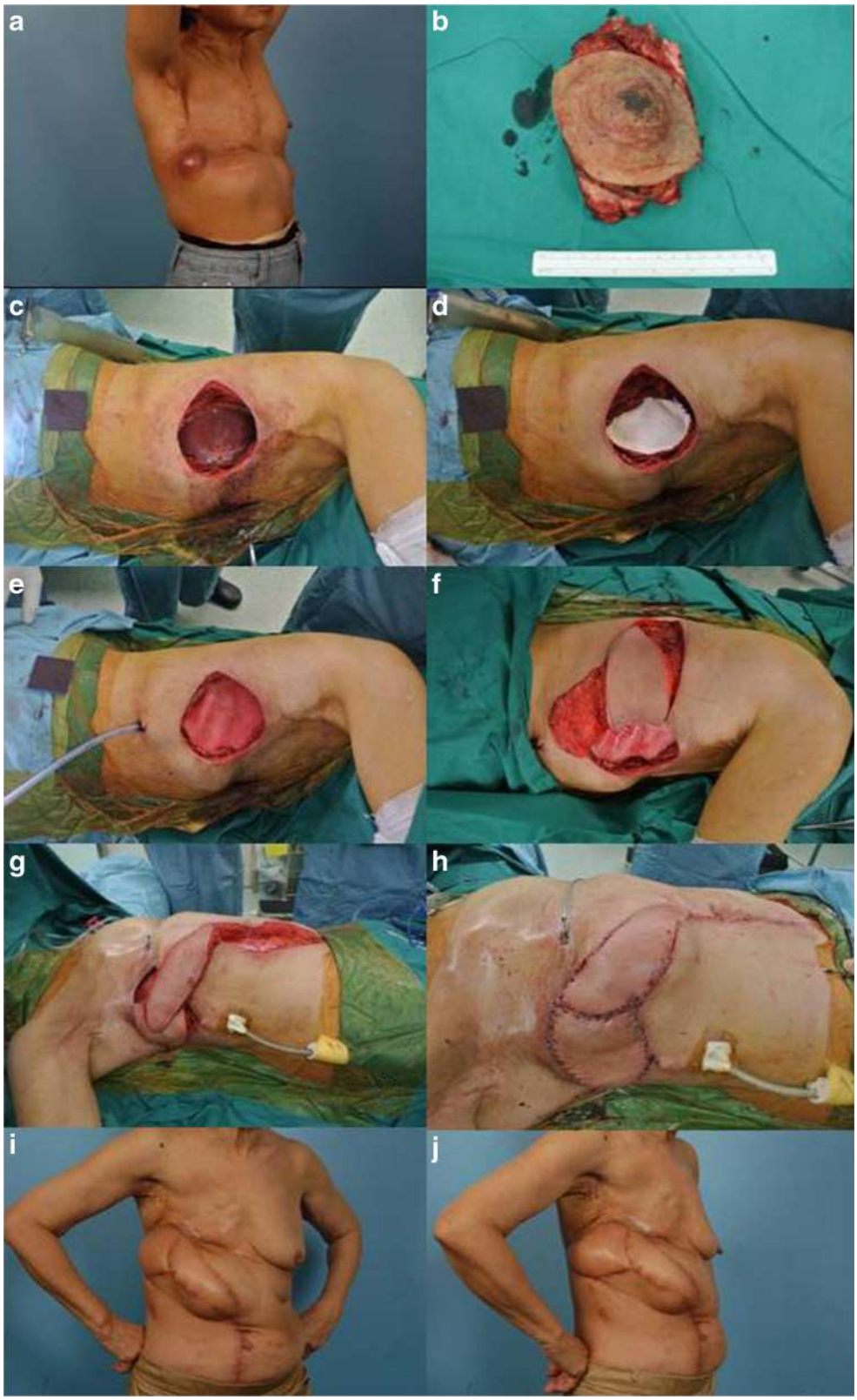

Fig. 3 **a** A 77-year-old lady presented with a right anterolateral chest sarcoma. **b** She underwent a wide resection of the mass which includes four ribs and the lateral part of the diaphragmatic dome, leaving a 7.5×10 cm diaphragmatic defect and a 11 cm×11 cm chest wall defect. **c**, **d**, **e** The diaphragm was reconstructed with a Gortex patch, and Permacol was used to reconstruct the skeletal chest wall. **f**, **g**, **h** A combination of a right V–Y advancement LD flap and a VRAM flap was raised to close the deep chest wall defect. **i**, **j** The complex three-dimensional anterolateral chest wound was successfully reconstructed, and these were the postoperative results 4 weeks later

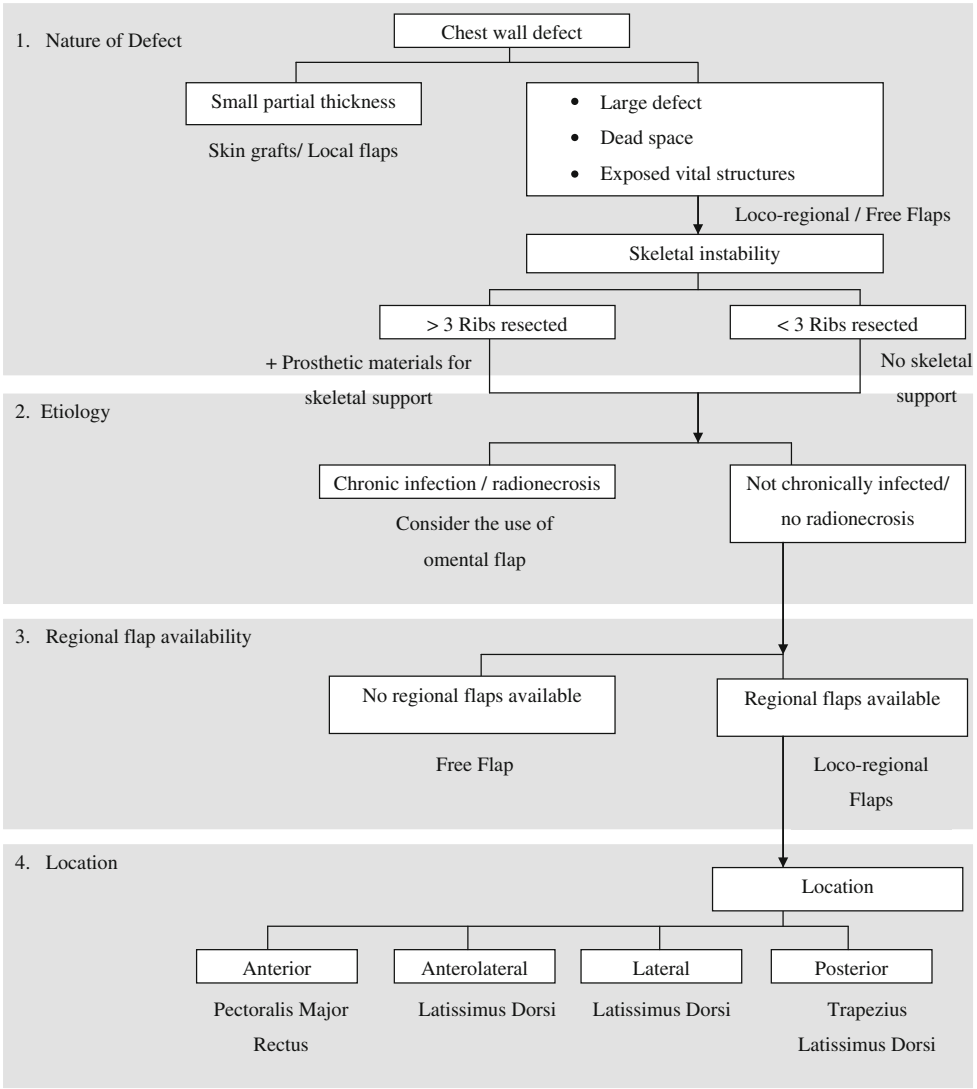

Fig. 4 Our algorithm for chest wall reconstruction

leaving a 7.5×10 cm diaphragmatic defect and a 11 cm×11 cm chest wall defect (Fig. 3b, c). The diaphragm was reconstructed with a Gortex patch, and Permacol was used to reconstruct the skeletal chest wall (Fig. 3c–e). A combination of regional flaps was used to close the deep three-dimensional defect. A right V–Y advancement LD flap was raised and advanced into the defect (Fig. 3f). The medial aspect of the skin paddle was deepithelised and folded over to fill the dead space. An ipsilateral vertical rectus abdomis musculocutaneous (VRAM) flap was also raised (Fig. 3g). The muscle and superior aspect of the skin paddle of the VRAM flap was also used to fill the remaining dead space.

Discussion

The causes of extensive chest wall defects include primary or metastatic chest wall neoplasms, contiguous tumours from breast or lung cancer, radiation necrosis, congenital defects, trauma and infections involving the median sternotomy or lateral thoracotomy wounds [1–3]. In our study, sternal osteomyelitis and other chest wall infections (e.g. chronic tuberculosis) were the most common diagnoses, followed by chest wall tumours (Table 1). These findings were similar to previous reports. In the largest series published on this topic, Pairolero had observed that an infected median sternotomy wound was the most common indication for chest wall

reconstruction [1]. Notwithstanding this, many recent case series have narrowed their management algorithm to oncological defects only [3–6]. Therefore, it is timely that we reexamine and identify a general working algorithm for chest wall reconstruction.

The chest wall is well suited for regional flap coverage as there are many potential muscle flaps in close proximity. These are the muscles that provide support to the shoulder girdle and the accessory muscles of respiration. The pectoralis major, latissimus dorsi, rectus abdominis, trapezius, serratus anterior and external oblique flap had been effectively used to provide safe and durable reconstruction [1, 2]. The myriad of pedicled muscle flaps abates the necessity for free flaps in chest wall reconstruction. Not surprisingly, pedicled flaps were used in 92.6 % of our patients. Their pliability allows them to be folded over to fill large three-dimensional intrathoracic dead space or stretched out to provide vascularized coverage over alloplastic skeletal supports, exposed hardware or vascular prostheses. They have reliable vascular pedicles and are associated with minimal donor site morbidity. To date, there is no evidence of detrimental changes to breathing mechanics when accessory muscles of respirations such as the pectoralis major or rectus abdominis are used for reconstruction [7]. Similarly, when the latissimus muscle function is compromised, most activities of daily living are unaffected due to compensation from other shoulder girdle muscles [7]. We found the latissimus dorsi (LD) flap to be the most versatile muscle flap in chest wall reconstruction due to its wide arc of rotation and reliable vascularity. It was successfully used alone or in combination to provide soft-tissue coverage for central, anterolateral, lateral or posterior chest wall defects in most of our patients (Table 3).

Local disease control and long-term survival of chest wall malignancy has been enhanced by wide surgical extirpation [8, 9]. Unfortunately, this presents increasingly complex chest wall defects to the reconstructive surgeon. A single regional flap is often inadequate to cover a large-volume defect. Due to the rigidity of the ribcage, pedicled regional flaps have difficulty reaching defects which extend just beyond the boundaries of the chest, such as the epigastrium or upper abdominal wall [7]. Moreover, the reliability of the distal ends of these flaps may be questionable and risk the exposure of vital intrathoracic structures or prosthesis [3]. In these situations, a single large free flap not only allows flexibility in inset but also offers the transfer of tissue from distant sites with a more dependable blood supply. The most reliable areas of the flap can be used to cover the critical defect and negative pressure wound therapy started in areas which can be skin grafted later. Free tissue transfer is also indicated when regional flaps have been expended in recurrent disease or are unavailable due to tumour involvement. Despite these indications, free tissue transfer was only required in 7.4 % of our patients due to the alternative of combining regional flaps. A combination of regional flaps is able to cover a large defect while avoiding flap failure risks and lengthy surgical times associated with a microsurgical free flap. We have successfully used combinations flaps in 13.0 % of our patients. Our options include a VY-advancement LD with a vertical rectus abdominis musculocutaneous (VRAM) flap and a pedicled-LD flap combined with an omentum flap to aid in the closure of massive chest wall defects.

Muscle and omental flaps are known for their ability to contain infection due to their rich blood supply [10]. A recent meta-analysis had suggested that the use of omental flaps in deep sternal infections may be associated with lower mortality and fewer complications compared to muscle flaps [11]. Furthermore, laparoscopically harvested omental flaps have been shown to be successful in the long-term control of sternal and intrathoracic infections when muscle flaps have failed [12]. The use of minimally invasive techniques has also reduced the risk of intraabdominal complications associated with laparotomy [12]. In our center, we select the use of omental flap in patients with radionecrosis or chronic recalcitrant infections due to its intrinsic immunologic properties and malleability. Its pliable nature allows complete obliteration of small dead spaces, further reducing the risk of recurrent infections.

Skeletal stabilization of the chest wall is performed to improve postoperative pulmonary function in the first 2 weeks after resection [7, 13]. Larson compared preoperative and postoperative pulmonary function tests in patients with post-tumour resection skeletal defects and showed that reconstruction with musculocutaneous flaps alone resulted in postoperative improvement, proving that these flaps provided sufficient chest wall rigidity to maintain adequate pulmonary mechanics [2]. However, most surgeons will still agree that skeletal reconstruction is necessary in a defect larger than 5 cm [2] or if four or more ribs are resected [7, 13]. This is also the guideline that we adopt in our center.

Materials that have been described for skeletal reconstruction include Marlex mesh, acrylic cement, polytetrafluroethylene (Gore-Tex^{tm};WL Gore and Associates, Flagstaff, AZ) patches, polypropylene mesh, bone

cement, autologous bone, fascia grafts or a combination of materials (methylmethacrylate sandwiched between two sheets of prolypropylene mesh) [1, 3, 14]. Prosthetic materials are widely available, have no donor-site morbidity and can be easily shaped to fit the defect. Due to the limited amount of autologous tissue available for repairing large skeletal defects, composite resection and reconstruction of large chest wall disease would be impossible without prosthetic materials. In our experience, we found the use of prolene mesh and a combination of prolene mesh–methylmethacrylate cement sandwich useful for skeletal reconstruction. However, we had anecdotally observed that they were associated with a small risk of seroma formation and infection. Recently, we have begun to use Permacol^{tm} (Covidien, Dublin, Ireland), a biological mesh derived from porcine dermis composed of intact native collagen, extracellular matrix and basement membrane. These biological meshes are believed to be superior because they provide the necessary support in the early postoperative period but are eventually resorbed and incorporated over time, alleviating the risks of a permanent prosthesis [15]. Prosthetic materials are also useful for diaphragmatic reconstruction. It is crucial to reconstruct diaphragmatic defects to maintain functional integrity and prevent visceral herniation. Although successful primary repair of large diaphragmatic defects has been reported, we prefer to restore the surfaces in a tension-free manner with a Gore-tex^{tm} patch [16, 17].

Many algorithms for chest wall reconstruction have been proposed, but there is still no general consensus on a management algorithm. We found a combination of the algorithms as defined by Losken and Bosc to be most useful [6, 14]. Our choice of reconstruction requires the consideration of four factors—nature of defect, etiology, location and regional flap availability. We have included partial-thickness chest wall defects into the algorithm, further defined the role of free flaps and changed the recommended locoregional flaps for the various defect locations based on the findings of our study (Fig. 4). With the inclusion of these modifications, we find this to be the most comprehensive working algorithm for chest wall reconstruction.

Being the workhorse of chest wall reconstruction, it is important to preserve locoregional muscle flaps as much as possible. They are versatile for a variety of defects and can be used in combination for extensive chest wall defects. Most skeletal and diaphragmatic reconstruction can be safely accomplished with the use of prosthetic materials. Free flaps are usually only indicated for large defects or when regional flaps are unavailable.

Ethical standards This retrospective review was conducted according to the guidelines of the Institutional Review Board of Singapore General Hospital and therefore had been performed in accordance with the ethical standards set forth in the 1964 Declaration of Helsinki and it later amendments. Details that might disclose the identity of the subjects under study had been omitted.

Conflict of interest Ee Hsiang Jonah Kua, Hui Ling Chia, Terence L. H. Goh, Chong Hee Lim, Siew Weng Ng and Bien-Keem Tan declare that they have no conflict of interest.

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