Journal of Plastic Surgery and Hand Surgery

ISSN: 2000-656X (Print) 2000-6764 (Online) Journal homepage: http://www.tandfonline.com/loi/iphs20

Diaphragm reconstruction combined with thoraco-abdominal wall reconstruction after tumor resection

Hiroaki Kuwahara, Juho Salo & Erkki Tukiainen

To cite this article: Hiroaki Kuwahara, Juho Salo & Erkki Tukiainen (2017): Diaphragm reconstruction combined with thoraco-abdominal wall reconstruction after tumor resection, Journal of Plastic Surgery and Hand Surgery, DOI: 10.1080/2000656X.2017.1372292

To link to this article: http://dx.doi.org/10.1080/2000656X.2017.1372292

Published online: 31 Aug 2017.

JOURNAL OF PLASTIC SURGERY AND HAND SURGERY, 2017
https://doi.org/10.1080/2000656X.2017.1372292

ORIGINAL ARTICLE

Diaphragm reconstruction combined with thoraco-abdominal wall reconstruction after tumor resection

Hiroaki Kuwahara[a,b], Juho Salo[a] and Erkki Tukiainen[a]

[a]Department of Plastic Surgery, Helsinki University Hospital, Helsinki, Finland; [b]Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School Hospital, Tokyo, Japan

ABSTRACT

Background: Thoraco-abdominal wall resection including diaphragm resection results in a challenging surgical defect. Various methods have been used for diaphragm reconstruction. The aim of this study was to describe our methods of diaphragm and thoraco-abdominal wall reconstruction after combined resection of these anatomical structures.

Methods: Twenty-one patients underwent diaphragm resection at our institution between 1997 and 2015. We used a mesh or direct closure for diaphragm defect and a mesh for chest wall stabilization. A pedicled or free flap for soft tissue coverage was used when direct closure was not possible.

Results: Indications for resection were primary sarcoma ($n = 14$), cancer metastasis ($n = 4$), desmoid tumor ($n = 2$), and solitary fibrous tumor ($n = 1$). The median patient age was 58.9 years. The diaphragm was pulled to its original position and sutured directly ($n = 15$) or reconstructed with mesh ($n = 6$). Chest wall reconstructions were performed with a mesh ($n = 14$), mesh and a pedicled flap ($n = 4$), mesh and a free flap ($n = 3$). No perioperative mortality occurred. One-year and 5-year survival rates were 85.7 and 65.9%, respectively, while overall recurrence-free rates were 80.4 and 60.8%, respectively.

Conclusions: We have described our surgical methods for the resection of tumors of the chest or abdominal wall, including our method of distal diaphragm resection with wide or clear surgical margins. The method is safe and the reconstructions provided adequate stability, as well as water-tight and air-tight closure of the chest cavity. There were no cases of paradoxical movement of the chest or of diaphragm or thoraco-abdominal hernia.

ARTICLE HISTORY
Received 18 May 2017
Revised 28 July 2017
Accepted 18 August 2017

KEYWORDS
Chest wall; diaphragm; reconstruction; mesh; sandwich mesh method

Introduction

Chest wall reconstruction is most commonly indicated for bone and soft tissue sarcomas, metastatic or locally advanced breast cancer [1,2], or lung cancer with extension into the chest wall [3]. A chest wall tumor can originate primarily within the chest wall, develop as local recurrence from a previously excised chest wall lesion, or present as metastasis invading or growing into the chest wall and diaphragm [4,5]. Diaphragm reconstruction is vital because the diaphragm separates the thoracic cavity and abdominal cavity and has an important role in respiratory function. The diaphragmatic defect should be reconstructed in order to restore proper respiratory function and prevent the development of a hernia [6]. If not properly reconstructed, resection of the thoraco-abdominal wall and diaphragm can lead to paradoxical movement of the chest or hernia.

The primary goals for chest wall reconstruction are obtaining water-tight and air-tight closure of the chest cavity with adequate soft tissue coverage and to maintain function of the chest wall and diaphragm. In this report, we retrospectively review our cases of diaphragm reconstruction combined with chest wall defect and describe our approach for repairing thoraco-abdominal wall defects combined with diaphragm defects.

Material and methods

Between 1997 and 2015, 21 patients (male and female; age: 23–81 years; mean age: 58.9 years) underwent diaphragm resection and reconstruction, in combination with thoraco-abdominal wall reconstruction, in the Department of Plastic Surgery at Helsinki University Hospital in Helsinki, Finland. Informed consent was obtained from all patients. Preoperatively, plain chest radiography and computed tomography were performed for trunk examination, and magnetic resonance imaging and/or ultrasonography (ultrasound-guided core needle biopsy) were performed on the tumor area, and these cases were discussed in the multidisciplinary tumor board. The outcome measures were recurrence and survival, as calculated using the Kaplan–Meier Method.

Chest wall and/or abdominal wall stabilization and large diaphragm defects were reconstructed with PROLENE® mesh (ETHICON, West Somerville, NJ), Proceed® surgical mesh (ETHICON, West Somerville, NJ), Parietex® composite mesh (Medtronic, Minneapolis, MN), Premilen® (B. Braun, Barcelona, Spain), and Gore-Tex® mesh (W. L. Gore & Associates, Flagstaff, AZ). If the diaphragm defect was <3–4 cm, the diaphragm was pulled directly and sutured to the mesh on thoraco-abdominal wall. In one extensive case (patient number 15; Tables 1 and 2), methyl methacrylate embedded between two layers of an artificial mesh [sandwich mesh method (SMM)] was used to provide additional

CONTACT Hiroaki Kuwahara hiroaki-pc@nms.ac.jp Department of Plastic, Reconstructive and Aesthetic Surgery, Nippon Medical School Hospital, 1-1-5 Sendagi, Bunkyo-ku, Tokyo, 113-8602, Japan

Table 1. Patient characteristics and surgical treatment.

No.	Sex	Age	BMI	Definite diagnosis (Grade)	Rib resection (No.)	Diaphragm resection (cm)	Chest wall reconstruction	Diaphragm reconstruction	Type of mesh	Date of operation (year/month)
1	Male	48	37	MFH (4)	2	1	Mesh + free TFL	Re-sutured	Prolene	1997/1
2	Female	34	18.9	Melanoma metastasis	2	2	Mesh	Re-sutured	Prolene	1998/3
3	Male	48	33.5	Chondrosarcoma (2)	5	5	Mesh	Mesh	Premilen + Gore-Tex	2001/9
4	Male	59	27.5	Myxoid liposarcoma (3)	3	3	Mesh	Re-sutured	Prolene	2003/8
5	Male	77	22.8	Chondrosarcoma (2)	2	6–7	Mesh	Mesh	Parietex	2004/11
6	Female	59	26.4	Chondrosarcoma (high)	2	3	Mesh	Re-sutured	Uk	2005/9
7	Female	55	17	Skin cancer metastasis	2	2	Mesh + pedicled LD	Re-sutured	Prolene	2006/3
8	Male	53	43.9	Chondrosarcoma (1)	2	4	Mesh	Mesh	Prolene	2007/5
9	Male	76	26.8	Chondrosarcoma (2)	3	2	Mesh	Re-sutured	Prolene	2009/4
10	Female	76	27.3	Desmoid tumor	3	2	Mesh	Re-sutured	Prolene	2009/4
11	Female	50	31.1	MFH (4)	5	3	Mesh	Re-sutured	Parietex	2009/9
12	Male	54	26.8	Chondrosarcoma (3)	3	5	Mesh	Mesh	Proceed	2010/10
13	Male	68	25.9	MFH (4)	4	2	Mesh + free TFL	Re-sutured	Parietex	2011/9
14	Male	57	25.3	Chondrosarcoma (2)	4	2	Mesh + free TFL	Re-sutured	Parietex	2011/12
15	Female	73	29.9	Ovarian carcinoma metastasis	3	4	SMM + pedicled LD	Mesh	Prolene	2012/10
16	Male	71	23.9	Desmoid tumor	2	3	Mesh	Re-sutured	Prolene	2012/8
17	Female	81	22.6	Adenocarcinoma metastasis	1	1	Pedicled LD	Re-sutured	None	2014/4
18	Male	23	24.7	Synovial sarcoma (4)	3	2	Mesh	Re-sutured	Parietex	2014/10
19	Male	52	25.5	Chondrosarcoma (2)	3	2	Mesh + pedicled LD	Re-sutured	Parietex	2014/12
20	Female	50	Uk	Solitary fibrous tumor	2	6	Mesh	Mesh	Parietex	2015/5
21	Male	74	25.3	Chondrosarcoma (1)	2	3	Mesh	Re-sutured	Parietex	2015/9

Uk: unknown; BMI: body mass index; TFL: tensor fascia lata musculocutaneous flap; LD: latissimus dorsi muscle; DM: diabetes mellitus

stability because the defect was large and with a part of the sternum resected.

Surgical procedure

Tumor resection

A skin incision was made or skin resection was done according to our standard procedures for each tumor (2–3-cm margin) [7,8]. Then, radical en bloc excision of the chest wall and/or abdominal wall (including the ribs, adjacent muscles, pleura, soft tissues of abdominal wall, peritoneum, and diaphragm) was performed. The diaphragm was resected because it provided a natural barrier for both tumors located just above or below it (Figure 1).

Thoraco-abdominal wall and diaphragm reconstruction

When a defect is located in the thoraco-abdominal region, it is important to consider maintaining a diaphragmatic dome to create a functional diaphragm (Figure 2). If the diaphragm resection was more than 3–4 cm (Figure 3), mesh was required for reconstruction because the diaphragm cannot be pulled to its original position with too much tension. An artificial mesh was inserted in the area of the diaphragmatic defect and sutured with 0 or 1/0 polypropylene and/or polyester sutures, with a sufficient margin. If the chest wall defect was large and stabilization was needed, mesh reconstruction was used. For chest wall defects located on the sternal area and larger than 10 × 10 cm, SMM was required for chest wall stabilization: methyl methacrylate cement was placed between two layers of polypropylene mesh (Figures 4–6), as reported in other studies [9,10]. The cement should be 1–2-cm smaller than the defect in order to avoid disturbing thoracic motion.

Chest wall reconstruction began with the suturing of a mesh from cranially. For the diaphragm reconstruction, the diaphragm (or diaphragm with mesh) was pulled distally and radially/laterally to its original position and sutured to the thoraco-abdominal wall reconstruction mesh (Figure 7). Then, the abdominal part of the defect is reconstructed by suturing the mesh into the muscular layers of the abdominal wall, and soft tissue coverage was achieved with direct closure or flap reconstruction. According to the size of the defect, location and reconstructive options, either latissimus dorsi pedicled flaps or tensor fascia lata free flaps were selected in our series (Table 1). Generally, one subcutaneous drain and one sub-diaphragmatic drain were placed.

Results

Indications for resection were primary sarcoma ($n = 14$), cancer metastasis ($n = 4$), desmoid tumor ($n = 2$), and solitary fibrous tumor ($n = 1$). The median patient age was 58.9 (23–81) years.

The diaphragm was pulled to its original position and sutured directly ($n = 15$) or reconstructed with mesh ($n = 6$). Chest wall or abdominal wall reconstructions were performed with mesh ($n = 14$), while chest wall defects with large soft tissue defects were reconstructed with a mesh and a free flap ($n = 3$), mesh and a pedicled flap ($n = 3$), and SMM and a pedicled flap ($n = 1$). We used tensor fascia lata musculocutaneous flaps for three patients and the pedicled latissimus dorsi musculocutaneous flaps for four patients. No perioperative mortality or flap loss occurred. One-year and 5-year survival rates were 85.7 and 65.9%, respectively, while overall recurrence-free rates were 80.4 and 60.8%, respectively (Figure 8). The mean intensive care unit and hospital stays were 2.4 and 12.3 days, respectively. In 16 cases, a histologically clear margin was achieved in tumor resection. However, clear

Table 2. Surgical outcomes.

No.	Defect size[a] (cm × cm)	ICU days	Hospital days	Past history	Extubation	Complications	Revision	Follow up (month)
1	13 × 30	4 (+5)	26	HT	ICU	Sepsis, venous thrombosis flap partial necrosis	Vein graft, skin graft	196[b]
2	6 × 14	5	10		ICU			6[c]
3	20 × 20	2	15		ICU			176
4	10 × 7	0	7		OR			34[c]
5	Uk	5	13	HT, COPD, HF, MI	ICU			27[b]
6	5 × 9	0	12	HT	OR			128
7	13 × 10	1	11		ICU			2[c]
8	9 × 7	3	10	HT	ICU			108
9	14 × 16	4	7	Af, HF, MI	ICU			86
10	13 × 6	4	10		ICU			86
11	16 × 18	1	17	HT	ICU	Wound infection		81
12	22 × 14	1	31		OR			2[c]
13	15.5 × 16	4	21	Af, MI	ICU			57
14	17 × 11	4	15		ICU			54
15	19 × 11	3	8		ICU	Flap partial necrosis	Simple suture	43[c]
16	8.5 × 8	0	6	DM, HT	OR			50
17	14 × 11	1	10	BA, HT	ICU	Pulmonary embolism		26
18	13 × 12	0	8		OR			20
19	16 × 11	1	9		ICU			18
20	9 × 15	0	7	DM, HT, hypothyroidism	OR			13
21	9 × 9	2	5	HT, Af	ICU	Pneumonia		9

[a]Thoraco-abdominal wall defect.
OR: operating room; ICU: intensive care unit; DM: diabetes mellitus; HT: hypertension; COPD: chronic obstructive pulmonary disease; HF: heart failure; Af: atrial fibrillation; MI: myocardial infarction.
[b]Died of a different disease.
[c]Died of the involved disease.

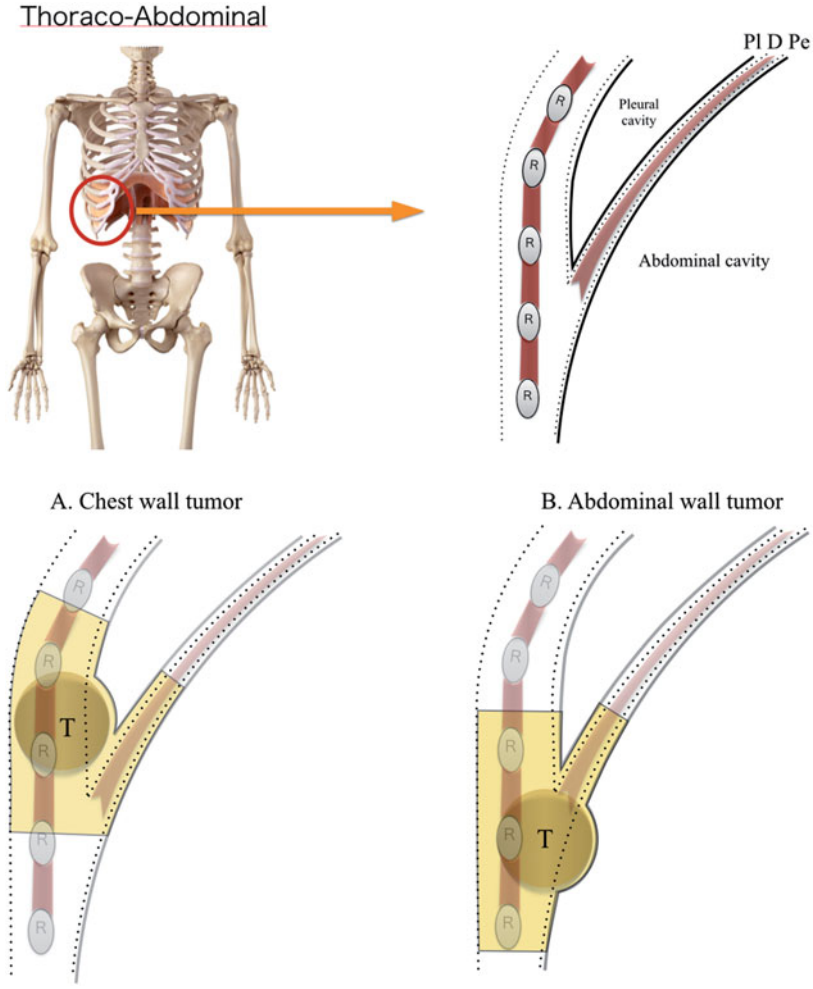

Figure 1. If tumor exists within the thoraco-abdominal wall, then diaphragm resection and reconstruction may be necessary depending on the tumor location. R: rib; Pl: pleura; D: diaphragm; Pe: peritoneum; T: tumor.

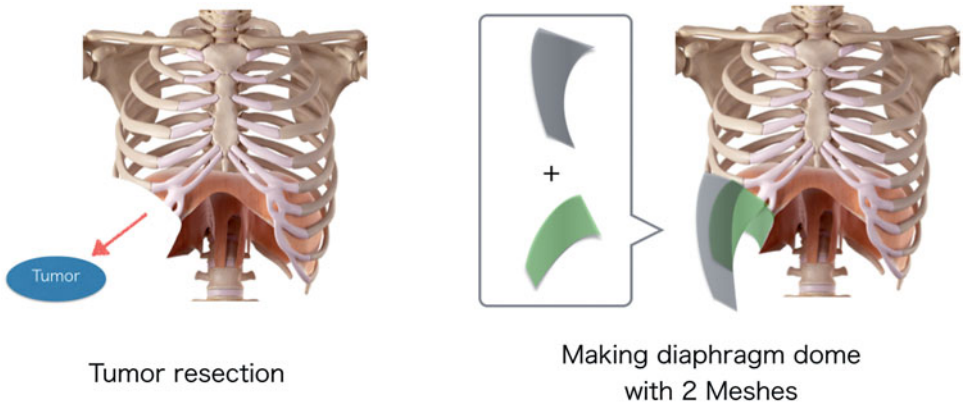

Figure 2. For defects located in the thoraco-abdominal region, creating a diaphragmatic dome is important for a functional diaphragm.

margins were not achieved in five cases [$n = 2$ metastatic tumors (ovarian carcinoma, squamous cell carcinoma), $n = 1$ multifocal synovial sarcoma, $n = 1$ grade 3 chondrosarcoma, $n = 1$ desmoid tumor]. In all five cases, the biological behavior of the tumors explains these results.

Although resection of two to five ribs was performed for all patients, none of the patients had paradoxical respiratory movement postoperatively. Small distal flap necrosis occurred in two patients and wound infection occurred in one patient. One venous thrombosis was corrected with re-anastomosis. Six patients were extubated in the operating room and the others were extubated in the intensive care unit within five postoperative days. The mean intensive care unit and hospital stays were 2.4 and 12.3 days, respectively. During follow-up, there was no late mesh infection (Tables 1 and 2).

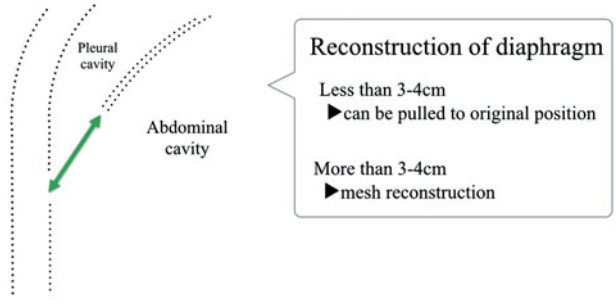

Figure 3. Green two-way arrow indicates the distance between the edge of the diaphragm and the chest wall. If the distance is more than 3–4 cm, then reconstruction with a mesh is necessary. If less than 3–4 cm, the edge of the diaphragm can be pulled to its original position.

Discussion

Our goals of chest wall reconstruction were chest wall stability, water-tight and air-tight closure, and acceptable cosmetic appearance. The most common clinical indication for this procedure was sarcoma [4]. This was not surprising since extensive full-thickness chest wall resections are performed for most primary sarcomas or local recurrences of breast cancer, and since the chest wall is a site of radiation-induced sarcoma.

In this report, we retrospectively reviewed our cases of thoraco-abdominal wall resection and reconstruction combined with diaphragm defect. Although there are many reports of diaphragm repairs for congenital diaphragmatic hernia, diaphragmatic eventration, or metastasis to the diaphragm from abdominal malignant tumors [11–15], there are few reports of diaphragm reconstruction combined with chest wall reconstruction or primary tumors of the diaphragm [16,17]. In this series, diaphragm was resected aiming to achieve an extra barrier for tumor growth.

Although we did not treat a primary tumor of the diaphragm in this study, if a tumor exists within the thoraco-abdominal region, then diaphragm resection and reconstruction may be required depending on the tumor location (Figure 1). Because the diaphragm separates the thoracic cavity and abdominal cavity and has an important role in respiratory function, it is important to restore it. The goals of diaphragm reconstruction are reliable separation of the thoracic and abdominal compartments, and maximization of residual pulmonary function [17]. If direct closure is too tight, this results in a flat drum-head diaphragm, which has very little function [18]. Numerous types of material and autologous reconstructions have been used for the purpose of diaphragm reconstruction, including alloplastic material such as

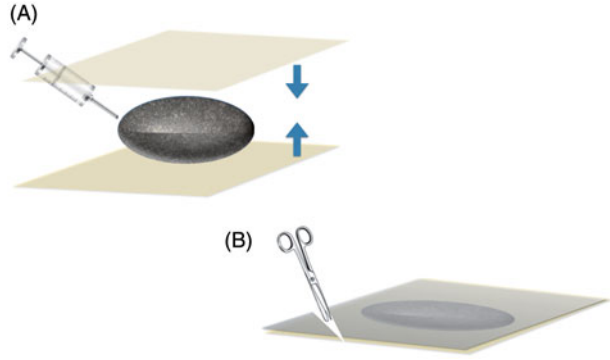

Figure 4. SMM: methylmethacrylate was embedded between two layers of mesh. (A) Methylmethacrylate was injected between two meshes using an exclusive syringe. (B) Excess mesh should be cut.

bovine or equine pericardial patch [19–21], and autologous reconstruction using the abdominal oblique muscle or transverse abdominal muscle [11], omentum, and latissimus dorsi flaps [17]. In addition, acellular cadaveric dermis may be an option. Buinewicz and Rosen [22] suggested that AlloDerm has similar success and benefits in the clinical setting because it provides durable and safe prosthetic support during ventral hernia repair.

Artificial material have traditionally been used for tissue reconstruction during thoracic and abdominal surgery. For example, expanded polytetrafluoroethylene and polypropylene have been used extensively because of their high tensile strength and reconstructive capabilities. Micro-porous mesh such as expanded polytetrafluoroethylene allows for fibrous ingrowths, resulting in soft tissue incorporation. Although these prostheses have widespread

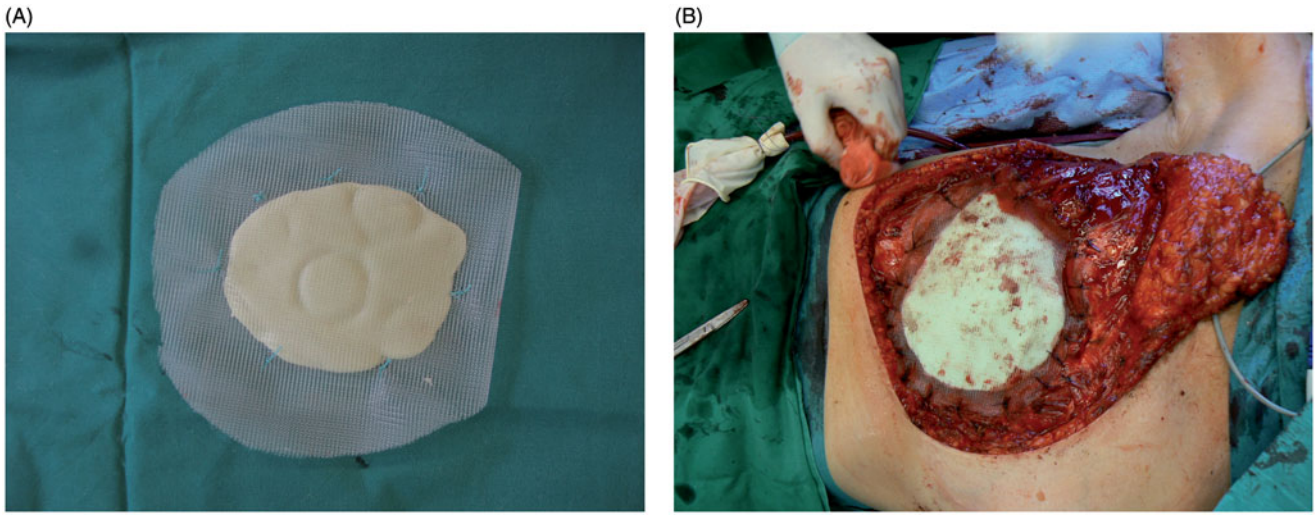

Figure 5. (A) Methylmethacrylate was embedded between two layers of mesh. (B) The cement should be 1–2-cm smaller than the defect in order to avoid disturbing thoracic motion.

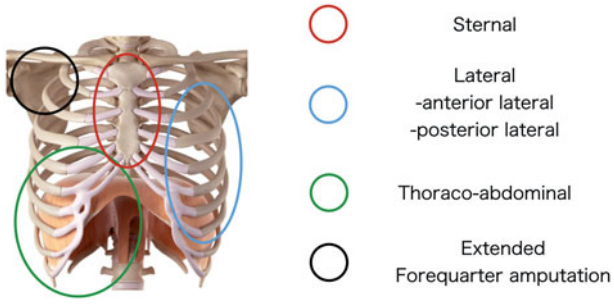

Figure 6. Areas of chest wall resection. Areas may overlap.

Figure 7. Artificial mesh was inserted into the diaphragm defect and sutured. Then, the other mesh was sutured into the chest wall defect. A suture line, which is located on the center part of the mesh indicates the diaphragm mesh.

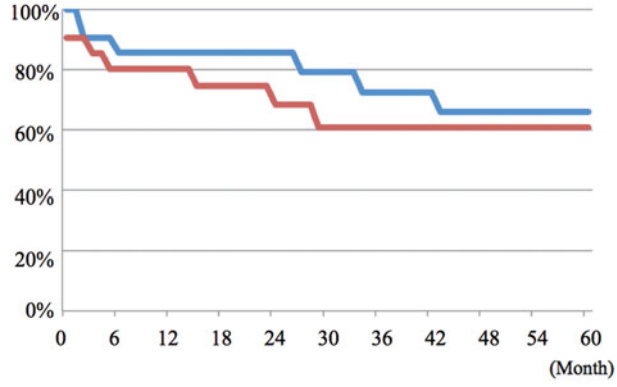

Figure 8. Kaplan–Meier curve of disease-free survival (red line) and overall survival (blue line).

use, complications such as hematoma, seroma, adhesion, inflammation/infection, allergic reaction, pain, hernia, fistula formation, and skin erosion have been observed [23]. Five types of synthetic material were used in our case series; and among these, we favored polypropylene mesh or Parietex® or PROCEED®. No differences were seen regarding complication rates, type of reconstruction method, diagnosis, and type of mesh used. Jacob et al. [24] reported that Parietex® composite mesh was superior to PROCEED® surgical mesh or polypropylene mesh, with less shrinkage, fewer and less dense adhesions, significantly stronger abdominal wall adherence, and tissue ingrowth at 28 days in an animal comparative study. Furthermore, Schreinemacher [25] suggested that Parietex® composite mesh significantly reduced adhesion formation at 7-day follow-up and 30-day follow-up. In this study, we preferred to use Parietex® composite mesh.

During this study, we discussed a method of diaphragm reconstruction and repair of chest wall defects located on the thoracoabdominal region. For partial thickness chest wall defects, extensive reconstruction is not necessary. If surgical margins demand, the diaphragm should be resected because this procedure does not increase morbidity. If the defect is located elsewhere on the other chest wall, then the size of the chest wall defect should be considered. In the case of defects smaller than 10×10 cm, reconstruction is performed using mesh alone; however, SMM is necessary if the defect is larger than 10×10 cm to provide additional stability. Moreover, direct closure of diaphragm defect is not recommended if the distance between the edge of the diaphragm and chest wall is more than 3–4–cm. Further investigation and future research are warranted to expand upon the results described in this study.

Conclusion

This study described our method of chest wall or abdominal wall tumor resections, including resection of the distal diaphragm, in

order to ensure a wide surgical margin. Our method of diaphragm reconstruction has low morbidity and mortality. These reconstructions involved adequate stability and water-tight and air-tight closure of the chest wall cavity. There were no cases of paradoxical movement of the chest or hernias.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

[1] Tukiainen E. Chest wall reconstruction after oncological resections. Scand J Surg. 2013;102:9–13.

[2] Micali E, Carramaschi FR. Extended V-Y latissimus dorsi musculocutaneous flap for anterior chest wall reconstruction. Plast Reconstr Surg. 2001;107:1382–1390.

[3] Voltolini L, Rapicetta C, Ghiribelli C, et al. Lung cancer with chest wall involvement: predictive factors of long-term survival after surgical resection. Lung Cancer. 2005;52:359–364.

[4] Popov P. Surgical treatment of soft tissue sarcomas. Helsinki: University Printing House; 2005.

[5] Yokoi K, Tsuchiya R, Mori T, et al. Results of surgical treatment of lung cancer involving the diaphragm. J Thorac Cardiovasc Surg. 2000;120:799–805.

[6] Gaissert H, Wilcox SR. Diaphragmatic dysfunction after thoracic operations. Thorac Cardiovasc Surg. 2016;64:621–630.

[7] Sampo M, Tarkkanen M, Huuhtanen R, et al. Impact of the smallest surgical margin on local control in soft tissue sarcoma. Br J Surg. 2008;95:237–243.

[8] Scandinavian Sarcoma Group. SSG XXIV. Recommendations for radiotherapy in bone and soft tissue sarcoma. Version 1, December 2015. Available from: http://www.ssg-org.net/wp-content/uploads/2011/05/SSG-RT-Guidelines-December-2015.pdf

[9] Rathinam S, Venkateswaran R, Rajesh PB, et al. Reconstruction of the chest wall and the diaphragm using the inverted Y Marlex methylmethacrylate sandwich flap. Eur J Cardiothorac Surg. 2004;26:197–201.

[10] Lardinois D, Muller M, Furre M, et al. Functional assessment of chest wall integrity after methylmethacrylate reconstruction. Ann Thorac Surg. 2000;69:919–923.

[11] Simpson JS, Gossage JD. Use of abdominal wall muscle flap in repair of large congenital diaphragmatic hernia. J Pediatr Surg. 1971;6:42–44.

[12] Tsao K, Lally PA, Lally KP. Minimally invasive repair of congenital diaphragmatic hernia. J Pediatr Surg. 2011;46:1158–1164.

[13] Lee SL, Poulos ND, Greenhoiz SK. Staged reconstruction of large congenital diaphragmatic defects with synthetic patch followed by reverse latissimus dorsi muscle. J Pediatr Surg. 2002;37:367–370.

[14] Ikeda M, Sonobe M, Bando T, et al. Reconstruction of recurrent diaphragmatic eventration with an elongated polytetrafluoroethylene sheet. Interact Cardiovasc Thorac Surg. 2013;17:433–435.

[15] Juretzka MM, Horton FR, Abu-Rustum NR, et al. Full-thickness diaphragmatic resection for stage IV ovarian carcinoma using the EndoGIA stapling device followed by diaphragmatic reconstruction using a Gore-tex graft: a case report and review of the literature. Gynecol Oncol. 2006;100:618–620.

[16] Medeiros CW, Kondo W, Baptista I Jr, et al. Primary rhabdomyosarcoma of the diaphragm: case report and literature review. Rev Hosp Clin Fac Med Sao Paulo. 2002;57:67–72.

[17] Edington ED, Evans S, Sindelar WF. Reconstruction of a functional hemidiaphragm with use of omentum and latissimus dorsi flaps. Surgery. 1989;105:442–445.

[18] Bax NM, Colling DL. The advantages of reconstruction of the dome of the diaphragm in congenital posterolateral diaphragmatic defects. J Pediatr Surg. 1984;19:484–487.

[19] Zardo P, Zhang R, Wiegmann B, et al. Biological materials for diaphragmatic repair: initial experiences with the PeriGuard Repair Patch®. Thorac Cardiovasc Surg. 2011;59:40–44.

[20] Ricci KB, Higgins R, Daniels VC, et al. Bovine pericardial reconstruction of the diaphragm after a heart transplant. Exp Clin Transplant. 2014;12:277–278.

[21] Asai K, Watanabe M, Matsukiyo H, et al. Combined hepatic resection with the inferior vena cava and diaphragm and reconstruction using an equine pericardial patch: report of a case. Surg Today. 2011;41:1670–1673.

[22] Buinewicz B, Rosen B. Acellular cadaveric dermis (AlloDerm): a new alternative for abdominal hernia repair. Ann Plast Surg. 2004;52:188–194.

[23] Baldes N, Schirren J. Primary and secondary tumors of the diaphragm. Thorac Cardiovasc Surg. 2016;64:641–646.

[24] Jacob BP, Hogle NJ, Durak E, et al. Tissue ingrowth and bowel adhesion formation in an animal comparative study: polypropylene versus proceed versus parietex composite. Surg Endosc. 2007;21:629–633.

[25] Schreinemacher MH, Emans PJ, Gijbels MJ, et al. Degradation of mesh coatings and intraperitoneal adhesion formation in an experimental model. Br J Surg. 2009;96:305–313.