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RESEARCH

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Complications of chest wall around malignant tumors: differences based on reconstruction strategy

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Abstract

Background Malignant chest wall tumors need to be excised with wide resection to ensure tumor free margins, and the reconstruction method should be selected according to the depth and dimensions of the tumor. Vascularized tissue is needed to cover the superficial soft tissue defect or bone tissue defect. This study evaluated differences in complications according to reconstruction strategy.

Methods Forty-five patients with 52 operations for resection of malignant tumors in the chest wall were retrospectively reviewed. Patients were categorized as having superficial tumors, comprising Group A with simple closure for small soft tissue defects and Group B with flap coverage for wide soft tissue defects, or deep tumors, comprising Group C with full-thickness resection with or without mesh reconstruction and Group D with full-thickness resection covered by flap with or without polymethyl methacrylate. Complications were evaluated for the 52 operations based on reconstruction strategy then risk factors for surgical and respiratory complications were elucidated.

Results Total local recurrence-free survival rates in 45 patients who received first operation were 83.9% at 5 years and 70.6% at 10 years. The surgical complication rate was 11.5% (6/52), occurring only in cases with deep tumors, predominantly from Group D. Operations needing chest wall reconstruction ($p = 0.0016$) and flap transfer ($p = 0.0112$) were significantly associated with the incidence of complications. Operations involving complications showed significantly larger tumors, wider areas of bony chest wall resection and greater volumes of bleeding ($p < 0.005$). Flap transfer was the only significant predictor identified from multivariate analysis (OR: 10.8, 95%CI: 1.05–111; $p = 0.0456$). The respiratory complication rate was 13.5% (7/52), occurring with superficial and deep tumors, particularly Groups B and D. Flap transfer was significantly associated with the incidence of respiratory complications ($p < 0.0005$). Cases in the group with respiratory complications were older, more frequently had a history of smoking, had lower FEV1.0% and had a wider area of skin resected compared to cases in the group without respiratory complications ($p < 0.05$). Preoperative FEV1.0% was the only significant predictor identified from multivariate analysis (OR: 0.814, 95%CI: 0.693–0.957; $p = 0.0126$).

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Conclusions Surgical complications were more frequent in Group D and after operations involving flap transfer. Severe preoperative FEV1.0% was associated with respiratory complications even in cases of superficial tumors with flap transfer.

Keywords Chest wall, Malignant, Surgical complication, Respiratory complication, Reconstruction, Flap, FEV1.0%

Background

Primary and metastatic malignant tumors arising around the chest wall represent about 5% of all thoracic malignancies [1]. For local control, wide resection with tumor-free margins is recommended [2] and strategies for wide resection and reconstruction differ according to the location and depth of the tumor. The thoracic wall consists of many layers of various tissues, including the skin, fat, pectoralis major (PM) and minor muscles, serratus anterior muscle, latissimus dorsi muscle (LD), intercostalis muscles, rib bones and pleura [3]. Superficial malignant tumors, categorized in this study as tumors located in the superficial layers and able to be resected without bone resection, mainly originate from soft tissue tumors. Wide resection results in a loss of soft tissues and occasionally a need for skin graft or musculocutaneous flap [4]. For soft-tissue transfer, vascularized tissue is needed to cover the thoracic wound, control infection and reduce dead space [5].

Deep malignant tumors, categorized in this study as tumors located in deep layers and requiring bone resection, originate from soft tissue and bone tumors. Wide resection results in a loss of costal or sternal bone and thus encounters the critical problem of chest wall reconstruction [6]. The strategy for chest wall reconstruction is decided by considering the resection area, scapular trapping, respiratory function, stability of the chest wall, organ protection, and organ herniation after bone resection [7, 8]. Flap transfer or artificial materials such as a mesh are used to cover the thoracic wound, control infection, stabilize the chest wall, cover the chest cavity, and reduce dead space. Using non-rigid reconstruction, good outcomes have been reported for resection of 1–5 ribs and defects with sizes of 80–352 cm^2 with suture stabilization, flap and mesh [9–11]. On the other hand, common indications for the need for rigid reconstruction are chest wall defects>5 cm in diameter or >10 cm in diameter around the scapula [6, 12]. Several authors have reported rigid reconstruction by minimum resection of three ribs [13–15]. However, Weyant et al. adopted rigid reconstruction for resections ranging from 1 to 8 ribs and 23 to 1200 cm^2 [12]. In the posterior area, full-thickness resection carried a high risk of scoliosis [15–18] and we previously suggested that rigid reconstruction should be considered for posterior lesions to diminish scoliosis even with defects under 10 cm in diameter [15]. As above, strict indications for defect reconstruction have yet to be decided. The reconstruction strategy is mostly dependent on the experience and decisions of the surgeon [19, 20].

With the wide variety of treatment strategies available for malignant chest wall tumors, reconstruction methods can be categorized into four broad groups based on the depth of the tumors with or without bone resection and with or without flap transfer. In this study, superficial tumors that were able to be resected without bone resection were divided into Group A with simple closure for small soft tissue defects, and Group B with flap coverage for wide soft tissue defects. Deep tumors requiring bone resection were divided into Group C with full-thickness resection with or without mesh reconstruction, and Group D with full-thickness resection covered by flap with or without polymethyl methacrylate (PMMA).

Given this, we hypothesized that surgical and respiratory complications would be affected by differences in reconstruction methods. The purposes of this study were to elucidate the surgical and respiratory complications associated with resection and reconstruction of the chest wall around malignant tumors and to clarify differences in the incidences of these complications in the four groups. Such results would allow the prediction of complication risks for planned operations and facilitate informed decision-making on treatment strategies for patients with severe medical problems.

Methods

This study enrolled 45 patients who underwent 52 operations with wide resection of a primary, recurrent or metastatic malignant tumor in the chest wall between 1997 and 2021 at Mie University Hospital. Our criterion for complete resection was aiming to achieve with wide margin of at least 2 cm of normal tissue surrounding the tumor. Pulmonary combined excision was not included in these operations. Histopathological diagnoses were verified by independent pathologists. All patients were retrospectively reviewed using data collected from hospital records and follow-up information.

Superficial tumors were categorized as tumors located in superficial layers and able to be resected without bone resection. Deep tumors were categorized as tumors located in deep layers and requiring bone resection. Patients were categorized as described above into Group A (simple closure for small soft tissue defect), Group B (flap coverage for wide soft tissue defect), Group C (full-thickness resection including pleura with or without mesh reconstruction), and Group D (full-thickness resection including pleura covered by flap with or without PMMA) (Fig. 1). Resections involving three or more ribs were reconstructed with Marlex mesh (Bard, Cranston, RI) or BARD mesh or covered by flap transfer. In cases involving sternum resection, rib resection exceeding 5 cm, or re-resection of ribs due to recurrence, rigid reconstruction was performed. Rigid reconstruction utilized a modified sandwich method, employing a combination of mesh and PMMA (Simplex P; Stryker Howmedica Osteonics, Mahwah, NJ). The PMMA was usually used for component fixation in artificial joint replacement. PMMA was reshaped to be smaller than the bone defect in the chest wall and was sandwiched using double-layer or quadri-layer mesh. The mesh surrounding the PMMA was sutured to securely affix the prosthetic in place using 3−0 proline or nylon. Excess mesh was trimmed, and 1−0 nylon sutures were meticulously tightened between the bone or soft tissue and mesh. Flap reconstruction was performed by LD or PM, and the wound was closed. We chose the sandwich method because of the poor long-term results of titanium plates [21] and the good long-term results of the sandwich method [22].

Adjunctive therapy such as systemic chemotherapy and radiotherapy was performed in several cases. Preoperative radiotherapy was performed in two operations, while postoperative radiation therapy was administered in ten operations. Preoperative chemotherapy was administered in two cases of leiomyosarcoma resection, while postoperative chemotherapy was administered in one case of rhabdomyosarcoma surgery. Pre- and postoperative chemotherapy were performed in three cases with resection of Ewing's sarcoma, one case of osteosarcoma resection, and one case with resection of hepatocellular carcinoma.

Preoperative respiratory function was tested for 47 operations and evaluated values including the percentage predicted forced expiratory volume in 1 s (FEV1.0%, calculated as FEV1.0/FVC) and percentage vital capacity (%VC, calculated as VC/predicted VC). In the postoperative period, the duration of opioid administration was assessed, along with the commencement time for ambulation activities.

Statistical analyses included the comparison of various parameters using the Mann–Whitney test for quantitative data. Fisher's exact test was utilized for qualitative

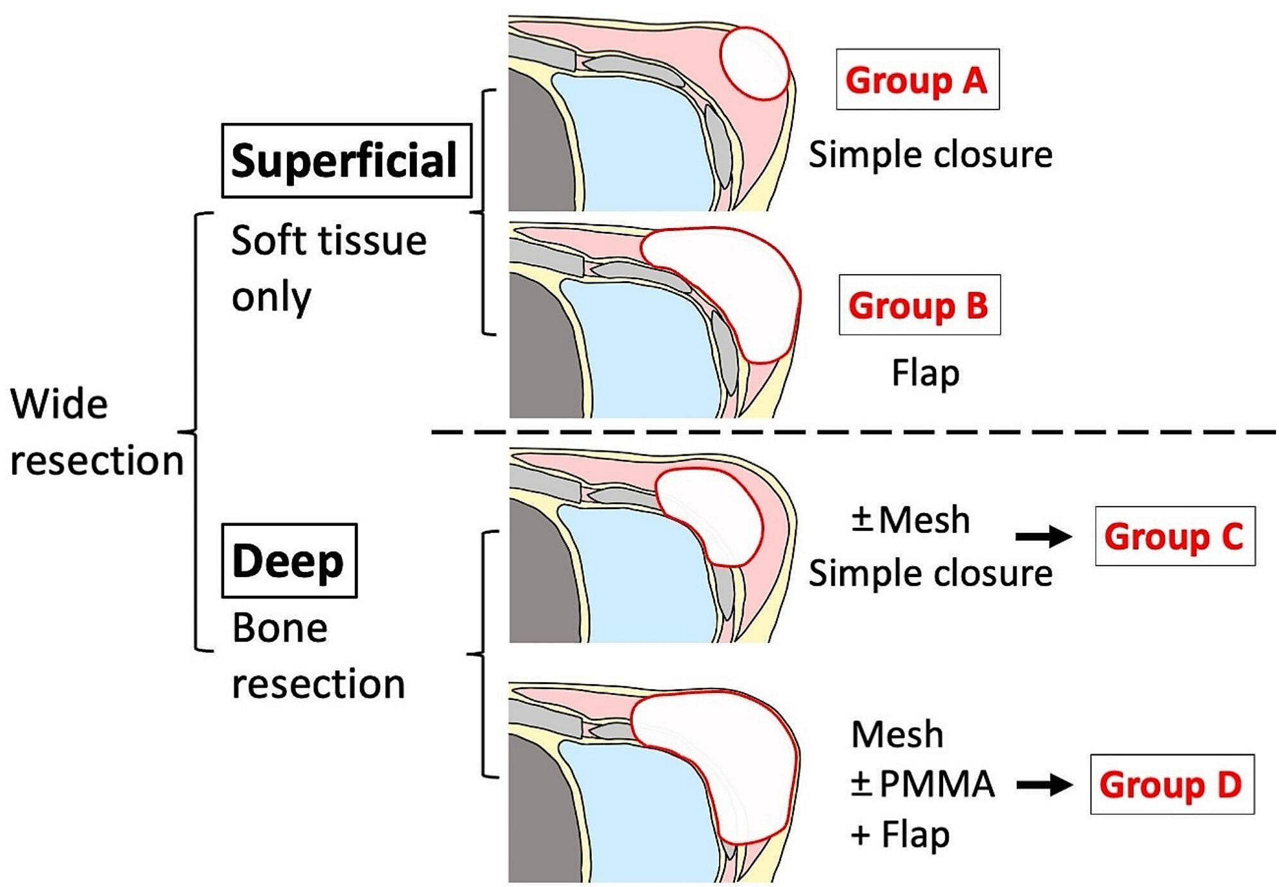

Fig. 1 Groups based on resection and reconstruction. (A) Resection of soft tissue only applied to Groups A (simple closure) and B (with flap transfer). Bone resection applied to Groups C (simple closure), and D (with flap transfer)

data. Local recurrence-free survival (LRFS) was defined as the duration from the time of operation to the documented date of local recurrence. Kaplan–Meier survival plots and log-rank tests were employed to assess differences in the time interval to local recurrence. A significance level of $p<0.05$ was considered statistically significant. All statistical analyses were conducted using the EZR software [23].

Results

Patient and tumor characteristics

We analyzed a total of 45 patients (27 males, 18 females) who had undergone 27 operations for primary tumors, 9 operations for metastatic tumors and 9 operations for tumors that had been inadequately resected in a previous hospital. An additional 7 operations were performed for tumor recurrence after resection. The mean age of patients was 55 years (range, 1–84 years) and mean tumor size was 7.5 cm (range, 2.5–23 cm). Wide resection was performed in all cases. Histopathological diagnoses are presented in Table 1. Superficial tumors originated from soft tissue sarcomas and deep tumors originated from bone and soft tissue sarcomas and carcinomas. Metastatic tumors were mainly located in deep areas because of metastasis to bones (Table 1). Eleven patients had low-grade tumors and 34 patients had high-grade tumors. R0 was 27 patients, R1 was 5 patients, and R2 was 1 patient.

The remaining 12 patients could not be determined from the records.

Mean duration of follow-up was 83.1 months (range, 3.5–252.6 months). Total LRFS rate was 83.9% at 5 years and 70.6% at 10 years for first operations in our hospital, excluding operations for recurrence. Superficial tumors and high-grade tumors tended to show worse LRFS rates, although the difference was not significant (Fig. 2). For the analysis of complications, a total of 52 operations (including the 7 resections for tumor recurrences) were assessed. The difference between first operations and operations for recurrence is shown in Table 2. Even with recurrent tumors, aggressive resection including 3- or 4-rib resection and flap transfer was performed. Resection and reconstruction data for the four groups are shown in Table 3. With the 19 operations for superficial tumors, simple closure was performed for 15 operations (Group A) and flap transfer for 4 operations (Group B). With the 33 operations for deep tumors, full-thickness resection involving 1 to 7 ribs, sternal resection and pleura was performed. Simple closure including mesh reconstruction was performed in 21 operations (Group C) and flap transfer was performed in 12 operations (Group D). Rigid reconstruction using the sandwich method was performed for three primary/metastatic tumors and one recurrence.

Table 1 Histopathological diagnosis and tumor data

Histology	n = 45	Superficial	Deep
Liposarcoma	5	5	
Well-differentiated	(2)	2	
Dedifferentiated	(2)	2	
Pleomorphic	(1)	1	
Leiomyosarcoma	6		6
Myxofibrosarcoma	5	3	2
UPS	4	3	1
MPNST	1	1	
SFT (intermediate)	3	1	2
Synovial sarcoma	2	1	1
Rhabdomyosarcoma	1		1
DFSP	1	1	
Extraskeletal osteosarcoma	1		1
Chondrosarcoma	6		6
Ewing's sarcoma	3		3
Osteosarcoma	2		2
Hepatocellular carcinoma	2		2
Renal cell carcinoma	2		2
Metastatic meningioma	1		1
Bone tumor	18		18
Soft tissue tumor	27	15	12
Low grade	11	6	5
High grade	34	9	25
Size	2.5–23 cm (mean, 7.6)	2.5–16 cm (mean, 6.4)	2.5–23 cm (mean, 7.9)

Surgical complications

Surgical complications were encountered in 6 of the 52 operations (overall complication rate, 11.5%). Details of the complications are shown in Table 4. Hematoma was identified in two cases. In one instance, reoperation revealed no evident bleeding, and no further bleeding occurred. In the other case, the patient recovered with the assistance of thoracic drainage, but chronic seroma remained. Seroma was one of the major complications after flap harvesting. In this study, flap transfer was performed for 16 operations. Asymptomatic chronic seroma was observed in this patient for whom chronic seroma remaining. Extubation could not be performed in one case, necessitating noninvasive positive-pressure ventilation for only 12 h. Another case experienced cardiac effusion, which was managed by aspiration and did not recur. Partial flap necrosis was observed in one case and was addressed through debridement and wound closure. One case developed infection, which was successfully treated using wound irrigation, antibiotic therapy, and the application of negative-pressure wound therapy.

Using Fisher's exact test, all six operations with surgical complications had deep tumors (Table 5. $p=0.075$) and 5 of the 6 were in Group D. Operations needing chest

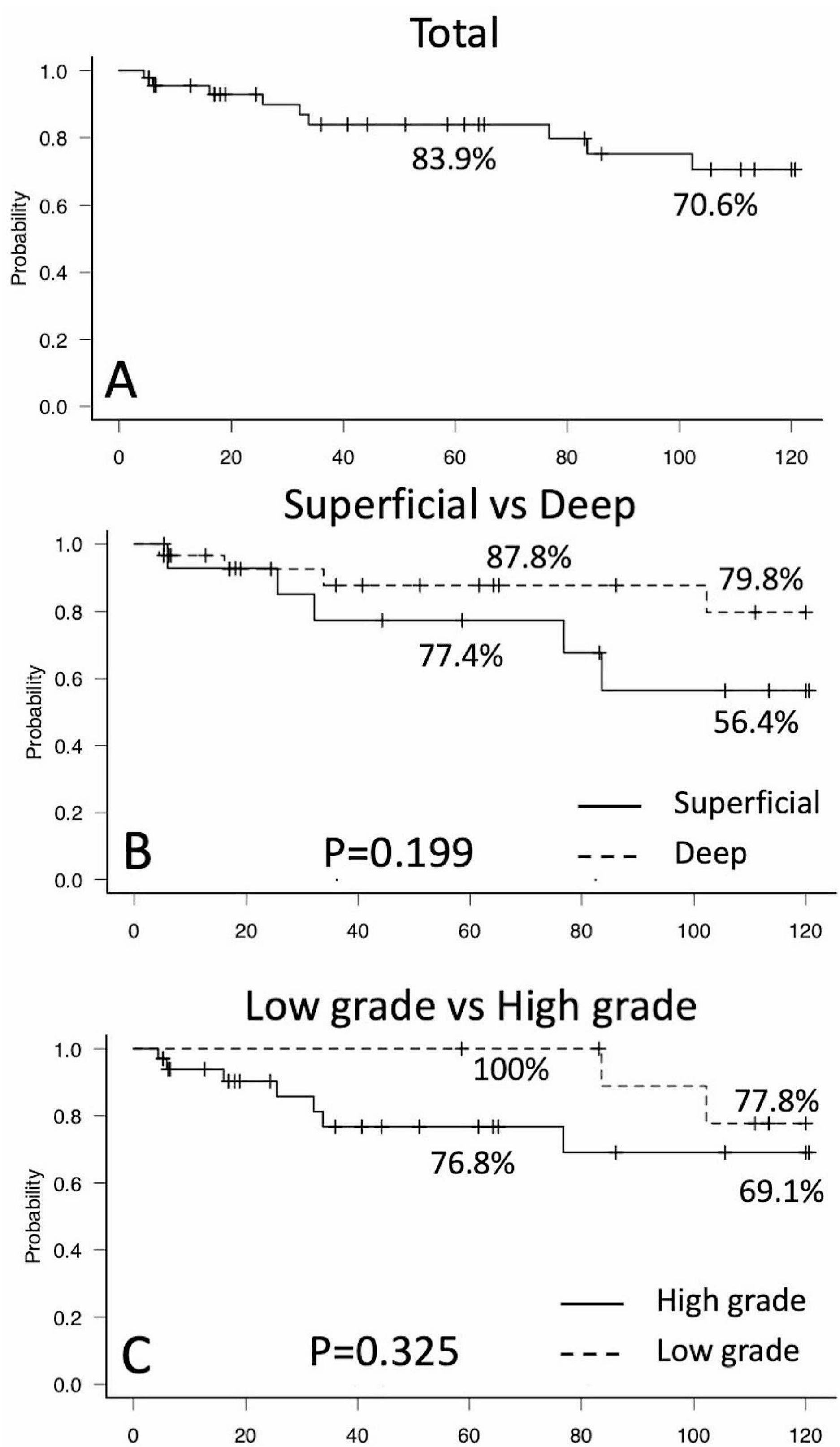

Fig. 2 LRFS in all patients. Five- and ten-year LRFS rates shown by Kaplan–Meier curve. **(A)** All patients; **(B)** superficial and deep tumors; **(C)** histologically high- and low-grade tumors. Log-rank values of $p < 0.05$ were considered statistically significant

Table 2 Surgical data in all operations at first wide resection and at resection of recurrent tumor

Depth	n	Group	n	Surgery	First operation	For recurrence
	52				45	7
Superficial	19				15	4
		A	15	Simple closure	12	3
		B	4	Flap	3	1
Deep	33				30	3
		C	21	Simple closure	17	
				Simple closure + mesh	4	
		D	12	Mesh + flap	6	2
				Mesh + PMMA + flap	3	1
Resected bone					45	7
				None	15	4
				1 rib	8	
				2 ribs	8	
				3 ribs	5	
				4 ribs	3	1
				7 ribs	2	
				Sternum	4	
Skin resection area (cm^2)					0-408 (mean, 34.1)	0-146.8 (mean, 68)
Bony chest wall resection area (cm^2)					16.5–387 (mean, 74.6)	109–115 (mean, 112)
Flap transfer (n)				Latissimus dorsi	10	3
				Pectoralis major		1
Operation time (h)					0.9–11 (mean, 3.7)	1.2–9.7 (mean, 5.4)
Bleeding (ml)					10-3170 (mean, 370)	50–720 (mean, 214)
Radiotherapy (n)					10	3
Chemotherapy (n)					8	

wall reconstruction (Table 5, $p<0.005$) and flap transfer (Table 5, $p<0.05$) were significantly associated with the incidence of complications. In Mann–Whitney test analysis, operations involving complications showed significantly larger tumors (Fig. 3A, $p<0.05$), wider areas of bony chest wall resection (Fig. 3B, $p<0.005$) and greater volumes of bleeding (Fig. 3C, $p<0.005$) compared to operations without complications. Logistic regression analyses to detect factors related to complications were performed. Univariate analysis indicated that size (OR: 1.2, 95%CI: 1.02–1.44; $p<0.05$) and flap transfer (OR 14.2, 95%CI 1.5–134; $p<0.05$) were significant factors (Table 6). With multivariate analysis, only flap transfer (OR: 10.8, 95%CI: 1.05–111; $p<0.05$) was a significant predictor of surgical complications (Table 6). In the deep group, the average duration of postoperative opioid administration was 2.1 days, which was significantly longer for the deep group than for the surface group (Table 3, $P<0.05$, Mann-Whitney test). The postoperative ambulation period was significantly slower in the deep group, averaging 2.4 days postoperatively for the superficial group and 4.8 days for the deep group (Table 3, $P<0.05$, Mann-Whitney test). However, these periods were not significant factor to detect surgical complications (Table 6). Six months after surgery, no one complained of wound pain and no analgesics were needed for operated chest.

Respiratory complications

Preoperative respiratory function was measured in 46 operations. Mean %VC was 104.6% (range, 48.2–155.5%) and mean FEV1.0% was 74.7% (range, 28.6–95%). Respiratory complications were defined as peri- or postoperative complications involving the respiratory system. Respiratory complications were encountered in 7 of the 52 operations, resulting in an overall respiratory complication rate of 13.5%. Among these, postoperative shortness of breath was seen in 6 cases, requiring noninvasive positive-pressure ventilation in 1 case. Medical Research Council Dyspnea Scale evaluation of 6 cases of postoperative shortness of breath showed that 1 was in 5 cases and 2 in 2 cases.

Respiratory complications occurred with both superficial and deep tumors ($p=1$, Fisher's exact test) and Groups B and D showed high complication rates. Flap

Table 3 Clinical and surgical data in all groups

		Superficial	Group A	Group B	Deep	Group C	Group D
Total		19	15	4	33	21	12
SEX	M/F	13/6	5/10	1/3	20/13	10/11	13/9
Age	yo	23–84	38–81	23–84	1–78	1–76	41–78
	(mean)	(61.4)	(62.1)	(59)	(53.7)	(46.8)	(65.8)
Size	cm	2.5–16	2.5–16	5.6-8	2.5–23	2.5–14	5–23
	(mean)	(7.2)	(7.3)	(6.9)	(7.7)	(6.3)	(10.1)
Smoke	n	14	11	3	15	6	9
		(73.7%)	(73.3%)	(75%)	(45.5%)	(28.6%)	(75%)
Cardiovascular diseases	n	12	10	2	6	5	1
		(63.2%)	(66.7%)	(50%)	(18.2%)	(23.8%)	(8.3%)
DM	n	3	3	0	2	2	0
		(15.8%)	(20%)	0	(6.1%)	(9.5%)	0
Pre ECOG PS	n (0/1)	17/2	14/1	2/1	30/3	20/1	10/2
Pre %VC	%	86-125.5	91–126	86–121	48–156	48–145	75-155.5
	(mean)	(107.1)	(108)	(103)	(103.2)	(102)	(105)
Pre FEV	%	28.6–85.3	44–85	29–69	48.6–95	61–95	49–91
	(mean)	(70.6)	(75)	(53)	(79.6)	(81)	(71)
Skin resection area	cm^2	0-112.3	0–57	85–112	0-408	0–63	0-408
	(mean)	(32.7)	(16.8)	(101.3)	(41.9)	(6.1)	(92.7)
Bony chest wall resection area	cm^2				16–387	17–108	46–387
	(mean)				(76.6)	(45.8)	(128)
Flap transfer	LD/PM	4		4	12		12
		(4/0)		(4/0)	(10/2)		(10/2)
Operation time	h	0.9–5.9	0.9–5.9	4.3–5.3	1.5–12.5	1.5–6.4	4-12.5
	(mean)	(2.4)	(1.8)	(4.8)	(5.1)	(2.8)	(8.5)
Bleeding	ml	10–900	10–900	50–208	19-3170	19-2800	52-3170
	(mean)	(131)	(137)	(105)	(461)	(414)	(540)
Radiotherapy	n	7	5	2	6	4	2
		(36.9%)			(18.2%)		
Chemotherapy	n	0	0	0	8	7	1
Post operative opioids	day	1	1	1	1–10	1–10	1–7
		(1)	(1)	(1)	(2.1)	(2.5)	(1.5)
Walking start	day	1–7	1–6	1–7	1–16	1–16	1–10
		(2.4)	(2.2)	(3.0)	(4.8)	(4.6)	(5.0)
Surgical complication	n	0			6		
					(18.2%)		
Respiratory complication	n	2			5		
		(10.5%)			(15.2%)		

Table 4 Surgical complication data

	Clavien-Dindo Classification	Age (years)	Tumor size (cm)	Skin resection area (cm^2)	Bony chest wall resection area (cm^2)	Bone resection	Reconstruction	Bleeding (ml)	Operation time (h)
Hematoma	IIIb	67	12	28.3	107.8	3 ribs	Mesh	751	4.4
Hematoma	IIIa	71	9	0	128	4 ribs	Mesh + LD	94	4
Seroma	IIIa								
Unable to extubate	IIIb	68	12.5	25.1	77.1	Sternum	Mesh + LD	100	7.6
Cardiac effusion	IIIa	41	5.6	25.1	100.6	Sternum	Mesh + PMMA + LD	400	9.4
Partial necrosis of flap	IIIb	50	23	408.2	134	4 ribs	Mesh + LD	700	11
Infection	IIIa	66	10	0	75.7	7 ribs	Mesh + LD	3170	12.5

Table 5 Comparison between presence and absence of surgical complications by Fisher's exact test

Superficial	19	0	0.075	A	15	0	0
				B	4	0	0
Deep	27	6		C	20	1	4.8%
				D	7	5	41.6%
Complication	**-**	**+**	**p-value**				
Reconstruction -	39	1	< 0.005				
Reconstruction +	7	5					
Flap -	34	1	< 0.05				
Flap +	12	5					

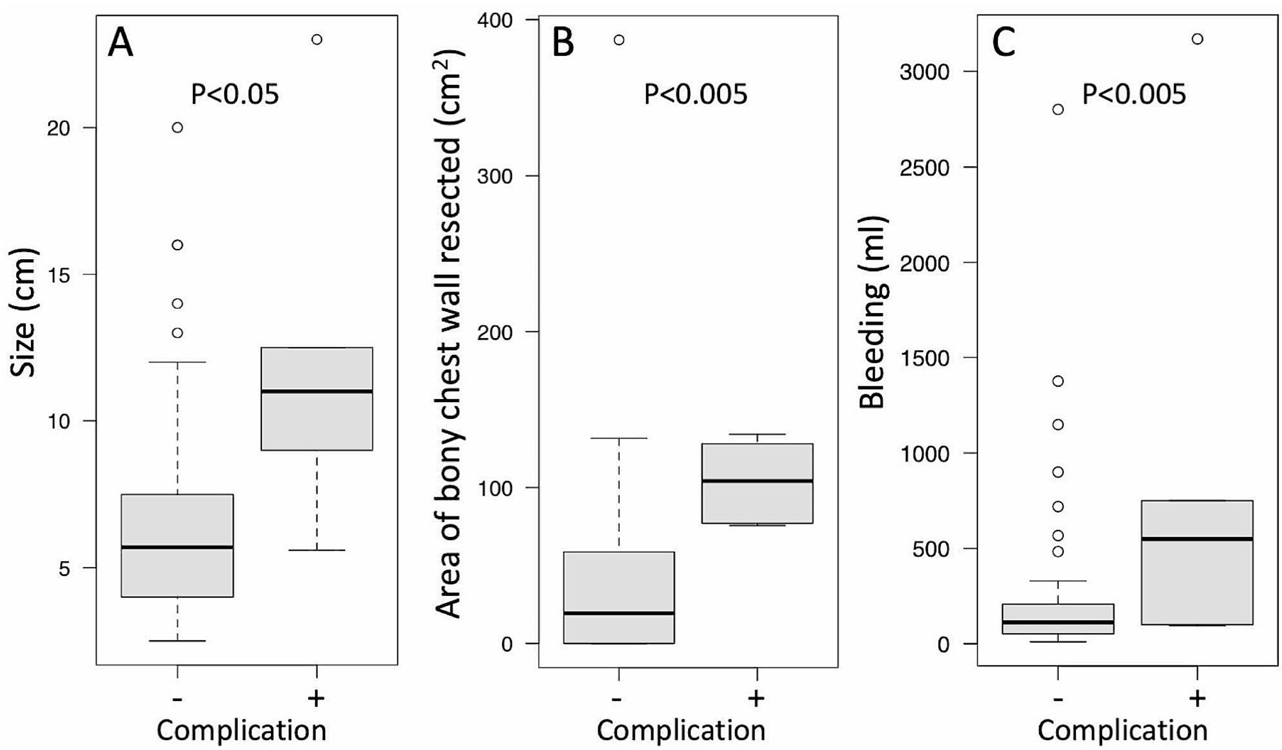

Fig. 3 Comparison with or without surgical complications. Each parameter was compared according to the presence (+) or absence (-) of surgical complications. **(A)** Size; **(B)** area of bony chest wall resected; and **(C)** bleeding. Log-rank values of $p < 0.05$ were considered statistically significant

transfer was significantly associated with the incidence of respiratory complications ($p < 0.0005$) (Table 7).

According to the Mann–Whitney test, cases in the group with respiratory complications were older (Fig. 4A, $p < 0.01$), more frequently had a history of smoking (Fig. 4B, $p < 0.05$), had lower FEV1.0% (Fig. 4D, $p < 0.0005$), had a wider area of skin resected (Fig. 4G, $p < 0.001$) and experienced a greater volume of bleeding (Fig. 4H, $p < 0.005$) compared to cases in the group without respiratory complications. Preoperative %VC (Fig. 4C), tumor size (Fig. 4E) and bony chest wall resection area (Fig. 4F) showed no significant differences between groups.

Logistic regression analyses for factors associated with respiratory complications were performed. Univariate analysis identified age (OR: 1.14, 95%CI: 1.01–1.3, $p < 0.05$) and preoperative FEV1.0% (OR: 0.827, 95%CI: 0.726–0.941, $p < 0.005$) as significant factors (Table 8). By multivariate analysis, only preoperative FEV1.0% (OR: 0.814, 95%CI: 0.693–0.957, $p < 0.05$) was a significant predictor of respiratory complications (Table 8). Postoperative respiratory rehabilitation was only performed after seven operations. Postoperative pneumonia was not observed after any operations. Perioperative radiation was performed in association with 12 operations. CT changes of radiation-induced pneumonitis were observed after four operations. Only one case was symptomatic and treated by medication.

Table 6 Logistic analysis of risk factors for surgical complications

Factor	OR	95%CI	p-value
Univariate			
Sex (M)	0.533	0.095–2.95	0.472
Age	1.01	0.96–1.06	0.604
Size	1.2	1.02–1.44	**< 0.05**
Smoking (+)	0.259	0.042–1.59	0.145
Smoking (pack-year)	1.02	0.94–1.12	0.601
Cardiovascular diseases	2.93	0.32–27.2	0.344
DM	1.69×10^{7}	/	0.995
Pre ECOG PS	5.91×10^{-8}	/	0.995
Pre %VC	1.02	0.97–1.06	0.507
Pre FEV1.0%	1.02	0.945-1.1	0.606
Skin resection area	1.01	0.997–1.02	0.176
Bone resection	6.99×10^{7}		0.994
Bony chest wall resection area	1.01	0.999–1.02	0.0833
Reconstruction	3.94×10^{8}	0	0.997
Flap	14.2	1.5–134	**< 0.05**
Bleeding	1	1	0.071
Radiation	0.567	0.06–5.35	0.62
Chemotherapy	1.11	0.113-11	0.926
Post operative opioids	1.07	0.73–1.56	0.733
Walking start	1.27	0.98–1.65	0.76
Multivariate			
Flap	10.8	1.05–111	**< 0.05**
Size	1.19	0.969–1.47	0.0969

Discussion

The efficacy of wide resection in achieving local control of malignant chest wall tumors has been evaluated by several authors. The local recurrence rate was 35% at 3 years and 11% at 5 years in sarcoma patients [24, 25], and 25% at 5 years and 59% at 10 years in sarcoma and carcinoma patients [1, 2]. LRFS rate was 64–88.5% at 5 years in sarcoma patients [15, 25, 26]. Our study included heterogeneous populations such as patients with superficial and deep tumors, and patients with sarcomas and carcinomas. Total LRFS rate was 83.9% at 5 years and 70.6% at 10 years. Our LRFS was not inferior to that in previous studies.

Previous studies have reported postoperative complication rates ranging from 12.6 to 33.2% for chest wall operations involving resection and reconstruction [5, 10, 12, 27, 28]. Surgical complications have been documented in these procedures, including local infection (2–17.3%), hematoma (2–9.1%), fistula (7.6%), pneumonia (1.08–11.3%), necrosis (1.9–22%), dehiscence (0–27%), respiratory failure (2.3–5.4%), and flap loss (2–27%) [19]. In our study, the overall surgical complication rate was 11.5% and we observed 2 cases of hematoma (3.8%), 1 case of respiratory failure (1.9%), 1 case of infection (1.9%), 1 case of partial flap necrosis (1.9%), and 1 case of asymptomatic chronic seroma (1.9%) (Table 4). Our results were comparable to rates reported in previous studies.

In previous studies about risk factors for complications, age, smoking, resected volume, number of ribs resected and pulmonary resection were reported as significant predictors of postoperative surgical complications [12, 29, 30]. In our cases, which did not include lung resection, most complications occurred in Group D (Table 5). According to the Mann–Whitney test, the surgical complication group showed larger tumors, a greater area of resection and greater bleeding (Fig. 3). According to Fisher's exact test, a higher incidence of surgical complications was observed with reconstruction and flaps (Table 5). In addition, multivariate logistic regression analysis showed only flap transfer (OR 10.8, 95%CI 1.05–111, $p=0.0456$) as a significant predictor of surgical complications (Table 6). Our criteria for chest wall reconstruction were resections involving three or more ribs or sternal resection and these wide tissue defects often need flap transfer. Given this, operations needing flap transfer for wide bony chest wall resection had a high risk of surgical complications. Conversely, two-rib resection without flap transfer can be performed with a low risk of surgical complications.

Several studies have evaluated respiratory function according to chest wall resection. Those reports included various numbers of resected ribs and various reconstruction methods and demonstrated that postoperative FEV1.0 and FVC tended to be reduced [14, 15, 28, 31]. Rib resection or a lower diffusion capacity of the lung for carbon monoxide and FEV1 (% predicted) were associated with postoperative respiratory complications [32]. Scarnecchia et al. found the incidence of postoperative acute respiratory complications was 100% in a non-reconstructed subgroup compared to 5.7% in a reconstructed subgroup [2]. In our data, postoperative respiratory complications occurred with 7 operations (13.5%), not only in Group D (full-thickness resection

Table 7 Comparison between presence and absence of respiratory complications by Fisher's exact test

Superficial	17	2	1	A	15	0	0
				B	2	2	50%
Deep	28	5		C	21	0	0
				D	7	5	41.6%
Complication	**-**	**+**	**p-value**				
Flap -	35	0	< 0.0005				
Flap +	10	7					

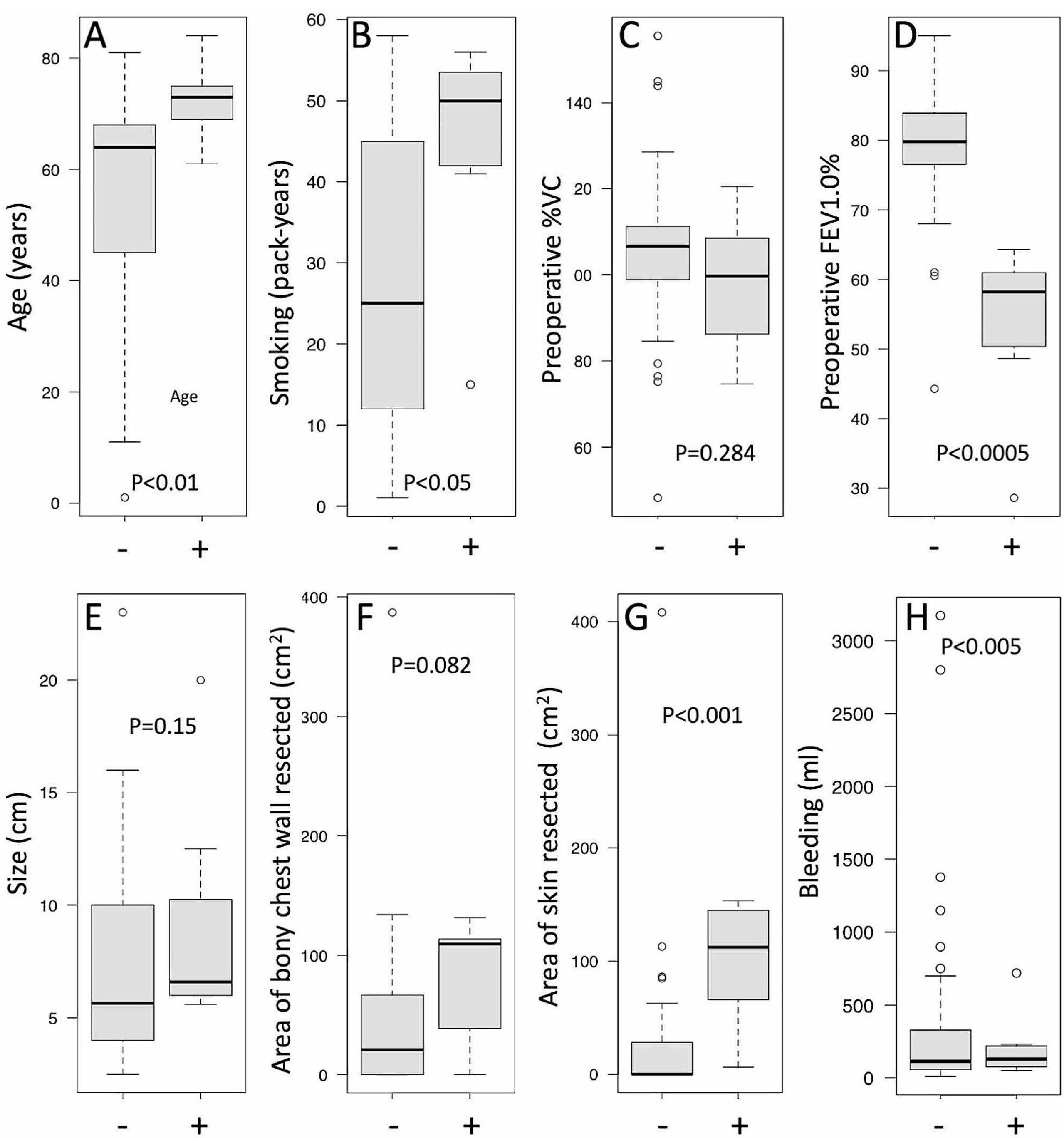

Fig. 4 Comparison with or without respiratory complications. Each parameter was compared according to the presence (+) or absence (-) of respiratory complications. **(A)** Age; **(B)** smoking history; **(C)** preoperative %VC; **(D)** preoperative FEV1.0%; **(E)** size; **(F)** area of bony chest wall resected; **(G)** area of skin resected; and **(H)** bleeding. Log-rank values of $p < 0.05$ were considered statistically significant

and flap), but also in Group B (soft tissue resection and flap) (Table 7).

The group with respiratory complications was older, with a higher frequency of smoking, lower preoperative FEV1.0%, and greater area of skin resection according to the Mann–Whitney test (Fig. 4). A higher incidence of respiratory complications was observed with use of flaps according to Fisher's exact test (Table 7). In multivariate logistic regression analysis, only preoperative FEV1.0% (OR: 0.814, 95%CI: 0.693–0.957, $p = 0.0126$) was a significant predictor of respiratory complications (Table 8).

After harvesting the LD or PM flap, wounds up to 8–10 cm in width can be closed primarily [4, 23]. In our series, donor sites for musculocutaneous flap (LD:

Table 8 Logistic analysis of risk factors for respiratory complications

	OR	95%CI	p-value
Univariate			
Sex (M)	4	0.443–36.1	0.217
Age	1.14	1.01–1.3	**< 0.05**
Size	1.08	0.929–1.26	0.308
Smoking (+)	1 x10^8	-	0.994
Smoking (pack-year)	0.999	0.897–1.11	0.984
Cardiovascular diseases	1.38	0.24–7.94	0.719
DM	2.02 x10^7	/	0.995
Pre ECOG PS	5.6	0.75-42	0.094
Pre %VC	1.02	0.97–1.06	0.507
Pre FEV1.0%	0.827	0.726–0.941	**< 0.005**
Skin resection area	1.01	0.999–1.02	0.078
Bone resection	1.52	0.265–8.71	0.64
Bony chest wall resection area	1.01	0.996–1.02	0.22
Reconstruction	4.98 x10^8	-	0.995
Flap	5.98 x10^8	-	0.995
Bleeding	0.999	0.997-1	0.55
Radiation	0.262	0.502–13.7	0.253
Chemotherapy	4.57 x10^{-8}	-	0.994
Post operative opioids	2.5 x10^{-7}	/	0.994
Walking start	1.05	0.81–1.36	0.704
Multivariate			
Age	1.3	0.957–1.77	0.0935
Pre FEV1.0%	0.814	0.693–0.957	**< 0.05**

14 operations; PM: 2 operations) were primarily closed without skin graft. This may have led to limitations on respiratory expansion due to the skin or soft tissue loss. The reason respiratory complications occurred in Group B likely involved skin or soft tissue loss in addition to lower preoperative FEV1.0%. Tacconi et al. demonstrated patients with preoperative FEV1.0% <80% showed significant decreases in Physical Component Summary score, related to quality of life [33]. In cardiac and abdominal surgery, preoperative inspiratory muscle training had the potential to reduce postoperative complications [34]. Patients with severe preoperative FEV1.0% in whom resection of a chest wall tumor with flap transfer is planned should potentially receive preoperative conditioning, such as preoperative respiratory rehabilitation or should be considered for free musculocutaneous flap, such as anterolateral thigh flap, which use tissue outside the chest wall as a donor [35]. Furthermore, Biomechanical reconstruction closer to the ribs may also preserve better respiratory function [36]. Titanium implants generally have a high failure rate [21]. However, devices that take tissue integration into account have increased long-term stability and may be worthwhile [37]. This may be a potential use for reconstruction in patients with poor preoperative respiratory status.

Resection of superficial tumors had a low risk of surgical complications (0%), while resection of deep tumors carried a high risk of surgical complications (22.2%). However, the incidence of respiratory complications did not differ significantly between superficial tumors with flap transfer (11.8%, 2/17) and deep tumors with flap transfer (17.9%, 5/28). In this analysis, not only patients with deep tumors, but also patients with superficial tumors with flap transfer could incur respiratory problems if preoperative FEV1.0% is severe.

Conclusions

Total 5- and 10-year LRFS rates for malignant tumors in the chest wall were 83.9% and 70.6%, respectively. The overall surgical complication rate was 11.5% and flap transfer was a risk factor for surgical complications. Respiratory complication rate was 13.5% and preoperative FEV1.0% was a risk factor for respiratory complications. Not only patients with deep tumors, but also patients with superficial tumors could incur respiratory problems if preoperative FEV1.0% is severe.

Limitation

This study was limited by its retrospective nature, sourcing from a single institution, and involving a small, unique cohort of cases, thereby limiting its statistical power. The rarity of the operations under review constrained the possibility of performing detailed statistical analysis for each pathological subtype. Despite these limitations, we believe the study contributes valuable insights into the management of malignant tumors of the chest wall and addresses postoperative complications.

Abbreviations

PM	Pectoralis major
LD	Latissimus dorsi muscle
PMMA	Polymethyl methacrylate
FEV1.0%	Forced expiratory volume in 1 s
%VC	Percentage vital capacity
LRFS	Local recurrence-free survival
UPS	Undifferentiated pleomorphic sarcoma
MPNST	Malignant peripheral sheath tumor
SFT	Solitary fibrous tumor
DFSP	Dermatofibrosarcoma protuberance

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Author contributions

K.A.; conception, design of the work, drafted the work, M.T.;review and editing, T.H.; analysis of data, T.N.;interpretation of data, T.K.; interpretation of data; T.U. ; acquisition of data, R.A.; acquisition of data, A.S. supervision, All authors have read and agreed to the published version of the manuscript.

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Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This retrospective study was approved by the Ethics Committee of the Mie University Graduate School of Medicine (approval number: H2020-224). All procedures performed in studies involving human participants were in accordance with the ethical standards of the Ethics Committee of Mie University and with the Declaration of Helsinki. The requirement for informed consent was waived by the Ethics Committee of Mie University because of the retrospective nature of the study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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