Original Article

Assessment of the Perioperative Hemodynamics and Right Ventricular Performance of Lung Cancer Patients Using a Continuous Cardiac Output Monitoring System: Comparison between Video-Assisted Thoracic Surgery and Muscle-Sparing Thoracotomy

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Purpose: This prospective study was conducted to assess the influences of hemodynamics and right ventricular (RV) performance after lobectomy by video-assisted thoracic surgery (VATS) and that by muscle-sparing thoracotomy (MST) using a continuous cardiac output (CCO) monitoring system.

Subjects and Methods: Between October 2002 and April 2004, 16 patients (VATS, 8; MST, 8) who underwent lobectomy with mediastinal lymphadenectomy were enrolled in this study. Changes in hemodynamics and RV performance were evaluated preoperatively and for 36 hours postoperatively.

Results: There were significant differences in operative blood loss (BL) and postoperative maxCPK/m^2 between VATS and MST groups. Postoperative values were expressed as a percentage of the preoperative values. For 36 hours perioperatively, the mean pulmonary artery pressure (mPAP), pulmonary capillary wedge pressure (PCWP) and total pulmonary resistance index (TPRI) decreased to greater extents in the VATS group than in the MST group. There were no significant differences between the two groups in RV performance including the continuous cardiac index (CCI), RV ejection fraction (RVEF), RV end-diastolic volume index (RVEDVI) and RV stroke index (SI) postoperatively.

Conclusion: Considering our previous report about postoperative RV performance using the VATS procedure and posterolateral thoracotomy procedure, this study suggests that pulmonary resection using either VATS or MST could be employed as minimally invasive surgery. (Ann Thorac Cardiovasc Surg 2006; 12: 166–73)

Key words: hemodynamics and right ventricular performance, thermodilution catheter, continuous cardiac output, video-assisted thoracic surgery, muscle-sparing thoracotomy

Introduction

Right ventricular (RV) overload resulting from increasing RV afterload by pulmonary resection may influences morbidity and mortality postoperatively. This was one of the significant factors affecting patients with impaired pulmonary function or elderly patients in the acute and chronic phases postoperatively. Pulmonary resections that had previously been managed by posterolateral thoracotomy were recently managed using muscle-sparing thoracotomy (MST) as a less invasive approach.[1)] Furthermore video-assisted thoracic surgery (VATS) introduced a minimally invasive approach for the surgical treatment of lung cancer.[2-5)]

In our study, we demonstrated measurements of RV

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performance and extravascular lung water (EVLW). As a result, we suggested that lobectomy using VATS less affected RV performance than using posterolateral thoracotomy.[3] But the invasiveness of MST that was advocated concurrently in VATS could not be examined. We employed a new device by which we could measure continuous RV performance, and investigated the influence of lobectomy with mediastinal lymphadenectomy on RV performance during the perioperative period. Additionally, we evaluated which is the less invasive of either VATS or MST thoracotomy in terms of RV performance.

Subjects and Methods

The institutional review board approved the protocol for this study and informed consent was obtained from all patients before surgery. From October 2002 to April 2004, 120 patients with primary lung cancer underwent a lobectomy with mediastinal lymphadenectomy at Nippon Medical School Hospital, Tokyo, Japan. Among them, 16 patients were included in this study. No patient had coronary artery disease, valve failure, or any other cardiac disease by previous clinical history and electrocardiogram preoperatively. The cases of bilobectomy, sleeve lobectomy, and lobectomy with combined resection were excluded from this study. The patient population was comprised of 8 men and 8 women with a mean age of 67 years (range: 52 to 77 years). Procedures included 3 right upper lobectomies (RUL), 2 right lower lobectomies (RLL), 4 left upper lobectomies (LUL), and 7 left lower lobectomies (LLL). Mediastinal lymph node dissections (ND2a) were performed in all patients. Postoperative histopathological diagnoses were 12 adenocarcinomas, 3 squamous cell carcinomas, and 1 large cell carcinoma. Twelve at stage I, 1 at stage II, and 3 at stage III were determined pathologically. The patients were classified into 2 groups: a VATS group (n=8) or a MST group (n=8) for differing access of the thorax. All patient characteristics are shown in Table 1.

Study protocol

All patients were placed in the supine position. After general anesthesia, a radial artery was cannulated for the continuous monitoring of mean arterial blood pressure (mBP). A multilumen thermodilution catheter (Swan-Ganz continuous cardiac output (CCO)/continuous end-diastolic volume (CEDV) thermodilution catheter, 774HF75; Edwards Lifesciences, Irvine, CA, USA) was inserted via the right internal jugular vein and positioned 10-15 cm distal to the pulmonary valve. CCO, the RV ejection fraction (RVEF), RV end-diastolic volume (RVEDV), and RV stroke volume (SV) were measured using this catheter and cardiac output computer (Vigilance CEDV monitor; Edwards Lifesciences, Irvine, CA, USA). Hemodynamic parameters measured from this multilumen catheter included the central venous pressure (CVP), mean pulmonary artery pressure (mPAP), and pulmonary capillary wedge pressure (PCWP). The heart rate (HR) was measured by electrocardiogram. Continuous cardiac indices (CCI), RVEDV indices (RVEDVIs) and RV stroke indices (SIs) of CCO, RVEDV and SV, divided by body surface area, were correction values. After appropriate positioning of the catheter and over a 15-minute stabilization period, preoperative hemodynamics and RV performance were obtained (time of base line: bl). At the end of the operation, the patient was extubated in the operating room. Postoperative hemodynamics and RV performance were examined for 36 hours (time of 00-36), from the beginning of the first gait on the morning of the second postoperative day and removal of the catheter. Continuous data (CCO, RVEF, RVEDV, SV and HR) were recorded every hour, but pressure values (mBP, mPAP, CVP, PCWP) were measured at intervals of 6 hours.

Operative technique

Patients underwent general anesthesia, and intubation with a double lumen endotracheal tube in place to allow selective contralateral lung ventilation. They were placed in the lateral decubitus position.

Video-assisted thoracic surgery (VATS)

In VATS, a 2.0-cm-long skin incision was made at the sixth intercostal space of the anterior axillary line as the first trocar hole for observing the pleural cavity with a 10-cm-diameter thoracoscope. A 5-10 cm (average 7 cm) small thoracotomy was made without dissection of the muscle layer or rib resection. In the upper and right middle lobectomy, a minithoracotomy was conducted at the fourth intercostal space of the anterior axillary line and at the fifth intercostal space of the posterior axillary line around the triangle of auscultation where a lower lobectomy of both lungs would be performed. The second trocar hole was made at the eighth intercostal space of the posterior axillary line and the third trocar hole was made at the third intercostal space of the midaxillary line if a wider thoracoscopic view was needed during ND2a mediastinal lymphadenectomy.

Table 1. Characteristics of the two groups

VATS

No.	Age (yrs)	Gender	Lobectomy	DS (min)	BL (g)	Subseg.	RLVI (%)	Pathology	p-stage
1	62	F	LLL	235	100	10	78	Ad	IA
2	70	F	LUL	160	10	10	78	Ad	IA
3	54	M	LLL	288	460	10	80	Ad	IB
4	64	M	RUL	318	180	6	90	Sq	IB
5	69	F	LLL	221	200	10	80	Ad	IB
6	77	M	LLL	275	10	10	78	Ad	IIIA
7	52	F	LLL	190	100	10	78	Ad	IA
8	71	F	RUL	259	330	6	88	Ad	IA

MST

No.	Age (yrs)	Gender	Lobectomy	DS (min)	BL (g)	Subseg.	RLVI (%)	Pathology	p-stage
1	65	F	LUL	225	520	10	78	Ad	IA
2	69	F	LLL	225	100	10	80	Sq	IB
3	64	F	RUL	250	310	6	88	La	IIA
4	76	M	RLL	315	680	12	75	Sq	IIIB
5	72	M	LLL	245	480	10	78	Ad	IA
6	67	M	LUL	190	110	10	78	Ad	IA
7	68	M	RLL	180	430	12	75	Ad	IIIA
8	66	M	LUL	275	730	10	78	Ad	IA

VATS, video-assisted thoracic surgery; DS, duration of surgery; BL, blood loss during operation; Subseg., number of resected subsegments; RLVI, residual lung volume index; F, female; M, male; LLL, left lower lobectomy; LUL, left upper lobectomy; RUL, right upper lobectomy; Ad, adenocarcinoma; Sq, squamous cell carcinoma; MST, muscle-sparing thoracotomy; RLL, right lower lobectomy; La, large cell carcinoma.

Muscle-sparing thoracotomy (MST)

In MST, a transverse 15-cm-long incision was performed from the anterior axillary line to the midportion of the belly of the latissimus dorsi muscle, approximately over the fifth intercostal space. Adequate subcutaneous dissection was performed to permit mobilization of the latissimus dorsi and serratus anterior muscles. The latissimus dorsi was retracted posteriorly to expose the serratus anterior. The serratus anterior was then split anteriorly in the direction of its fibers. After dissection of the intercostal muscle, the chest was entered through the fourth or fifth intercostal space as well as VATS. In our institute, a 2-cm-long partial resection of the two ribs which composed the thoracotomy space was performed in all cases of MST, to obtain a wide window in the thorax useful for operative manipulations.

The operative management in the thorax was consistent for all patients.[5] Pulmonary arteries and veins were divided for ligation and/or stapling. Ligation was done using a knot pusher (Ethicon Endo-Surgery, LLC Caguas, Puerto Rico, USA). The bronchus was transected by a stapler (Endoscopic Transecting Stapler, ATB45 or ATG45; Ethicon Endo-Surgery, LLC Caguas, Puerto Rico, USA). Mediastinal lymphadenectomy (ND2a) was conducted using electrocautery and an ultrasonic dissector. In the VATS group, the resected pulmonary lobe was removed from the thorax using a plastic retrieval bag to avoid contaminating the surrounding tissues. After pulmonary resection, a 24F double lumen chest tube was placed into the pleural cavity, and 1.0% lidocaine was used to block the intercostal nerves for all intercostal spaces of the thoracotomy and trocar ports. For postoperative care, epidural analgesia was administrated to all patients to reduce postoperative pain.

Statistical analysis

Nominal data were analyzed using Fisher's exact probability test. In the case of continuous data, statistical analyses were performed with a parametric test after a normal distribution was confirmed with the Kormogorove-Smirnov test. In the other case, variance was analyzed to investigate any differences between 2 groups; Welch's t-test was applied when the variance was considered to be different from that of the F-test. A p-value of less than 0.05 was considered to denote significance. All p-values were two tailed. The difference in the mean was also presented as the 95% confidence interval (95%CI). All data are presented as the mean ± standard deviation (SD).

Table 2. Comparison of preoperative conditions and operative factors between the two groups

	VATS (n=8)	MST (n=8)	Statistics	p-value	95%CI
Age (yrs)	64.8 (52~77)	68.4 (64~76)	NS	0.32	−11~4
Gender (male/female)	3/5	6/2	NS	0.32	
BI	684 (0~2,720)	973 (0~1,920)	NS	0.52	−1,228~650
%VC (%)	105.4±13.7	88.2±18.0	NS	0.05	0~34.3
$FEV_{1.0}$% (%)	79.0±9.6	73.0±12.1	NS	0.30	−5.8~17.7
$FEV_{1.0}$ (ml)	2,216±582	1,736±267	NS	0.05	−6~966
Pathology (Ad/Sq/La)	7/1/0	5/2/1	NS	0.44	
p-stage (stage I/II/III)	7/0/1	5/1/2	NS	0.44	
Lobectomy (RUL/RLL/LUL/LLL)	2/0/1/5	1/2/3/2	NS	0.20	
Subseg.	9.0±1.9	10.0±1.9	NS	0.30	−3.0~1.0
RLVI (%)	81.3±4.9	79.4±3.8	NS	0.41	−2.9~6.6
DS (min)	243±52	238±44	NS	0.84	−46~57
BL (g)	174±157	420±235		0.03*	−461~−32
maxCPK/m^2	438±178	803±280		0.01*	−617~−114
HR (b/min)	61.8±7.7	60.6±10.4	NS	0.81	−8.7~10.9
mBP (mmHg)	77.1±9.2	70.1±10.4	NS	0.18	−3.5~17.5
mPAP (mmHg)	20.4±4.2	19.0±4.1	NS	0.52	−3.1~5.8
CVP (mmHg)	11.6±3.0	10.4±4.4	NS	0.52	−2.8~5.3
PCWP (mmHg)	14.3±3.4	13.3±3.5	NS	0.57	−2.7~4.7
CCI (l/min/m^2)	2.6±0.6	3.0±0.6	NS	0.21	−1.0~0.2
RVEF (%)	35.1±8.4	37.0±6.6	NS	0.63	−10.0~6.2
RVEDVI (ml/m^2)	124±24	134±25	NS	0.46	−35.5~17.0
SI (ml/b/m^2)	42.6±6.7	48.9±6.8	NS	0.13	−14.6~2.1
PARI (dyne*sec*cm*m^2)	188±93	177±148	NS	0.87	−122~143
TPRI (dyne*sec*cm*m^2)	666±192	547±234	NS	0.28	−110~349
SVRI (dyne*sec*cm*m^2)	2,158±616	1,687±51	NS	0.12	−132~1,072
LVSWI (g*m*m^2)	36.6±8.7	37.1±5.0	NS	0.89	−8.1~7.1
RVSWI (g*m*m^2)	5.3±3.2	5.5±2.0	NS	0.85	−3.1~2.6

BI, Brinkman's index; VC, vital capacity; $FEV_{1.0}$, forced expired volume in one second; CPK, creatine phosphokinase; HR, heart rate; mBP, mean arterial blood pressure; mPAP, mean pulmonary artery pressure; CVP, central venous pressure; PCWP, pulmonary capillary wedge pressure; CCI, continuous cardiac index; RVEF, right ventricular ejection fraction; RVEDVI, right ventricular end-diastlic volume; SI, stroke index; PARI, pulmonary artery resistance index; TPRI, total pulmonary resistance index; SVRI, systemic vascular resistance index; LVSWI, left ventricular stroke work index; RVSWI, right ventricular stroke work index; NS, not significant; 95%CI, 95% confidence interval.
All data are presented as means±SD (standard deviation).
*, $p<0.05$.

Results

The preoperative conditions and operative factors of both groups are shown in Table 2. There were no significant differences in age, gender, Brinkman's indices, pulmonary function, histology, p-stage, hemodynamics and RV performances between VATS and MST groups. For operative factors, there were no significant differences in resected lobes, number of resected subsegments, and the duration of surgery (DS) between the two groups. The amount of intraoperative blood loss (BL) in the MST group was 2.4 times greater than in VATS group (p=0.03). In the MST group, maximum postoperative serum creatine phosphokinase per body surface area (maxCPK/m^2), as a parameter of chest wall injury, was 1.8 times greater than in the VATS group (p=0.01). Also there was no operative mortality, and no patients developed RV dysfunction requiring catecholamine administration postoperatively.

Changes in postoperative hemodynamics and RV performance

Postoperative values of hemodynamics and RV performance were expressed as percentages of the preoperative values (%parameter = actual value/preoperative value ×100). Data of the percent parameter in the 36 hours post-

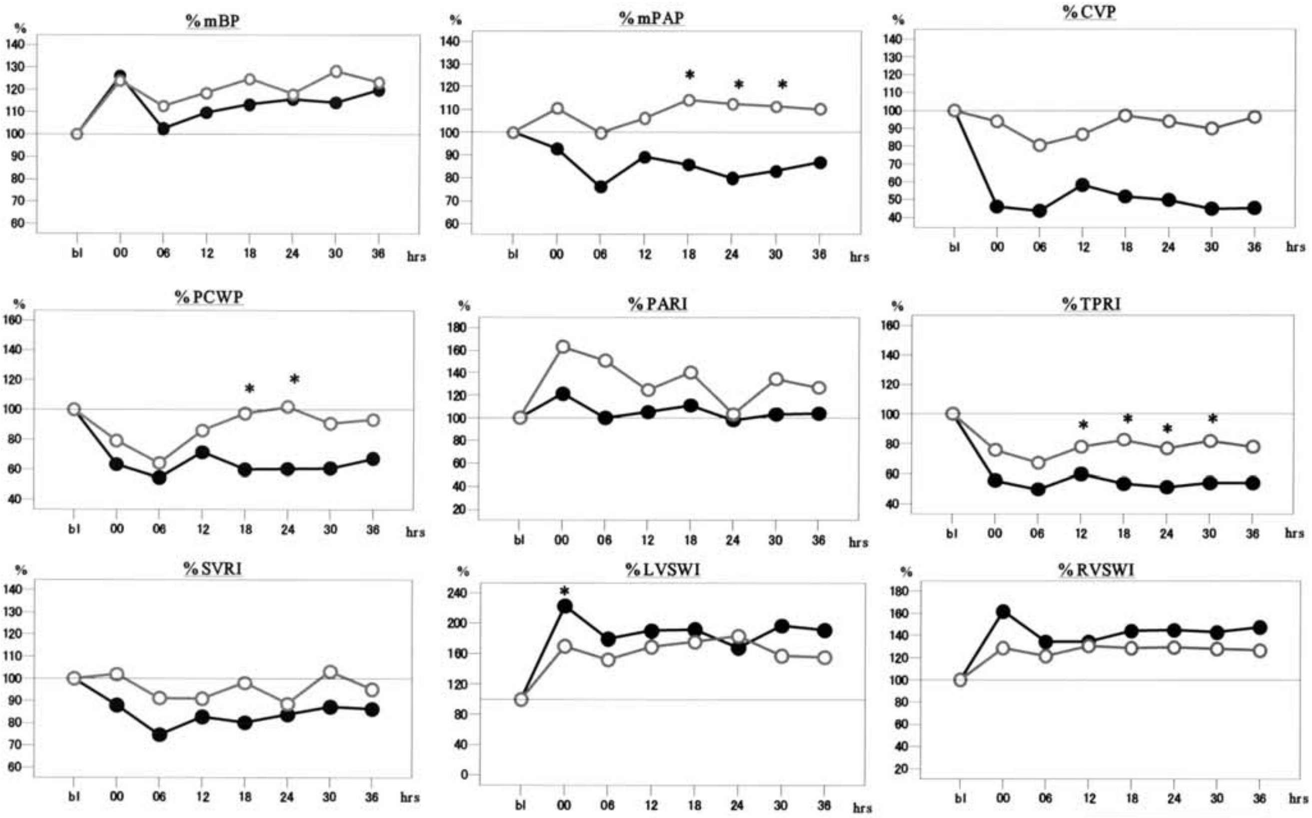

Fig. 1. Postoperative hemodynamics between the 2 groups.

operatively in both the VATS and MST groups are shown in Figs. 1 and 2.

The %HR increased and was comparable throughout 36 hours postoperatively in both groups. The %mBP tended to increase in the 36 hours postoperatively in both groups. The %mPAP showed a decrease in the VATS group, in contrast, in the MST group it showed a slight increase in the 36 hours postoperatively. There were significant differences in the %mPAP between the 2 groups at 18, 24 and 30 hours postoperatively. The %CVP and the %PCWP tended to decrease in the 36 hours postoperatively in both groups. The MST group showed minimal changes compared to the base line in the %CVP and the % of PCWP in the 36 hours postoperatively. There were significant differences in the %PCWP between the 2 groups at 18 and 24 hours postoperatively.

Regarding the RV afterload, even though the percent pulmonary artery resistance indices (%PARI) increased in both groups in the 36 hours postoperatively, the percent of total pulmonary resistance indices (%TPRI) showed a decrease associated with a reduction in the percent systemic vascular resistance indices (%SVRI). At 12, 18, 24 and 30 hours postoperatively, there were significant differences in the %TPRI between the two groups. According to these changes in hemodynamics, the %CCI, %RVEF and %SI showed increases in the VATS group more than in the MST group in the 36 hours postoperatively. There were no significant differences in the %CCI, %RVEF and %SI in the 36 hours postoperatively between the 2 groups. The %RVEDVI showed minimal changes in both groups in the 36 hours postoperatively. The percent of left ventricular stroke work indices (%LVSWI) and the percent of RV stroke work indices (%RVSWI) showed increases in the VATS patients more than in the MST patients in the 36 hours postoperatively. These differences between the 2 groups resulted from the differences in the %SI between the 2 groups.

Discussion

Since Swan et al. developed a pulmonary catheter with a thermistor and occlusion balloon in 1970,[6] measurements

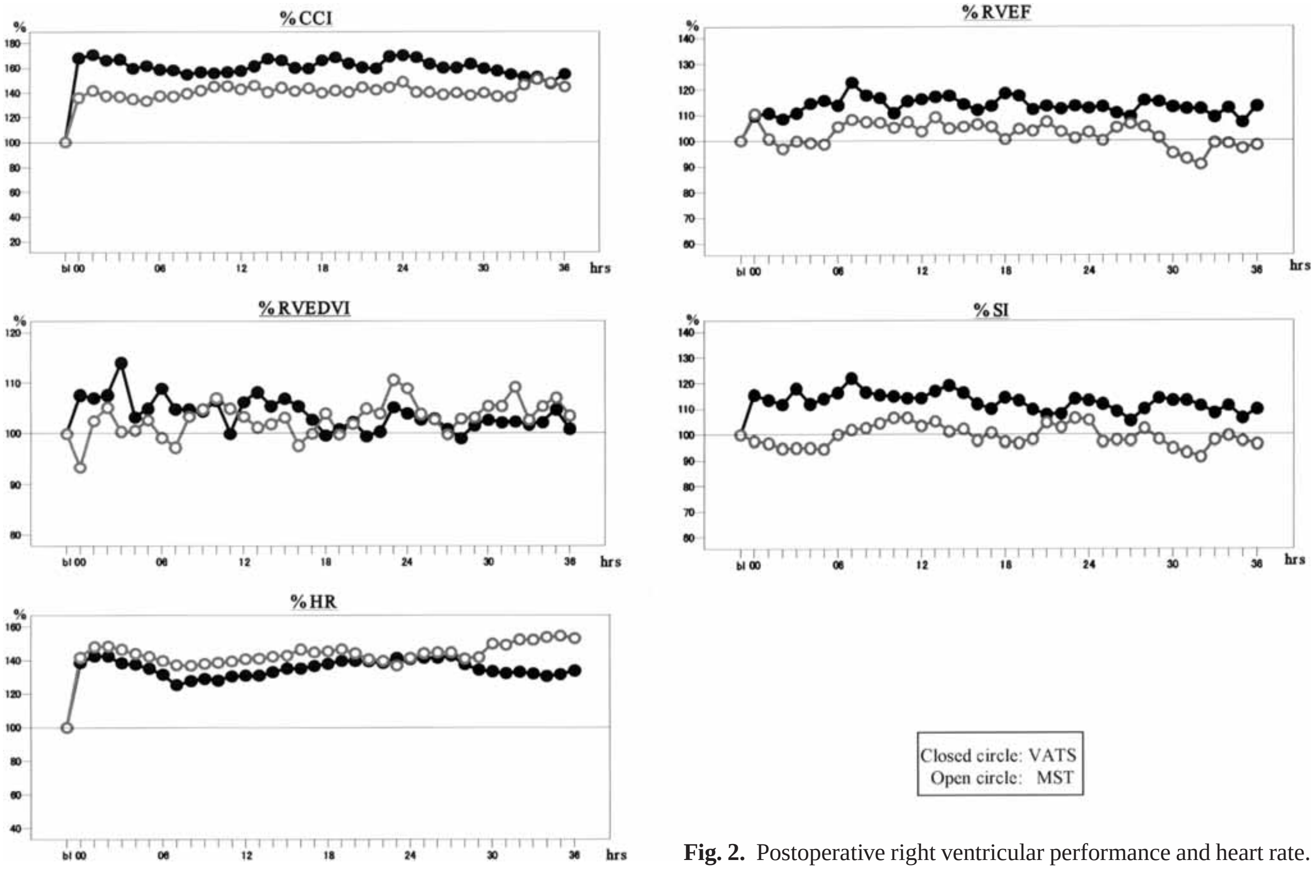

Fig. 2. Postoperative right ventricular performance and heart rate.

of hemodynamics and heart function became one of the most reliable ways for circulatory management. Subsequently, a thermodilution catheter with the function of RVEF measurement was developed, clinical research on RV performance began and there were several reports on RV function in a postoperative pulmonary resection.[7-12] Okada et al.[10] observed that PAP and pulmonary vascular resistance were significantly increased in patients after pulmonary resection during exercise. Mahler et al.[13] reported that the same marked increases in PAP and pulmonary vascular resistance (PVR) were observed in patients with chronic obstructive pulmonary disease during exercise. In addition, Okada et al.[12] mentioned that the increases in the RV afterload may be the main cause of RV pump failure. But they also suggested that RV may serve as a "reservoir" for afterload, masking the increases in PAP and PVR with its dilation at rest. Reed et al.[11] observed that RV contractility was not markedly improved by decreases in PVR and RV afterload using prostaglandin E1, and that the reduction of RVEF always occurred with an acceleration of HR. They suggested that RV dysfunction after pulmonary resection was not caused by primary alternations in contractility or immediate changes in RV afterload, so they emphasized that better control of HR with minimal effects on inotropy may enhance RV pump function.

In our institute, the study of hemodynamics after pulmonary resection using the thermodilution catheter has been carried out since 1985.[3,14-17] Koizumi et al.[15] reported (1) more than a 150% increase in the HR; (2) less than a 60% decrease in the SI; and (3) more than a 200% increase in the PARI values at 24 hours postoperatively relative to the preoperative base line values should be take into account for the acute exacerbation of RV dysfunction. So, we should firstly employ inotropy, secondly, volume loading and thirdly, vasodilator and bronchodilator agents to improve both hemodynamics and RV performances. Mikami et al.[3] suggested that VATS lobectomy for elderly patients offers not only minor changes in the RV afterload but also acceleration in the expected compensatory hyperdynamics in the postoperative acute phase. Recently, we could make use of the CCO/CEDV thermodilution catheter and Vigilance CEDV monitor which enabled us to measure continuous RV performances. Then, we evaluated hemodynamics and RV performance using these instruments after lobectomy, and investigated the effect of RV performance postoperatively between the VATS group, as a minimally invasive surgery, and the MST group, as a standard thoracotomy.

The CCO/CEDV thermodilution catheter could measure CCO by the principle of the thermodilution method, employing its thermal filament. This catheter with the signal from the electrocardiogram could calculate RVEF and RVEDV continuously. There was no need for the calibration of this catheter, but we were capable of accurate values with simple management. Compared to the previous thermodilution catheter using bolus injection, there were no measurement errors due to manipulations and no volume overloading or induction of arrhythmias. It was useful to investigate the tendency of hemodynamics whereas values were obtained every 30 seconds. On the other hand, if there was inadequate positioning of the CCO/CEDV catheter, the data tended to be overestimated. Also, the measurement values could not always be taken in synchronization, such as when drastic changes in hemodynamics occurred, e.g. rapid and heavy bleeding or at the time of aortic clamping. But the reliability of both CCO and RVEF using this system have already been demonstrated in many institutes.[18-21]

At the present time, MST is being performed as a standard thoracotomy in our institute. We managed to spare muscles using the technique described by Ginsberg in 1993.[1] But the two ribs which compose the thoracotomy space are partially resected routinely to obtain a wide window in the thorax to facilitate easier operative manipulations. In this research, the MST group was assumed to comprise a more invasive group, compared with the VATS group. It was evident that there were significant differences in postoperative maxCPK/m^2, as a parameter of chest wall injury, between the 2 groups.

In the present study, changes in hemodynamics and RV performance in all patients showed increases in %HR, %mBP and %PARI associated with %CCI, %RVEF and %LVSWI due to compensatory hyperdynamic cardiac function after surgery. As for changes in the hemodynamics between the 2 groups, the VATS patients showed a greater decrease in %SVRI compared to the MST patients in the 36 hours postoperatively. This could be attributed to differences in the approach to the thorax, regarding injury of chest wall. In other words, the degree of increased postoperative pulmonary resistance was considered to depend on the extents of parenchymal injury, vasospasm and bronchiolospasm due to chest damage and manipulation during surgery. Consequently, the %TPRI in the VATS group was less than in the MST group in the 36 hours postoperatively. We obtained similar results in our previous studies using the thermodilution catheter.[3,17] In regard to RV performance, in the VATS group the %HR was lower, but the %CCI and %SI were higher and were accompanied with an increase in the %RVEF as compared with each parameter in the MST group in the 36 hours postoperatively. These findings indicated that the VATS procedure produced an acceleration in the expected compensatory hyperdynamics, as compared with the MST procedure, in the acute postoperative phase.

In regard to the surgical treatment for lung resection, it should be possible to predict RV dysfunction postoperatively through the evaluation of preoperative conditions and observations of postoperative vital signs (HR, BP, and urine volume). But when (1) the pulmonary resection is over 16 subsegments (more than 35% of the lung; e.g. right middle & lower lobectomies and ipsilateral pneumonectomy); (2) the pulmonary resection is greatly invasive (e.g. lobectomy with ND3 lymph node dissection; Hirata et al. reported[17]); or (3) the lobectomy is for a patient with impaired pulmonary function and/or severe cardiac complications, we consider that measurements of hemodynamics and RV performance using a thermodilution catheter are valuable in cardiopulmonary management postoperatively. We also believe that the CCO/CEDV catheter and Vigilance CEDV monitor can be employed as convenient and reliable instruments.

Conclusion

In spite of the fact that the number of patients we studied was small, and the efficacy of drug and fluid therapy during postoperative intensive care cannot be ignored in this study, in the 36 hours postoperatively there were no significant differences detected in RV performance between the VATS and MST groups using a CCO monitoring system. Considering our previous report about postoperative RV performance using the VATS procedure and posterolateral thoracotomy procedure, this study suggests that pulmonary resection using either VATS or MST could be employed as minimally invasive surgery improving hemodynamics.

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