의 학 박 사 학 위 논 문

Changes of Diaphragmatic Excursion and Lung Compliance during Gynecologic Surgery: Open Laparotomy versus Pelviscopy

울 산 대 학 교 대 학 원

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이 논문을 의학박사 학위 논문으로 제출함

2020년 2월

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김경미의 의학박사 학위 논문을 인준함

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2020년　2월

Abstract

Introduction: The present study aimed to compare the impact of type of surgery on diaphragmatic excursion and lung compliance during operation between open radical hysterectomy and laparoscopic radical hysterectomy.

Methods: Total forty patients, twenty of open radical hysterectomy and twenty of laparoscopic radical hysterectomy, were enrolled. Diaphragmatic excursions were measured in tidal ventilation using M-mode sonography before the intubation (T0), after the intubation with mechanical ventilation (T1), 90 minutes (T2) after incision, and at the end of operation with recovery of muscle relaxation (T3). Pulmonary parameters such as peak inspiratory pressure and static lung compliance were measured using an anesthesia machine combined with a ventilator.

Results: Diaphragmatic excursion in patients who underwent laparoscopic radical hysterectomy was significantly lower than those of open radical hysterectomy at T2 (5.3 ±

1.7 mm vs 7.7 ± 2.0 mm, $P < 0.001$) and T3 (8.4 ± 1.9 vs 10.4 ± 2.4, $P = 0.011$). Impaired diaphragmatic excursion at T3 defined as less than 10mm of diaphragmatic excursion under mechanical ventilation occurred in 15 patients (83.3%) who underwent laparoscopic radical hysterectomy while there were 7 patients (38.9%) had diaphragmatic impairment in open group ($P = 0.006$). The changes in peak inspiratory pressure and static lung compliance over time were significantly different between the two groups ($P < 0.001$, respectively).

Conclusion: Laparoscopic radical hysterectomy decreased diaphragmatic excursion and static lung compliance more severely than open radical hysterectomy since it requires Trendelenburg position and pneumoperitoneum.

Table of Contents

Table and figure legends

Introduction

Laparoscopic surgery is preferred to open abdominal surgery since the incidences of pulmonary complication and lengths of hospital stays of laparoscopic surgery are lower than those of open abdominal surgery [1, 2]. However, our previous study revealed laparoscopic radical hysterectomy developed impaired diaphragmatic excursion at the end of operation [3]. Because laparoscopic radical hysterectomy, which requires the steep Trendelenburg position with pneumoperitoneum, incurs cephalic displacement of the diaphragm, also decreases diaphragmatic movement. General anesthesia, in addition, induces atelectasis formation and decreases the diaphragmatic movement due to using muscle relaxant and supine position so that it is well known one of responsible factors of postoperative diaphragmatic dysfunction [4].

We assumed laparoscopic radical hysterectomy aggravated physiologic change of pulmonary parameters and worsened diaphragmatic excursion. This study was designed to compare the impact of type of gynecological surgery on diaphragmatic excursion and lung compliance between open radical hysterectomy and laparoscopic radical hysterectomy.

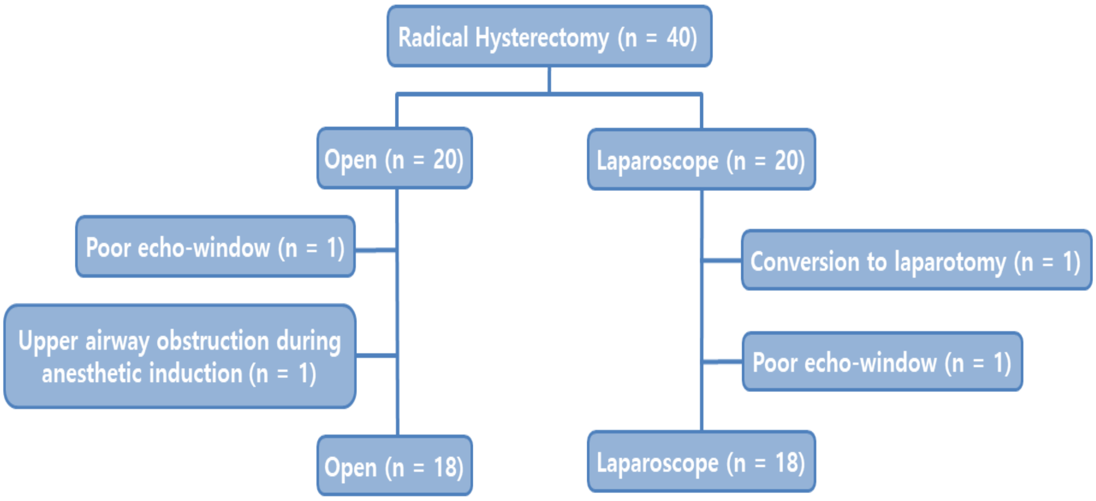
Materials and Methods

Subjects

Written informed consent was obtained from all patients following approval by the Institutional Ethics Committee (AMC IRB 2019-0761, Seoul, Korea) and registration in the Korean Clinical Trials Registry (KCT0004477). This study enrolled 20 adult patients (ASA physical status I-II) who underwent elective open radical hysterectomy prospectively. The data of previous study (AMC IRB 2015-0494, Seoul, Korea, KCT0001710) [3], 20 patients who underwent laparoscopic radical hysterectomy, were using control group with the permission of Institutional Review Board. Exclusion criteria of this study were as followings: patients with chronic obstructive pulmonary disease or respiratory dysfunction, and body mass index of over 30 kg/m^2. Two patients were, withal, dropped out of this study: one had a poor echo window due to an operation field and the other had upper airway obstruction during anesthetic induction. This study was performed according to the STROBE guidelines (Figure 1).

Figure 1. Enrolment of patients undergoing radical hysterectomy.

Forty patients were enrolled this study. Two patients were dropped out in each group. Data of 36 patients were used for analysis.



Clinical data

Baseline characteristics were defined as an age of patients, body mass index, and history of systemic disease (i.e., hypertension, diabetes, and so on). Besides, we recorded operative time, amount of administered fluid, and results of intraoperative arterial blood gas analysis. Pulmonary mechanics, including peak inspiratory pressure (PIP) and static lung compliance, were acquired from an anesthesia machine (Primus®, Dragger, Lubeck, Germany) combined with a ventilator. For assessing postoperative pulmonary complication, such as pleural effusion or atelectasis, chest X-ray findings within postoperative 15 days were checked.

Anesthesia and mechanical ventilation

During the study, all anesthetic procedures were carried out accordance with the standard of performance of anesthesia in our institution. To induce an anesthesia, pentothal sodium (5 mg/kg), rocuronium (0.6 mg/kg), and remifentanil (2.0-5.0 ng/ml effective site concentration) were used. For maintaining of anesthesia, desflurane (1.0 minimum alveolar concentration), continuous infusion of remifentanil (1.0 - 3.0 ng/ml effective site concentration), and rocuronium infusion (0.3 mg/kg/h) were used. At the end of operation, sugammadex (2.0

mg/kg) was used for reversal of muscle relaxation and recovery of relaxation was checked with train-of-four (TOF, peripheral nerve stimulation) ratio (> 0.9). Vital sign of patients were monitored during surgery: heart rate, peripheral oxygen saturation, electrocardiograph, continuous arterial blood pressure, bispectral index, TOF ratio, and end-tidal carbon dioxide concentration. Mechanical ventilation was maintained with volume-controlled mode in 50% of inspired oxygen fraction. Ventilator setting was as follows: 8 mL/kg of ideal body weight was target tidal volume without positive end expiratory pressure and a respiratory rate was set 10 – 14 times/min based on end tidal carbon dioxide concentration.

Measurement of diaphragmatic excursion

A single well-trained expert (K. K.) measured diaphragmatic excursion twice at each time point with a 5-2 MHz convex transducer of an Edge II ultrasound machine (SonoSite, Inc, Bothell, WA). A measurement technique of diaphragm excursion was mentioned previous study [3], the value of diaphragmatic excursion at each time point was defined as an average of two measurements.

Diaphragmatic excursions were measured following time points: before the intubation with mechanical mask ventilation (T0, bispectral index < 60, TOF ratio > 0.9) with the tidal volume as 8 mL/kg of ideal body weight with a respiratory rate of 12 times/min), after the intubation with mechanical ventilation (T1, bispectral index < 60, TOF ratio = 0), 90 minutes (T2) after incision, and at the end of operation with recovery of muscle relaxation (T3, bispectral index < 60, TOF ratio > 0.9) under mechanical ventilation.

Statistical analysis and sample size calculation

Referring to a pilot study, the mean difference of diaphragmatic excursion at T3 between the two groups was 2.0 ± 2.2 mm. While α was 0.05, power was set 0.8 with assumption of 10% dropout rate, it required 20 patients in each operation. Baseline characteristics and perioperative variables were compared between the two groups: Student T-test was an analysis tool of continuous variables which were expressed as mean ± standard deviation. And χ^2 or Fisher's exact test was used for categorical variables which were summarized as number and percentage. Repeated measures two way ANOVA followed by Bonferroni correction was used for analyses of serial changes of diaphragmatic excursion and pulmonary variables between the two groups. Data management and statistical analyses were executed using IBM SPSS Statistics 21.0 (IBM, Armonk, NY).

Results

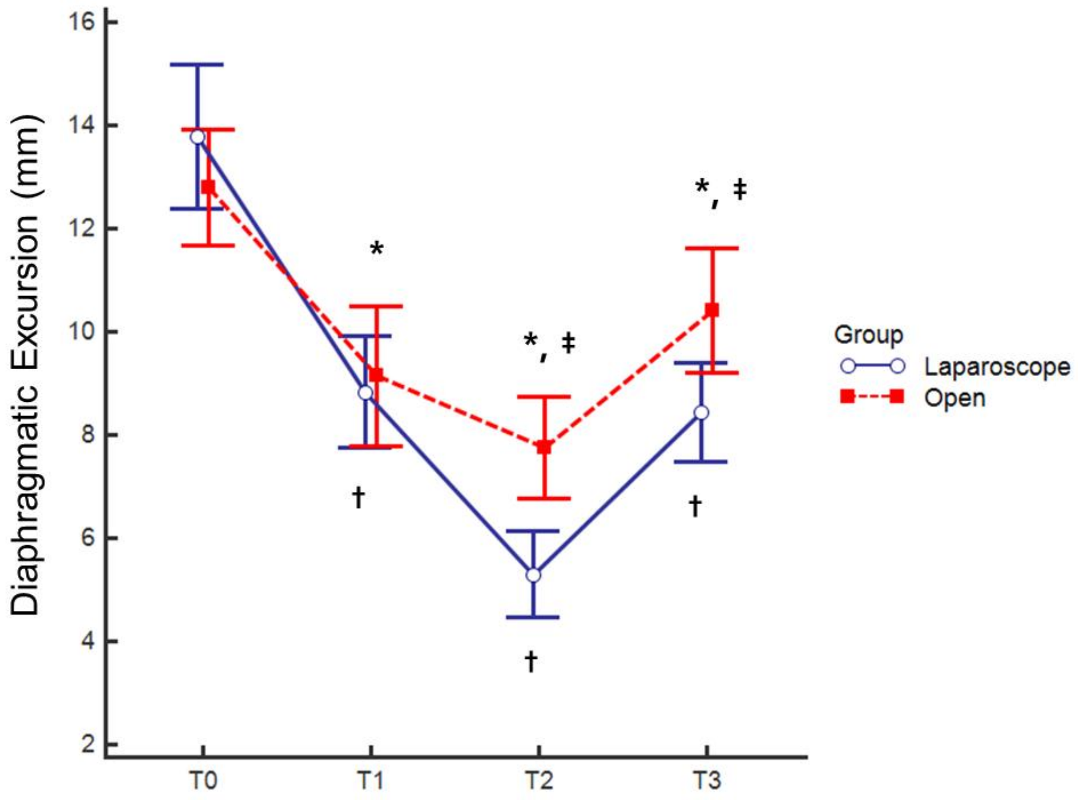
Demographic data was shown Table 1. There were no significant differences between patients undergoing open radical hysterectomy and patients undergoing laparoscopic radical hysterectomy. Diaphragmatic excursions were showed Figure 2. There was no difference of changes in diaphragmatic excursion over time between the two groups (Figure 2, $P = 0.079$). However, diaphragmatic excursion in patients who underwent laparoscopic radical hysterectomy was significant lower at T2 (5.3 ± 1.7 mm vs 7.7 ± 2.0 mm, $P < 0.001$) and T3 (8.4 ± 1.9 vs 10.4 ± 2.4, $P = 0.011$) than those who underwent open radical hysterectomy. Impaired diaphragmatic excursion at T3, defined as less than 10mm of diaphragmatic excursion under mechanical ventilation, occurred in 15 patients (83.3%) who underwent laparoscopic radical hysterectomy while there were 7 patients (38.9%) had diaphragmatic impairment in patients undergoing open radical hysterectomy ($P = 0.006$). The intra-observer correlation coefficient of measuring diaphragmatic excursion was 0.991 (95% confidence interval 0.987 - 0.993, $P < 0.001$). Table 2 presented parameters of arterial gas analyses and pulmonary variables during operation. PIP was increased at T2 and slightly decreased at T3 in both groups. The changes in PIP over time were significantly different between the two groups ($P < 0.001$). Static lung compliance was, also, decreased at T2 and recovered at T3. The changes in static lung compliance over time were significantly different between the two groups (Figure 3, $P < 0.001$). The abnormal findings of chest X-ray within 15 postoperative days were showed in 6 (33.3%) patients who underwent open radical hysterectomy versus in 7 (38.9%) patients undergoing laparoscopic radical hysterectomy ($P = 0.729$)

Table 1. Demographic and perioperative characteristics of the study patients

	Open (n=18)	Laparoscope (n=18)	*P*
Age (years)	45.5 ± 9.6	49.4 ± 9.0	0.212
Body mass index (kg/m^2)	21.4 ± 2.5	22.8 ± 3.5	0.158
Hypertension	2 (11.1 %)	2 (11.1%)	> 0.999
Diabetes mellitus	0 (0%)	0 (0%)	
Other systemic disease	3 (16.7%)	3 (16.7%)	> 0.999
Hospital stay (days)	10.2 ± 7.3	10.2 ± 7.9	0.983
Intraoperative Data			
Operative time (min)	184.3 ± 72.9	226.1 ± 68.0	0.085
Admitted crystalloid (mL)	1819.4 ± 940.1	2352.8 ± 789.2	0.074

Data are expressed as mean ± standard deviation or number (percentage).

Figure 2. Diaphragmatic excursions at each surgical time point. Diaphragmatic movement decreased after anesthetic induction and gradually decreased during operation in both groups. Diaphragmatic excursion in patients undergoing laparoscopic surgery (blue line) was significantly lower than that of open group (red line) at T2 ($P < 0.001$) and T3 ($P = 0.011$).



* Each value of diaphragmatic excursion was significantly lower than T0 in patients undergoing open radical hysterectomy.

† Each value of diaphragmatic excursion was significantly lower than T0 in patients undergoing laparoscopic radical hysterectomy.

‡ The two groups differed significantly.

T0 = before the intubation; T1 = after the intubation; T2 = 90 minutes after incision; T3 = at the end of operation with recovery of muscle relaxation.

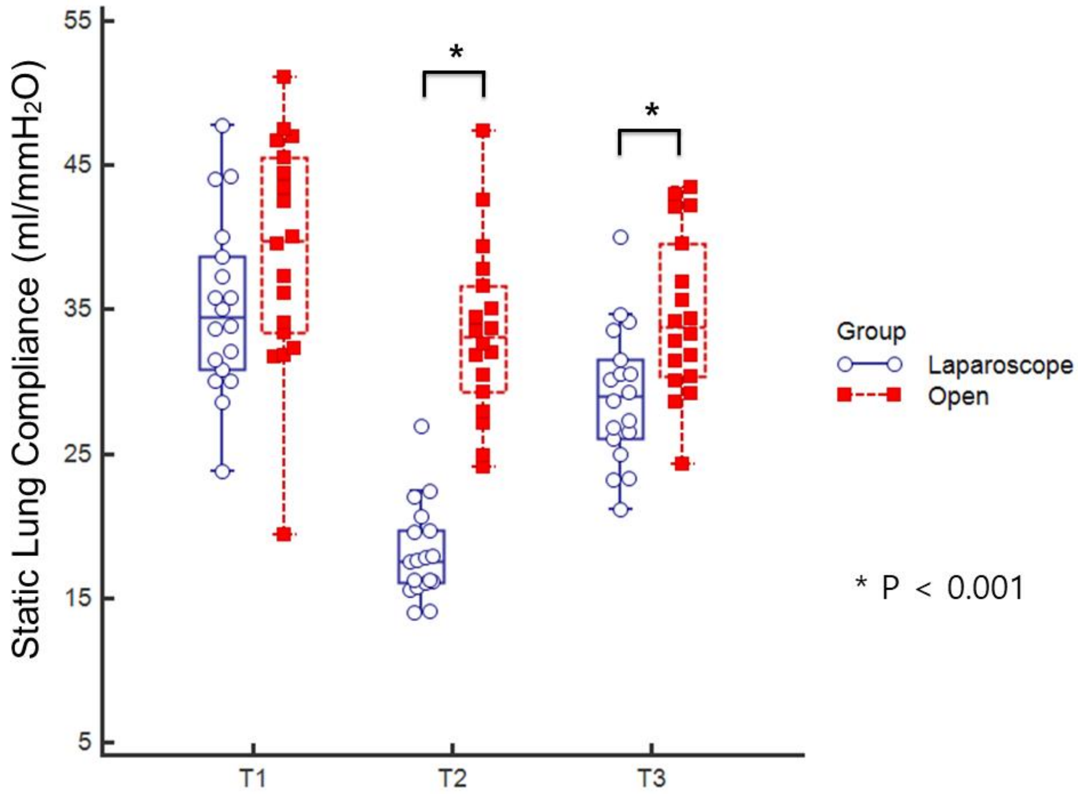
Table 2. Pulmonary variables during the operation

	Group	T1	T2	T3	*P*	
					Group * time	Intergroup
PaO_2 on FiO_2 0.5 (mmHg)	Open	244.7 ± 69.3	217.2 ± 41.0	229.7 ± 26.9	0.047	0.634
	Laparoscope	240.2 ± 52.4	204.6 ± 40.2	210.6 ± 39.0		
$PaCO_2$ (mmHg)	Open	36.1 ± 4.5	37.5 ± 10.4	39.1 ± 3.7	0.640	0.989
	Laparoscope	35.8 ± 4.1	40.7 ± 4.7	39.3 ± 5.5		
PIP (mmH_2O)	Open	10.9 ± 2.4	13.1 ± 1.4	12.9 ± 1.8	< 0.001	< 0.001
	Laparoscope	12.8 ± 2.0	25.5 ± 2.8	15.9 ± 2.1		
Static lung compliance (ml/mmH_2O)	Open	39.1 ± 7.8	33.4 ± 6.0	34.6 ± 5.6	< 0.001	< 0.001
	Laparoscope	35.2 ± 6.1	18.1 ± 3.3	29.0 ± 4.7		

Data are expressed as mean ± standard deviation

T1 = after the intubation; T2 = 90 minutes after incision; T3 = at the end of operation with recovery of muscle relaxation under mechanical ventilation; FiO_2 = fraction of inspired oxygen; ; PIP = pmeasured by an anesthesia machine (Primus®, Dragger, Lubeck, Germany)Static lung compliance = measured by an anesthesia machine (Primus®, Dragger, Lubeck, Germany)

Figure 3. Static lung compliance during operation with reference to type of surgery. Box-and-Whisker plots of static lung compliance in patients who underwent laparoscopic radical hysterectomy (blue box) and open radical hysterectomy (red box). Note that static lung compliance in patients undergoing laparoscopic surgery was reduced significantly during operation and it was lower than that of open group at the end of operation ($P < 0.001$).



* The two groups differed significantly.

T1 = after the intubation; T2 = 90 minutes after incision; T3 = at the end of operation with recovery of muscle relaxation

Discussion

The present study revealed a greater decrease of intraoperative diaphragmatic excursion in patients undergoing laparoscopic radical hysterectomy than those of open radical hysterectomy. Static lung compliance during operation in patients who underwent laparoscopic radical hysterectomy was also lower than those in patients undergoing open radical hysterectomy. Furthermore, impaired diaphragmatic excursion occurred more frequently in patients who underwent laparoscopic radical hysterectomy at the end of surgery. Our previous study showed laparoscopic radical hysterectomy decreased the diaphragmatic excursion and lung compliance not only during operation but also end of surgery with neuromuscular reversal [3]. In addition, this study showed laparoscopic radical hysterectomy worsened diaphragmatic excursion and lung compliance compared with open radical hysterectomy. Laparoscopic radical hysterectomy starts with pneumoperitoneum and needs steep Trendelenburg position. Pneumoperitoneum leads to the cephalic displacement of diaphragm, increasing peak and plateau airway pressure and decreasing lung compliance.

Steep Trendelenburg position aggravates these pulmonary mechanics during operation. Laparoscopic radical hysterectomy, therefore, reduces the diaphragm movement and lung compliance [5-8]. Volpino et al. compared the lung compliance between open cholecystectomy and laparoscopic cholecystectomy during operation, the more significant reduction in compliance was observed in the patients who underwent laparoscopic cholecystectomy [9]. Consistent with Volpino and his colleagues, our data showed laparoscopic radical hysterectomy worsened the pulmonary mechanics as if reduced the lung compliance following with decreased diaphragmatic excursion.

Open radical hysterectomy decreases the diaphragmatic excursion and lung compliance as well even if the degree of decreased excursion and lung compliance were less than laparoscopic radical hysterectomy. Therefore, we could presume general anesthesia affects diaphragmatic excursion and decreases the lung compliance. There are some studies that general anesthesia changes the placement and movement of diaphragm because of the supine position with use of muscle relaxant under mechanical ventilation and decreases the lung volume due to atelectasis and airway collapse [10, 11]. In agreement with previous reports, our results showed diaphragmatic excursion at T1 was lower than T0 in both surgery groups. Reduced diaphragmatic excursion during operation, moreover, was not returned as the value of T0 at T3 in spite of the confirmation of recovery of muscle relaxation in both groups (TOF ratio > 0.9). Kim et al. reported postoperative diaphragmatic movement was significantly decreased than preoperative values [12]. Eichenberger and his colleagues, also, found postoperative atelectasis was persisted 24 hours in laparoscopic surgery or 48 hours in open surgery [13]. Similar to these studies, our results showed an impairment of diaphragmatic excursion at T3 though muscle relaxation was confirmed to recover with TOF ratio > 0.9. Despite the fact that the exact mechanism of impaired diaphragmatic excursion was still remained questionable, it may be from a decreased lung volume during operation and an anatomical peculiarity of diaphragm which was C-shaped fibrous structure. Further study is required to evaluate the mechanism of diaphragmatic excursion after operation.

Numerous studies confirmed the ultra-sonographic reliability of diaphragmatic excursion qualitatively and quantitatively [14-17]. Holtzhausen et al. reported sonographic evaluation of the diaphragm may be a feasible alternative test for assessing diaphragmatic function [16]. Ultrasound is repeatable without exposure to hazardous chemical, takes in few minutes and it is more precise to diagnose the diaphragmatic dysfunction than fluoroscopy [15, 18]. It is a helpful to interpret the diaphragmatic function within intraoperative or immediate postoperative period and will be able to become a routine examination for patient with high risk of postoperative pulmonary complication. Current reports support the ultrasound is a useful tool for assessing diaphragmatic kinetics [19]. Our data, likewise, suggest the importance of ultrasonographic evaluation the diaphragm when investigating the respiratory function.

There are several limitations in our study. This observational study was performed in a single center and an only single examiner measured diaphragmatic excursion. It was not designed a random assign of operation type, nonetheless, there was no difference of baseline characteristics of study patients between the two groups. We also checked the intra-observer correlation coefficient after measuring of diaphragmatic excursion. Several studies, meanwhile, recommended applying positive end expiratory pressure and recruit maneuver for increasing oxygenation and improving lung mechanics during operation because laparoscopic abdominal surgery aggravated atelectasis formation and decreased lung compliance [6, 20]. Our study, however, was designed only to evaluate diaphragmatic movement during operation so that we couldn't assess the impact of positive end expiratory pressure or recruit maneuver on diaphragmatic excursion. To confirm the effect of positive end expiratory pressure, further study is required. And finally, we couldn't measure the diaphragmatic excursion on postoperative days though we checked the postoperative chest X-ray as a postoperative outcome which was not showed significant difference between the two groups. It needs additional studies to evaluate the recovery time of diaphragmatic impairment and to assess the postoperative outcome.

Conclusions

Laparoscopic radical hysterectomy decreases diaphragmatic excursion and lung compliance more severely than open radical hysterectomy since it requires Trendelenburg position and pneumoperitoneum. Furthermore, impaired diaphragmatic excursion occurred more frequently in patients who underwent laparoscopic radical hysterectomy than in patients undergoing open radical hysterectomy at the end of surgery.

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Abbreviation

TOF = train-of-four

PIP = peak inspiratory pressure

국 문 요 약

도입: 본 연구는 개복 근치적 자궁절제술과 복강경 근치적 자궁절제술을 받는 환자에 있어서 수술 방법이 횡격막 운동과 폐탄성에 미치는 영향을 비교하고자 하였다.

방법: 개복 근치적 자궁절제술을 받는 환자 20 명과 복강경 근치적 자궁절제술을 받는 20 명의 환자가 본 연구에 참여하였다. 횡격막 운동은 M-mode 초음파를 이용하여 마취 유도 전 (T0), 기관 삽관 후 기계 환기를 적용한 상태로 (T1), 수술을 위한 절개 90 분 후 (T2), 근이완을 회복 한 수술 종료 시점 (T3)에 측정하였다. 최대 흡기 압력, 정적 폐탄성과 같은 호흡계 변인들은 마취기에 나타나는 값을 기록하였다.

결과: 복강경 근치적 자궁 절제술을 시행 받는 환자군의 횡격막 움직임이 T2 (5.3 ± 1.7 mm vs 7.7 ± 2.0 mm, P < 0.001) 와 T3 (8.4 ± 1.9 vs 10.4 ± 2.4, P = 0.011) 시점에서 개복 근치적 자궁 절제술을 시행 받은 환자군보다

유의미하게 작았다. T3 시점에서 횡격막 움직임이 10mm 미만인 환자는 복강경 수술에서 15 명 (83.3%), 개복 수술에서 7 명 (38.9%) 이었으며 이는 통계적으로 의미 있는 차이를 보였다. ($P = 0.006$). 최대 흡기 압력과 정적 폐탄성은 시간에 따라 그룹간 차이를 보였으며, 이는 통계적으로 유의한 결과를 보였다 (각각 $P < 0.001$).

결론: 복강경 근치적 자궁 절제술은 트렌델렌버그 자세와 기복증을 필요로 하기 때문에 개복 근치적 자궁 절제술 보다 수술 중 횡격막 움직임이 더 많이 감소하였다. 정적 폐탄성 역시 복강경 근치적 자궁 절제 수술을 받는 환자군의 값이 개복 근치적 자궁 절제술을 시행 받은 환자 군의 값 보다 낮았다.