Venous Air Embolism during Total Laparoscopic Hysterectomy

Comparison to Total Abdominal Hysterectomy

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Background: Total laparoscopic hysterectomy (TLH) has become a widely accepted alternative to total abdominal hysterectomy (TAH). The aim of this study was to compare the incidence and grade of venous air embolism (VAE) in TLH to those in TAH using transesophageal echocardiography.

Methods: Eighty-two American Society of Anesthesiologists physical status I patients scheduled for either TLH or TAH were enrolled. After induction of general anesthesia, a multiplane transesophageal echocardiography probe was inserted. The midesophageal four-chamber or bicaval view was continuously monitored. An independent transesophageal echocardiography–certified anesthesiologist graded VAE.

Results: All patients undergoing TLH showed VAE, and 37.5% of patients had VAE grade higher than III. Fifteen percent of patients undergoing TAH showed VAE, and all of them were grade I. No patient in this study showed hemodynamic instability or electrocardiogram changes at the time of VAE occurrence. Most instances of VAE during TLH occurred during transection of the round ligament and dissection of the broad ligament.

Conclusion: The incidence of VAE in patients undergoing TLH was 100%. VAE grade in TLH was higher compared to that in TAH, especially during transection of the round ligament and dissection of the broad ligament. Although the hemodynamic instability associated with VAE during TLH was not observed in this study, anesthesiologists must be vigilant for detection of VAE during TLH.

VENOUS air embolism (VAE) has been defined as the entrainment of air and/or medical gases such as carbon dioxide,[1,2] nitrous oxide,[3,4] nitrogen,[5,6] or helium[7] from broken veins to the central venous system, producing embolism to the right heart or pulmonary artery. Laparoscopic procedures are well known to be related to VAE from carbon dioxide gas used for pneumoperitoneum. Varying degrees of VAE, including fatal massive air embolism, have been reported during laparoscopic cholecystectomy,[8] transurethral resection of the prostate,[9] and gynecological laparoscopy.[10–12]

Total laparoscopic hysterectomy (TLH) is an endoscopic surgical procedure to remove the uterus. Its general indications are similar to those of total abdominal hysterectomy (TAH), including leiomyoma, adenomyosis, pelvic organ prolapse, intractable uterine bleeding, premalignant disease, and gynecologic malignancies such as cervical or endometrial cancer.[13] The incidence of VAE from room air entrainment during open gynecologic surgeries is low; as new laparoscopic approaches for gynecologic surgery are introduced, however, concerns of VAE related to carbon dioxide have been raised.

Although there are some controlled studies on VAE in laparoscopic cholecystectomy[8] or hepatic resection,[14] no study exists regarding the incidence and grade of VAE related to carbon dioxide during TLH. Therefore, the purpose of this study was to assess the incidence and grade of VAE related to carbon dioxide during TLH and to compare with the incidence and grade of VAE during TAH with transesophageal echocardiography (TEE).

Materials and Methods

The study was approved by the Institutional Review Board (Seoul, Korea), and written informed consent was obtained from all patients.

Eighty-two female patients with American Society of Anesthesiologists physical status I scheduled for TAH (n = 40) or TLH (n = 42) under general anesthesia for benign gynecologic conditions such as leiomyoma, cervical dysplasia, adenomyosis, ovarian carcinoma, or endometrial carcinoma were enrolled from January 2007 to December 2007. The surgical method in each case was determined by a surgeon who had performed more than 500 TLH procedures, and all operations were performed by the same surgeon. Patients with preexisting cardiopulmonary, hepatorenal, and esophageal disease were excluded. Cases in which the surgical method was changed during operation were excluded from analysis.

Patients were premedicated with intramuscular midazolam (0.05 mg/kg) 60 min before induction of anesthesia. In the preanesthetic room, lactated Ringer's solution was started. On arrival in the operation room, standard monitoring devices, including three-lead electrocardiogram, noninvasive blood pressure, and pulse oximetry, were applied. All patients received IV glycopyrrolate (0.2 mg). Anesthesia was induced with propofol at 2 mg/kg and remifentanil at 1 μg/kg. Orotracheal intubation was facilitated with 0.6 mg/kg rocuronium. Anesthesia was maintained with sevoflurane (1.5–3 vol%) and

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remifentanyl infusion ($0.1 \, \mu g \cdot kg^{-1} \cdot min^{-1}$). Neuromuscular relaxation was maintained with continuous infusion of rocuronium (2-$5 \, \mu g \cdot kg^{-1} \cdot min^{-1}$) with monitor. Patients' lungs were ventilated with a tidal volume of 8–10 ml/kg at a rate of 8–12 breaths/min in 50% O_2/50% air (2 l) adjusted to maintain the end-tidal carbon dioxidepartial pressure (P_{ETCO_2}) at 30–40 mmHg. Patients received about 1 l of lactated Ringer's solution during anesthetic induction. Intraoperative fluid was subsequently administered with an infusion set (Control-A-Flo Set$_{TM}$ Model FMC5905; Baxter Ltd., Marsa, Malta) at a rate of 50 ml/h to avoid echocardiographic artifacts caused by rapid intravenous infusion.[8] After induction of anesthesia, a 5.0 MHz multiplane TEE probe (SONOS 4500; Philips, Boeblingen, Germany) was inserted. Before the surgery, complete TEE examination of the heart, including the existence of patent foramen ovale with agitated saline was performed. The ultrasound gain setting was lowered to minimize artifact misinterpretation, and three TEE views were recorded rapidly for later interpretation of the stage. The midesophageal four-chamber view was continuously monitored during surgery and videotaped. When a bubble was detected in the right atrium (RA), the probe was turned to the right side, and the angle was adjusted to the midesophageal bicaval view to confirm its entrance from the inferior vena cava. Then, the angle was rapidly readjusted to view the midesophageal right ventricle (RV) inflow-outflow view to confirm the extent of air embolism through the right ventricular outflow tract (RVOT). When gas bubbles filled more than half the diameter of the RA, RV, and RVOT, the midesophageal four-chamber, midesophageal two-chamber, midesophageal long-axis, and transgastric mid short-axis views were obtained for visual assessment of left ventricular function and RV overload. No quantitative evaluation was performed. TEE images were videotaped throughout surgery. To avoid interobserver variability, an independent cardiac anesthesiologist who did not know the groups reviewed and divided VAE into four grades: Grade I, single gas bubble in RA, RV, and RVOT; Grade II, gas bubbles filling less than half the diameter of RA, RV, and RVOT; Grade III, gas bubbles filling more than half the diameter of RA, RV, and RVOT; Grade IV, gas bubbles completely filling the diameter of RA, RV, and RVOT.[15]

Arterial blood pressure (systolic, diastolic, and mean), pulse oximetric saturation (Sp_{O_2}), and P_{ETCO_2} were monitored throughout surgery at 5-min intervals. Hemodynamic instability was defined as a sudden decrease in mean arterial blood pressure over 20 mmHg from the previous measurement and/or an acute fall in Sp_{O_2} below 90%. A sudden decrease in P_{ETCO_2} over 2 mmHg from the baseline value was also recorded. Electrocardiogram changes related to VAE such as ST elevation and depression and paroxysmal supraventricular tachycardia (PSVT) were also checked.

After surgery, major neurologic complications (defined as clinical evidence of focal cerebral infarction, including hemiparesis, visual, or gait disturbance; mental changes such as confusion, agitation, inability to make contact with other people) were also evaluated until discharge.

Statistical Analyses

The sample size was predetermined using a power analysis program (Power and Sample Size Calculation, Version 3.0; Vanderbilt University, Nashville, TN) based on the assumptions that (a) the incidence of VAE (grade III or IV) in patients undergoing TLH would be approximately 40% (based on the results of a preliminary study with 10 subjects), (b) the incidence of VAE in patients undergoing TAH would be about 10%, and (c) $\alpha = 0.05$ with a power ($1 - \beta$) of 0.8. The analysis led us to conclude that 40 patients per group would be sufficient.

Statistical analyses were performed with SPSS 12.0 software (Statistical Package for the Social Sciences, Chicago, IL). Patient characteristics were compared using Student t test and chi-square test where appropriate. Differences in the incidence of VAE between the two groups were analyzed by Mann–Whitney U test. $P < 0.05$ was considered statistically significant.

Results

All 80 patients (40 TAH, 40 TLH) completed the study protocol. Two patients in the TLH group were excluded from analysis due to change in surgical method during operation (from TLH to TAH). Patient characteristics were similar in both groups except anesthetic and operative time (table 1). Twelve patients in the TAH group and nine in the TLH group had patent foramen ovale. There was no statistical difference between groups in the incidence of patent foramen ovale. There were no significant differences in hemodynamic variables between groups except for the intraoperative P_{ETCO_2} level, which was higher in the TLH group after carbon dioxide insufflation ($P < 0.05$).

In the TAH group, VAE was detected in 15% (6 of 40) of patients on two-dimensional TEE. All patients with VAE in this group showed grade I VAE, and there

Table 1. Patient Characteristics

	TAH (n = 40)	TLH (n = 40)	P Value
Age, yr	44.6 ± 6.2	43.3 ± 6.1	0.393
Weight, kg	57.3 ± 8.3	57.5 ± 7.5	0.876
Height, cm	157.7 ± 5.3	159.1 ± 4.7	0.181
Operative time, min	110.5 ± 38.2	133.0 ± 36.4	0.027*
Anesthesia time, min	126.1 ± 30.1	149.5 ± 34.9	0.022*

The values are mean ± SD.

* There were significant differences between the two groups.

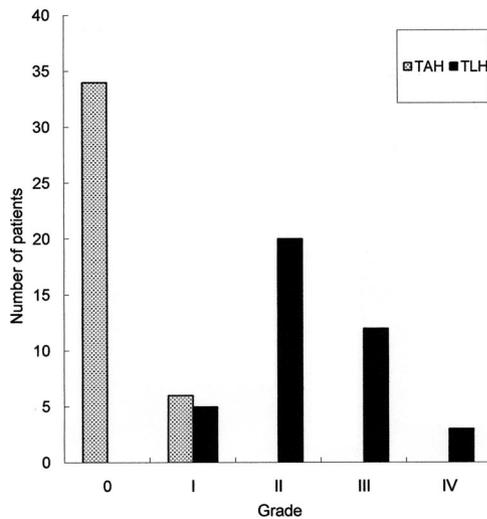TAH = total abdominal hysterectomy; TLH = total laparoscopic hysterectomy.

Fig. 1. Number of patients in each grade of venous air embolism (VAE). Total laparoscopic hysterectomy (TLH) group showed significantly higher stage of VAE than total abdominal hysterectomy (TAH) group (Mann–Whitney *U* test, *P* < 0.001).

was no change in either hemodynamic variables or electrocardiogram.

In the TLH group, VAE was detected in all 40 patients, with 5 (12.5%) in grade I VAE, 20 (50.0%) in grade II, 12 (30.0%) in grade III, and 3 (7.5%) in grade IV (fig. 1 and 2). VAE grade in the TLH group was significantly higher than in the TAH group (Mann–Whitney *U* test, Wilcoxon w = 835.0, Z = -7.955, *P* < 0.001). In two patients in the TLH group with grade VI VAE, a sudden decrease of P_{ETCO_2} greater than 2 mmHg from baseline value was noted, but no hemodynamic or electrocardiogram change was observed. Most VAE in the TLH group occurred during round ligament transection and broad ligament dissection. There was no ventricular dysfunction on visual assessment of TEE in patients with grade

III and IV VAE. All patients were discharged from the hospital without any major neurologic complications of presumed VAE.

Discussion

This study demonstrates that VAE occurred in all patients undergoing TLH. Although 37.5% of these patients showed bubbles filling more than half of the right heart, hemodynamic variables remained stable.

Despite a longer learning curve,[16] TLH is becoming more popular these days because it shows lower morbidity, faster recovery, and shorter length of stay compared to TAH.[17-20] TLH is performed in the Trendelenburg position under peritoneal carbon dioxide insufflation, similar to most other laparoscopic surgeries. The rate or amount of carbon dioxide entrainment depends on the opened vascular lumen and pressure gradient between the vascular lumen and right heart. The Trendelenburg position increases right atrium pressure and is the recommended position when a VAE is detected. In addition, positive pressure insufflation of carbon dioxide creates an even larger pressure gradient, thus enhancing the risk of VAE. In the current study, severe VAE occurred at the time of round ligament transection and broad ligament dissection. This may be a result of the opening of the venous plexus during transection and dissection of ligaments because the ligaments and surrounding tissues should be in traction for a while.

Carbon dioxide has been widely used in laparoscopic surgery because it is highly soluble in blood, and venous carbon dioxide embolism is considered less harmful than other gas embolisms such as helium or nitrous ox-
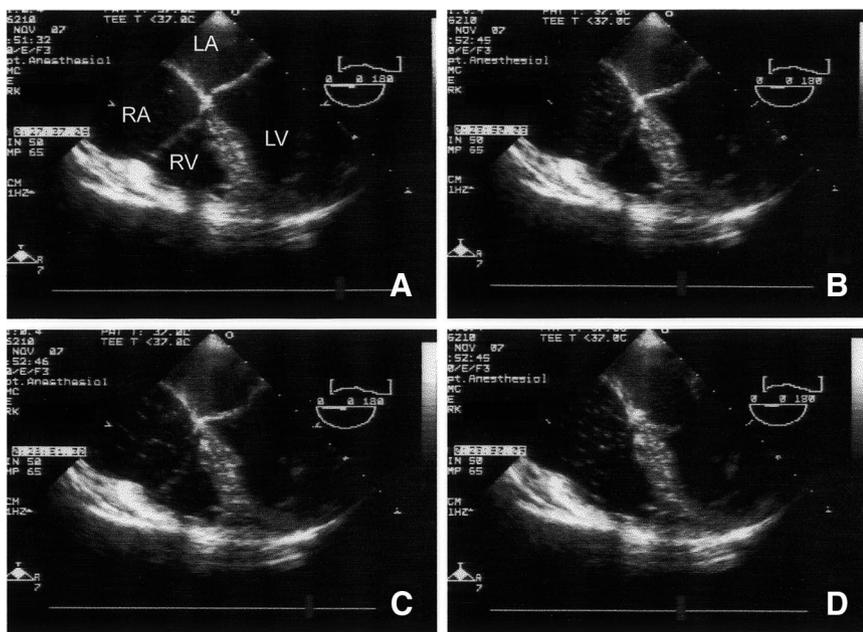

Fig. 2. Venous air emboli (VAE) detected by transesophageal echocardiography in a patient undergoing total laparoscopic hysterectomy (TLH); mid-esophageal four-chamber view. (*A*) grade I; (*B*) grade II; (*C*) grade III; (*D*) grade IV. This patient showed all grades of VAE. End-tidal carbon dioxide was suddenly decreased during broad ligament dissection (from 35 mmHg to 32 mmHg) but recovered soon after 100% oxygen inhalation. LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle.

ide.[21,22] However, considering the possibility of massive embolism and other pathophysiologic damage such as systemic inflammatory response syndrome[23] or pulmonary edema,[24,25] proper surveillance by the attending anesthesiologist for carbon dioxide embolism is warranted during laparoscopic surgery.

The ideal monitoring device for VAE should be sensitive, specific to VAE, and easily obtainable in practice. Unfortunately, a device to diagnose VAE in time for prevention and treatment does not exist.[26] TEE is the most sensitive, but it is relatively invasive. TEE can detect a bolus dose of air as small as 0.02 ml/kg.[27] Mirsky *et al.*[26] mentioned that TEE is too sensitive, detecting virtually any amount of air in the circulation, most of which do not lead to adverse sequelae. Therefore, TEE could catch grade I VAE in 15% of patients undergoing TAH.

In anesthetized patients, severe VAE may manifest as an acute decrease in $Petco_2$, an increase in end-tidal nitrogen, hypotension, or hypoxia that cannot be explained by deep anesthesia or hypovolemia. In this study, even high-grade VAE was not associated with hypotension or hypoxia as described in the Results section, which is consistent with other studies of VAE using TEE.[8,14] This may have resulted because patients involved in this study were healthy without preexisting cardiopulmonary, which enhances the effects of VAE, producing marked hemodynamic changes. Therefore, care should be taken in patients with cardiopulmonary disease as well as those with risk of intracardiac right-to-left shunt, which can occur with patent foramen ovale or liver cirrhosis due to the possible occurrence of paradoxical air emboli.

The goals of management when severe VAE is suspected or manifested are prevention of further gas entry, removal of entrained gas, and maintenance of hemodynamic stability.[28] When VAE is presumed and hemodynamic deterioration is manifested, the anesthesiologist must inform the surgeon and start inhalation of 100% O_2. The surgeon should stop carbon dioxide insufflation and flood the surgical field with a fluid, such as normal saline, and eliminate any origin of gas entry if possible. Placing the patient in the Trendelenburg position for central venous catheterization or hemodynamic support may increase the negative pressure gradient, thereby increasing gas influx even further. Therefore, the surgical field should be flooded before positioning. Placing the patient in a left lateral recumbent position may be helpful for trapping and aspirating gas entrained in the RA and may prevent and relieve the airlock in the right heart.[29] Maintenance of coronary perfusion pressure is essential to prevent further deterioration of the right ventricle and to improve right ventricular function.[30] Norepinephrine can significantly improve ventricular performance without constricting either pulmonary or renal circulation.[31,32]

This study was not randomized because the surgical method (TAH or TLH) was chosen by the surgeon after considering abdominal surgical history and surgical complexity. History of surgery has been reported to be related to an increased risk of embolism.[33] Although it seems likely that laparoscopy and associated pneumoperitoneum were responsible for VAE, there could be other possibilities related to the type of procedure. For example, if more dissection was performed due to more complex surgery or surgical technique, this could result in more gas exposure. The instrumentation could affect the occurrence of VAE. A vessel sealing technique with more disruption such as bipolar cautery was used for TLH, and this could have played a role. The skill or experience of the operator could also affect VAE stage. Another limitation of this study is the lack of modalities to test the effect of VAE on brain. Cognitive dysfunction is frequently associated with patients undergoing cardiopulmonary bypass surgery, in whom no major neurologic complications were diagnosed.[34,35] The addition of transcranial Doppler signal analysis may also have yielded information on the entrance of VAE into cerebral circulation. Although there were no major neurologic complications, even in patients with PFO, transcranial Doppler and careful neurocognitive tests may have revealed some differences between the groups.

The rate of intraoperative fluid was 50 ml/h to avoid echocardiographic artifacts and was based on the study by Derouin *et al.*[8] We also confirmed that this rate did not induce echocardiographic artifacts by TEE before the study.

In conclusion, the incidence of VAE in patients undergoing TLH was 100%, whereas VAE incidence in patients undergoing TAH was only 15%. VAE grade in TLH was higher compared to TAH, especially during transection of the round ligament and dissection of the broad ligament. Although VAE in this study was clinically insignificant, monitoring and care should be taken because fatal VAE is possible in patients with cardiopulmonary disease and those at risk for intracardiac shunts, such as patent foramen ovale or liver cirrhosis.

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