Int J Clin Exp Med 2016;9(5):8075-8080
www.ijcem.com /ISSN:1940-5901/IJCEM0019417

Original Article

Effect of high central venous pressure on the incidence of air embolism in patients receiving posterior lumber interbody fusion

Wen-Yi Liu[1], Shi-Duan Wang[1], Lin-Shan Yang[2], Min Xu[3], Chuan-Shan Zang[4], Li Song[1]

[1]Department of Anesthesiology, The Affiliated Hospital of Qingdao University, Qingdao 266000, China; [2]Department of Cardiac Surgery, The Affiliated Hospital of Qingdao University, Qingdao 266000, China; [3]Department of Gynecology, The Affiliated Hospital of Qingdao University, Qingdao 266000, China; [4]Department of Otorhinolaryngology, The Affiliated Hospital of Qingdao University, Qingdao 266000, China

Received November 9, 2015; Accepted April 5, 2016; Epub May 15, 2016; Published May 30, 2016

Abstract: Background: Venous air embolism (VAE) can lead to severe clinical events and takes place at higher frequency in spine surgery recently. In this study, we applied transesophageal echocardiography (TEE) to observe the effect of high central venous pressure (CVP) on the incidence of air embolism in patients. Method: Eighty-two posterior lumber interbody fusion (PLIF) patients that would receive PLIF under general anesthesia were randomly divided into two groups, control group (C group, n=40) and high CVP group (HCVP group, n=42). These patients were monitored by TEE during surgery. After surgery, two cardiac anesthesiologists reviewed TEE images and assessed the grades of VAE. Results: In C group, VAE was not detected in 17.5% of the patients; grade I VAE was detected in 22.5% of patients, grade II in 37.5% of patients, grade III in 17.5% of patients, and grade IV in 5% of patients. For HCVP group, VAE was not detected in 50% of the patients; grade I VAE was detected in 23.8% of patients, grade II in 16.7% of patients, grade III in 9.5% of patients, and grade IV in none of the patients. The grade and incidence of VAE were obviously lower in HCVP group than C group ($P<0.001$). Conclusion: For patients receiving PLIF, maintaining HCVP can effectively reduce the incidence of VAE and therefore enhance the safety of surgery.

Keywords: Venous air embolism, central venous pressure, transesophageal, echocardiography

Introduction

Venous air embolism (VAE) is a rare but fatal surgical complication caused by the entry of air from the surgical site to the venous system. VAE has been reported in neurosurgery, bone surgery, urological surgery, laparoscopy, cesarean section and removal of central venous catheter [1, 2]. VAE during spine surgery is described in literature with high mortality [3-6], but it is mostly presented as case report rather than in prospective large-sample trial. Since VAE may be asymptomatic, undiagnosed or unreported, its incidence is hard to estimate and no preventive measures have been established yet. To gain more understanding of VAE, we observed the incidence of VAE and the effect of high central venous pressure (HCVP) on the incidence by applying transesophageal echocardiography (TEE).

Materials and method

Patient recruitment

As shown in **Figure 1**, 82 patients were recruited. The experiment was approved by the Ethics Committee of Qinghai University Affiliated Hospital. Informed consent was obtained from 82 patients that would receive PLIF. The patients were aged 30-50 years and classified as ASAI-II. The history of abnormal cardiopulmonary function, congenital heart disease and gastric and esophageal disease was excluded. Using random number generator, 82 patients were divided into two groups: odd numbers for control group (C group, n=40) and even numbers for high CVP group (HCVP group, n=42). The CVP value high than 15 cmH_2O was considered HCVP. All surgeries were performed by one surgeon. VAE was monitored intraoperatively and graded postoperatively using TEE.

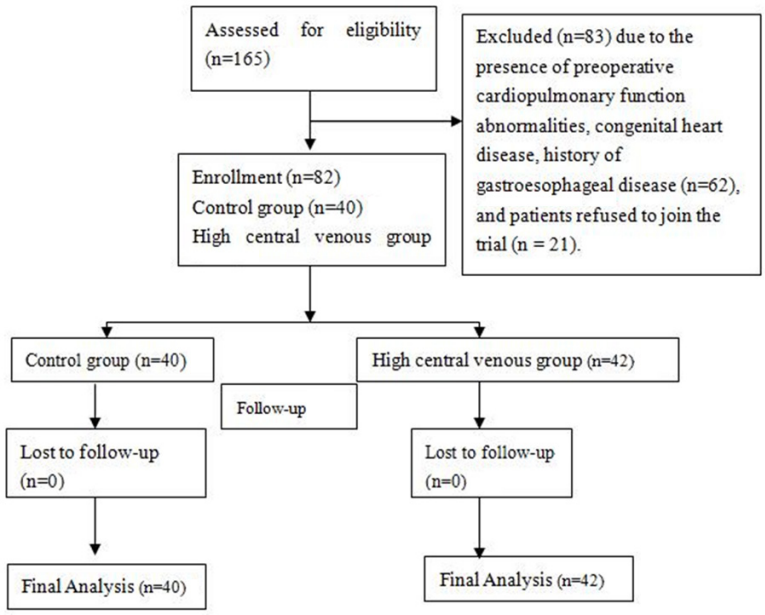

Figure 1. The flow chart of patients included.

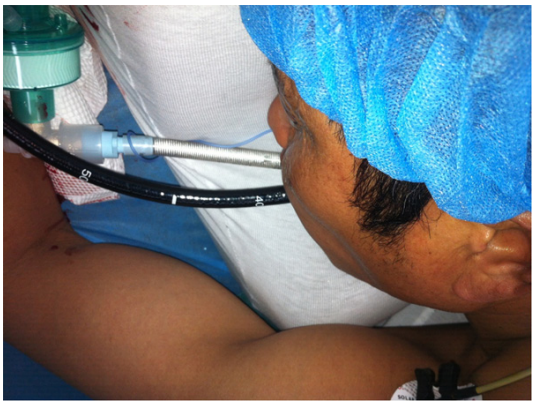

Figure 2. TEE probe was inserted.

The patients were fasted for 8 h before surgery. Intramuscular injection of 0.1 g Luminal and 0.3 mg scopolamine was performed 30 min before surgery. Upper extremity vascular access was established in supine position. ECG, non-invasive blood pressure and SpO_2 were monitored, and radial artery puncture and catheterization were performed under local anesthesia with invasive blood pressure measurement. Anesthesia was induced by intravenous injection of sufentanil (0.3 ug/kg), propofol (2 mg/kg) and vecuronium bromide (0.12 mg/kg). After endotracheal intubation, right central venous cannulation was performed to monitor CVP. Anesthesia was maintained with sevoflurane (1.5-3 vol%) and remifentanil (0.1 μg/kg/min). Muscular relaxation was maintained by intermittent intravenous injection of vecuronium bromide (0.03 mg/kg) every 30 min. Mechanical ventilation was adopted using 50% oxygen/50% air (2 L), end tidal carbon dioxide tension (PET-CO_2) was maintained at 35-40 mmHg. Before the patient was turned over, 5.0-MHz ultrasound transducer (SONOS 4500, Philips, Boeblingen, Germany) was inserted into the esophagus (**Figure 2**). After turning over, the zero point of the transducer was leveled using a U-shaped tube. For HCVP group, the point of spinous process was located, and the pressure difference between this point and the zero point was defined as the target value of CVP. The patient was infused with 0.9% lactated Ringer's injection and 6% hydroxyethyl starch 130/0.4 (Voluven, Fresenius Kabi, Germany). Hydroxyethyl starch was intended to supplement the lost blood volume (1:1). Amount of infusion in C group = compensatory expansion of vascular volume + deficient volume + maintenance volume + lost volume + third-space deficient volume. Before the destruction of bone structure in HCVP group, 0.9% lactated Ringer's injection was infused to achieve the target value of CVP. The amount and rate of fluid infusion were adjusted such that the target value of CVP was maintained. The position of transducer and the scan angle were adjusted for the imaging of the mid esophageal four-chamber view (**Figure 3**); the right atrium was observed. TEE monitoring was performed throughout the surgery, and the time of onset of VAE was recorded. When the air bubbles were detected in the right atrium (RA), the transducer was turned right; the scan angle was adjusted to observe the superior and inferior vena cava and to confirm whether the air bubbles entered from the inferior vena cava. Then the scan angle was adjusted again to observe the right ventricle (RV) and the right ventricular outflow tract (RVOT). When the air bubbles accumulated to over one half of RA, RV and RVOT, the functions of left and right ventricles were assessed from four-chamber view,

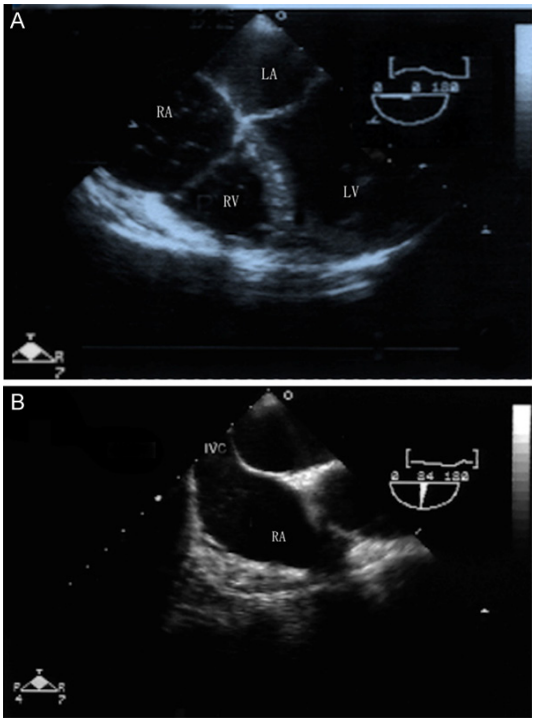

Figure 3. A. Mid-esophageal four-chamber view. B. Bicaval view. RA, right atrium; RV, right ventricle; LA, left atrium; LV, left ventricle.

two-chamber view, long-axis view and short-axis view. Ultrasound images of esophagus were collected during the course of surgery [7]. The grades of VAE were assessed by two cardiac anesthesiologists by reviewing the TEE images. Each grade of VAE was defined as follows: grade 0, no vascular air emboli in RA, RV and RVOT; grade I, a single air embolus in RA, RV and RVOT; grade II, volume of bubbles less than the radius of RA, RV and RVOT; grade III, volume of bubbles larger than the radius of RA, RV and RVOT; grade IV, bubbles completely filling up RV, RV and RVOT [8]. Invasive arterial pressure, heart rate, CVP, SpO_2 and $PETCO_2$ were measured. Unstable hemodynamic condition was defined as drop of average arterial pressure over 20 mmHg, oxygen saturation below 90%, and sudden decrease of $PETCO_2$ by over 2 mmHg from the baseline. Continuous ECG monitoring was performed to observe the occurrence of ST segment elevation, ST segment depression and paroxysmal supraventricular tachycardia related to VAE.

Postoperative neurological complications were observed until discharge from hospital, including the clinical signs of focal cerebral infarction and psychiatric symptoms.

Statistical process

The sample size was estimated by Power Analysis Software (Power and Sample Size Calculation, Version 3.0; Vanderbilt University, Nashville, TN). The assumptions made for the estimation were as follows: 1) the incidence of VAE (above grade II) was about 60% in patients receiving PLIF in C group (obtained by pre-experiment in 15 patients); 2) the incidence of VAE (above grade II) was about 30% in patients receiving PLIF in HCPV group; 3) α=0.05, (1-β)=0.8. Thus, according to the estimate, the sample size of each group should be no less than 40.

Statistical analyses were performed using SAS software (version 6.12, SAS Cary Academy, North Carolina, USA). The means of baseline data of patients in the two groups were compared with t-test. The means of vital signs were compared with analysis of variance. Bonferroni test was adopted for post-hoc analysis. Chi-square test and Fisher's exact test were used for the difference in the incidence of VAE between the two groups. $P<0.05$ was considered as significant difference.

Results

Full data were collected from all 82 patients. The baseline data of the two groups did not show significant difference (**Table 1**), and the intraoperative vital signs manifested similar variations in two groups except CVP (**Table 2**).

As shown in **Figure 4**, TEE images indicated that VAE did not occur in 17.5% (7/40) of the patients in C group; grade I VAE was detected in 22.5% (9/40) of the patients, grade II in 37.5% of patients, grade III in 17.5% of patients, and grade IV in 5% of patients. For HCVP group, VAE was not detected in 50% of the patients; grade I VAE was detected in 23.8% of patients, grade II in 16.7% of patients, grade III in 9.5% of patients, and grade IV in none of the patients. HCVP group had lower grades and incidence of VAE as compared with C group ($P<0.001$).

Grade IV VAE was detected in 2 patients of C group, with a sudden decline of $PETCO_2$ by over 2 mmHg but no obvious hemodynamic and ECG changes. The time of onset of VAE was from the damage of vertebral lamina to suturing of muscles. All patients were discharged from hospital after recovery without VAE-related neurological

Table 1. Patient characteristics

	Control group (n=40)	High central venous group (n=42)	*P* value
Age (yrs)	40.2±7.34	41.6±6.9	0.315
Sex ratio (M/F)	19/21	20/22	
Weight (kg)	65.9±9.8	64.4±8.7	0.736
Height (cm)	165.0±9.3	167.7±11.2	0.511
Operative time (min)	168.5±34.4	176.1±40.4	0.508
Blood loss	381.2±98.0	481.2±120.0	0.08

The values are reported as mean ± SD.

complications, such as neurological dysfunction, altered mental state and coma.

Discussion

Spine surgery will inevitably cause damage to the vertebral lamina, vertebral bodies and vertebral pedicle. Subsequently the air may enter the venous system via the exposed cancellous bone [9], leading to VAE. To lower the inferior vena cava pressure (IVCP) and hence the intraoperative bleeding, a frame is usually used to elevate the abdomen. However, the decreased blood pressure gradient between the operated site and the right atrium adds the risk of air entering the blood circulation [10]. It is reported that when the blood pressure gradient decreases to 5 cm, the air may enter the vein [11]. We infer that the incidence of VAE can be reduced by increasing the blood pressure gradient through the increase of CVP (i.e., right atrium pressure), and this is exactly what was done during surgery. Results showed that the incidence of VAE in HCVP group was significantly lower than that in C group.

Vertebral lamina decompression in prone position is unable to fully expose the chest, which restricts the manipulation of transducer. TEE is the most sensitive method to monitor VAE and also free from such constraint for this type of surgery [12]. Although TEE is able to detect air at the amount of 0.02 ml/kg in a single injection [13], it is an invasive technique not yet popularized in department of anesthesia. In this study, intravenous fluid infusion was mainly performed via the peripheral vein using the infusion pump. The infusion rate was less than 50 mL/min to avoid infusion via the central venous catheter and rapid peripheral vein infusion that would generate the interfering air emboli on TEE images. TEE monitoring was stopped during intravenous injection until the disturbance to TEE images disappeared [14].

To adjust CVP for HCVP group, the amount of fluid infusion was varied in this study. Rapid fluid infusion was performed during the period from establishing venous access to the damage of bone structure to achieve the target value of CVP. According to the definition of CVP in the experimental section, CVP was affected by the changes of arterial pressure and heart rate. To control for the changes of arterial pressure and heart rate, the depth of anesthesia was adjusted properly and the vasoactive drugs were administered, including norepinephrine, ephedrine, atropine, trinitroglycerol and Esmolol, so that the fluctuation would be less than 20% from the baseline.

In case of severe VAE, central venous catheter can be used to remove the air entering the atria, and the multi-hole central venous catheter is more effective than single-hole central venous catheter [15, 16]. Although only about 50% of the air will be removed, the fatal events can be avoided [17]. The degree of damage caused by VAE is determined by amount, rate and type of the entering air and the position of the patient [18]. Large dose of air rapidly entering the veins and the pulmonary vessels will induce vascular endothelial injury [19, 20]. This will cause gaps between endothelial cells and pulmonary edema [21], severely affecting pulmonary gas exchange function, increasing pulmonary circulation resistance and pulmonary arterial pressure. VAE may also lead to decreased cardiac output, arrhythmia, right heart damage and finally heart failure and death [22-24]. On ECG, the manifestations include ST-T changes and the subsequent supraventricular and ventricular arrhythmia [25]. Even small dose of air entering the arterial circulation via the ventricular septal defect or atrial septal defect such as patent foramen ovale (PFO) will result in paradoxical embolism and severe clinical events. The risk is especially high when the air emboli accumulate, thereby increasing the pulmonary arterial pressure. Autopsies show that the incidence of VAE in adults with PFO is 20%-35% [26]. Physicians should be fully aware of the risk of right-to-left shunting which may lead to air embolism in heart and brain.

Table 2. Changes in vital signs

Group	Before induction		5 minutes after Bone destruction		30 minutes after Bone destruction		60 minutes after Bone destruction	
	Control	HCVP	Control	HCVP	Control	HCVP	Control	HCVP
SBP	132.3±18.8	129.3±16.6	112.3±13.7	118.9±19.5	122.5±17.9	129.3±19.8	110.3±12.2	116.3±11.1
DBP	84.7±15.4	85.7±16.4	75.7±12.3	79.9±15.5	78.7±15.4	80.7±16.5	73.9±10.8	74.6±13.5
MBP	100.7±18.3	99.3±19.2	90.5±14.9	92.8±16.3	96.6±17.8	98.1±18.2	90.1±13.1	93.0±16.7
PR	74.2±13.6	77.2±12.3	68.2±10.4	70.8±10.6	79.1±13.5	80.2±15.3	78.2±13.9	77.1±12.6
$PETCO_2$	-	-	33.2±3.6	34.1±2.1	32.2±1.6	34.2±1.9	32.9±1.7	33.7±2.0
Pao_2	99.7±0.4	99.8±0.2	99.5±0.5	99.4±0.6	99.2±0.5	99.2±0.6	99.5±0.4	99.0±0.4
CVP	5.3±1.3	6.3±1.2	5.2±1.4	10.3±1.1*	4.4±1.1	9.8±0.8*	4.2±0.9	10.1±1.0*

SBP, systolic blood pressure; DBP, diastolic blood pressure; MBP, mean blood pressure; PR, pulse rate per minute; $PETCO_2$, end-tidalCO_2 partial pressure; PaO_2, pulse oximetric saturation. CVP, central venous pressure. The values are reported as mean ± SD. There was no significant difference between the two group (P>0.05). *The CVP in HCVP group were significantly higher than those in the Control group (P<0.001).

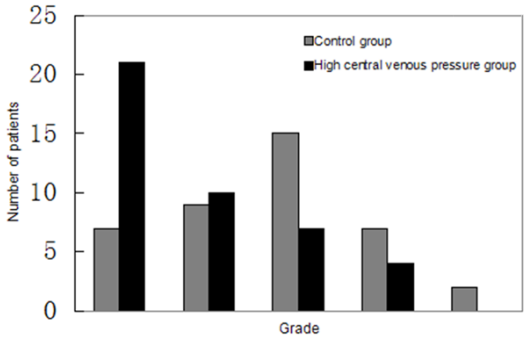

Figure 4. Number of patients in each grade of venous air embolism (VAE). Control group showed significantly higher stage of VAE than high central venous group (Mann-Whitney U test, P<0.05).

Among all cases, two had grade III VAE, and the surgery was stopped immediately. The surgical site was applied with normal saline and the head was placed higher than the feet [27] so as to avoid severe VAE. However, no air was aspirated from the central venous catheter; there was neither instability of circulations, nor ECG changes such as ST-T changes or supraventricular and ventricular arrhythmia. These findings agreed with the TEE monitoring of VAE in other studies [7, 12, 14, 28] due to small dose of air entering the heart.

To conclude, the incidence and grades of VAE were lower in HCVP group than in C group. Maintaining HCVP is beneficial for reducing the incidence of VAE. Although intraoperative bleeding will increase due to HCVP, this defect can be resolved by large-dose fluid infusion and the use of blood recovery unit, especially for high-risk population such as patients with PFO. According to case report, severe VAE is most frequent in patients with normal heart function [3-5], which may be attributed to lower CVP in these patients. Therefore, the changes of CVP in patients with normal heart function deserve extra attention for reducing the incidence of VAE and increasing the safety of surgery.

Disclosure of conflict of interest

None.

Address correspondence to: Dr. Shi-Duan Wang, Department of Anesthesiology, The Affiliated Hospital of Qingdao University, No. 16, Jiangsu Road, Qingdao 266000, China. Tel: +86+0532-82912515; E-mail: wangshid2015@163.com

References

[1] Palmon SC, Moore LE, Lundberg J and Toung T. Venous air embolism: a review. J Clin Anesth 1997; 9: 251-257.

[2] Wosko J, Dabrowski W, Zadora P, Sawulski S and Tomaszewski A. Coronary air embolism during removal of a central venous catheter. Anaesthesiol Intensive Ther 2012; 44: 21-4.

[3] McDouall SF and Shlugman D. Fatal venous air embolism during lumbar surgery: the tip of an iceberg? Eur J Anaesthesiol 2007; 24: 803-5.

[4] Albin MS, Ritter RR, Pruett CE and Kalff K. Venous air embolism during lumbar laminectomy in the prone position: report of three cases. Anesth Analg 1991; 73: 346-9.

[5] Dumont TM, Stockwell DW and Horgan MA. Venous air embolism: an unusual complication of atlantoaxial arthrodesis: case report. Spine (Phila Pa 1976) 2010; 35: E1238-40.

[6] Wills J, Schwend RM, Paterson A and Albin MS. Intraoperative visible bubbling of air may be the first sign of venous air embolism during

posterior surgery for scoliosis. Spine (Phila Pa 1976) 2005; 30: E629-35.
[7] Kim CS, Kim JY, Kwon JY, Choi SH, Na S, An J and Kim KJ. Venous air embolism during total laparoscopic hysterectomy: comparison to total abdominal hysterectomy. Anesthesiology 2009; 111: 50-4.
[8] Schmandra TC, Mierdl S, Bauer H, Gutt C and Hanisch E. Transoesophageal echocardiography shows high risk of gas embolism during laparoscopic hepatic resection under carbon dioxide pneumoperitoneum. Br J Surg 2002; 89: 870-6.
[9] Austin LS, VanBeek C and Williams GR. Venous air embolism: an under-recognized and potentially catastrophic complication in orthopaedic Surgery. J Shoulder Elbow Surg 2013; 22: 1449-54.
[10] Palmon SC, Moore LE, Lundberg J and Toung T. Venous air embolism: a review. J Clin Anesth 1997; 9: 251-7.
[11] Harris MM, Yemen TA, Davidson A, Strafford MA, Rowe RW, Sanders SP and Rockoff MA. Venous embolism during craniectomy in supine infants. Anesthesiology 1987; 67: 816-9.
[12] An J, Shin SK, Kwon JY and Kim KJ. Incidence of venous air embolism during myomectomy: the effect of patient position. Yonsei 2013; 54: 209-14.
[13] Furuya H, Suzuki T, Okumura F, Kishi Y and Uefuji T. Detection of air embolism by transesophageal echocardiography. Anesthesiology 1983; 58: 124-9.
[14] Derouin M, Couture P, Boudreault D, Girard D and Gravel D. Detection of gas embolism by transesophageal echocardiography during laparoscopic cholecystectomy. Anesth Analg 1996; 82: 119-24.
[15] Bunegin L, Albin MS, Helsel PE, Hoffman A and Hung TK. Positioning the right atrial catheter: a model for reappraisal. Anesthesiology 1981; 55: 343-8.
[16] Hicks HC and Hummel JC. A new catheter for detection and treatment of venous air embolism. Technical note. J Neurosurg 1980; 52: 595-8.
[17] Adornato DC, Gildenberg PL, Ferrario CM, Smart J and Frost EA. Pathophysiology of intravenous air embolism in dogs. Anesthesiology 1978; 49: 120-7.
[18] Ostocan MA and Aslani A. A life-saving procedure for treatment of massive pulmonary air embolism. J Invasive Cardiol 2007; 19: 355-6.
[19] Albertine KH, Wiener-Kronish JP, Koike K and Staub NC. Quantification of damage by air emboli to lung microvessels in anesthetized sheep. J Appl Physiol 1984; 57: 1360-8.
[20] Townsley MI, Barman SA and Taylor AE. Pulmonary embolism: emboli and fibrinolysis inhibition in isolated canine lungs. Am J Physiol 1990; 258: H754-8.
[21] Moosavi H, Utell MJ, Hyde RW, Fahey PJ, Peterson BT, Donnelly J and Jensen KD. Lung ultrastructure in noncardiogenic pulmonary edema induced by air embolization in dogs. Lab Invest 1981; 45: 456-64.
[22] Muth C and Shank E. Gas embolism. N Engl J Med 2000; 342: 476-82.
[23] Jersenius U, Fors D, Rubertsson S and Arvidsson D. The effects of experimental venous carbon dioxide embolization on hemodynamic and respiratory variables. Acta Anaesth Scand 2006; 50: 156-162.
[24] Souders JE. Pulmonary air embolism. J Clin Monit Comput 2000; 16: 375-383.
[25] Gildenberg PL, O'Brien RP, Britt WJ and Frost EA. The efficacy of Doppler monitoring for the detection of venous air embolism. J Neurosurg 1981; 54: 75-8.
[26] Schneider B, Zienkiewicz T, Jansen V, Hofmann T, Noltenius H and Meinertz T. Diagnosis of patent foramen ovale by transesophageal echocardiography and correlation with autopsy findings. Am J Cardiol 1996; 77: 1202-9.
[27] Simon G. Management of venous air embolism. Anesth Analg 2014; 119: 215.
[28] Koo BN, Kil HK, Choi JS, Kim JY, Chun DH and Hong YW. Hepatic resection by the Cavitron Ultrasonic Surgical Aspirator increases the incidence and severity of venous air embolism. Anesth Analg 2005; 101: 966-70.