Inverse Ratio Ventilation for Preventing Intra-Operative Hypercapnia in Children Undergoing Laparoscopic Surgery

XD Han
wenzhou cental hospital
Wangping Zhang (✉ zhang650679@163.com)
Jiaxing University
XH Qian
jiaxing university

Research

Keywords: inverse ratio ventilation, hypercapnia, laparoscopy, children

Posted Date: February 2nd, 2021

DOI: https://doi.org/10.21203/rs.3.rs-154630/v1

Abstract

Background

High end-tidal carbon dioxide tension ($P_{ET}CO_2$) and respiratory acidosis occurs frequently in patients undergoing laparoscopic surgery. The aim of this study is to be investigate the effect of pressure-controlled inverse ratio ventilation (IRV) with inspiratory to expiratory ratio (I: E) of 2:1 on children undergoing laparoscopic surgery.

Methods

Eighty children undergoing elective laparoscopic surgery were allocated randomly to the IRV group (1: E=2:1) and the control group (I: E=1:2). Children received pressure-controlled ventilation with I: E ratio of 2:1 or 1:2. Hemodynamic parameters and respiratory mechanics were recorded. Side effects were also recorded.

Results

At 30 min after CO_2 pneumoperitoneum, tidal volume (Vt) and arterial partial pressure of oxygen (PaO_2) were greater in the IRV group than the control group (100.6 ± 6.6 vs. 95.1±7.9 ml, 282.7 ± 45.6 vs.246.5 ± 40.1mmHg, respectively) ($P < 0.01$), but $PaCO_2$ was lower than the control group (43.9 ± 5.45 vs. 46.7 ± 4.90 mmHg, $P = 0.013$). The incidence of intra-operative hypercapnia was lower in the IRV group (25% vs. 42.5%, $P = 0.03$).

Conclusion

IRV may reduce the incidence of intra-operative hypercapnia as well as increasing Vt and thus improving CO_2 elimination in children undergoing laparoscopy. (Registration number: ChiCTR2000035589)

Introduction

At present, laparoscopic technology is widely used for pediatric surgery. Insufflation of carbon dioxide (CO_2) could result in hypercapnia and acidemia in the patients undergoing laparoscopic surgery. [1] We are confronted with difficulty in maintaining end-tidal carbon dioxide tension ($P_{ET}CO_2$) in normal range without lung injury. It is difficult to improve the hypercapnia by increasing the respiratory frequency under pressure control ventilation mode. Pressure control ventilation with positive end-expiratory pressure (PEEP) would improve oxygenation accompanied with a decrease in tidal volume (Vt). However, pressure control ventilation with higher airway pressure would increase Vt, but high airway pressure might lead to lung barotrauma and volutrauma. The documents indicated that inverse ratio ventilation (IRV) could improve oxygenation and reduce peak airway pressure compared with conventional ventilation mode. [2–6] Moreover, it was reported that the optimal I: E ratio was 2:1 when using IRV. [7] So we investigated the effect of pressure-controlled IRV (PC-IRV) with inspiratory/expiratory (I: E) ratio of 2:1 on respiratory function in children undergoing laparoscopic surgery. PC-IRV has been used extensively in the past to improve oxygenation in patients with acute hypoxemic respiratory failure. The aim of this study was to investigate whether PC-IRV might have the benefit of also improving ventilation without increasing the peak airway pressure. We hypothesized that pressure-controlled IRV with I: E ratio of 2:1 could increase Vt, improve gas exchange and promote CO_2 elimination in the children undergoing laparoscopic surgery.

Methods

This study was approved by the Jiaxing Hospital's Institutional Review Board. Written informed consent was obtained from the children’s guardians. The trial was registered at www.chictr.org.cn (Registration number: ChiCTR2000035589). From August 10 to October 9, 2020, we recruited a total of 82 children undergoing elective laparoscopy (appendectomy or herniorrhaphy). Inclusion criteria: ASA grade I or II, age 2–6 years, weight 10–25 kg and expected duration of surgery lasted more than 30 min. The children with cardiopulmonary disease, obesity (index body mass $\geq 30kg/m^2$) and airway hyper-response were excluded from the study. Eighty children were randomly divided into the IRV groups (I: E = 2:1) and the control group (I: E = 1:2), based on a computer-generated randomization table.

All children had no premedication. On arrival at operating room, monitoring including electrocardiogram, noninvasive blood pressure (BP), heart rate (HR) and pulse oxygen saturation (SpO_2) was applied with anesthesia monitor, and venous access was established. Anesthesia was induced with inhalation of 5%-7% sevoflurane, intravenous fentanyl 4 ug/kg, propofol 2 mg/kg, and tracheal intubation was facilitated with intravenous cis-atracurium 0.1 mg/kg. Anesthesia was maintained with inhalation of sevoflurane. The lungs were mechanically ventilated with pressure-controlled mode and respiratory parameters of anesthesia ventilator were set as follows: driving pressure of 15 cmH_2O, respiratory rate of 20 breaths/min, PEEP of zero, oxygen flow of 1 L /min, fraction of inspired oxygen of 1.0 and I: E ratio of 1:2. When establishing CO_2 pneumoperitoneum, the driving pressure value was adjusted to 18 cmH_2O in both groups, and I: E ratio was set as 2:1 in the IRV groups and I: E ratio was still 2:1 in control group, other respiratory parameters were constant.

Anesthesia was maintained with 2–3% end-tidal sevoflurane to keep the bispectral index (BIS) value between 40 and 55 (BIS monitor Model A2000, USA) and control the hemodynamic response to the surgical procedure within a 20% range of the preoperative value. Muscle relaxation was monitored by the train-of-four (TOF) stimulation (Organon Corporation, type: TOF-Watch SX, Holland). Cis-atracurium was infused at a rate of 0.1 mg. $kg^{-1}.h^{-1}$ to keep TOF value below 5%. The driving pressure was increased to maintain $P_{ET}CO_2$ below 50 mmHg if the value of the end-tidal carbon dioxide tension ($P_{ET}CO_2$) exceeded 50 mmHg. Spirometry readings included inspiratory V_T, mean airway pressure (Pmean), $P_{ET}CO$ and total PEEP (PEEPtot) using a side-stream spirometry device (Type: D-FPD15-00, GE company, Taipei, China). During the study period, lactated Ringer’s solution was infused at a rate of 5–6 $ml.kg^{-1}.h^{-1}$.

CO_2 pneumoperitoneum tension value was set at the level of 8 mmHg during operation. Immediately after establishing CO_2 pneumoperitoneum, the children were turned to a supine position with head down at 10 degrees below horizon. Noninvasive systolic blood pressure (SBP) and diastolic blood pressure (DBP) and HR were recorded at baseline or before anesthesia (T0), 2 minutes before establishing CO_2 pneumoperitoneum (T1), 30 min after initiation of CO_2 pneumoperitoneum (T2) and the end of surgery (T3). Respiratory mechanics were recorded at T1 and T2. Arterial blood was drawn and analyzed using a blood gas analyzer (Type: ABL8000, Denmark) at T1 and T2 respectively. Hypercapnia was defined as $PaCO_2 > 45$ mmHg. The time to extubation and discharge time from post-anesthesia care unit (PACU) were recorded. Post-operative complications, if any, were also recorded, such as post-operative hypoxemia (post-operative hypoxemia was defined as SpO_2 below 91% while receiving air), pneumothorax and other pulmonary complications. The children could be discharged from PACU when Modified Aldrete Score was 9 or above. [8]

Statistical analysis

Data were analyzed with a SPSS 17.0 statistical software (SPSS Inc.,Chicago□USA). Quantitative variables with normal distribution were compared with *t* test and one- side analysis of variance. Data with non-normal distribution were used two-side Mann-Whitney *U*-test in both groups. Categorical variables were evaluated with the Chi-square test. All quantitative data were expressed as mean ± standard deviation. A $P < 0.05$ was considered statistically significant.

The sample sizes were determined based on the primary outcome. The primary variable was V_T in this study. A priori power analysis using two-sided analysis with α error of 0.05 and a power of 0.8 showed that 32 patients were needed to detect a 7 ml increase in V_t from the mean value in each group for this study. Sample size was increased to 40 to allow for dropout in each group in this study.

Results

Eighty-two children were enrolled into the study (Fig. 1). Eighty children finished this study and two patients were excluded for hesitations in participation. No significant differences in terms of age, weight and duration of surgery between the groups (Table 1) ($P > 0.05$). At T1, there were no significant differences in PaO_2, $PaCO_2$ and pH in both groups ($P > 0.05$). At T2, PaO_2 and pH were greater in the IRV group than in the control group (282.7 ± 45.6 vs. 246.5 ± 35.5 mmHg, 7.34 ± 0.03 vs. 7.32 ± 0.03) (Table 2) ($P < 0.01$), while $PaCO_2$ was lower in the IRV group than in the control group (43.9 ± 4.65 vs. 46.7 ± 4.90 mmHg) ($P = 0.013$), there were significant differences in PaO_2, $PaCO_2$ and pH at T2. SaO_2 were similar in both groups ($P < 0.05$).

Table 1
Data of children (n = 40)

Index	IRV group	Control group	*P* -value
Age (year)	4.0 ± 1.2	4.2 ± 1.3	0.521
Weight (kg)	17.5 ± 4.1	18.1 ± 4.5	0.545
Gender (Male/Female)	28/12	24/16	0.321
Surgery performed,1/2 (n)	16/24	18/22	0.723
Duration of pneumoperitoneum (min)	53.9 ± 12.6	58.0 ± 16.1	0.272
Duration of surgery (min)	66.5 ± 6.8	71.2 ± 7.6	0.681
Time to extubation (min)	13.6 ± 4.7	12.5 ± 5.3	0.332
PACU discharge time(min)	43.6 ± 6.5	45.3 ± 7.2	0.274
Intaoperative hypercapnia (n)	8(25%)	17(42.5%)	0.030*
Postoperative hypoxemia (n)	0	0	0.999

Data are expressed as the mean (standard deviation) or number. Surgery performed: 1, appendectomy; 2, herniorrhaphy.

Table 2
Blood gas of children (n = 40)

Index	IRV group	Control group	*P* -value
pH	7.34 ± 0.03	7.32 ± 0.03$^{\#}$	0.005*
PaO_2 (mmHg)	282.7 ± 45.6	246.5 ± 40.1	0.005*
$PaCO_2$ (mmHg)	43.9 ± 4.65	46.7 ± 4.90	0.013*
SaO_2 (%)	99.7 ± 1.5	99.6 ± 1.7	0.782

Data are expressed as the mean (standard deviation). Comparison between the two groups, *$P < 0.05$.

The V_T, Pmean and auto-PEEP were higher in the IRV group than those in control group at T2, there was statistical significance on V_T, Pmean and auto-PEEP (100.6 ± 6.6 vs. 95.1 ± 7.9 ml, 13.7 ± 1.1 vs.12.0 ± 1.2 cmH_2O and 2.60 ± 0.50 vs. 1.73 ± 0.55 cmH_2O, respectively) ($P < 0.01$) (Fig. 3). $P_{ET}CO_2$ was lower at T2 in the IRV group than in the control group (42.0 ± 2.37 vs. 43.4 ± 2.83 mmHg) ($P = 0.023$), there were significant differences in $P_{ET}CO_2$. Blood pressure and HR are shown in Fig. 2, there were no statistical significances in blood pressure and HR between the 2 groups at T2 ($P > 0.05$).

Eight cases of hypercapnia occurred in IRV group within 30 minutes after initiation of CO_2 pneumoperitoneum and 17 cases of hypercapnia occurred in the control group, there were statistical significances in the incidence of intra-operative hypercapnia between the 2 groups ($P = 0.03$). No postoperative hypoxemia was observed and there was no statistical significance in incidence of hypercapnia, extubation time and PACU discharge time between the 2 groups ($P > 0.05$) (Table 1). There were no respiratory complications observed during the hospital stays.

Discussion

Longer inspiratory time with ongoing flow will increase the tidal volumes. Larger tidal volume at the same rate will lead to higher minute ventilation and peak airway pressure. Ventilation with PEEP may improve oxygenation, but increase peak airway pressure. Hypercapnia is the most common complication in the patients undergoing laparoscopic surgery, and anesthesiologists face challenges in maintaining $P_{ET}CO_2$ without increasing obviously the peak airway pressure. In view of the above mentioned, we didn't use PEEP in this study.

In this study, we discussed the respiratory effects of pressure-controlled IRV (I: E = 2) ventilation in children undergoing laparoscopy, and found that pressure-controlled IRV could significant decreases $P_{ET}CO_2$, improve oxygenation and gas exchange in children undergoing laparoscopy compared to conventional ratio ventilation.

IRV is different from the conventional ventilation mode. Prolonging inspiratory time can increase the alveolar ventilation volume and functional residual capacity and expand the collapsed alveolar. Besides, IRV may reduce dead-space, which is contributed to the gas distribution in the lungs. At present, the studies on IRV are fewer in children undergoing laparoscopy. Under the pressure-controlled mode, the Vt and Pmean will be higher in IRV group than those in the control group. As inspiratory time was prolonged and inspiratory flow velocity slowed down, the airway resistance decreased, which brought about an increase in Vt. Moreover, IRV could generate auto-PEEP (endogenous PEEP), [9] which was beneficial to oxygenation. Besides, it was reported that arterial blood oxygenation is directly related to mean airway pressure, [6, 10] so higher Pmean was also contribute to oxygenation and gas exchange in a certain range. [11]

As inspiratory time is prolonged, the expiratory time is relatively short under pressure-controlled IRV mode, IRV may generate endogenous PEEP. IRV could lead to an increase in Pmean and reduce venous return. In our study, blood pressure and heart rate had no statistical differences in both groups. It meant that IRV with I: E of 2:1 didn't affect venous return. IRV might reduce cardiac output only I: E ratio beyond 2:1. [3, 12] Only when inspiratory time was excessive prolonged and Pmean reached a certain high level, IRV would result in a decrease in cardiac output, and have an effect on hemodynamics. [3, 13] IRV could bring about an increase in the Pmean and PaO_2, as was agree with the study of *Mercat A, et al.* [5] However, Pmean has an important effect on hemodynamics. Although the Pmean was significantly higher in the IRV group than conventional ventilation group, there were no significant differences in hemodynamic parameters between the 2 groups. Hence, Pmean has no effect on hemodynamics in a certain range, it was similar to the results of *Movassagi R, et al.* [13]

PaO_2 was significantly higher in the IRV group than conventional ventilation group at 30 min after initiation of CO_2 pneumoperitoneum. It indicated that IRV could obviously increase the oxygen content, and promote oxygenation. $PaCO_2$ was lower in IRV group than the control group, there was significantly different between the 2 groups. $PaCO_2$ increased obviously in both groups 30 min after initiation of CO_2 pneumoperitoneum. The main reason was caused by the CO_2 absorption in blood, [14] IRV did not affect the discharge of CO_2. $PaCO_2$ fell down 5.3 mmHg in patient with normal weight during mechanical ventilation when tidal volumes decrease per 100 ml, $PaCO_2$ fell 3.6 mmHg in morbidly obese patients. [15] So the tidal volume was the main factor that determined CO_2 discharge during mechanical ventilation. Moreover, CO_2 pneumoperatoneum might affect hemodynamics during laparoscopic surgery. [16]

The limitations of our study are as following: IRV is different from the conventional ventilation mode, it may have some potential risks: the long-term complications of respiratory system remain to be studied. The large sample sizes are needed to investigate the adverse respiratory and hemodynamic effects.

Conclusion

Pressure controlled IRV may reduce the incidence of intra-operative hypercapnia as well as increasing Vt and thus improving CO_2 elimination in children undergoing laparoscopy compared to conventional ventilation. It is superior to conventional ratio ventilation in terms of gas exchange and respiratory mechanics in children undergoing laparoscopy.

Declarations

Ethics approval and consent to participate: This study was approved by the Ethics Committee of Jiaxing hospital and written informed consent was obtained from the children’s guardians.

Consent for publication: Yes

Availability of data and material: Authors will allow sharing the data, such as blood pressure, heart rate and respiratory parameters. The data will be accessible 6 months after publication**.**

Competing interests: None declared.

Funding: No

Authors' contributions: Study design and data analysis: X.D

Patient recruitment and data collection: Z.W

Writing up of the first draft of the paper: X.D and Z.W

Acknowledgements: We thank Jiang Y for her encouragement in this study.

References

1. Gutt CN, Oniu T, Mehrabi A, et al. Circulatory and respiratory complications of carbon dioxide insufflation. Dig Surg 2004; 21:95–105.
2. Talab HF, Zabani IA, Abdelrahman HS, et al. Intraoperative ventilatory strategies for prevention of pulmonary atelectasis in obese patients undergoing laparoscopic bariatric surgery. Anesth Analg 2009, 109:1511–16.
3. Almarakbi WA, Fawzi HM, Alhashemi JA. Effects of four intraoperative ventilatory strategies on respiratory compliance and gas exchange during laparoscopic gastric banding in obese patients. Br J Anaesth 2009, 102:862–8.
4. Markstrom AM, Lichtwarck-Aschoff M, Hedlund A J, et al. Under open lung conditions inverse ratio ventilation causes intrinsic PEEP and hemodynamic impairment. Ups J Med Sci 1996, 101: 257-71.
5. Mercat A, Titiriga M, Anguel N, et al. Inverse ratio ventilation (I/E-2/1) in acute respiratory distress syndrome. Am J Respir Crit Care Med 1997, 155:1637–42.
6. Huang CC, Shih MJ, Tsai YH, et al. Effects of inverse ratio ventilation versus positive end-expiratory pressure on gas exchange and gastric intramucosal PCO_2 and pH under constant mean airway pressure in acute respiratory distress syndrome. Anesthesiology 2001, 95: 1182–8.
7. Sari AYamashita SToriumi T, et a1.The effects of inversed ratio ventilation (IRV) on arterial oxygenation during mechanical ventilation in patients with acute respiratory failure. Resuscitation 19912293-101.
8. Schmitz A, Weiss M, Kellenberger C, et al.Sedation for magnetic resonance imaging using propofol with or without ketamine at induction in pediatrics-A prospective randomized double-blinded study. Paediatr Anaesth. 2018 ;28:264-274.
9. Yanos J, Watling SM, Verhey J.The physiologic effects of inverse ratio Chest. 1998;114:834-8.
10. Xu L, Shen J, Yan M. The effect of pressure-controlled inverse ratio ventilation on lung protection in obese patients undergoing gynecological laparoscopic surgery. J Anesth.2017, 31:651-656.
11. Ludwigs U, Klingstedt C, Baehrendtz S, et al. A comparison of pressure- and volume-controlled ventilation at different inspiratory to expiratory ratios. Acta Anaesthesiol Scand 1997, 41:71-7.
12. Gore DC. Hemodynamic and ventilatory effects associated with increasing inverse inspiratory-expiratory ventilation. J Trauma 1998, 45: 268-72.
13. Movassagi R, Montazer M. Mahmoodpoor A, et al. Comparison of pressure vs. volume-controlled ventilation on oxygenation parameters of obese patients undergoing laparoscopic cholecystectomy. Pak J Med Sci. 2017; 33:1117-1122.

14. De Waal EE, Kalkman CJ. Haemodynamic changes during low-pressure carbon dioxide pneumoperitoneum in young children. Paediatr Anaesth.2003;13:18-25
15. Sprung J, Whalley DG, Falcone T, et al. The impact of morbid obesity, pneumoperitoneum and posture on respiratory system mechanics and oxygenation during laparoscopy. Anesth Analg 2002; 94:1345-50.
16. Rademaker BM, Odoom JA de, Wit LT, et al. Hemodynamic effects of pneumoperitoneum for laparoscopic surgery: A comparison of CO2 with N2O insufflation. Eur J Anesthesiology 1994, 11:301-306.

Figures

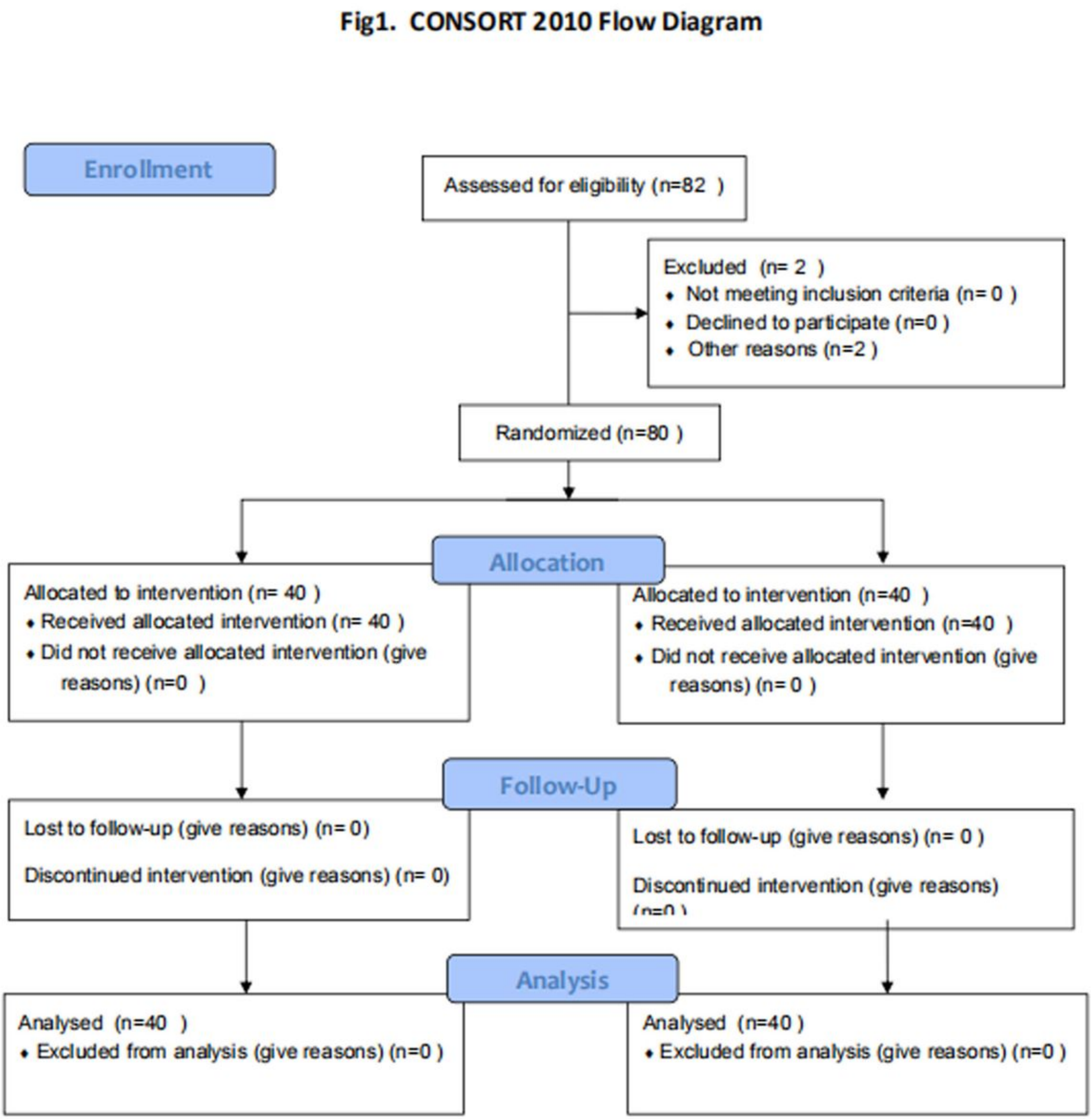

Figure 1

Flow diagram of study.

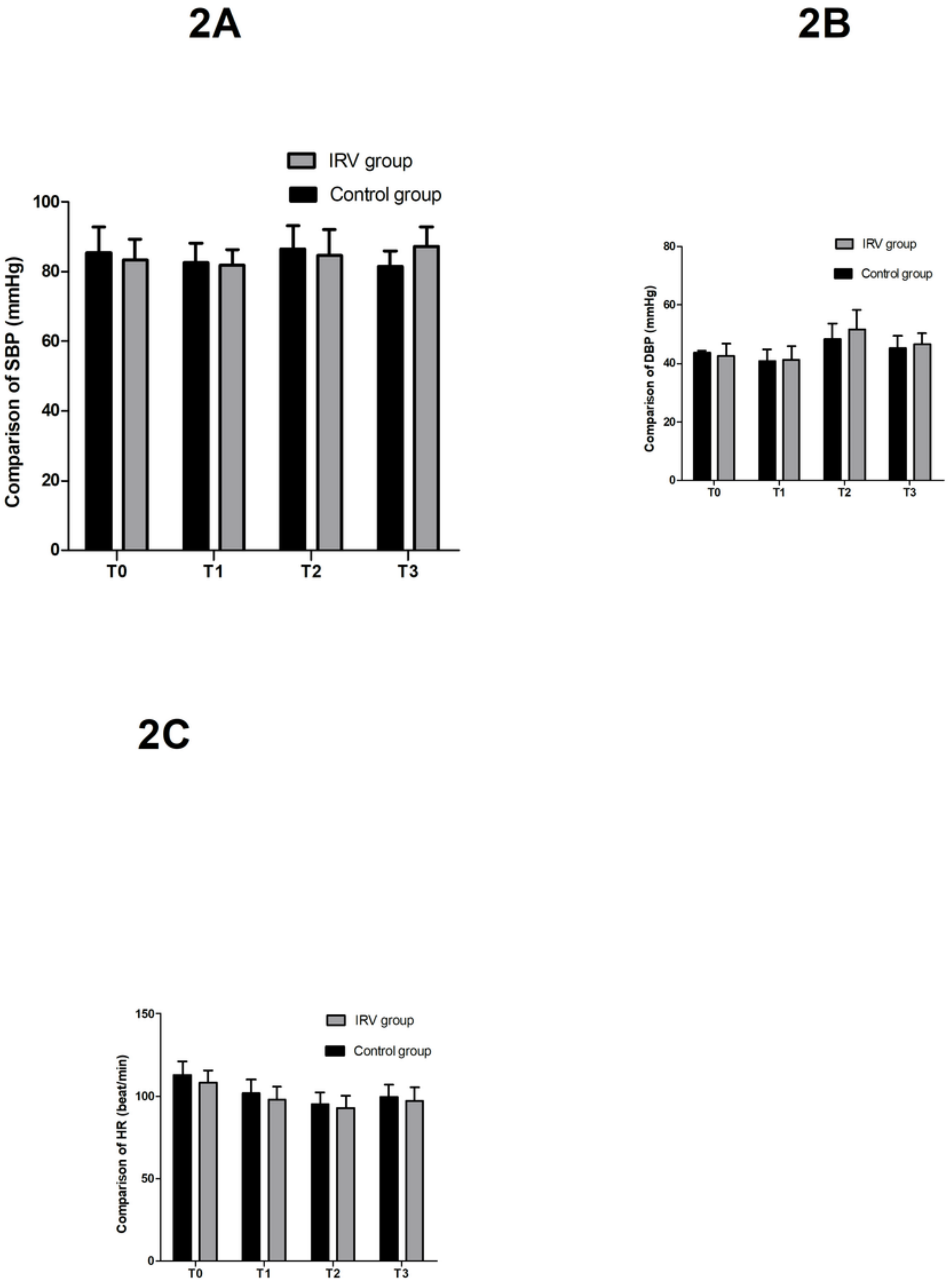

Figure 2

Comparison of hemodynamic parameters (SBP, DBP and HR) between the 2 groups. At T0, T1, T2 and T3, there were no significant differences in SBP, DBP and HR between the 2 groups ($P > 0.05$). SBP: systolic blood pressure, DBP: diastolic blood pressure, HR: heart rate. T0: at baseline or before anesthesia, T1: immediately before establishing CO2 pneumoperitoneum, T2: 30 min after initiation of CO2 pneumoperitoneum and T3: the end of surgery.

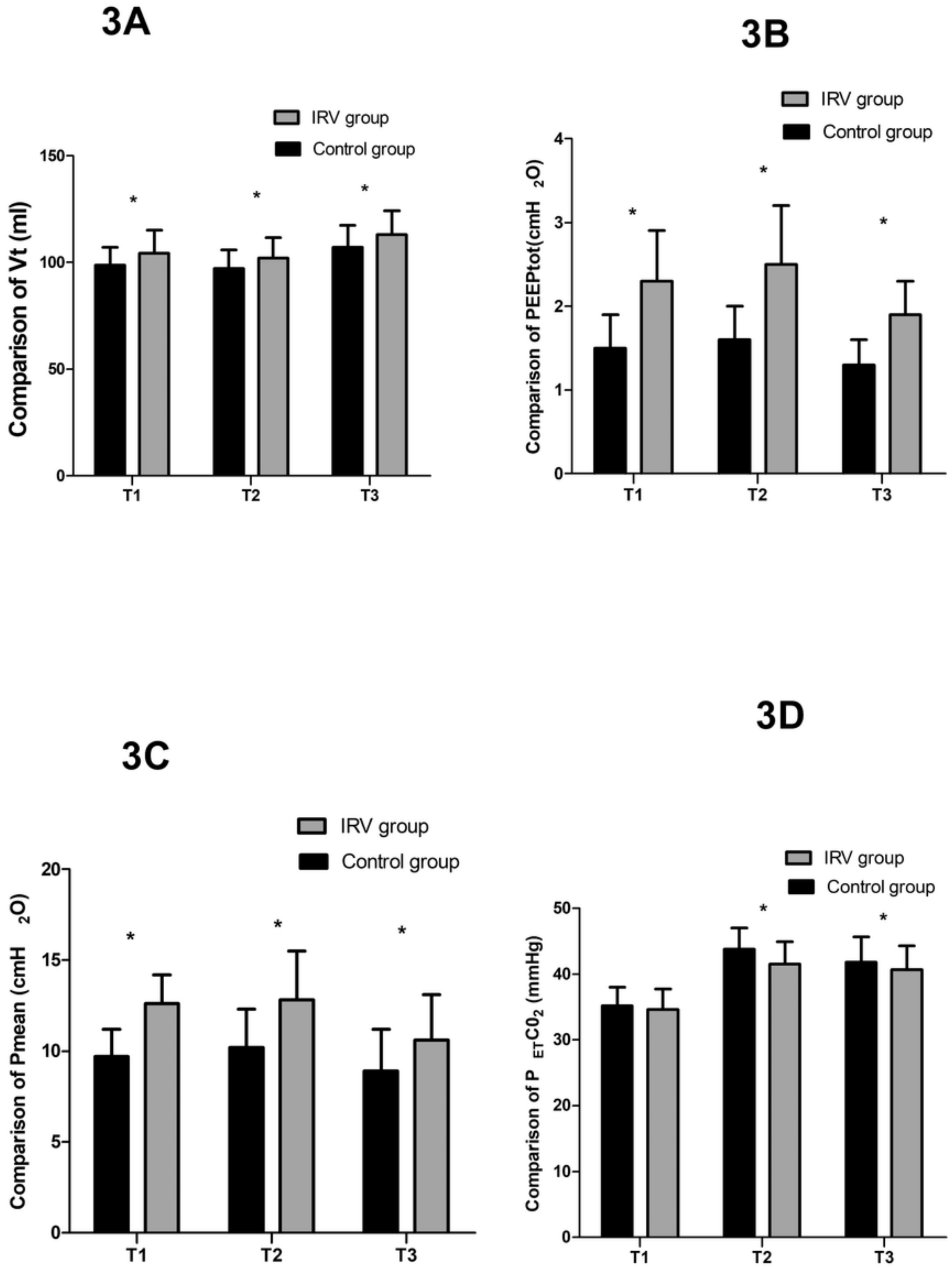

Figure 3

Comparison of respiratory mechanics between the 2 groups. At T1, T2 and T3, there were significant differences in VT, Pmean, PEEPtot and PETCO2 between the 2 groups (*P<0.05). T1: immediately before establishing CO2 pneumoperitoneum, T2: 30 min after initiation of CO2 pneumoperitoneum and T3: the end of surgery.