

驱动压导向个体化 PEEP 滴定对妇科腹腔镜手术肥胖患者术后肺部并发症的影响

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[摘要] 目的 探讨基于肺超声(lung ultrasound, LUS)及机械功(mechanical power, MP)评估驱动压导向个体化呼气末正压(positive end-expiratory pressure, PEEP)滴定对腹腔镜手术肥胖患者术后肺部并发症(postoperative pulmonary complications, PPCs)的影响。方法 选择2020年1月—2021年9月择期在全身麻醉气管插管下行妇科腹腔镜手术的患者137例,年龄18~70岁,体重指数(body mass index, BMI) >28 ,美国麻醉医师协会(American Society of Anesthesiologists, ASA)分级Ⅱ或Ⅲ级,分为驱动压组(D组, $n=69$)和固定呼气末正压组(P组, $n=68$),2组全身麻醉中均采用容量控制通气,吸呼比为1:2, V_T 6 mL/kg(理想体重),呼吸频率10~15次/min,吸氧浓度为80%,PETCO₂维持在35~40 mmHg(1 mmHg=0.133 kPa)。P组头低位期间PEEP维持5 cmH₂O(1 cmH₂O=0.098 kPa)。D组在头低位期间施加个体化的最低驱动压,即在头低位开始5 min后进行PEEP滴定试验,选择能产生最低驱动压的PEEP,然后在整个机械通气期间维持该PEEP。记录插管后10 min(T1)、头低位开始后30 min(T2)、手术结束即刻(T3)的心率(heart rate, HR)、收缩压(systolic blood pressure, SBP)、舒张压(diastolic blood pressure, DBP)、气道峰压(peak airway pressure, Ppeak)、气道平台压(plateau airway pressure, Pplat)、PEEP及氧合指数(oxygenation index, OI)结果。T2时计算驱动压(驱动压=Pplat-PEEP)、死腔率(VD/VT)、动态肺顺应性(dynamic lung compliance, Cdyn)、肺内分流率(intrapulmonary shunt fraction, Qs/Qt)、呼吸指数(respiratory index, RI)及MP变化。对2组入室和手术结束后进行肺部超声检查并进行改良LUS评分并记录。结果 D组拔管后30 min LUS评分、7 d的PPCs发生率及氧疗时间超过48 h比例分别为(12.4±2.9)分、12例(17.39%)、5例(7.25%),明显低于P组($P<0.05$)。2组术中出入量比较,差异无统计学意义($P>0.05$)。D组去甲肾上腺素和去氧肾上腺素分别为:34例(49.27%)、36例(52.17%),明显高于P组($P<0.05$)。与T1和T3时比较, D组和P组T2时Ppeak、Pplat分别为(22.2±0.6)cmH₂O、(21.6±3.1)cmH₂O、(20.8±0.4)cmH₂O、(20.3±3.1)cmH₂O呈明显上升趋势($P<0.05$)。2组组间、时间点、组间·时间点HR、SBP、DBP及OI比较差异无统计学意义($P>0.05$)。T2时D组驱动压、Qs/Qt、RI、VD/VT及MP分别为:14.2(4.8)cmH₂O、(26.4±4.0)%、(0.13±0.02)、(6.1±2.5)%、(10.3±2.1)J/min明显低于P组($P<0.05$);T2时D组Cdyn及最佳PEEP分别为(27.2±5.4)mL/cmH₂O、10.0(4.0)cmH₂O明显高于P组($P<0.05$)。结论 驱动压导向个体化PEEP滴定保护肺通气策略相对于传统固定PEEP通气策略可以降低妇科腹腔镜肥胖患者术后PPCs发生率以及氧疗时间,降低LUS,但术中使用血管活性药物需求增加。

[关键词] 驱动压; 术后肺部并发症; 机械功 doi:10.3969/j.issn.1007-3205.2025.11.006

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Effect of driving pressure-guided individualized PEEP titration on postoperative pulmonary complications in obese patients undergoing gynecological laparoscopic surgery

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[Abstract] Objective To investigate the impact of individualized positive end-expiratory pressure (PEEP) titration guided by driving pressure based on lung ultrasound (LUS) and mechanical power (MP) on postoperative pulmonary complications (PPCs) in obese patients undergoing laparoscopic surgery. **Methods** A total of 137 patients scheduled for gynecological laparoscopic surgery under general anesthesia with endotracheal intubation from January 2020 to September 2021 were selected. The patients were aged 18 to 70 years, with BMI > 28, and ASA physical status II or III. They were divided into the driving pressure group (group D, $n=69$) and the fixed PEEP group (group P, $n=68$). Both groups received volume-controlled ventilation during general anesthesia, with the inspiratory-to-expiratory ratio of 1:2, V_T 6 mL/kg (ideal body weight), respiratory rate (RR) of 10–15 breaths/min, the fraction of inspired oxygen of 80%, and PETCO₂ maintained at 35–40 mmHg (1 mmHg=0.133 kPa). In group P, the PEEP was maintained at 5 cmH₂O (1 cmH₂O=0.098 kPa) during the Trendelenburg position. In group D, individualized minimal driving pressure was applied during the Trendelenburg position; specifically, a PEEP titration test was performed at 5 min after the initiation of the Trendelenburg position to select the PEEP level that produced the lowest driving pressure and was then maintained throughout mechanical ventilation. Heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), peak airway pressure (P_{peak}), plateau airway pressure (P_{plat}), PEEP, and oxygenation index (OI) were recorded at 10 min after intubation (T1), at 30 min after the initiation of the Trendelenburg position (T2), and immediately after surgery (T3). At T2, driving pressure (driving pressure = P_{plat} – PEEP), dead space fraction (VD/VT), dynamic lung compliance (C_{dyn}), intrapulmonary shunt fraction (Q_s/Q_t), respiratory index (RI), and MP were calculated. Lung ultrasound examinations were performed on both groups upon admission to the operating room and at the end of surgery, with modified LUS scores recorded. **Results** The LUS score at 30 min after extubation, the incidence of PPCs at 7 d, and the ratio of oxygen therapy exceeding 48 h in group D were (12.4±2.9), 12 (17.39%), and 5 (7.25%), respectively, significantly lower than those in group P ($P<0.05$). There was no significant difference in the intraoperative fluid balance between the two groups ($P>0.05$). The proportions of norepinephrine and dobutamine used in group D were 34 (49.27%) and 36 (52.17%), respectively, significantly higher than those in group P ($P<0.05$). Compared with those at T1 and T3, the P_{peak} and P_{plat} at T2 in groups D and P were (22.2±0.6) cmH₂O, (21.6±3.1) cmH₂O, (20.8±0.4) cmH₂O and (20.3±3.1) cmH₂O, showing a significant upward trend ($P<0.05$). There were no significant differences in interaction between groups, time points, and time points between groups with respect to HR, SBP, DBP, and OI ($P>0.005$). At T2, the driving pressure, Q_s/Q_t, RI, VD/VT, and MP in group D were 14.2 (4.8) cmH₂O, (26.4±4.0)%, (0.13±0.02), (6.1±2.5)%, and (10.3±2.1) J/min, significantly lower than those in group P ($P<0.05$). At T2, the C_{dyn} and optimal PEEP in group D were (27.2±5.4) mL/cmH₂O and 10.0 (4.0) cmH₂O, significantly higher than those in group P ($P<0.05$). **Conclusion** The lung-protective ventilation strategy using driving pressure-guided individualized PEEP titration, compared with the conventional fixed PEEP ventilation strategy, can reduce the incidence of PPCs and the duration of oxygen therapy in obese patients undergoing gynecological laparoscopy, as well as decreasing LUS. However, it is associated with an increased requirement

for intraoperative vasoactive drugs.

[Key words] driving pressure; postoperative pulmonary complication; mechanical power

妇科腹腔镜手术因创口小,出血少,恢复快而被广泛应用于临床,但长时间的头低脚高位以及腹腔压力的增加,对呼吸系统产生不利的影响。研究^[1]显示妇科腹腔镜术后肺部并发症(postoperative pulmonary complications, PPCs)发生率在10%~30%,由于肥胖患者有肺部顺应性差、膈肌运动受限、通气/血流比例失调和氧合障碍的特点,因此肥胖患者PPCs发生率更高^[2-3]。目前肺保护性机械通气策略逐渐受到重视,其核心目标是通过优化潮气量与呼气末正压(positive end-expiratory pressure, PEEP)等参数,以降低通气相关性肺损伤(ventilator-induced lung injury, VILI)的发生^[4]。传统的PEEP设置多采用固定PEEP,常忽视了个体肺部力学特征的差异,导致肺泡萎陷与过度膨胀之间失衡^[5]。目前研究^[6]认为驱动压指导下的PEEP滴定法展现较好的肺保护潜力。驱动压指促使肺泡开放的直接压力,其抵消了呼吸系统的弹性阻力^[7],低潮气量(tidal volume, VT)和驱动压指导的PEEP可以降低PPCs发生率。然而驱动压导向个体化PEEP滴定能否安全的降低腹腔镜手术肥胖患者PPCs的发生仍值得进一步研究。肺超声作为一种简便、无创、可反复操作的影像学手段,肺超声评分(lung ultrasound scores, LUS)已被用于评估肺水肿、肺不张及通气状态,能及时反馈通气策略的效果。另外,机械功(mechanical power, MP)是指机械通气过程中,呼吸机单位时间内向呼吸系统传递的能量总量,综合反映了潮气量、气道压力、呼吸频率、气流速度及PEEP等多个参数的作用,有助于指导机械通气参数的调整,避免过度能量传递导致的肺损伤,MP作为评价机械通气安全性和肺保护效果的指标,正逐渐被临床重视^[8]。本研究旨在探讨基于LUS及MP评估驱动压导向个体化PEEP滴定对腹腔镜手术肥胖患者PPCs的影响。

1 资料与方法

1.1 一般资料 本研究为前瞻性研究,随机选取2020年1月—2021年9月在贵州省人民医院择期全身麻醉气管插管下行妇科腹腔镜手术患者150例为研究对象,年龄18~70岁,体重指数(body mass index, BMI) > 28,美国麻醉医师协会(American Society of Anesthesiologists, ASA)分级II或III级。排除标准:①术前肺部感染;②肺气肿及气胸;③戒

烟时间短于2个月。剔除标准:①术中转开腹手术;②手术时间 < 1 h 或 > 4 h;③术中出血量 > 500 mL;④病例资料不完整。

本研究经贵州省人民医院伦理委员会批准通过(2020-70号),患者或家属均签署知情同意书。

1.2 试验分组及处理 参考既往研究^[9],使用固定PEEP(5 cmH₂O, 1 cmH₂O=0.098 kPa)肺保护性通气的患者PPCs发生率为62.7%,假设使用驱动压指导的肺保护性通气患者PPCs发生率降低30%,设定 $\alpha=0.05$, $1-\beta=0.8$,预计25%的脱落率,每组拟纳入患者75例。采用随机数字表法将患者按1:1随机分为2组:驱动压组(D组, $n=75$)、固定呼气末正压通气组(P组, $n=75$)。本研究为单盲研究,分组安排被密封在连续编号的不透明信封中,分组情况仅有术中麻醉医生知晓。2组全身麻醉期间均采用容量控制通气,吸呼比为1:2, VT 6 mL/kg(理想体重),呼吸频率10~15次/min,吸氧浓度为80%, PETCO₂ 维持在35~40 mmHg(1 mmHg=0.133 kPa)。P组机械通气期间PEEP维持在5 cmH₂O。D组在头低位期间施加个体化的最低驱动压,即在头低位开始5 min后进行PEEP滴定试验,选择能产生最低驱动压的PEEP,然后在整个机械通气期间维持该PEEP。2组均分别在完成气管插管后、头低位前、恢复仰卧位以及拔管前分别进行手法肺复张:手控呼吸,用力挤压呼吸球囊20 s,维持气道压30 cmH₂O。

PEEP滴定试验:将PEEP从2 cmH₂O逐渐增加到10 cmH₂O,每个PEEP水平维持10个呼吸循环,并记录每个PEEP所能产生的驱动压,最后选择能产生最低驱动压的PEEP。

1.3 麻醉方法 入室后监测心电图(electrocardiogram, ECG)、血压(blood pressure, BP)、心率(heart rate, HR)和血氧饱和度(peripheral oxygen saturation, SpO₂),建立静脉输液通路后于局部麻醉下行桡动脉穿刺置管。麻醉诱导:依次静脉注射舒芬太尼0.3~1.0 $\mu\text{g}/\text{kg}$,丙泊酚2~3 mg/kg、罗库溴铵0.45~0.9 mg/kg,可视喉镜辅助下完成气管插管,连接麻醉机行机械通气。麻醉维持:吸入7%~9%地氟烷,新鲜气体流量2 L/min,静脉输注丙泊酚2~4 mg \cdot kg⁻¹ \cdot h⁻¹,间断静脉注射舒芬太尼0.1~0.4 $\mu\text{g}/\text{kg}$,罗库溴铵10 mg。并根据血流动力学改变调整血管活性药物

的剂量、输液种类和速度,维持术中 MAP > 60 mmHg。

1.4 观察指标 本研究主要结局指标为术后 7 d 内 PPCs 的发生。PPCs 采用 MGS 标准^[10],符合以下 4 项及以上者即可诊断:①胸部 X 线片显示肺不张/实变;②无诱因的白细胞计数(white blood cell, WBC) > 11.2 × 10⁹/L 或术后给予抗生素治疗肺部感染;③发热(> 38 °C)且无肺外病灶;④痰微生物学检查结果提示肺部感染;⑤产生脓性痰且与术前性质不同;⑥ SpO₂ < 90% (吸空气时);⑦主治医师诊断为肺炎/肺部感染;⑧因呼吸系统疾病而再次入住重症监护病房(intensive care unit, ICU)或高依赖性病房(高依赖病房, ICU 与普通病房之间的特别加护病房),或在 ICU 或高依赖病房中长时间停留(> 36 h)。

记录手术时间、麻醉时间、头低位时间、术毕带管时间、术后氧疗时间及总住院时间。记录术中出入量和血管活性药物使用情况。记录插管后 10 min (T1)、头低位开始后 30 min (T2)、手术结束即刻 (T3) 的 HR、SBP、DBP、气道峰压(peak airway pressure, Ppeak)、气道平台压(plateau airway pressure, Pplat)、PEEP 及氧合指数(oxygenation index, OI)结果。T2 时计算驱动压(驱动压 = Pplat - PEEP^[11])、死腔率(V_D/V_T)、动态肺顺应性(dynamic lung compliance, C_{dyn})、肺内分流率(intrapulmonary shunt fraction, Q_s/Q_t)、呼吸指数

(respiratory index, RI) 及机械功(mechanical power, MP = 0.098 × VT × RR × (Ppeak - 1/2 × 驱动压)^[12])变化。肺超声检查:拔管后 30 min 由同一位经过超声培训的麻醉医师进行肺超声检查。仰卧位或半侧卧位状态下对患者两侧前胸壁、侧胸壁上、下部共 8 个肺区进行检查。对患者两侧前胸壁、侧胸壁及后胸壁的上下部分。评分标准为:0 = A 线;1 = 散在 B 线;2 = 融合 B 线;3 = 实变^[13]。

1.5 统计学方法 应用 SPSS 24.0 统计学软件进行数据分析。正态分布计量资料以均数 ± 标准差($\bar{x} \pm s$)表示,比较采用单因素方差分析和重复测量的方差分析;非正态分布计量资料以中位数和四分位数间距 M(QR)表示,比较采用 Kruskal-Wallis 检验。计数资料以例(%)表示,比较采用 χ^2 检验或 Fisher 精确检验。P < 0.05 为差异有统计学意义。

2 结 果

本研究初始纳入患者 150 例,共剔除病例 13 例,其中 D 组有 1 例资料不完善,3 例转为开腹手术,2 例手术时间超过 4 h;P 组 4 例转为开腹手术,3 例资料不完善。最终纳入 137 例,D 组(n = 69),P 组(n = 68)。

2.1 2 组一般情况比较 2 组年龄、身高、理想体重、BMI、ASA 分级、术前合并症、手术类型、手术时间、麻醉时间、头低位时间、术毕带管时间、总住院时间比较差异无统计学意义(P > 0.05)。见表 1。

表 1 2 组一般资料情况比较

Table 1 Comparison of baseline data of patients between the two groups

组别	例数	年龄($\bar{x} \pm s$, 岁)	身高($\bar{x} \pm s$, cm)	理想体重($\bar{x} \pm s$, kg)	BMI($\bar{x} \pm s$)	ASA 分级(例数, %)		
						Ⅱ级	Ⅲ级	
P 组	68	42.0 ± 12.3	157.34 ± 4.67	82.5 ± 8.7	32.8 ± 3.1	18(26.47)	50(73.53)	
D 组	69	41.9 ± 13.3	157.15 ± 5.41	83.1 ± 9.3	33.7 ± 3.0	20(28.99)	49(71.01)	
t/ χ^2 值		0.045	0.221	0.391	1.733		0.093	
P 值		0.964	0.826	0.696	0.085		0.760	
组别	例数	术前合并症(例数, %)				手术类型(例数, %)		
		糖尿病	高血压	阻塞性睡眠呼吸暂停	哮喘	子宫全切	附件切除	肌瘤切除
P 组	68	32(47.06)	45(66.18)	8(11.76)	2(8.70)	28(41.18)	25(36.76)	15(22.06)
D 组	69	29(42.03)	43(62.32)	5(0.77)	4(1.47)	30(43.48)	22(31.88)	17(24.63)
t/ χ^2 值		0.177	0.086	0.373	0.159	0.074	0.349	0.127
P 值		0.674	0.77	0.541	0.69	0.786	0.555	0.721
组别	例数	手术时间	麻醉时间	头低位时间	术毕带管时间	总住院时间		
		($\bar{x} \pm s$, h)	($\bar{x} \pm s$, h)	($\bar{x} \pm s$, min)	($\bar{x} \pm s$, min)	($\bar{x} \pm s$, d)	($\bar{x} \pm s$, d)	
P 组	68	1.8 ± 0.6	2.1 ± 0.5	68.3 ± 15.2	10.4 ± 7.9	6.1 ± 1.2		
D 组	69	1.7 ± 0.7	2.1 ± 0.5	70.1 ± 14.8	11.4 ± 6.8	5.9 ± 1.1		
t/ χ^2 值		0.894	0.122	0.719	0.815	0.973		
P 值		0.373	0.903	0.473	0.417	0.332		

2.2 2 组术后肺部并发症情况 D 组氧疗时间 > 48 h 比例、拔管后 30 min LUS 评分、PPCs 发生率

明显低于 P 组,差异有统计学意义(P < 0.05)。见表 2。

2.3 2组术中出入量及血管活性药物使用情况与P组比较,D组去甲肾上腺素、去氧肾上腺素使用率增加,差异有统计学意义($P < 0.05$)。2组液体总入量、失血量、尿量比较差异无统计学意义($P > 0.05$)。见表3。

2.4 2组术中呼吸及血流动力学改变与插管后10 min、手术结束即刻时比较,头低位开始后30 min时2组Ppeak、Pplat明显呈上升趋势,差异有统计学意义($P < 0.05$);2组组间、时间点及组间·时间点交互作用的SBP、DBP、HR及OI比较差异无统计学意义($P > 0.05$)。见表4。

2.5 2组头低位期间呼吸指标 D组驱动压、Qs/

Qt、RI、VD/VT及机械功率明显低于P组,差异有统计学意义($P < 0.05$);与P组比较,D组Cdyn及最佳PEEP值明显升高,差异有统计学意义($P < 0.05$),见表5。

表2 2组术后肺部并发症情况比较

Table 2 Comparison of postoperative pulmonary complications between the two groups

组别	例数	氧疗>48 h	拔管后30 min LUS	PPCs发生率
		(例数,%)	评分($\bar{x} \pm s$,分)	(例数,%)
P组	68	15(22.06)	18.6±3.8	25(36.76)
D组	69	5(7.25)	12.4±2.9	12(17.39)
χ^2/t 值		4.898	10.687	5.575
P值		0.027	<0.001	0.018

表3 2组术中出入量及血管活性药物使用情况比较

Table 3 Comparison of intraoperative fluid balance and use of vasoactive drugs between the two groups

组别	例数	总入量	失血量	尿量	去甲肾上腺素	去氧肾上腺素
		[M(QR), mL]	[M(QR), mL]	[M(QR), mL]	(例数,%)	(例数,%)
P组	68	1571.5(225.0)	75.4(50.0)	626.1(425.0)	11(16.17)	15(22.06)
D组	69	1647.9(500.0)	76.8(50.0)	687.4(500.0)	34(49.27)	36(52.17)
Z/ χ^2 值		1.823	0.235	1.190	16.244	12.184
P值		0.068	0.814	0.234	<0.001	<0.001

表4 2组不同时点呼吸及血流动力学指标比较

Table 4 Comparison of respiratory and hemodynamic parameters between the two groups

组别	例数	Ppeak(cmH ₂ O)			Pplat(cmH ₂ O)				
		T1	T2	T3	T1	T2	T3		
		F值=0.874		P值=0.351		F值=1.203		P值=0.275	
P组	68	18.3±0.4	20.8±0.6	18.9±0.5	17.6±1.8	20.3±3.1	18.3±2.7		
D组	69	19.2±0.4	22.2±0.6	19.7±0.5	18.3±2.7	21.6±3.1	18.9±3.1		
组间		F值=0.874		P值=0.351		F值=1.203		P值=0.275	
时间点		F值=23.541		P值<0.010		F值=22.197		P值<0.010	
组间·时间点		F值=0.733		P值=0.478		F值=0.412		P值=0.665	

组别	例数	OI(mmHg)			SBP(mmHg)				
		T1	T2	T3	T1	T2	T3		
		F值=2.456		P值=0.119		F值=0.332		P值=0.565	
P组	68	413.0±8.5	381.4±14.3	397.4±10.2	121.6±11.6	121.3±12.7	123.6±10.8		
D组	69	401.2±9.0	385.8±15.0	397.9±10.7	123.4±10.7	127.2±10.6	121.2±11.6		
组间		F值=2.456		P值=0.119		F值=0.332		P值=0.565	
时间点		F值=1.864		P值=0.153		F值=2.114		P值=0.123	
组间·时间点		F值=1.245		P值=0.289		F值=0.887		P值=0.413	

组别	例数	DBP(mmHg)			HR(次/min)				
		T1	T2	T3	T1	T2	T3		
		F值=0.987		P值=0.322		F值=1.112		P值=0.293	
P组	68	75.8±10.6	73.9±10.6	75.5±9.5	71.5±10.3	73.6±11.4	72.4±10.1		
D组	69	72.5±9.2	76.7±11.3	71.7±10.5	74.0±9.5	72.1±9.8	77.2±7.9		
组间		F值=0.987		P值=0.322		F值=1.112		P值=0.293	
时间点		F值=3.456		P值=0.133		F值=4.221		P值=0.617	
组间·时间点		F值=1.021		P值=0.361		F值=0.654		P值=0.521	

表5 2组头低位期间呼吸指标比较

Table 5 Comparison of respiratory parameters between the two groups during the Trendelenburg position

组别	例数	驱动压[M(QR), cmH ₂ O]	VD/VT ($\bar{x} \pm s$,%)	Cdyn($\bar{x} \pm s$, mL/cmH ₂ O)	Qs/Qt ($\bar{x} \pm s$,%)	RI ($\bar{x} \pm s$)	最佳PEEP [M(QR), cmH ₂ O]	机械功率 ($\bar{x} \pm s$, J/min)
P组	68	18.3(4.4)	8.5±3.5	24.6±4.0	27.9±1.2	0.25±0.05	5.0(0.0)	12.8±3.0
D组	69	14.2(4.8)	6.1±2.5	27.2±5.4	26.4±1.5	0.13±0.02	10.0(4.0)	10.3±2.1
Z/t值		6.324	4.429	3.179	5.560	17.677	9.698	5.437
P值		<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001

3 讨 论

肥胖患者具有膈肌抬高、顺应性差、通气/血流比例失调等特点,因此在肥胖患者中实施肺保护通气显得尤为重要^[14]。固定的 PEEP(如 5 cmH₂O)已被用于多种类型手术中,作为一种基础的肺保护性通气策略,在肥胖患者中固定 PEEP 虽然可以一定程度上减少肺泡萎陷的风险,但固定 PEEP 并未考虑到每个患者肺部的个体差异,因此无法精准满足不同患者的生理需求^[15],尤其是在肥胖患者中,固定 PEEP 可能不足以有效改善氧合或降低肺部损伤。近年来,国内外学者提出可以通过驱动压来指导 PEEP 的个体化调整。驱动压被认为是影响肺损伤的关键因素,低驱动压有助于降低 VILI 的发生。基于驱动压的通气策略逐渐成为腹腔镜手术中肺保护的一项重要措施,特别是在肥胖患者中,已被证实能够显著改善呼吸功能和减少 PPCs^[16-17]。个体化 PEEP 的设置,旨在找到能够最大程度减少驱动压的 PEEP 值,这一策略在妇科腹腔镜手术的患者中已获得一定的临床验证^[18-19]。此外,虽然基于驱动压指导的 PEEP 设定已取得一定的进展,但在临床中仍缺乏统一的个体化 PEEP 设定标准。

驱动压作为肺损伤的重要预测因子,其值越高,意味着肺泡受到的压力和应力越大,发生通气性肺损伤的风险越高。研究^[18]表明,使用最低驱动压的通气策略能够有效减少 VILI 的发生。本研究中,D 组驱动压明显低于 P 组,这一结果与当前文献中的研究一致,认为优化 PEEP 值能够降低驱动压^[20],从而减少术后肺损伤。既往肺保护研究中 PEEP 的设定通常固定在 5 cmH₂O 左右,但不同患者的肺部生理条件差异较大,固定 PEEP 可能无法有效避免肺部并发症的发生。本研究的结果表明,D 组通过 PEEP 滴定能够显著改善肺顺应性,同时减少 MP 和 VD/VT,这些改变有助于减少肺泡萎陷和肺过度膨胀的风险,进而降低 PPCs 的发生率。在 D 组中,尽管最佳 PEEP 值的设定相对较高,但其 OI 和肺 Qs/Qt 保持在较好的范围内,这表明个体化 PEEP 滴定能够在改善氧合的同时,避免过高 PEEP 可能带来的负面影响。这一点与当前关于个体化肺保护性通气策略的研究成果相似^[14,21],表明在肥胖患者中,个体化 PEEP 的调整能更精确地满足患者的需求,进一步提高术后恢复质量。

肺超声作为一种便捷且无创的影像学工具,能够评估肺部气体和液体分布状态,改良 LUS 评分能显著预测术后肺部并发症风险,强调术后 LUS 评分

与并发症发生率密切相关^[22]。本研究使用肺超声对患者肺部情况进行评估,结果显示 D 组术后 LUS 显著低于 P 组,提示 D 组患者的肺部病变程度较轻。另外,结合 MP 的改变进一步评估了驱动压导向的个体化 PEEP 滴定的安全性。研究认为驱动压是预测 VILI 的有效指标,MP 则进一步整合了驱动压与呼吸频率等因素,能更全面反映肺组织所受机械应力^[23-24]。本研究中 D 组 MP 明显低于 P 组,提示个性化的 PEEP 滴定能产生较低的 MP,虽然 PEEP 较高,但肺组织收到的机械应力更小。值得注意的是,尽管 D 组在呼吸力学方面体现出优势,但仍需注意两组在液体管理和血管活性药物使用上的差异,D 组去甲肾上腺素和去氧肾上腺素的使用率明显增加,这可能是由于较高的 PEEP 造成回心血量减少有关,尤其是低容量下会放大对平均动脉压的负面影响^[25-26]。这些结果提示,个体化 PEEP 滴定在改善肺功能的同时,可能需要更多的监测和管理,以避免较高的 PEEP 造成的血流动力学改变。

综上所述,与传统的固定 PEEP 通气策略相比,基于驱动压导向的个体化 PEEP 滴定通气显著改善了患者的呼吸力学状态,减少机械应力,并改善肺功能和通气效果,可以有效减少肥胖患者 PPCs 的发生,但术中可能需要更多的血管活性药物。

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