综 述

术后早期低氧与术后并发症的关系研究进展

王欢[1]，黄毓韬[2]，聂煌[1*]

[1]空军军医大学西京医院麻醉与围术期医学科，陕西西安 710000；[2]四川大学华西医院神经外科，四川成都 610041

[中图分类号] R614 [文献标志码] A [DOI] 10.11855/j.issn.0577-7402.1032.2025.0326
[声明] 本文所有作者声明无利益冲突
[引用本文] 王欢, 黄毓韬, 聂煌. 术后早期低氧与术后并发症的关系研究进展[J]. 解放军医学杂志, 2025, 50(8): 1045-1050.
[收稿日期] 2024-07-09 [录用日期] 2024-09-22 [上线日期] 2025-03-26

[摘要] 术后早期低氧为全身麻醉后常见的不良事件，与患者的病理生理改变密切相关，可延长麻醉后恢复室(PACU)及重症监护室(ICU)的停留时间，且与术后1年死亡率增高相关。然而，由于低氧定义的差异、研究人群的异质性以及术后监测方法的不同，文献报道术后早期低氧的发生率和持续时间存在较大差异。本文通过系统回顾相关文献，阐述术后早期低氧的定义、相关特征性指标，探讨术后早期低氧与术后呼吸系统并发症、心血管系统并发症、手术部位感染的相关性，通过分析现有研究证据，探索有预警价值的术后早期低氧特征，以期为该领域的研究提供参考。

[关键词] 术后早期低氧；并发症；呼吸系统；心血管系统；手术部位感染

Research progress on the relationship between early postoperative hypoxemia and complications

Wang Huan[1], Huang Yu-Tao[2], Nie Huang[1*]

[1]*Department of Anesthesiology, Xijing Hospital, Air Force Medical University, Xi'an, Shaanxi 710000, China*

[2]*Department of Neurosurgery, West China Hospital, West China Medical School, Sichuan University, Chengdu, Sichuan 610041, China*

[*]*Corresponding author, E-mail: niehuang@163.com*

This work was supported by the Key Research and Development Projects in Shaanxi Province (2020SF-295)

[**Abstract**] Early postoperative hypoxemia, a common adverse event following general anesthesia, is closely associated with pathophysiological changes in patients, prolonging stays in the post-anesthesia care unit (PACU) and intensive care unit (ICU), and correlating with increased one-year postoperative mortality rate. Nevertheless, due to differences in definitions of hypoxemia, heterogeneity of study populations, and variations in postoperative monitoring methods, the reported incidence and duration of early postoperative hypoxemia in the literature vary significantly. This review systematically summarizes relevant literature to elucidate the definition and characteristic indicators of early postoperative hypoxemia, and explores its correlations with postoperative respiratory complications, cardiovascular complications, and surgical site infections. By analyzing existing research evidence, this review aims to identify early-warning indicators of postoperative hypoxemia with predictive value, thereby providing a reference for future research in this field.

[**Key words**] postoperative hypoxemia; complications; respiratory system; cardiovascular system; surgical site infection

术后早期低氧(通常定义为术后72 h内发生的低氧[1-2])是全身麻醉后常见的不良事件[3]，其发生率因手术类型的不同而存在差异(5%~65.5%)，原因主要为手术人群、对低氧的定义标准(严重程度和持续时间)及监测方法不同[1]。一项观察性研究发现，21%~55%的患者术后48 h内出现不同程度的低氧[4]。Sun等[5]对833例非心脏手术患者的脉搏血氧饱和度(oxygen saturation，SpO_2)进行连续监测，发现低氧的发生频率和严重程度较高，术后48 h内至少37%的患者出现持续1 h的失饱和状态(SpO_2<90%)，3%的患者甚至出现持续30 min以上的严重低氧(SpO_2<80%)。一项前瞻性队列研究对结直肠癌患者术后SpO_2进行连续监测，发现36%的患者在术后48 h或出院前出现持续1 h以上的低氧(SpO_2<90%)[6]。由此

[基金项目] 陕西省重点研发计划(2020SF-295)
[作者简介] 王欢，硕士研究生，主要从事术后早期低氧与并发症关系方面的研究
[通信作者] 聂煌，E-mail：niehuang@163.com

可见，术后早期低氧的发生率较高。不同程度或持续时间的低氧与不同临床结局的关系是临床医师关心的重点问题。2020年的一项研究发现，术后1~3 d发生SpO_2<85%(无论持续多久)的患者术后1年死亡率高于未发生者[1]，提示术后早期的严重低氧可能与远期预后不良有关。本文综述了术后早期低氧的诊断标准、临床特征及与相关并发症的关联性，以期为该领域的研究提供参考。

1 术后早期低氧的阈值与特征

术后早期低氧的诊断主要基于SpO_2或动脉血氧分压(partial pressure of arterial oxygen，PaO_2)的阈值，通常以SpO_2<90%或PaO_2<60 mmHg为标准[7-9]；也有研究以氧合指数[PaO_2/吸入氧浓度(fraction of inspired oxygen，FiO_2)]<300 mmHg为诊断标准[7,10-14]；而欧洲麻醉学会(European Society of Anesthesiology，ESA)和欧洲重症监护医学会(European Society of Intensive Care Medicine，ESICM)均将低氧血症定义为PaO_2/FiO_2≤300 mmHg[4]。但目前对术后早期低氧严重程度的划分标准尚未达成共识[15]。考虑到低氧严重程度和持续时间的不同，有研究建议从持续时间、发生频率以及患者基础SpO_2值等多个维度进行综合评估，以提高诊断的准确性并降低偶然性误差[16-19]。基于此，目前对术后早期低氧的特征描述主要涵盖阈值、发生次数、持续时间以及基线下降比例等多项指标。

1.1 按脉搏SpO_2或氧分压阈值定义术后早期低氧 早期研究中术后早期低氧通常被定义为SpO_2<90%，并根据具体数值范围进行严重程度分级[20-22]。Moller等[20]提出了三级分类标准，将术后SpO_2在86%~90%定义为轻度低氧，81%~85%为中度低氧，<81%为重度低氧；该研究纳入296例全身麻醉患者，发现53%的患者至少经历一次持续时间长达34.6 min的轻度低氧事件，34%发生中度低氧，20%发生重度低氧。关于手术部位与术后低氧相关性的研究则采用不同的分级标准，即将SpO_2≤90%(86%~90%)定义为低氧，而SpO_2≤85%则被归类为重度低氧[21]。一项多中心随机对照研究将低氧定义为吸入空气状态下PaO_2<60 mmHg或SpO_2<90%，其中轻度低氧可通过补充氧气改善；将需无创或有创通气支持且PaO_2<60 mmHg或SpO_2<90%定义为重度低氧[23]。Belcher等[24]研究非心脏手术患者术后镇痛方案对低氧的影响时，采用了更为严格的标准，即将术后48 h内SpO_2<95%、<90%及<85%分别作为不同严重程度低氧的阈值。以上结果表明，SpO_2<90%是采用较多的术后低氧指征。

1.2 按发生频率描述术后早期低氧 Bartels等[1]探讨术后3 d内低氧与术后1年死亡率的关系，将术后早期低氧定义为从麻醉后恢复室(post-anesthesia care unit，PACU)至术后第3天期间任何时间发生过≥1次SpO_2<85%；该研究共纳入43 011例患者，结果显示术后第1、2、3天分别有7179例(66.9%)、5340例(49.8%)、3455例(32.3%)发生至少一次低氧事件；与未发生术后低氧的患者相比，发生低氧的患者术后1年死亡率明显升高[1]，提示早期低氧与不良临床结局相关。

1.3 按持续时间描述术后早期低氧 Gill等[18]的研究探讨了围手术期低氧与心肌缺血事件的关系，将低氧事件定义为SpO_2<90%且持续时间≥30 s；结果显示，术前合并心血管疾病的11例患者中，术后有10例发生了低氧事件，平均持续时间为9.6 min，较术前延长2.7 min；患者手术前后最低SpO_2均<84%；进一步分析最低SpO_2与心肌缺血事件的同步性，发现当SpO_2<85%时低氧事件与心肌缺血事件同时发生的比例明显高于SpO_2≥85%时。此外，有研究表明，麻醉恢复期患者的体位与术后低氧血症的发生具有明显相关性，该研究将低氧定义为SpO_2<90%且持续时间超过10 s，将重度低氧定义为SpO_2<85%并持续10 s以上[10]。Andualem等[25]的前瞻性研究将术后早期低氧定义为SpO_2<90%且持续时间至少3 min，结果显示，入PACU后前3 min有24.5%的患者发生低氧，1 h后仍有18.4%的患者处于低氧状态。

1.4 按基线下降比例描述术后早期低氧 Rosenberg等[17,19]提出了突发性低氧的明确定义，即SpO_2较基线水平下降≥5%且持续时间≥2 min；他们发现，患者的最低SpO_2中位数呈进行性下降的趋势：术前夜间为86%，术后第1天夜间降至83%，术后第2天夜间进一步降至78%；接受大型腹部手术的患者术后平均SpO_2值和最低SpO_2值均明显降低，而当SpO_2<80%时，术后低氧事件的发生频率明显增高。Gögenur等[26]的观察性研究将夜间间歇性低氧定义为SpO_2较基线水平下降≥5%且持续时间为30 s至2 min；结果显示，在87个监测夜晚中，患者的SpO_2中位数为95%(范围84%~100%)，最低SpO_2值为81%；共观察到78个夜晚SpO_2<90%，53个夜晚SpO_2<85%，32个夜晚SpO_2<80%；在低氧发作期间，4%的患者同时出现了ST段改变，提示心肌缺血的发生。

综上，术后早期低氧的定义和评估标准因研究目的和临床需求的不同而存在明显差异。尽管SpO_2<90%被广泛接受为基本定义，但针对术后早期低氧严重程度、发生频率、持续时间以及基线下降比例等维度进行综合评估，能够更全面地反映低氧事件的临床意义。

2 术后早期低氧与预后不良的关系

全身麻醉及大手术后第2、3天夜间是术后低氧事件的高发期，持续性低氧或偶发性严重缺氧对患者术后器官功能可产生严重的不良影响[19,27]。研究发现，大型非心脏手术患者术后早期低氧相关并发症的发生率高达19%[28]。严重且长时间的低氧状态(SpO_2明显降低)可引起脑损伤、心肌缺血、心律失常、肺部感染、手术切口愈合不良和吻合口瘘等严重并发症，从而延长住院时间，增加住院费用[5,16,24,29-32]。即使术后早期短暂性低氧也可能增加患者远期不良事件发生的风险[33]。基于此，以下系统探讨术后早期低氧与呼吸系统并发症、心血管系统并发症以及手术部位感染(surgical site infection，SSI)之间的相关性。

2.1 呼吸系统并发症　术后肺部并发症(postoperative pulmonary complications，PPCs)中较常见的是肺不张和胸腔积液[34]，急性呼吸窘迫综合征(acute respiratory distress syndrome，ARDS)和气胸相对少见[35]。研究发现，PPCs的发生率为6%~80%[36-37]，主要集中于术后第1周[38-40]，可显著延长氧疗时间，其中ARDS和术后机械通气(postoperative mechanical ventilation，POMV)为早期死亡的重要危险因素[16]。即使是症状相对较轻的肺部并发症如肺炎、肺不张或胸腔积液等，在成功治疗后仍可能导致患者长期生存率降低[41]。无PPCs患者的死亡率仅为0.2%~3.0%，而合并PPCs患者的死亡率则高达14%~30%[36]。2017年一项回顾性研究结果显示，0.3%(351/125 740)的患者发生了术后早期呼吸系统并发症，而PACU内最低SpO_2≤89%及氧疗时间≥60 min是术后早期肺部并发症的独立预测因素[16]。Duan等[11]发现，术后发生低氧的老年(≥65岁)股骨颈骨折患者围手术期肺炎、谵妄、心律失常、多器官功能障碍的发生率及死亡率均明显高于未发生低氧者。从病理生理机制来看，全身麻醉接受机械通气的患者可能发生术后肺不张，其严重程度和持续时间可因术前并发症及手术创伤而增加[36,42]。例如，上腹部手术患者的功能残气量(functional residual capacity，FRC)通常在术后1~2 d达到最低值，并在5~7 d缓慢恢复[43]。此外，一项针对非胸部手术患者术后肺不张的研究发现，57%的患者存在肺不张的影像学证据，且术后第3天肺不张仍无明显缓解的迹象[44]。而接受体外循环下心脏手术的患儿，术后肺不张(13.0% *vs.* 3.0%，P=0.001)、胸腔积液(13.0% *vs.* 6.1%，P=0.036)和术后呼吸功能不全需要机械通气支持>7 d(9.7% *vs.* 0%，P<0.001)的发生率在发生低氧的患儿中较未发生低氧的患儿更常见[45]。Xie等[46]的前瞻性研究观察了接受非心脏手术的全身麻醉患者在PACU拔管后20 min内发生低氧(SpO_2<92%，持续时间>30 s)的情况，并通过床旁超声评估术后PPCs的发生情况；结果显示，低氧事件主要发生于腹部手术和胸腔镜手术患者，其次为骨科、神经外科及其他类型手术的患者；72.6%的患者被诊断为肺不张，24.8%的患者发生气胸，34.5%的患者出现胸腔积液，表明术后早期低氧与PPCs的发生存在明显相关性。另有研究发现，腹部手术患者术后第1天有6.5%出现低氧；术后第2天低氧发生率上升至13.95%，且53%的患者出现肺部并发症；术后第2天PaO_2降低是PPCs的预测指标，其敏感度和特异度分别为94.12%和92.93%[47]。因此，术后低氧是肺部并发症的重要临床表现之一，即使PACU中发生短暂性低氧也与PPCs密切相关[48-49]，而预测严重PPCs发生的低氧特征仍待进一步研究。

2.2 心血管系统并发症　全球每年有超过2亿成人接受非心脏手术，其中超过1000万患者术后30 d内出现重大心血管并发症，由此导致的死亡占围手术期死亡的1/3，存活者则面临预后不良、住院时间延长、医疗费用增加等问题[50]。术后心肌缺血是非心脏手术后不良结局的重要预测指标，与心动过速密切相关，而偶发的心动过速可与间歇性低氧血症同时发生[51]，提示术后低氧可能是心血管系统并发症的诱发或加重因素。多项研究证实，术后低氧尤其是严重低氧和夜间低氧，与心肌缺血的发生密切相关[6,17-18,26]。Rosenberg等[17]发现，接受腹部大手术的患者术后SpO_2值与心率呈负相关关系。Gill等[18]发现，心血管疾病患者的术后无症状心肌缺血事件与长时间(持续时间>5 min)和严重(SpO_2<85%)低氧关系密切。另一项针对腹部大手术患者术后第2、3天夜间间歇性低氧的研究显示，52例患者中有50例发生了间歇性低氧和心动过速，19例发生了ST段改变(138次下移和126次抬高)，且ST段下移相较抬高时氧饱和度降低、心率加快[26]。有研究发现，非心脏手术患者术后高敏肌钙蛋白水平升高不仅与术后30 d内死亡率及心肌缺血事件的发生风险增高相关[52]，还可能影响患者的长期预后[53-54]。在88例接受右半结肠切除术的患者中有11例(13%)术后SpO_2<88%的持续时间延长，且其肌钙蛋白I峰值升高超过15 ng/L[6]，提示低氧事件可能通过心肌氧供需失衡导致心肌损伤。一项前瞻性队列研究揭示了术后肌钙蛋白T峰值与术后30 d死亡率之间的相关性，发现二者呈明显的剂量-效应关系，肌钙蛋白T峰值≤0.01 ng/ml、0.02 ng/ml、0.03~0.29 ng/ml和≥0.30 ng/ml的患者术后30 d死亡率分别为1.0%、4.0%、9.3%和16.9%[55]。

综上，术后低氧与心肌缺血、心肌损伤及心律失常的发生密切相关，后续研究应关注对于心血管事件高危患者改善术后低氧能否减少心血管不良事件的发生。

2.3 SSI SSI是麻醉和手术后最常见的并发症之一。SSI患者的住院时间较未感染者延长5~20 d，再次入院或手术的风险明显增加，死亡率也明显升高[56-57]。自20世纪60年代Hunt等[58]首次提出SSI与术后低氧的潜在关联以来，这一领域的研究不断深入。Hopf等[59]监测术后6 h内及术后第1、2天的组织氧分压，发现组织氧合降低是SSI的强预测因子。有研究监测结直肠癌患者术后75 min(患者通常于术后1 h停止吸氧，加上15 min洗脱时间)的外侧上臂组织氧饱和度，发现组织氧饱和度降低可预测SSI，其截断值为66%[60]。一项针对重大非心脏手术后组织氧合与术后结局的观察性研究显示，术后30 d低氧相关并发症(死亡、深部切口感染、肺部并发症、卒中、急性心肌梗死等)总体发生率为19%，其中深部或器官间隙SSI发生率最高(12.9%)，术中及术后2 h内监测的组织氧饱和度最小值与低氧相关并发症呈负相关(P=0.02)，最低组织氧饱和度每提高5%，并发症发生风险降低18%[28]。一项随机对照试验根据术中及术后2 h的FiO_2将500例接受结直肠手术的患者分为高氧组(FiO_2为80%)和常规氧组(FiO_2为30%)，结果显示，高氧组SSI发生率为5.2%，常规氧组为11.2%[56]。研究发现，氧气在伤口愈合过程中扮演着至关重要的角色，可促进血管生成和胶原蛋白合成、维持白细胞和成纤维细胞的功能活性以及调控生长因子和活性氧的生成[61]。不同原因造成的全身低氧可能加重创伤组织的缺氧，因为组织损伤导致血液循环障碍，加之损伤组织的耗氧量增加，进一步加剧局部缺氧，从而影响伤口愈合[61]。综上，术后低氧可能通过加重组织缺氧而增加切口感染的风险，合并糖尿病、营养不良等切口感染高危因素的患者是否更易在轻度或相对短时间低氧时发生SSI有待进一步研究。

3 总结与展望

术后早期低氧在临床中较为常见，相较于传统的间断监测，连续生命体征监测能够更早、更准确地识别术后早期低氧事件[62-64]。低氧事件的发生率因SpO_2阈值的界定标准不同而异。识别术后早期低氧的意义在于早期干预与术后并发症相关的低氧事件，减少术后并发症的发生。因此，揭示有临床意义的术后低氧特征尤为重要。目前的研究显示，术后3 d内发生的低氧事件与呼吸系统并发症、心血管系统并发症以及SSI关系密切，尤其与肺不张、肌钙蛋白I水平增高明显相关。然而，目前对于低氧程度(如SpO_2阈值)及持续时间与特定并发症的关系尚不清楚。未来的研究应明确与上述并发症相关的术后早期低氧特征，如SpO_2阈值的临界范围及持续时间是否可作为独立危险因素，进而探索具有针对性的治疗措施，以期改善高危患者的临床预后。

【参考文献】

[1] Bartels K, Kaizer A, Jameson L, *et al*. Hypoxemia within the first 3 postoperative days is associated with increased 1-year postoperative mortality after adjusting for perioperative opioids and other confounders[J]. Anesth Analg, 2020, 131(2): 555-563.

[2] 柳旦, 蔡栋臣, 杜高峰. 普通外科老年患者术后早期低氧血症与感染的临床分析[J]. 中华医院感染学杂志, 2015, 25(7): 1604-1606.

[3] 赵金珍, 吕萍, 朱鹏, 等. BMI联合术前氧合指数对Stanford A型主动脉夹层术后低氧血症的预测价值[J]. 解放军医学杂志, 2023, 48(12): 1445-1450.

[4] Leone M, Einav S, Chiumello D, *et al*. Noninvasive respiratory support in the hypoxaemic peri-operative/periprocedural patient: a joint ESA/ESICM guideline[J]. Intensive Care Med, 2020, 46(4): 697-713.

[5] Sun Z, Sessler DI, Dalton JE, *et al*. Postoperative hypoxemia is common and persistent: a prospective blinded observational study [J]. Anesth Analg, 2015, 121(3): 709-715.

[6] Bojesen RD, Fitzgerald P, Munk-Madsen P, *et al*. Hypoxaemia during recovery after surgery for colorectal cancer: a prospective observational study[J]. Anaesthesia, 2019, 74(8): 1009-1017.

[7] Ehrenfeld JM, Funk LM, van Schalkwyk J, *et al*. The incidence of hypoxemia during surgery: evidence from two institutions[J]. Can J Anaesth, 2010, 57(10): 888-897.

[8] Turner RA, Simmons CG, Ramirez S, *et al*. Hypoxemia and postoperative monitoring after anesthesia: a prospective observational study using portable pulse oximetry in a resource-limited setting in guatemala[J]. Cureus, 2025, 17(1): e78075.

[9] Berhanu M, Dadi N, Mengistu B, *et al*. Magnitude of early postoperative hypoxemia and its associated factors among adult patients who undergo emergency surgery under general anesthesia at Jimma Medical Center, Jimma, Southwest Ethiopia, 2021: a prospective observational study[J]. Perioper Med (Lond), 2023, 12 (1): 1.

[10] Wang X, Guo K, Sun J, *et al*. Semirecumbent positioning during anesthesia recovery and postoperative hypoxemia: a randomized clinical trial[J]. JAMA Netw Open, 2024, 7(6): e2416797.

[11] Duan XZ, Zhang X, Tong DK, *et al*. Risk factors for and predictive nomogram of postoperative hypoxaemia in elderly patients with femoral neck fractures[J]. J Int Med Res, 2020, 48(10): 300060520945132.

[12] Zhang Q, Zhu L, Yuan S, *et al*. Identifying risk factors for hypoxemia during emergence from anesthesia in patients undergoing robot-assisted laparoscopic radical prostatectomy[J]. J Robot Surg, 2024, 18(1): 200.

[13] 黄符香, 高长胜, 张爽, 等. 老年全麻术后患者麻醉复苏期发生低氧血症的影响因素[J]. 中国老年学杂志, 2022, 42(21): 5232-5235.

[14] 刘熠, 张毅, 唐永忠, 等. 麻醉恢复室低氧血症预测模型的建立与校验[J]. 临床麻醉学杂志, 2021, 37(1): 55-58.

[15] 黄秋瑞, 王明明, 邹圣强, 等. 全身麻醉术后麻醉恢复室内低氧血症相关危险因素的研究进展[J]. 临床与病理杂志, 2023, 43(9): 1733-1740.

[16] Ramachandran SK, Thompson A, Pandit JJ, *et al*. Retrospective observational evaluation of postoperative oxygen saturation levels and associated postoperative respiratory complications and hospital resource utilization[J]. PLoS One, 2017, 12(5): e0175408.

[17] Rosenberg J, Rasmussen V, von Jessen F, *et al*. Late postoperative episodic and constant hypoxaemia and associated ECG abnormalities[J]. Br J Anaesth, 1990, 65(5): 684-691.

[18] Gill NP, Wright B, Reilly CS. Relationship between hypoxaemic and cardiac ischaemic events in the perioperative period[J]. Br J Anaesth, 1992, 68(5): 471-473.

[19] Rosenberg J, Oturai P, Erichsen CJ, *et al*. Effect of general anesthesia and major *versus* minor surgery on late postoperative episodic and constant hypoxemia[J]. J Clin Anesth, 1994, 6(3): 212-216.

[20] Moller JT, Svennild I, Johannessen NW, *et al*. Perioperative monitoring with pulse oximetry and late postoperative cognitive dysfunction[J]. Br J Anaesth, 1993, 71(3): 340-347.

[21] Xue FS, Li BW, Zhang GS, *et al*. The influence of surgical sites on early postoperative hypoxemia in adults undergoing elective surgery [J]. Anesth Analg, 1999, 88(1): 213-219.

[22] Marcondes G, Soeiro FS, Ferreira Ede A, *et al*. Transportation of patients to the post-anesthetic recovery room without supplemental oxygen: repercutions on oxygen saturation and risk factors associated with hypoxemia[J]. Rev Bras Anestesiol, 2006, 56(4): 352-361.

[23] Hemmes SN, Gama de Abreu M, Pelosi P, *et al*. High *versus* low positive end-expiratory pressure during general anaesthesia for open abdominal surgery (provhilo trial): a multicentre randomised controlled trial[J]. Lancet, 2014, 384(9942): 495-503.

[24] Belcher AW, Khanna AK, Leung S, *et al*. Long-acting patient-controlled opioids are not associated with more postoperative hypoxemia than short-acting patient-controlled opioids after noncardiac surgery: a cohort analysis[J]. Anesth Analg, 2016, 123 (6): 1471-1479.

[25] Andualem AA, Yesuf KA. Incidence and associated factors of postoperative hypoxemia among adult elective surgical patients at dessie comprehensive specialized hospital: an observational study [J]. Ann Med Surg (Lond), 2022, 78: 103747.

[26] Gögenur I, Rosenberg-Adamsen S, Lie C, *et al*. Relationship between nocturnal hypoxaemia, tachycardia and myocardial ischaemia after major abdominal surgery[J]. Br J Anaesth, 2004, 93 (3): 333-338.

[27] Kendale SM, Blitz JD. Increasing body mass index and the incidence of intraoperative hypoxemia[J]. J Clin Anesth, 2016, 33: 97-104.

[28] Abdelmalak BB, Cata JP, Bonilla A, *et al*. Intraoperative tissue oxygenation and postoperative outcomes after major non-cardiac surgery: an observational study[J]. Br J Anaesth, 2013, 110(2): 241-249.

[29] Zorrilla-Vaca A, Grant MC, Rehman M, *et al*. Postoperative hypoxemia after dual-controlled *vs* volume-controlled ventilation in lung surgery[J]. Ann Thorac Surg, 2023, 116(1): 173-179.

[30] 刘涛, 王秀华, 潘慧斌. 开腹大手术麻醉恢复期低氧血症危险因素分析及指导意义[J]. 中国现代医生, 2020, 58(8): 128-132, 136.

[31] 裘治慧, 宋丹丹, 刁玉刚, 等. 经鼻高流量吸氧对老年经内镜逆行胰胆管造影手术监测麻醉中低氧血症发生率影响[J]. 临床军医杂志, 2023, 51(7): 683-687.

[32] Bartlett E, Urman RD, Urits I, *et al*. The role of inspiratory oxygen fraction in postoperative pulmonary complications[J]. J Clin Anesth, 2022, 79: 110162.

[33] Rostin P, Teja BJ, Friedrich S, *et al*. The association of early postoperative desaturation in the operating theatre with hospital discharge to a skilled nursing or long-term care facility[J]. Anaesthesia, 2019, 74(4): 457-467.

[34] Yang Y, Geng Y, Zhang D, *et al*. Effect of lung recruitment maneuvers on reduction of atelectasis determined by lung ultrasound in patients more than 60 years old undergoing laparoscopic surgery for colorectal carcinoma: a prospective study at a single center[J]. Med Sci Monit, 2021, 27: e926748.

[35] 骆学勤, 臧娜, 罗健, 等. 原发性纤毛运动障碍致新生儿呼吸窘迫1例并文献复习[J]. 解放军医学杂志, 2023, 48(1): 84-90.

[36] Miskovic A, Lumb AB. Postoperative pulmonary complications[J]. Br J Anaesth, 2017, 118(3): 317-334.

[37] Elefterion B, Cirenei C, Kipnis E, *et al*. Intraoperative mechanical power and postoperative pulmonary complications in noncardiothoracic elective surgery patients: a 10-year retrospective cohort study[J]. Anesthesiology, 2024, 140(3): 399-408.

[38] Fernandez-Bustamante A, Frendl G, Sprung J, *et al*. Postoperative pulmonary complications, early mortality, and hospital stay following noncardiothoracic surgery: a multicenter study by the perioperative research network investigators[J]. JAMA Surg, 2017, 152(2): 157-166.

[39] Jin B, Yao M, Shen W, *et al*. Effect of post-extubation high-flow nasal cannula combined with respiratory training *versus* conventional oxygen therapy on postoperative pulmonary complications in patients after major abdominal surgery: protocol for a single-centre randomized controlled trial[J]. Trials, 2023, 24 (1): 396.

[40] 韩琳, 王东信. 术后肺部并发症及其对临床结局的影响研究进展[J]. 中国医药导报, 2024, 21(27): 45-49.

[41] Abbott TEF, Fowler AJ, Pelosi P, *et al*. A systematic review and consensus definitions for standardised end-points in perioperative medicine: pulmonary complications[J]. Br J Anaesth, 2018, 120(5): 1066-1079.

[42] Lagier D, Zeng C, Fernandez-Bustamante A, *et al*. Perioperative pulmonary atelectasis: Part Ⅱ. Clinical implications[J]. Anesthesiology, 2022, 136(1): 206-236.

[43] Shander A, Fleisher LA, Barie PS, *et al*. Clinical and economic burden of postoperative pulmonary complications: patient safety summit on definition, risk-reducing interventions, and preventive strategies[J]. Crit Care Med, 2011, 39(9): 2163-2172.

[44] Mavros MN, Velmahos GC, Falagas ME. Atelectasis as a cause of postoperative fever: where is the clinical evidence?[J]. Chest, 2011, 140(2): 418-424.

[45] Sun Y, Deng XM, Cai Y, *et al*. Post-cardiopulmonary bypass hypoxaemia in paediatric patients undergoing congenital heart disease surgery: risk factors, features, and postoperative pulmonary complications[J]. BMC Cardiovasc Disord, 2022, 22(1): 430.

[46] Xie C, Sun K, You Y, *et al*. Feasibility and efficacy of lung ultrasound to investigate pulmonary complications in patients who developed

postoperative hypoxaemia-a prospective study[J]. BMC Anesthesiol, 2020, 20(1): 220.

[47] Nguyen TH, Tran TTP, Bui HM, *et al*. Early postoperative arterial hypoxemia can predict postoperative pulmonary complications[J]. Anaesth Pain Intensi, 2022, 26(2): 137-142.

[48] Laporta ML, Sprung J, Weingarten TN. Respiratory depression in the post-anesthesia care unit: Mayo clinic experience[J]. Bosn J Basic Med Sci, 2021, 21(2): 221-228.

[49] Douville NJ, Jewell ES, Duggal N, *et al*. Association of intraoperative ventilator management with postoperative oxygenation, pulmonary complications, and mortality[J]. Anesth Analg, 2020, 130(1): 165-175.

[50] Devereaux PJ, Sessler DI. Cardiac complications in patients undergoing major noncardiac surgery[J]. N Engl J Med, 2015, 373(23): 2258-2269.

[51] Rosenberg-Adamsen S, Lie C, Bernhard A, *et al*. Effect of oxygen treatment on heart rate after abdominal surgery[J]. Anesthesiology, 1999, 90(2): 380-384.

[52] Writing Committee for the VISION Study Investigators, Devereaux PJ, Biccard BM, *et al*. Association of postoperative high-sensitivity troponin levels with myocardial injury and 30-day mortality among patients undergoing noncardiac surgery[J]. JAMA, 2017, 317(16): 1642-1651.

[53] van Waes JA, Grobben RB, Nathoe HM, *et al*. One-year mortality, causes of death, and cardiac interventions in patients with postoperative myocardial injury[J]. Anesth Analg, 2016, 123(1): 29-37.

[54] Beattie WS, Wijeysundera DN, Chan MTV, *et al*. Implication of major adverse postoperative events and myocardial injury on disability and survival: a planned subanalysis of the enigma-Ⅱ trial[J]. Anesth Analg, 2018, 127(5): 1118-1126.

[55] Devereaux PJ, Chan MT, Alonso-Coello P, *et al*. Association between postoperative troponin levels and 30-day mortality among patients undergoing noncardiac surgery[J]. JAMA, 2012, 307(21): 2295-2304.

[56] Greif R, Akca O, Horn EP, *et al*. Supplemental perioperative oxygen to reduce the incidence of surgical-wound infection[J]. N Engl J Med, 2000, 342(3): 161-167.

[57] Badia JM, Casey AL, Petrosillo N, *et al*. Impact of surgical site infection on healthcare costs and patient outcomes: a systematic review in six european countries[J]. J Hosp Infect, 2017, 96(1): 1-15.

[58] Hunt TK, Dunphy JE. Effects of increasing oxygen supply to healing wounds[J]. Br J Surg, 1969, 56(9): 705.

[59] Hopf HW, Hunt TK, West JM, *et al*. Wound tissue oxygen tension predicts the risk of wound infection in surgical patients[J]. Arch Surg, 1997, 132(9): 997-1004.

[60] Govinda R, Kasuya Y, Bala E, *et al*. Early postoperative subcutaneous tissue oxygen predicts surgical site infection[J]. Anesth Analg, 2010, 111(4): 946-952.

[61] Younis I. Role of oxygen in wound healing[J]. J Wound Care, 2020, 29(Sup5b): S4-S10.

[62] Saab R, Wu BP, Rivas E, *et al*. Failure to detect ward hypoxaemia and hypotension: contributions of insufficient assessment frequency and patient arousal during nursing assessments[J]. Br J Anaesth, 2021, 127(5): 760-768.

[63] Li K, Saab R, Bravo M, *et al*. Wearable device for prevention of postoperative and post-discharge hypoxemia: a randomized pilot trial[J]. Acta Anaesthesiol Scand, 2023, 67(4): 440-447.

[64] Breteler MJM, Kleinjan E, Numan L, *et al*. Are current wireless monitoring systems capable of detecting adverse events in high-risk surgical patients? A descriptive study[J]. Injury, 2020, 51 (Suppl 2): S97-S105.

(责任编辑：纪方方)

解放軍医學雜誌®