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经鼻高流量氧疗的生理效应及其在内镜手术麻醉中的应用进展

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摘　要

内镜手术麻醉过程中，镇静或麻醉药物容易导致上气道塌陷、通气不足及低氧血症发生，尤其在老年、肥胖或心肺储备功能较弱患者中更为常见。与传统氧疗方式相比，经鼻高流量氧疗(high-flow nasal cannula, HFNC)具有提供稳定较高的吸入氧浓度、产生一定水平的气道正压、冲洗上气道无效腔、降低呼吸功及改善气道湿化等优点，可增强氧合并改善呼吸生理状态。近年来，HFNC在多种内镜手术麻醉中的应用逐渐增多，研究证明HFNC在改善围术期氧合、降低低氧血症发生、减少气道干预和提高操作连续性方面具有一定优势。本文就HFNC的主要生理效应及HFNC在内镜手术麻醉中的应用进展作一综述，以期为临床实践及今后的研究提供参考。

关键词

经鼻高流量氧疗，生理效应，内镜手术，麻醉，气道管理

Physiological Effects of High-Flow Nasal Cannula and Its Application Progress in Endoscopic Procedural Anesthesia

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Abstract

During endoscopic procedural anesthesia, sedative and anesthetic agents can easily cause upper airway collapse, hypoventilation, and hypoxemia, especially in older patients, obese patients, and patients with poor cardiopulmonary reserve. Compared with conventional oxygen therapy, high-flow nasal cannula (HFNC) has several advantages. HFNC can provide a relatively stable and high inspired oxygen concentration, generate a certain level of positive airway pressure, wash out upper airway dead space, reduce the work of breathing, and improve airway humidification. These effects help improve oxygenation and respiratory physiology. In recent years, the use of HFNC in different types of endoscopic procedural anesthesia has increased gradually. Current studies show that HFNC has certain advantages in improving perioperative oxygenation, reducing the incidence of hypoxemia, decreasing airway interventions, and maintaining procedural continuity. This article reviews the main physiological effects of HFNC and summarizes the progress of its application in endoscopic procedural anesthesia, with the aim of providing a reference for clinical practice and future research.

Keywords

High-Flow Nasal Cannula, Physiological Effects, Endoscopic Procedures, Anesthesia, Airway Management

1. 前言

随着消化内镜、支气管镜及其他诊疗性内镜技术的不断发展，内镜检查和内镜下治疗在临床中的应用越来越广泛[1]。为减轻检查或治疗的操作不适，提高患者依从性和舒适度，无痛内镜及麻醉镇静技术也越来越普及[2]。然而，内镜手术麻醉大多是在自然气道、未插管的情况下进行，操作中常常需要与手术医生共享气道空间，因此呼吸管理一直是内镜手术麻醉中的重点和主要挑战[3]。特别是应用镇静、镇痛药物后，患者容易出现上气道塌陷、通气不足以及缺氧等并发症，严重时还会影响操作连续性，增加围术期不良事件的风险[4]。

目前，普通鼻导管、简易面罩等传统氧疗仍是内镜手术麻醉常用的给氧方式[5]，但这几种供氧方式在供氧流量、吸入氧浓度(fraction of inspired oxygen, FiO_2)稳定性及呼吸支持等方面存在一定局限，尤其是对老年、肥胖、阻塞性睡眠呼吸暂停及心肺储备功能下降等高危患者常不能很好地达到内镜手术呼吸管理目标[6] [7]。因此，寻求更加安全、有效且耐受性良好的氧疗方式十分重要。

经鼻高流量氧疗(high-flow nasal cannula, HFNC)是近年来较为新兴的一种氧疗方式，相比于传统的给氧方式，HFNC 不仅可以提供较高流量和相对稳定的 FiO_2，还可起到加温加湿、冲洗上气道无效腔、产生一定气道正压等作用，对改善氧合和优化呼吸支持具有一定优势[8]-[10]。近年来，HFNC 在消化内镜、支气管镜及其他手术室外麻醉中的应用逐渐增多，其临床价值也越来越受到重视[11]-[13]。基于此，本文就 HFNC 的主要生理效应及其在内镜手术麻醉中的应用进展作一综述，以期为临床实践提供一定参考。

2. HFNC 的生理效应

HFNC 是一种新型氧疗方式，主要是通过空氧混合装置向患者提供高流量、恒定 FiO_2 且经过主动加

温加湿处理的气体[14]。HFNC 装置一般由空氧混合机、流量调节器、主动加温加湿系统以及专用鼻塞导管等部分组成[15] [16]。

2.1. 稳定吸入氧浓度与氧合改善

HFNC 最基本的作用是提供相对稳定的 FiO_2. 并改善患者氧合。正常成年人吸气峰流速一般为 40~60 L/min，而传统鼻导管或普通面罩的供氧流量往往低于这一水平[17]。因此，患者在吸气过程中会吸入大量环境空气，导致实际吸入的 FiO_2 会受到吸气时间、吸呼比、潮气量和分钟通气量等因素的影响，从而与预设氧浓度存在偏差[18] [19]。HFNC 最高可提供约 80 L/min 的气体流量，能够减少空气对吸入气体的稀释。这样一来 HFNC 提供的 FiO_2 更稳定，也更接近设定值[20]。Ritchie 等的研究发现，当受试者吸气峰流速低于 HFNC 输出流量时，即使其吸气速度发生变化，HFNC 仍能维持相对恒定的 FiO_2，有利于提高患者氧合[21]。

2.2. 呼气末正压效应与肺泡复张维持

HFNC 在持续输注高流量气体过程中，能形成一定的持续气道正压。该压力在呼气末达到峰值，即产生低水平的呼气末正压(positive end-expiratory pressure, PEEP) [22]。这一作用虽弱于无创通气，但对维持气道开放、增加功能残气量和减少肺泡塌陷仍具有积极意义。既往研究表明，HFNC 所产生的气道正压与气体流量有关，流量越高，气道正压越明显。在清醒成年受试者中，HFNC 以 60 L/min 流量运行时，不管采用加热还是非加热模式，均可产生约 7 cmH_2O 的气道正压[23]。这有助于维持上气道开放，并促进肺泡复张[24]。另有研究发现，HFNC 可增加拔管后的重症患者呼气末肺容积[25]。还有研究显示，在反 Trendelenburg 体位、60 L/min 高流量及闭口呼吸条件下，HFNC 可更明显地增加呼气末肺容积，并改善肺内通气分布[26]。

2.3. 解剖无效腔清除与通气效率优化

HFNC 提供的高流量气体可更快地清除鼻腔、口腔和咽腔内残留的二氧化碳(carbon dioxide, CO_2)，并用富氧新鲜气体替代，从而减少 CO_2 的重复吸入[27]。这不仅可以降低无效通气比例，还可在一定程度上提高肺泡通气效率[28]。研究证实，在健康志愿者中，当 HFNC 流量超过 20 L/min 时，计算所得的死腔通气量可减少约 50%。同时，分钟通气量也会下降，但毛细血管 CO_2 分压保持稳定。这个结果提示 HFNC 可在不影响 CO_2 清除的前提下减少死腔通气[29]。对于存在轻度低通气倾向或分钟通气需求增加的患者而言，这种“死腔冲刷”效应十分重要。

2.4. 呼吸力学改善与呼吸功降低

HFNC 输送的气体具有合适的温度、湿度，也具有较高的流速。这一流速超过了患者自身吸气产生的流速，可以直接减少吸气用力，从而减少了吸气阻力和呼吸功[24]。另一方面，呼气末正压和无效腔清除可以进一步降低气道阻力，改善肺泡通气，减轻患者维持通气所需的代偿性负担[16]。研究表明，在拔管后的危重患者中，HFNC 较标准氧疗可明显降低呼吸做功，他们的食管压力摆动幅度减小、压力－时间乘积下降，膈肌电活动减弱，呼吸频率也明显下降[25]。这些结果说明，HFNC 不仅改善了氧合和通气，也在一定程度上改善了患者的呼吸模式。

2.5. 主动加温加湿与气道防御功能维护

与传统冷干氧气不同，HFNC 输出气体经过主动加温和加湿处理，这不仅提高了患者舒适度，还可以帮助维持正常的气道生理环境[30]。相关研究指出，HFNC 可改善黏膜纤毛功能，减少因冷干气体刺激

所致的分泌物潴留和支气管痉挛等问题。在舒适性方面，有研究发现，HFNC 在不同流量和温度条件下，患者的主观耐受性并不完全相同[31]。在相同流量条件下，加热模式(37℃)带来的不适感低于较非加热模式(21℃) [23]。此外，在慢性阻塞性肺疾病急性加重患者中，HFNC 在 30 L/min 和 40 L/min 流量下可提供比无创通气更好的舒适度[32]。对于接受内镜麻醉患者来说，较好的舒适性和耐受性有助于减少体动、呛咳等情况，也更利于操作顺利进行。

3. HFNC 在内镜手术麻醉中的应用

3.1. HFNC 在消化内镜麻醉中的应用

研究大多认为，HFNC 在消化内镜镇静或麻醉中具有一定优势。Lin 等开展的一项多中心随机研究纳入 1994 例丙泊酚镇静下常规胃镜患者，结果显示 HFNC (30~60 L/min)可降低低氧血症和严重低氧血症的发生率[33]。Ng 等比较了 HFNC (60 L/min)与常规氧疗(2 L/min)在预计操作时间超过 20 min 的上消化道内镜中的应用效果，发现 HFNC 组未出现低氧血症，而常规氧疗组发生率为 20%，且 HFNC 组脉搏血氧饱和度(pulse oxygen saturation, SpO_2) ≤ 94%的比例也更低[34]。针对接受内镜逆行胰胆管造影(endoscopic retrograde cholangiopancreatography, ERCP)老年患者，Kim 和 Lee 等的研究同样提示，HFNC 可减少术中 SpO_2 的下降和低氧事件的发生，且不会造成操作中断[35] [36]。Kim 的研究进一步表明 HFNC 在俯卧位患者中亦显示出一定优势[35]。Zhaxi 等人对超高海拔(3500 m 以上)地区全身麻醉胃镜患者进行研究，与标准鼻导管吸氧(15 L/min)相比，HFNC (60 L/min)可进一步降低低氧血症及严重低氧血症的发生率[37]。近期一项针对肥胖患者的多中心随机试验进一步显示，HFNC 可将低氧发生率由 21.2%降至 2.0%，同时降低亚临床呼吸抑制和严重低氧发生率[38]。不过，不是所有随机研究都得出了相同结论。Riccio 和 Sawase 等分别对结肠镜病态肥胖患者及 ERCP 重度镇静患者进行研究，均未观察到 HFNC 较标准鼻导管具有明显优势[39] [40]。这些结果说明，HFNC 的实际效果可能受到患者特征、操作类型、镇静深度及氧疗方案等因素影响。

除单项随机研究外，现有综合证据亦支持 HFNC 在消化内镜中的应用价值。Gu 等的荟萃分析显示，与常规氧疗相比，HFNC 可降低低氧血症风险并提高最低 SpO_2，但研究间存在一定异质性[41]。另一项分析纳入了 12 项随机对照试验，共涉及 3726 名患者，也得出了类似结论。该分析进一步发现，HFNC 减少了气道干预事件，但对高碳酸血症或手术持续时间没有明显影响[11]。不过，不同研究在纳入人群、对照方式及参数设置等方面仍存在差异。因此，HFNC 在不同消化内镜场景中的最佳应用策略还需要进一步明确。

3.2. HFNC 在支气管镜麻醉中的应用

由于支气管镜检查和治疗等操作直接占据气道，加上镇静/麻醉对呼吸作用的抑制，患者更容易出现氧合下降[9]。HFNC 作为一种能够提供高流量、稳定吸氧浓度并具有一定气道支持作用的氧疗方式，近年来在支气管镜镇静/麻醉中的应用逐渐受到关注。Douglas 等在清醒镇静下接受支气管镜检查的成人患者中发现，HFNC (30~70 L/min)可提高预氧合后的血氧水平，并改善术中最低 SpO_2 [42]。Wang 等针对深镇静下诊断性柔性支气管镜患者开展研究，将患者分为常规鼻导管(5 L/min)和 HFNC (25、45、65 L/min)，结果提示 HFNC 可显著降低低氧事件风险，其作用方式与流量依赖有关，同时可在一定程度上减少 CO_2 潴留[43]。Zhang 等进一步探讨了 HFNC 的最佳流量。该研究将接受支气管镜的患者随机分配到不同的流量组，各组患者均接受 HFNC 配合丙泊酚镇静，吸入氧分率 100%，流量分别为 10、20、30、40、50 和 60 L/min。结果发现随着 HFNC 流量增加，低氧事件发生风险逐渐降低，其中 50~60 L/min 可能是预防镇静期血氧下降的更适宜流量范围[44]。HFNC 在儿童及高危患者中的应用价值可能更明显。Sharluyan 等在接受柔性支气管镜检查的儿童中发现，HFNC 较标准低流量鼻导管可显著降低低氧血症发生率，尤其

在支气管肺泡灌洗(bronchoalveolar lavage, BAL)患者中，可进一步减少低饱和事件次数[45]。Qin 等开展的多中心随机对照研究纳入病态肥胖、气道狭窄以及基线低氧血症和/或高碳酸血症等高风险患者，结果显示 HFNC 不仅可显著降低低氧血症发生率，提高最低 SpO_2，还可以减少检查中断和治疗升级[46]。除此之外，HFNC 还在部分特殊支气管镜操作中显示出一定优势。Yue 等针对支气管内超声引导下经支气管针吸活检(endobronchial ultrasound-guided transbronchial needle aspiration, EBUS-TBNA)患者的随机研究表明，与鼻咽通气道供氧(6 L/min)相比，HFNC (45 L/min)可降低缺氧发生率，减少气道辅助干预，并改善术中氧合和 CO_2 潴留情况[47]。

系统综述与荟萃分析的结果总体支持 HFNC 在支气管镜中的应用。Sampsonas 等纳入 6 项随机对照试验、1170 例患者的荟萃分析显示，与低流量氧疗相比，HFNC 可减少低氧事件、操作中断及部分支气管镜相关并发症，而且这种氧合改善效应在术后短时间内仍可持续[48]。另一项荟萃分析进一步表明，与传统氧疗相比，HFNC 可显著降低低氧血症发生率，提高最低 SpO_2，同时还能缩短操作时间并提高术末动脉血氧分压(partial pressure of arterial oxygen, PaO_2)。而在与无创通气比较时，两者在改善氧合方面均具有一定效果，提示 HFNC 有望成为部分高危支气管镜患者中无创通气的一种可行替代方案[13]。

不过，HFNC 并不是在所有情况下都能预防低氧血症。Burton 等在清醒镇静下支气管镜及 EBUS 患者中比较 HFNC 与低流量氧疗时发现，两组在整体氧合和低氧血症发生率方面差异并不显著[49]。这一结果提示，HFNC 的临床效果可能受到患者基础风险、镇静深度、操作类型及对照氧疗方式等多因素影响。对于基础状态较好、操作刺激较轻或镇静程度较浅的人群，HFNC 带来的额外获益可能相对有限。

3.3. HFNC 在耳鼻喉科内镜麻醉中的应用

耳鼻喉科内镜检查及相关手术多涉及上气道，麻醉管理中常面临共享气道和术野暴露的双重挑战[50]。现有文献在这一领域更多提到经鼻加温湿化快速通气交换(transnasal humidified rapid-insufflation ventilatory exchange, THRIVE)技术。THRIVE 本质上属于高流量经鼻氧疗在麻醉中的一种特殊应用[51]。近年来，HFNC 或 THRIVE 在耳鼻喉科内镜麻醉中的应用逐渐增多，现有研究主要集中于喉显微镜、支撑喉镜及其他上气道短时操作。

HFNC/THRIVE 在耳鼻喉科内镜麻醉中一方面可提供高流量、稳定的氧输送，延长无呼吸安全时间，降低术中低氧发生风险[52]；另一方面可减少气管导管或其他通气装置对术野的遮挡，为术者提供更清晰的操作视野[53]。费青等对支撑喉镜下声带息肉摘除术患者的研究显示，与传统气管内插管相比，采用 HFNC (60 L/min)通气可明显缩短诱导时间、麻醉时间及苏醒时间，且未见围术期高流量通气相关肺损伤及明显气道并发症[54]。姜蕾等将湿化高流量鼻导管氧疗应用于可视喉镜下环杓关节脱位复位术，结果表明，与传统给氧方式相比，HFNC 组患者术中及术后 SpO_2 更高，有效呼吸时间更长[55]。研究还发现传统组术中呼气末二氧化碳分压(end-tidal carbon dioxide, $EtCO_2$)更高，低氧血症发生率也更高，因此麻醉医生需更频繁地进行呼吸干预。另有一项荟萃分析显示，在成人喉部手术中，与传统通气方式相比，THRIVE 组手术时间更短，但低氧血症、救援干预及峰值 $EtCO_2$ 升高的发生率也更高[51]。这些结果表明，HFNC 或 THRIVE 虽有助于改善术野暴露，并满足部分无管化手术需求，但目前还不能完全替代传统通气方式。

目前耳鼻喉科内镜麻醉领域关于 HFNC 或 THRIVE 的研究仍然较少，且证据多来自文献综述、病例系列及观察性研究，高质量随机对照研究仍然不足。此外，研究也提示 HFNC 或 THRIVE 的临床效果受多种因素影响，包括手术时间、麻醉深度、患者体型、基础气道条件及病变部位等。需要注意的是，HFNC 或 THRIVE 虽然能在一定时间内维持较好氧合，但它们对 CO_2 清除能力有限。随着操作时间延长，CO_2 蓄积风险可能逐渐增加。严重肥胖、明显气道梗阻或通气储备较差的患者，安全范围往往更小。此外，在激光或电凝相关耳鼻喉手术中，医生还需警惕高氧环境下潜在的气道着火风险。

3.4. HFNC 在宫腔镜麻醉中的应用

宫腔镜检查及相关治疗中，患者常常采取截石位，加上丙泊酚、阿片类药物对呼吸的抑制，围术期易出现通气不足和氧合下降[56]。近年来，HFNC 因可提供高流量、稳定吸氧浓度和一定呼气末正压效应，逐渐被应用于宫腔镜麻醉的氧合管理。

Tang 等纳入 960 名接受宫腔镜检查的女性患者，比较 HFNC (30~60 L/min)与常规鼻导管(3~6 L/min)的低氧发生率。结果显示 HFNC 可显著降低低氧血症、亚临床呼吸抑制及严重低氧的发生率[57]。Frassanito 等开展的随机非劣效试验纳入 180 例宫腔镜手术患者，比较 HFNC (70 L/min)与喉罩机械通气在 30 分钟全麻中的呼吸支持效果，结果显示两组术中呼吸支持成功率均为 99%，提示 HFNC 在该场景下对术中呼吸支持不劣于喉罩机械通气，且 HFNC 组术后呼吸道症状更少[58]。但该研究也指出 HFNC 组术中经皮二氧化碳水平更高，且约 43%的患者出现高碳酸血症。国内研究也提示 HFNC 在宫腔镜麻醉中具有一定临床应用价值。周礼生、曹媛媛及肖悦等的研究均表明，经鼻高流量湿化氧疗有助于改善宫腔镜全凭静脉麻醉患者的围术期氧合，并减少低氧相关干预[59]-[61]。不过，这些研究多为单中心临床观察，样本量较小，研究对象及麻醉方案也并不完全一致。因此，后续仍需要更多高质量研究进一步验证。

4. HFNC 在内镜麻醉中的优势与局限

4.1. 不同内镜场景下 HFNC 应用特点及主要优势

尽管 HFNC 在不同内镜手术麻醉中均可改善氧合、减少低氧事件并降低气道干预需求，但不同手术场景的呼吸管理重点并不完全相同[62] [63]。消化内镜麻醉的主要挑战多与镇静后上气道塌陷、低通气及部分特殊体位有关，HFNC 的优势主要体现在提供更稳定的 FiO_2、增加氧储备并减少低氧相关中断。支气管镜及耳鼻喉科内镜则更多涉及共享气道，除镇静本身引起的呼吸抑制外，还存在操作对通气的直接影响，因此 HFNC 的价值不仅在于改善氧合，还在于尽量维持操作连续性、减少额外气道装置干扰，并在部分耳鼻喉科手术中改善术野暴露[46] [64]。相比之下，宫腔镜麻醉并不涉及共享气道，其主要问题多与截石位、静脉麻醉药物导致的低通气及短小手术对快速恢复的要求有关，因此 HFNC 更多作为优化氧合和减少围术期干预的支持手段。总体而言，HFNC 在不同内镜场景中的共同优势包括提供高流量且相对稳定的 FiO_2、形成低水平 PEEP、冲刷上气道无效腔及改善气体加温加湿，从而提高围术期氧合稳定性，减少低氧血症及相关气道干预，并在部分共享气道操作中兼顾术野需求和患者舒适性[65]-[67]。

4.2. 局限性

尽管 HFNC 在内镜麻醉中具有一定优势，但其局限性同样不容忽视。首先，HFNC 的主要优势在于改善氧合，而非真正意义上的通气替代，因此对于镇静过深、舌后坠、上气道明显塌陷或自主呼吸减弱所致的低通气，单纯依赖 HFNC 通常不足以解决问题，必要时仍需及时采取开放气道、辅助通气甚至建立人工气道等措施[68]。其次，HFNC 的临床效果还受患者基础状况、手术类型、体位特点、镇静深度及参数设置等多种因素影响，目前不同内镜场景中的最佳流量和 FiO_2 策略尚未完全统一[69] [70]。再次，HFNC 对 CO_2 清除的作用有限，尤其在操作时间较长、镇静较深或患者本身存在高碳酸血症倾向时，仍需警惕 CO_2 蓄积风险[71]。此外，此外，HFNC 的规范应用还依赖于设备管理和操作经验，在耳鼻喉科激光或电凝等特殊场景中还需警惕高氧环境下的安全风险[72] [73]。

5. 总结与展望

总体来看，HFNC 作为一种新的氧疗方式，在内镜麻醉中显示出较好的应用前景。HFNC 能够在一定程度上改善围术期氧合，降低低氧血症发生率，减少气道干预，并在部分共享气道操作中兼顾术野暴

露和操作连续性。不过，现阶段的证据仍提示，HFNC 的临床定位需要保持理性。它更适合作为传统氧疗与更高级气道支持之间的一种优化方式，既不能替代基础气道管理，也不能作为适用于所有患者的通用方案。HFNC 的临床效果受患者基础状况、手术类型、镇静深度及参数设置等多种因素影响，目前在不同内镜麻醉场景中的最佳应用策略仍未完全明确。

未来研究应更多围绕现有证据空白和争议问题展开。对于肥胖、阻塞性睡眠呼吸暂停、老年及基础肺功能受损等高危人群，可进一步开展 HFNC 与鼻咽通气道、无创通气等呼吸支持方式的随机对照比较研究，重点评估低氧血症、CO_2 潴留、气道干预需求等结局。同时，还需结合不同内镜类型、镇静深度及体位特点，进一步探索 HFNC 的最佳流量和 FiO_2 设置，推动其应用标准化。在监测方面，除持续关注 CO_2 监测外，未来也可通过前瞻性研究评估 ROX 指数等指标在预测 HFNC 失败和识别需升级气道支持患者中的价值。此外，还应进一步关注 HFNC 在门诊化、日间化及快速康复麻醉模式中的实际应用效果。

总体而言，HFNC 在内镜麻醉中的应用已显示出较好的发展潜力，不过 HFNC 规范化和精准化应用，仍需要更多高质量研究的支持。随着循证依据不断积累及适应证逐渐清晰，HFNC 有望在内镜麻醉中发挥更重要的作用。

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