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心脏结构–电生理体系下精细化麻醉管理策略研究

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摘　要

心脏结构–电生理(structural electrophysiology, SEP)体系是一种融合先进影像技术与精准解剖定位的创新介入治疗模式。该体系涵盖心血管植入型电子器械(cardiovascular implantable electronic devices, CIED)与经静脉导线拔除术(transvenous lead extraction, TLE)、左心耳封堵术(left atrial appendage occlusion, LAAO)及复杂导管消融术等关键手术。随着手术适应症的扩展与技术复杂度的提升，麻醉管理面临巨大挑战。这要求麻醉医师具备专业的电生理麻醉素养，以应对个体化手术需求、管理高危患者、维持术中血流动力学稳定及快速处理并发症。本文系统综述了SEP体系下三类核心手术的围术期麻醉策略，强调基于深度评估的个体化管理、多学科协作及新型麻醉药物的合理应用。通过循证化、精准化的麻醉干预，旨在提升手术安全性与患者预后。

关键词

心脏，结构电生理，麻醉

Research on Refined Anesthesia Management Strategies under the Cardiac Structure-Electrophysiology System

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Abstract

The cardiac structural-electrophysiology (SEP) system represents an innovative model for interventional therapy that integrates advanced imaging technology with precise anatomical targeting. This system includes key procedures such as cardiovascular implantable electronic devices (CIED), transvenous lead extraction (TLE), left atrial appendage occlusion (LAAO), and complex catheter ablation. As surgical indications expand and technical complexity increases, anesthesia management encounters significant challenges. Anesthesiologists must possess specialized expertise in electrophysiology anesthesia to address individualized surgical needs, manage high-risk patients, maintain intraoperative hemodynamic stability, and respond swiftly to complications. This article systematically reviews perioperative anesthesia strategies for the three core procedures within the SEP system, emphasizing individualized management based on comprehensive assessments, multidisciplinary collaboration, and the rational application of new anesthetic agents. By employing evidence-based and precision anesthetic interventions, this work aims to enhance surgical safety and improve patient outcomes.

Keywords

Cardiac, Structural Electrophysiology, Anesthesia

1. 引言

心脏结构－电生理(structural electrophysiology, SEP)体系的核心在于利用实时三维成像技术进行精准定位，并针对特定心脏解剖结构进行干预。该体系涵盖的关键手术包括心血管植入型电子器械(cardiovascular implantable electronic devices, CIED)植入术、经静脉导线拔除术(transvenous lead extraction, TLE)、经导管左心耳封堵术(left atrial appendage occlusion, LAAO)以及日益复杂的导管消融术。本文聚焦于结构电生理体系关键手术的围术期麻醉管理策略，旨在为麻醉医师提供循证干预框架，降低手术风险并改善患者短期与长期临床预后。

2. 房颤的流行病学介绍

2019 年，美国约有 1055 万成年人罹患心房颤动(AF) [1]。全球疾病负担(Global Burden of Disease, GBD)研究进一步揭示，2021 年全球有 5255 万人罹患心房颤动或心房扑动，该疾病在北美、澳洲及西欧等高收入国家尤为高发[2]。在中国，2023 年心律失常住院病例高达 1113.2 万例，其中房性心律失常占 55.9% [3]。对于有症状的阵发性心房颤动患者，导管消融作为一线治疗方案，可有效改善症状并延缓其进展为持续性心房颤动。对于合并射血分数降低的心力衰竭(heart failure with reduced ejection fraction, HFrEF)的 AF 患者，导管消融治疗可改善生活质量、左心室收缩功能及心血管结局(包括死亡率和心力衰竭住院率) [4]-[6]。CABANA 研究表明，年龄低于 65 岁且接受导管消融治疗的房颤患者，其生活质量持续改善，房颤复发率降低 44%，全因死亡率降低 43% [7] [8]。

3. 房颤导管消融手术麻醉方案

3.1. 房颤导管消融手术的麻醉评估

心房颤动(Atrial Fibrillation, AF)是射血分数保留型心力衰竭(heart failure with preserved ejection fraction, HFpEF)的重要表型，因此对 AF 患者应加强心力衰竭(heart failure, HF)的筛查与评估[9] [10]。CHA2DS2-VASc-60 评分是房颤患者卒中风险评估的核心工具，对于 CHA2DS2-VASc-60 评分 ≥ 2 分的男性或≥3 分的女性房颤患者，建议使用直接口服抗凝药物(direct oral anticoagulants, DOAC) [11]。在 AF 患者的术前评估中，经胸超声心动图(transthoracic echocardiography, TTE)或经食管超声心动图(transesophageal echocardiography, TEE)不仅能够评估左心室(Left Ventricle, LV)功能，还能检测左心房及左心耳(left atrial appendage, LAA)的血栓形成，尤其适用于已接受连续 3 周以上抗凝治疗的患者[12] [13]。Diab M 等对 900 例 AF 患者开展的大型观察性研究发现，对于消融术前已连续 3 周以上使用 DOAC 的患者，术前无需进行 TEE 检查，这些患者的术后血栓栓塞事件发生率仅为 0.3% [14]。术前评估应包括以下内容：首先，评估双心室功能以判断患者的手术耐受性；其次，明确主动脉瓣病变，以确保左心室逆行通路的可行性；此外，还需评估冠状动脉解剖结构，若存在缺血性心脏病风险则应重点考量[15]。所有具有电生理效应的药物，如 β 受体阻滞剂、钙通道阻滞剂、地高辛以及 I 类和 III 类抗心律失常药物，都需在手术前停用 3 至 5 个半衰期(胺碘酮需提前 1 个月停药)，以避免对心律失常的诱发和诊断造成影响[16]。对于行消融治疗的患者，术前继续服用或中断新型口服抗凝药治疗均属合理方案[17]。然而，对于涉及心外膜消融的手术，必须暂停或逆转抗凝治疗。

3.2. 房颤导管消融手术的麻醉管理

3.2.1. 监测方式

采用 ASA 标准监测，对于 CHA_2DS_2-VASc-60 评分或围术期卒中风险高的患者，监测脑氧饱和度(regional cerebral oxygen saturation, rSO_2)，可能降低卒中风险[18]。对于手术方式及/或患者本身可能导致血流动力学不稳定者，应首选动脉导管置入进行实时血压监测[19]。在房间隔穿刺时给予负荷剂量肝素，随后持续输注，维持活性凝血时间(activated coagulation time, ACT) 300~400 s [20]。

3.2.2. 麻醉方式

尽管冷冻球囊消融术相较于射频消融术，手术时间缩短，疼痛程度减轻，清醒镇静或深度镇静可以满足手术需求[21]，但患者因疼痛或刺激而深呼吸或身体移动时，可能发生左心房顶部穿孔。此类手术应首选全身麻醉或深度镇静，并确保气道安全[22] [23]。超过 50%患者术后 24 小时内存在中度或剧烈疼痛[24]，因此术后常规提供镇痛治疗，必要时可使用舒芬太尼等阿片类药物[19]。

3.2.3. 麻醉药物

麻醉药物的选择应综合评估手术时长、心律失常诱导需求及患者健康状况(包括肥胖、OSA、气道问题与整体心血管状态)，以优化麻醉剂与镇痛剂的选择，从而降低手术风险并改善患者预后[25]。

Iacopino S [26]等对 66 例接受脉冲场消融(pulsed field ablation, PFA)治疗的 AF 患者实施了以氯胺酮为基础、保留自主呼吸的深度镇静(deep analgosedation, DAS)方案。研究显示，在分次给予小剂量咪达唑仑(4 mg)与芬太尼(1.5 μg/kg)后，于首次 PFA 前 5 分钟静脉注射氯胺酮(1 mg/kg)，并根据血氧饱和度、收缩压/舒张压、疼痛反应、咳嗽及心率变化滴定调整剂量。达到目标麻醉深度后，以 10 mg/次间断追加氯胺酮，可有效维持深度镇静状态并促进患者早期苏醒。Sochorová V [27]等对 127 例接受 PFA 治疗的 AF 患者进行了不同麻醉方案的对比研究。结果表明，瑞马唑仑－氯胺酮为基础的 DAS 方案在降低围术期低

氧血症与低血压风险方面优于传统丙泊酚–阿片类全凭静脉麻醉(total intravenous anesthesia, TIVA)或丙泊酚–阿片类 DAS 方案。尤其在传统丙泊酚–阿片类 DAS 组中，80%的患者发生了需临床干预的围术期低氧血症。Lee S [28]等对 53 例接受射频消融治疗(radiofrequency catheter ablation, RFCA)的 AF 患者进行的研究表明，瑞马唑仑–氟马西尼组患者在快速复苏与血流动力学稳定方面优于丙泊酚组患者。

4. 经导管左心耳封堵术的麻醉方案

Osmancik P 等对 402 例 AF 患者开展的 4 年随访研究表明，在预防严重心脑血管事件及大出血方面，LAAO 不劣于新型口服抗凝药阿哌沙班，并可显著降低非手术相关出血风险[29]。截至于 2021 年底，我国 LAAO 总数已突破 30,000 例，可实施 LAAO 的中心数量超过 500 家[30]。简化式 LAAO 常规采用局部浸润麻醉，而经典式 LAAO 则需全身麻醉气管插管[31]。

4.1. 经典式 LAAO 手术的麻醉评估

4.1.1. 生理功能与影像评估

术前常规通过 TTE/TEE 评估左心房存储功能(包括左心房最大容积、扩张指数和应变参数)及收缩功能(包括左心房射血分数和应变参数) [30] [32]，同时进行左心耳形态学定量分析和血流速度检测。

4.1.2. 替代影像与功能指标

多层螺旋电子计算机断层扫描仪(multislice computed tomography, MSCT)适用于不耐受 TEE 患者的评估。然而，与 TEE 相比，MSCT 在检测左心房和左心耳内血栓方面的敏感性和特异性较低[30]。左心房功能指数(left atrial function index, LAFI)可用于评估左心房重构程度，而左心房扩张指数(left atrial expansion index, LAEI)则能够无创评估肺循环动力状态[33] [34]。此外，左心房僵硬度增加是心力衰竭患者活动耐量下降的独立预测因子[35]。

4.1.3. 术前用药评估

对于术前存在 HF 的患者，需明确其心功能分级，并评估指南指导药物治疗(guideline-directed medical therapy, GDMT)的达标率，包括血管紧张素受体脑啡肽酶抑制剂、β 受体阻滞剂、盐皮质激素受体拮抗剂和钠–葡萄糖共转运蛋白 2 抑制剂的四联治疗方案[36]。对于使用钠–葡萄糖共转运蛋白 2 抑制剂的患者，应监测血酮水平及 pH 值[37]。使用螺内酯治疗的患者，需维持血钾水平在 4.0~5.0 mmol/L 之间，且波动幅度应小于 0.5 mmol/h [38]。心室率控制目标应低于 110 次/分，优先选择 β1 选择性阻滞剂。对于服用非维生素 K 拮抗剂抗凝药的患者，应在手术当天停用[30] [31]。

4.2. 经典式 LAAO 手术的麻醉管理

4.2.1. 监测方式与液体管理

一项纳入 4130 例患者的 Meta 分析表明，LAAO 可显著降低卒中远期相对风险[38]。连续有创动脉血压监测联合 rSO_2 监测能显著降低术后神经认知障碍的发生率。对肾功能不全患者实施限制性水化方案(输液速率 ≤ 1 mL/kg/h)，同时需监测尿量。对于 HF 患者，术中应及时使用血管活性药物，维持平均动脉压 ≥65 mmHg，以避免容量高负荷或低灌注诱发 HF 加重。术中需维持左心房压 ≤12 mmHg，防止左心房扩张；在封堵器释放时，应维持收缩压在 100~120 mmHg，以减少封堵器移位的风险[39] [40]。常规使用普通肝素抗凝(60~100 IU/kg)，在完成房间隔穿刺后，维持 ACT 在 250~350 秒[30]。

4.2.2. 麻醉药物

Kleinecke C [41]等对 303 例接受 LAAO 手术患者的随机对照研究表明，丙泊酚联合芬太尼或瑞芬太

尼作为麻醉方案，可有效降低术中血流动力学波动幅度和体动发生率，并提升患者舒适度。Li Q [42]等开展的一项纳入 84 例行 LAAO 手术患者的随机对照试验显示，与丙泊酚－瑞芬太尼－顺式阿曲库铵－新斯的明方案相比，采用丙泊酚－瑞芬太尼－罗库溴铵－舒更葡糖钠的全身麻醉气管插管方案可显著缩短麻醉时间，并降低低氧血症及躁动发生率。随着瑞马唑仑、环泊酚等新型麻醉药物在心血管手术中的广泛应用[43] [44]，LAAO 麻醉药物选择有望进一步多样化。

5. 心血管植入型电子器械与起搏导线拔除术的麻醉方案

CIED 包括心脏起搏器、ICD、CRT 起搏器和除颤器、ICM 以及植入型心血管监测器，主要用于心律失常和 HF 的诊断与治疗[45]。根据欧洲心脏病学会(European Society of Cardiology, ESC)的统计数据显示，其成员国每年 CIED 植入量超过 50 万例次[46]。与此同时，我国 CIED 植入数量也呈现迅速增长趋势[47]。CIED 相关性感染和静脉闭塞等并发症的发生率亦显著增加[48]。Hernández-Meneses M 等[49]开展的一项为期 40 年的研究表明，CIED 相关感染性心内膜炎的发病率增长至原来的四倍以上。此外，Ferro EG 等[50]基于 649,524 例接受 CIED 植入患者的队列研究显示，共有 28,214 例发生导线相关静脉阻塞。Lee JZ [51]等对 12999 例因 CIED 感染行导线拔除术的患者进行了研究，结果显示，与早期拔除组(n = 4165)相比，延迟拔除组(>7 天，n = 8834)的院内死亡率显著升高(8.3% vs 3.5%)，这一发现进一步证实了早期干预的重要性。

5.1. 起搏导线拔除术的麻醉评估

5.1.1. 基础心脏功能评估

需明确心脏植入式电子设备(CIED)的植入病因、当前参数设置、起搏器依赖状态、恶性心律失常治疗史、导线的数量、年限和植入位置，并于术前进行 CIED 程控，关闭异常感知等非必要功能[52] [53]。值得注意的是，根据 ASA 身体状况分级，IV 级患者全身麻醉使用率显著提升 27% [52]。

5.1.2. 影像学评估

通过 TTE 和 TEE 评估心脏收缩与舒张功能、心内分流(明确位置与分流量)、心腔内导线走行路径以及导线或瓣膜附着的赘生物或血栓情况，同时需评估三尖瓣反流或狭窄程度。对于基线 LVEF<40%的患者，需在术前予以强化治疗，包括静脉用正性肌力药物支持及超滤治疗以纠正容量过负荷[53]。胸壁侧支循环显影是静脉闭塞的重要标志，通常提示血管撕裂风险升高[54]。

5.1.3. 实验室检查

术前 72 小时内需完成全血细胞分析，重点监测白细胞计数和血红蛋白水平，以筛查隐匿性感染与贫血。同时，应评估肝肾功能及电解质情况，当肾小球滤过率低于 60 mL/min/1.73m^2 时，需启动肾保护策略[55]。血钾应维持在 4.0~5.0 mmol/L，以预防围术期心律失常。对于接受抗凝治疗的患者，应采用肝素桥接方案(INR > 2.0 者需在术前 48 小时停用华法林)。当纤维蛋白原水平低于 1.5 g/L 时，应预警大出血风险。此外，需完成血型鉴定及抗体筛查，并准备 2~4 单位浓缩红细胞，以应对术中输血需求[53] [56]。

5.2. 麻醉管理

5.2.1. 麻醉方式选择

全身麻醉的适应证包括：BMI < 25 kg/m^2、女性、需拔除多根导线、移除双线圈 ICD 导线、导线植入时间 >1 年、ASA 分级 ≥III 级或 NYHA 分级 ≥III 级。若导线植入时间 <1 年且患者基础状态良好(ASA I~II 级)，可考虑在深镇静下进行手术。无论采用全身麻醉或深镇静，行 TLE 时均需心外科团队及体外循环支持待命[57]。Bontempi L 等提出的 LED 评分系统(LED 评分 = 拟拔除导线数量 + 最旧导线植入年

限 ＋1 分[双线圈 ICD 导线移除]－1 分[导线体部赘生物])显示，LED 评分 ≥10 分者围术期风险极高，需实施气管插管全身麻醉[58]。

5.2.2. 监测方式

TLE 手术需在具备体外循环支持条件的杂交手术室、心外科专用手术室或配备心外科团队的电生理术间进行[58]-[60]。采用滴定法完成麻醉诱导后，置入 TEE 探头，建立左侧股静脉通路用于临时心脏起搏，并预留右股静脉通路以备紧急体外循环之需。术中，TEE 持续监测心脏结构与功能，动态评估心室充盈状态、心肌收缩力及瓣膜功能，实时预警心包填塞、电极断裂、瓣膜损伤等心血管并发症。

5.2.3. 麻醉药物

Bode K [60]等对 220 例起搏导线拔除手术患者的研究证实，由经验丰富的心血管麻醉医师实施咪达唑仑－芬太尼－丙泊酚 DAS 方案，可显著降低术中低血压、低氧血症及气道干预的发生率。

6. 总结

脉冲场消融(pulsed field ablation, PFA)作为新兴技术，对麻醉提出了更高要求。未来研究应进一步优化 PFA 的麻醉药物组合与给药策略，实现更精准的镇静深度调控。局部麻醉联合镇静在心腔内超声心动图(intracardiac echocardiography, ICE)引导下的 LAAO 术式中逐渐得到广泛应用，减少了对气道和镇静深度的要求，但仍需密切监测血流动力学变化，尤其是左心房压和脑氧饱和度，以预防封堵器移位和神经认知并发症。人工智能(artificial intelligence, AI)通过整合多模态生理数据、影像学参数与患者基线特征，可实现对术中低血压、心包填塞、卒中等并发症的早期预测，为麻醉医师提供决策支持。未来需推动 AI 模型在真实世界的验证与临床应用，构建智能化、实时化的风险预警体系，进一步提升 SEP 手术麻醉的安全性与精准性。

综上所述，SEP 体系下的麻醉管理正朝着循证化、个体化和智能化的方向迈进。通过深化对新型消融技术的麻醉适应、优化影像引导下的麻醉策略，并融合人工智能的风险管理工具，有望显著提升复杂电生理手术的整体疗效与患者预后。

利益冲突

所有作者均声明不存在利益冲突。

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