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· 综述与讲座 ·

脓毒症与老年急性肾损伤

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[摘要] 脓毒症是老年急性肾损伤(AKI)的首要致病因素,二者叠加显著增加老年患者病死率、延长住院时间并加重医疗负担。随着人口老龄化加剧,脓毒症相关老年 AKI 的临床关注度持续提升。本文结合近年循证医学证据,从脓毒症诱发老年 AKI 的病理生理机制、临床特点、早期诊断方法及个性化综合管理策略等方面进行系统综述,重点探讨老年人群肾脏衰老、衰弱状态及多基础疾病对疾病的影响,为临床优化诊疗方案、改善患者预后提供参考。

[关键词] 脓毒症; 老年; 急性肾损伤

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随着社会和经济的发展,根据 WHO 2013 年发布的数据,我国男性预期寿命已延长至 73.5 岁,女性至 79.9 岁^[1],人口老龄化背景下,年龄 ≥ 65 岁老年人群占比持续升高,到 2050 年该类人群的占比将达到 25%^[2],肾脏作为衰老过程中功能衰退最显著的器官之一^[3-4],使老年群体成为急性肾损伤(AKI)的高发人群^[5-6]。脓毒症是机体对感染的失控性炎症反应,而老年 AKI 是脓毒症最常见的严重并发症之一。数据显示,脓毒症相关 AKI 在老年患者中的发生率可达 30% ~ 50%,显著高于年轻人群,且一旦发生,患者 ICU 入住率、远期肾功能不全风险及死亡率均大幅升高^[7-9]。老年患者肾脏结构退行性改变、肾功能储备下降,叠加脓毒症引发的全身炎症反应、微循环障碍等病理过程,使疾病诊疗更具复杂性。本文基于近年最新研究成果,围绕脓毒症与老年 AKI 的核心关联点展开阐述,以期为临床实践提供循证依据。

一、脓毒症诱发老年 AKI 的病理生理机制

1. 肾脏衰老与肾功能下降:肾脏衰老与氧化应激^[10-11]、细胞衰老^[12]、Klotho 蛋白减少^[13-14]、慢性炎症^[15-16]等密切相关。伴随年龄的增长,肾脏会出现以局灶性和全身性肾小球硬化、管性萎缩、间质性纤维化

和动脉硬化为特征的肾硬化和肾小球肥大的微观解剖学变化及肾皮层体积减少,伴随良性囊肿和肿瘤形成的宏观解剖学变化^[12],这使功能性肾小球数量下降,进而导致肾脏出现肾小球滤过率(GFR)下降、管功能减退、内分泌功能下降及纤维化等^[6,17-18],这些功能改变及由此产生的纤维化和使得肾脏承受和恢复的能力下降,因此肾脏衰老过程与老年人群发生肾病的风险增加存在密切联系。

2. 表观遗传:AKI 会引起上皮损伤,其后的修复过程往往并不完整而导致慢性肾脏病。表观基因组变化如组蛋白乙酰化、DNA 甲基化及微小 RNA(miRNA, miR)在近年来的 AKI 向慢性肾脏疾病转变的驱动因素中成为研究热点^[19]。组蛋白乙酰化是 AKI 和修复中研究最为深入的表观遗传机制之一,证据表明 H3 乙酰化水平与脓毒症诱导 AKI 有关,且 $\alpha 2$ -肾上腺素受体激动剂可通过抑制组蛋白去乙酰化酶(HDAC)2 和 HDAC5 诱导 H3 乙酰化及骨形态发生蛋白(BMP)7 表达,保护小鼠免受败血性 AKI 的侵害^[20]。而 DNA 甲基化则是 AKI 的一个新兴研究领域,异常 DNA 启动子高甲基化可被视为 AKI 的生物标志物^[21],AKI 后 α -平滑肌肌动蛋白(Acta2)抑制子 Ybx2 的超甲基化会促进 AKI 向慢性肾脏病(CKD)进展。在脓毒症引起的 AKI 中,miR-107 增加可以通过靶向内皮细胞中的双特异性磷酸酶(DUSP)7 诱导肿瘤坏死因子(TNF)分泌而导致管状细胞的死亡^[22]。

3. 全身炎症反应与氧化应激损伤:随着年龄的衰老,免疫系统发生失调,可表现为慢性炎症状态^[23],而慢性炎症状态已被证实与多种疾病相关^[24-25]。发生脓毒症时,细菌毒素及 TNF- α 、IL-6 等炎症介质大量释

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放,进而引发全身炎症反应综合征。老年患者炎症调节能力减弱,过度炎症反应可直接损伤肾实质细胞,同时引发氧化应激反应,产生大量活性氧,进一步加重肾小管上皮细胞凋亡与坏死。近年研究表明,NOD 样受体热蛋白结构域相关蛋白(NLRP)3 炎症小体激活在脓毒症相关老年 AKI 中发挥关键作用,通过调控炎症瀑布反应加剧肾损伤^[26-27]。

肾脏微循环障碍:脓毒症导致的血管扩张、通透性增加及血流动力学紊乱会使老年患者原本处于低灌注状态的肾脏供血进一步减少。同时,微血栓形成、内皮细胞损伤等因素加剧肾组织缺氧缺血,最终诱发 AKI^[28-29]。多普勒超声研究结果证实,老年脓毒症患者肾动脉阻力指数显著升高,反映肾脏微循环灌注不足^[30]。

4. 肾素-血管紧张素-醛固酮系统激活:脓毒症引发的有效循环血量不足会激活该系统,导致肾血管收缩,GFR 下降。老年患者肾脏血管对血管活性物质的敏感性改变,进一步放大了这一病理效应^[27,31-32]。

5. 药物与营养因素叠加:老年脓毒症患者常需使用多种抗菌药物、血管活性药物等,部分药物可通过多种机制而引起 AKI^[33-34],如非甾体类抗炎药物可引起血管收缩导致内壁灌注减少及缺血性损伤进而导致 AKI^[35],ICU 常用抗生素万古霉素可能通过引起急性肾小管损伤和堵塞肾小管而导致 AKI^[36-37]。同时,老年患者营养储备不足、代谢能力下降,进一步削弱了肾脏的防御与修复能力^[38-40]。

6. 肠道菌群失调参与损伤过程:脓毒症时肠道屏障功能受损,肠道内致病菌及毒素移位进入血液循环,加重全身炎症反应,同时直接或间接损伤肾脏组织,这一机制在老年患者中因肠道功能衰退而更为显著^[41-42]。

二、脓毒症相关老年 AKI 的临床特点

1. 起病隐匿,早期症状不典型:老年患者反应迟钝,脓毒症的发热、寒战等全身症状可能不明显,AKI 的少尿、水肿等表现也易被基础疾病掩盖,常因实验室检查发现肾功能指标异常而确诊^[27,43]。衰弱老年患者可能仅表现为乏力、食欲减退等非特异性症状,延误早期识别。

2. 基础疾病影响显著:80% 以上的老年 AKI 患者合并至少 1 种慢性基础疾病,糖尿病、高血压、CKD 等会预先损伤肾脏功能,使脓毒症相关老年 AKI 进展更快、病情更重,且肾功能恢复难度更大^[8,44]。

3. 并发症多,预后较差:老年患者免疫功能低下,脓毒症相关老年 AKI 常合并肺部感染、心功能不全、

电解质紊乱等多种并发症,导致治疗难度增加,病死率显著高于年轻患者^[44-45]。

4. 肾功能恢复不完全率高:衰老对 CKD 的进展有很大影响,使其滤过能力及修复能力下降,部分老年患者 AKI 后无法完全恢复肾功能,最终进展为 CKD,需行长期肾脏替代治疗(KRT)或随访监测^[46-47]。

5. 多器官功能受累风险高:老年患者脏器储备功能下降,脓毒症相关老年 AKI 发生后,易引发多器官功能障碍综合征,进一步恶化预后^[48]。

三、脓毒症相关老年 AKI 的早期诊断

1. 传统肾功能指标的优化应用:血肌酐、尿素氮及尿量仍是临床基础诊断指标,但老年患者肌肉量减少,血肌酐基础水平较低,早期肾损伤时升高不明显,需结合 CKD-流行病学协作组(EPI)公式估算 GFR 动态评估^[49-50]。动态监测指标变化趋势比单次检测更具价值,血肌酐短期内升高 26.5 $\mu\text{mol/L}$ 以上应警惕早期 AKI。

2. 新型生物标志物的临床应用:中性粒细胞明胶酶相关脂质运载蛋白(NGAL)在肾损伤后数小时即可升高,特异度和敏感度较高,能提前 24 ~ 48 小时预警 AKI,尤其适用于脓毒症相关老年 AKI 的早期诊断^[51]。肾损伤分子(KIM)-1 可特异性反映肾小管上皮细胞损伤^[52],半胱抑素 C(Cys C)不受肌肉量影响,二者与 NGAL 联合检测可显著提高老年 AKI 的早期诊断准确率^[53-54]。此外,由于 miRNA 出色的稳定性及其可在体液如血液、尿液等检出及定量测量的特性,展现了其成为诊断 AKI 的新型标志物的潜力^[55],如 miR-21 在 AKI 患者血液及尿液样本中均有持续升高^[56]。

3. 影像学与实验室检查结合:肾脏超声可无创评估肾脏大小、形态及血流灌注,有助于排除梗阻性肾病等病因^[57]。结合炎症指标(如降钙素原、C 反应蛋白)及病原学检查,可明确脓毒症诊断及致病原,为针对性治疗提供依据^[58-59]。

4. 衰弱评估与风险分层:临床衰弱量表(CFS)评分 ≥ 5 分的老年人群脓毒症相关 AKI 发生率较健康人群升高 2.3 倍^[60-61]。将衰弱评估与生物标志物结合,可更精准地进行风险分层,指导早期干预。

四、脓毒症相关老年 AKI 的综合管理策略

1. 抗感染治疗:目前脓毒症相关 AKI 患者抗生素剂量调整缺乏统一指南,但早期明确或疑似脓毒症时,应及时启动经验性抗菌治疗,根据病原学检查结果调整为目标性治疗^[62-63]。选择药物时需充分考虑老年

患者肾功能状态,减少使用肾毒性药物,而部分 AKI 患者因需要进行 KRT 治疗而影响药物的药效动力学及药代动力学,因此必要时应进行治疗药物监测并调整药物使用剂量^[64-65]。

2. 液体复苏与血流动力学支持:遵循“个体化、精准化”原则进行液体复苏,首选晶体液,避免过量补液导致肺水肿^[66-68]。对液体复苏后仍存在低血压的患者,可合理使用血管活性药物维持肾脏灌注,但需避免血压过高或过低对肾脏造成二次损伤^[69-70]。

3. 药物治疗:目前仍缺少针对 AKI 的特效药物,但是一些已经上市且广泛应用的药物在相关模型中被证实可以降低 AKI 的死亡率及随之而来的 CKD 发生率,如左西孟旦可以改善肾脏供血及血流情况而降低重症 AKI 的透析率,而在肾脏功能恢复后氯沙坦则对 AKI 的愈合提供正向帮助^[71-72]。此外益母草提取物 leonurine 对 AKI 表现出治疗潜力^[73],针对氧化应激、线粒体损伤、炎症、细胞修复等通路的药物已进入早期临床试验,一些潜在的治疗靶点如转录因子 P65 和 Snail 以及 miRNA 已经进入人们视线^[74-75]。

4. KRT 的优化:KRT 在去除毒素、维持液体平衡以及纠正酸碱和电解质失衡方面极为重要,其能显著改善 AKI 患者的临床结局并降低死亡率,使之成为 AKI 的主要治疗方式^[76-77]。即使有相关研究表明 AKI 患者早期行 KRT 或延迟使用对于患者的生存率无显著影响且早期行 KRT 治疗出现不良事件如低血压及感染等的概率会相应提高,启动 KRT 的时机仍存在争议^[77-79]。但当患者出现严重电解质紊乱、肺水肿、代谢性酸中毒或严重尿毒症症状时,早期及时启动 KRT 仍是一种必要的治疗手段^[79-83]。老年患者可根据年龄、基础疾病及病情严重程度,选择血液透析或连续 KRT(CRRT),无论是间歇性血液透析(IHD)或者是 CRRT 对于老年 AKI 患者在出院时肾功能恢复方面均无显著差异^[84],其中 CRRT 因血流动力学稳定可以降低低血容量及低血压的风险且具有持续渐近的去溶质等特性,更适用于病情不稳定的老年重症患者^[43,85-86]。IHD 能快速清除液体和毒素且成本效益高,也常用于 AKI 治疗,尤其适用于血流动力学稳定的患者^[87]。对于脓毒症引起的 AKI,CRRT 联合吸附技术可以消除血液中的炎症因子从而降低脓毒症患者的死亡率^[88]。在确定透析模式后,应确定透析剂量,IHD 的推荐剂量为每周 3.9 Kt/V,而 CRRT 的推荐排放量为 20~25 ml·kg⁻¹·h⁻¹^[89-90]。

5. 衰弱导向的支持治疗:基于全面老年评估制定个体化营养方案,保证热量与蛋白质摄入,维持肌肉量与营养储备^[47,91]。积极预防和治理肺部感染、消化道

出血等并发症,改善患者整体预后。

6. 多学科协作诊疗模式:整合急诊科、肾内科、感染科、老年病科等多学科资源,为老年患者提供全程化、个体化诊疗方案,优化治疗流程^[92-93]。

7. 康复期随访与管理:AKI 缓解后,需对老年患者进行至少 1 年的随访,监测肾功能、尿常规等指标,评估是否进展为 CKD^[94-95]。加强基础疾病管理,指导患者合理用药、健康饮食,避免肾损伤诱因。

五、小结

脓毒症与老年 AKI 的关系紧密,且老年人群的生理特殊性、基础疾病分布及衰弱状态等因素使疾病诊疗更具挑战性。早期识别、及时干预是改善患者预后的关键,需结合传统指标与新型生物标志物提高早期诊断准确率。治疗过程中,应采取抗感染、液体复苏、KRT 及支持治疗相结合的综合管理策略,同时重视老年患者的个体化差异。未来,仍需开展更多针对老年人群的临床研究,探索更有效的早期诊断方法和治疗方案,进一步降低脓毒症相关老年 AKI 的病死率和远期并发症发生率。

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2026 年 1 期《临床内科杂志》综述与讲座——“老年急性肾损伤的早期诊断与综合管理”栏目导读

随着我国老龄化程度不断加深,老年人群的健康问题日益受到关注。该类人群往往一身多病,且各脏器功能衰退,急性肾损伤(AKI)作为常见且严重的临床综合征,其发病率与病死率在老年人群中显著升高。因此,加强对老年 AKI 的早期识别、精准干预与全程管理,已成为当前内科临床与公共卫生领域的重要课题。本期“综述与讲座”栏目聚焦老年 AKI 的病理生理特点、危险因素、早期诊断策略与综合管理模式,特别邀请武汉大学中南医院肾病内科吴小燕教授和王惠明教授为“老年急性肾损伤的早期诊断与综合管理”专栏组稿,并邀请该领域的资深专家撰稿,期为临床实践提供系统性参考。四川大学华西医院肾内科付平教授撰写的《老年急性肾损伤的诊疗进展》,系统阐述了老年 AKI 的临床特征、发病机制、诊断评估与风险预测,并对新型治疗与预防策略进行了展望。陆军军医大学第二附属医院肾内科赵景宏教授撰写的《老年急性肾损伤生物标志物研究进展》,全面梳理了传统与新型生物标志物在老年 AKI 早期识别中的作用,为临床早期诊断提供依据。武汉大学中南医院肾病内科查冬青教授撰写的《老年急性肾损伤的危险因素与临床表现特点》,详细分析了老年 AKI 的常见危险因素与临床特征,助力临床早期识别与干预。针对常见合并症,中南大学湘雅二医院重症医学科张东山教授撰写的《脓毒症与老年急性肾损伤》,深入探讨了脓毒症诱发 AKI 的病理生理机制与临床管理策略,强调在衰老、衰弱及共病状态下诊疗的特殊性。武汉大学人民医院肾内科梁伟教授撰写的《糖尿病与老年急性肾损伤》,则聚焦糖尿病与 AKI 的关联,系统介绍糖尿病老年患者发生 AKI 的特征、机制与防治进展。华中科技大学同济医学院附属协和医院护理部刘义兰教授撰写的《老年急性肾损伤患者的综合管理》,从多学科协作视角出发,整合内科、外科、重症医学科、感染科、中医科等多专业力量,系统阐述涵盖老年综合评估、人文关怀、中医适宜技术与延续性护理的综合照护模式,体现以患者为中心、全程整合的管理理念。

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