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·综述·

N-乙酰半胱氨酸在口腔感染性疾病防治中的研究进展

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【摘要】 N-乙酰半胱氨酸（NAC）是半胱氨酸的乙酰化衍生物，具有抗氧化、抗炎、抗菌及黏液溶解等多重生物学活性，目前已广泛应用于呼吸系统疾病的治疗。NAC不仅可通过直接清除活性氧/氮自由基及促进谷胱甘肽合成增强机体抗氧化防御能力，还可调控免疫反应、抑制核因子-κB等炎症信号通路，从而减轻炎症反应。此外，NAC通过断裂二硫键破坏生物膜结构、降低微生物毒力并提高抗菌药物的渗透性，表现出良好的抗菌及抗生物膜作用。龋病、牙周病、牙髓根尖周病及感染性口腔黏膜炎等口腔疾病的发生发展与致病菌感染、氧化应激及免疫炎症失衡密切相关。NAC可抑制变异链球菌的黏附与生物膜形成，降低其致龋毒力；通过抗菌、抗炎及抗氧化作用减轻牙周组织破坏，并可能调节骨代谢；增强对粪肠球菌生物膜的清除效果，提高抗菌药物疗效；同时抑制白色念珠菌生长及菌丝形成。随着NAC在口腔感染性疾病防治研究中逐渐展现出重要应用潜力，本文对NAC的主要生物活性及其在口腔感染性疾病中的作用机制与应用前景进行综述，以期为相关基础与临床研究提供理论依据。

【关键词】 N-乙酰半胱氨酸；　龋病；　牙周炎；　牙髓根尖周病；　口腔黏膜感染；　变异链球菌；　粪肠球菌；　白色念珠菌；　生物膜；　氧化应激
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Research progress on N-acetylcysteine in the prevention and treatment of oral infectious diseases

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【Abstract】 N-acetylcysteine (NAC) is an acetylated derivative of cysteine that exerts multiple biological activities, including antioxidant, anti-inflammatory, antimicrobial, and mucolytic effects, and has been widely used clinically for the treatment of respiratory diseases. NAC not only directly scavenges reactive oxygen and nitrogen species and strengthens endogenous antioxidant defenses by promoting glutathione synthesis but also modulates immune responses and suppresses inflammatory signaling pathways such as nuclear factor kappa B, thereby attenuating inflammation. In addition, NAC disrupts biofilm architecture by cleaving disulfide bonds, reduces microbial virulence, and enhances the penetration of antimicrobial agents, conferring robust antibacterial and antibiofilm activities. The initiation and progression of oral diseases—including dental caries, periodontal disease, pulpal-periapical disease, and infectious oral mucositis—are closely associated with pathogenic infection, oxidative stress, and dysregulated immune-inflammatory responses. NAC can inhibit *Streptococcus mutans* adhesion and biofilm formation, thereby reducing cariogenic virulence; mitigate

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periodontal tissue destruction through antimicrobial, anti-inflammatory, and antioxidant actions, and may modulate bone metabolism; enhance the clearance *of Enterococcus faecalis* biofilms and improve the efficacy of antimicrobial therapy; and inhibit the growth and hyphal formation of *Candida albicans*. Collectively, NAC is emerging as a promising agent for the prevention and treatment of oral infectious diseases. This review systematically summarizes the major bioactivities of NAC, its mechanistic actions in oral infectious diseases, and its therapeutic prospects, with the aim of providing a theoretical basis for future basic and clinical investigations.

【Key words】 N-acetylcysteine; dental caries; periodontitis; pulp and periapical diseases; oral mucosal infection; *Streptococcus mutans*; *Enterococcus faecalis*; *Candida albicans*; biofilm; oxidative stress

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N-乙酰半胱氨酸(N-acetylcysteine,NAC)是半胱氨酸的乙酰化衍生物,兼具抗炎、抗氧化和抗菌等多重生物活性,最早作为黏液溶解剂和解毒剂用于临床,广泛应用于慢性阻塞性肺疾病、慢性支气管炎及囊性纤维化等呼吸系统疾病的治疗,并被作为对乙酰氨基酚过量的特效解毒药物[1-2]。随着研究不断深入,NAC被发现具有更为广泛的生物学功能,其强效抗氧化能力可清除自由基、缓解氧化应激[3-4];通过调控免疫细胞活性促进免疫稳态恢复[5-6];并可抑制炎症通路、下调促炎因子表达,发挥抗炎作用[7-8]。此外,NAC还能抑制细菌生物膜形成并提高抗生素渗透性,具备一定的抗菌潜力[9]。在纳米技术等新型递药系统的支持下,与抗生素或免疫调节剂联合使用的NAC在生物利用度和靶向性方面均获得显著提升[10-11]。NAC的多重生物学作用使其在全身多系统疾病中有广泛研究,比如生殖系统[12-13]、心脑血管系统[14-15]、神经系统[16-18]、消化系统[19]等。

龋病、牙髓根尖周病、牙周炎及口腔黏膜感染等多种口腔感染性疾病在发生与发展过程中,普遍存在致病菌感染、氧化应激水平升高与免疫炎症反应失衡。尽管NAC所具有的多重生物学作用,使其在口腔疾病防治领域展现出重要的应用潜力,但仍然存在临床研究匮乏、局部用药剂量不统一、作用机制的口腔特异性证据薄弱等不足。本综述旨在系统阐述NAC的生物活性及其作用机制,总结其在常见口腔感染性疾病中的最新研究进展,以期为开发基于NAC的口腔疾病防治策略提供理论依据。

1　乙酰半胱氨酸的理化特性与药代动力学特点

NAC的分子式为$C_5H_9NO_3S$,具有较好的水溶性,水溶液呈弱酸性,在弱酸性环境中稳定性较好,在碱性环境中容易电离出氢离子发生氧化反应[20-21]。NAC含有巯基和乙酰基两个主要官能团,其中巯基能够与多种自由基和重金属离子发生反应,发挥抗氧化和解毒作用,同时,巯基也能断裂细菌蛋白质中的二硫键,是其发挥抗菌效应的重要机制之一[22]。

药代动力学显示,NAC口服吸收快,达峰时间通常在0.5~2 h,餐后给药会降低其吸收率;分布容积小,主要集中在血浆和肝脏中[23-24];半衰期为12~18 h,代谢产物主要经肾脏排泄[25]。口服NAC存在显著的肝脏首过效应,导致其绝对生物利用度较低,仅为4%~10%[26]。在肝脏中,NAC经氨基酸酶去乙酰化生成的半胱氨酸,参与谷胱甘肽的合成,通过提升体内谷胱甘肽水平发挥间接抗氧化作用[27]。目前,缺乏NAC局部用药的药代动力学研究。

NAC在治疗剂量范围内具有较高的安全性,不良反应多发生在大剂量使用的情况下,表现为轻度胃肠道症状,如恶心、呕吐等[28-29];静脉给药时偶见皮疹、支气管痉挛等过敏样反应,通常停药后可自行缓解[30]。这些不良反应可能与NAC对黏膜的局部刺激作用,以及少数个体对巯基结构产生的特异性反应有关[31]。NAC糊剂在局部使用时,其细胞毒性高于氢氧化钙,提示存在牙髓及根尖周组织刺激的风险[32]。

2　乙酰半胱氨酸的生物活性及在口腔感染性疾病中的作用机制

2.1　NAC的黏液溶解活性

NAC有显著的黏液溶解活性,临床上主要应用于肺部炎症相关性疾病。在肺部炎症状态下,气道产生大量黏稠的痰液,其黏稠度主要来自痰液中的黏蛋白,黏蛋白分子之间通过二硫键相互

交联，形成复杂的网状结构。二硫键是维持黏蛋白高度交联聚合网络结构，以及赋予黏液典型黏弹性的关键化学键[33-34]。而NAC分子中的巯基可断裂黏蛋白分子中的二硫键，破坏黏蛋白的聚合结构从而发挥黏液溶解作用，显著降低黏液的黏稠度和内聚力，促进其排出[35]。

除呼吸系统外，NAC在其他以黏蛋白异常增加或黏度升高为特征的疾病中亦具有潜在应用价值。重度眼干燥症患者由于泪膜黏蛋白层异常增厚，出现黏液黏度升高、形成黏液栓或黏液丝，影响泪液排出[36-37]。放射性唾液腺损伤患者因唾液水分减少、黏蛋白相对增多，唾液异常黏稠伴明显口干[38]。NAC同样可通过断裂泪液及唾液中黏蛋白二硫键，降低其黏度，从而改善相关症状。基于其良好的黏液溶解能力，NAC已被用于人工泪液及人工唾液的配方中，从而改善舍格伦综合征患者的眼干和口干表现[39]。

2.2　NAC的抗氧化活性

在生理条件下，机体持续受到活性氧/活性氮（reactive oxygen species，ROS）/（reactive nitrogen species，RNS）的攻击，依赖抗氧化防御系统维持体内的氧化还原平衡。当ROS/RNS的生成超过机体的清除能力时，便会诱发氧化应激，造成脂质、蛋白质和核酸等生物大分子的氧化损伤，从而促进多种疾病的发生与发展[40-42]。

NAC具有显著的抗氧化能力，包括直接清除自由基和通过生化代谢增强内源性抗氧化系统的抗氧化能力。NAC分子中的还原性巯基能够与ROS/RNS直接反应，减少自由基对脂质、蛋白质和DNA等细胞成分的氧化损害[43-44]。在体内，NAC还能经去乙酰化生成半胱氨酸，为谷胱甘肽合成提供前体物质，从而显著提升机体谷胱甘肽水平，增强抗氧化防御能力[4，45-46]。NAC还可修复氧化修饰的蛋白质结构，例如还原被氧化的血清白蛋白中胱氨酸的二硫键，恢复其抗氧化活性[47]。

2.3　NAC的抗炎活性

炎症反应是机体应对损伤或感染的基本防御机制，有助于清除有害刺激并促进组织修复，然而，若炎症反应过度或持续存在，则可能引发继发性组织损伤。NAC能够通过直接中和细菌产生的脂多糖，减少其与相应受体的结合，从而抑制炎症反应的初始激活[48]；同时，NAC可调控关键炎症信号通路，如抑制核因子κB（nuclear factor kappa B，NF-κB）炎症信号通路活化，降低肿瘤坏死因子-α（tumor necrosis factor-alpha，TNF-α）、白细胞介素-1β（interleukin-1 beta，IL-1β）、白细胞介素-6（interleukin-6，IL-6）等多种促炎细胞因子的表达，削弱炎症反应的强度[49-51]

氧化应激与炎症反应在多种疾病状态中相互促进，形成正反馈环路。炎症反应促进ROS生成，而ROS的积累又进一步增强炎症介质的释放，形成持续放大的病理过程。NAC凭借其强大的自由基清除能力及提升细胞内谷胱甘肽水平的作用，能够有效打破这一恶性循环，从氧化还原平衡的层面实现对炎症过程的双向调控[52]。

2.4　NAC的抗菌活性及抑制生物膜能力

NAC虽不属于传统抗生素，但具有良好的抗菌活性及抑制生物膜形成的能力，在多种感染性疾病中展现出治疗潜力。研究表明，NAC可有效抑制细菌、真菌的多种病原微生物的生物膜形成，包括铜绿假单胞菌[9]、葡萄球菌[53-54]、幽门螺杆菌[55]、结核分枝杆菌[56]、白色念珠菌[57]、粪肠球菌[48，58]。此外，NAC与其他抗菌药物联合使用可以产生协同增效的作用，与β-内酰胺类抗生素联合使用时，NAC能够显著增强β-内酰胺类抗生素对耐药肺炎克雷伯菌和鲍曼不动杆菌的抗菌活性[59]；与多黏菌素联合使用时，能增强多黏菌素对铜绿假单胞菌成熟生物膜的抗菌活性[60]。其作用机制主要包括两方面：通过断裂生物膜基质中多糖和糖蛋白分子间的二硫键，破坏生物膜结构完整性，从而促进药物渗透至生物膜深层[61-62]；干扰细胞代谢，抑制细菌素、弹性蛋白酶、溶血素等毒力因子的合成，降低致病性[60，63]。NAC对口腔主要致病菌的作用见表1。

3　N-乙酰半胱氨酸对口腔感染性疾病的影响

3.1　龋病

龋病是由细菌为主的多因素参与的慢性感染性疾病，其发生发展与牙菌斑生物膜的形成和代谢密切相关[77]。变异链球菌是主要致龋菌，主要通过黏附牙面形成生物膜、产酸及耐酸、合成胞外多糖等机制发挥致龋作用[78-80]。NAC可抑制变异链球菌生长，最低抑菌浓度（minimum inhibitory concentration，MIC）范围为0.78～10 mg/mL[65，70，81]。经NAC处理后的变异链球菌细胞呈分散状态，不再以典型的链状结构聚集；细胞形态异常，小型细胞及球形细胞增多；细胞外基质明显减少[81]。推测NAC巯基可与细菌表面结构蛋白中的二硫键反

表1　N-乙酰半胱氨酸对口腔主要致病菌的作用

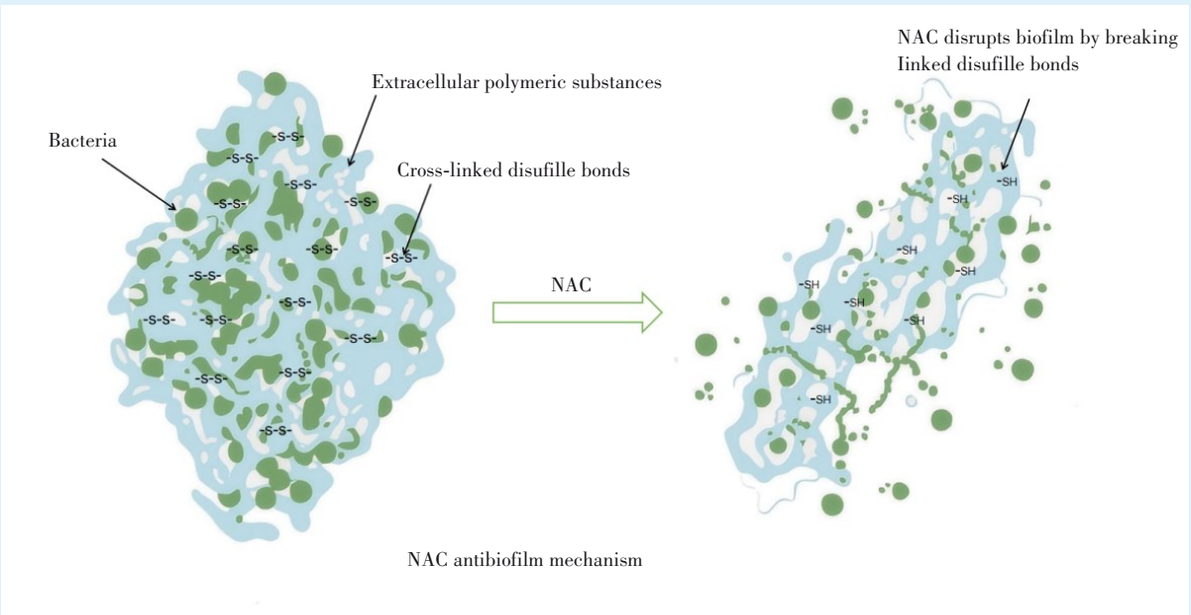
Table 1　Effects of N-acetylcysteine on major oral pathogens

Author	Year	Bacteria	MIC	NAC combined effect
Hamed[64]	2025	*Candida albicans*	Not reported	NAC exhibits synergistic antifungal activity against *Candida albicans* when combined with metal nanoparticles. NAC educes the MIC of metal nanoparticles against *Candida albicans*, with reductions of up to approximately 20-fold.
Khoury[48]	2024	*Enterococcus faecalis*, *Escherichia coli*	Not reported	Not reported
Subiksha[58]	2024	*Enterococcus faecalis*	Not reported	Not reported
Calefi[32]	2022	*Enterococcus faecalis*	Not reported	Not reported
Shen[65]	2020	*Escherichia coli*	5 - 10 mg/mL	Not reported
	2020	*Streptococcus mutans*	5 - 10 mg/mL	Not reported
Nunes[66]	2020	Fluconazole-susceptible *Candida albicans* strain	25 mg/mL	Synergistic with caspofungin; mostly indifferent or additive when combined with fluconazole or nystatin.
		Fluconazole-resistant *Candida albicans* strain	25 mg/mL	
Rastegar[67]	2019	*Enterococcus faecalis*	Not reported	Combination with levofloxacin results in a significantly greater reduction in bacterial load compared with levofloxacin alone.
Hamed[68]	2017	*Escherichia coli*	0.5 mg/mL	Combination of NAC with silver nanoparticles significantly enhances the antimicrobial activity of the silver nanoparticles.
		Candida albicans	0.125 mg/mL	
Ulusoy[69]	2016	*Escherichia coli*	12.5 mg/mL	Not reported
Moon[70]	2016	*Actinomyces naeslundii*	0.78 - 1.56 mg/mL	Not reported
		Lactobacillus salivarius	0.78 - 1.56 mg/mL	Not reported
		Streptococcus mutans	0.78 - 1.56 mg/mL	Not reported
		Enterococcus faecalis	0.78 - 1.56 mg/mL	Not reported
		Actinomyces naeslundii	0.78 mg/mL	Not reported
		Streptococcus mutans	0.78 mg/mL	Not reported
		Lactobacillus salivarius	1.56 mg/mL	Not reported
		Enterococcus faecalis	1.56 mg/mL	Not reported
Palaniswamy[71]	2016	*Enterococcus faecalis*	Not reported	Not reported
Moon[72]	2015	*Prevotella intermedia*	3 mg/mL	Not reported
Mahmoud[73]	2014	Clinical isolates of *Candida albicans*	20 mg/mL	Not reported
		Reference strain of *Candida albicans*	16.5 mg/mL	Not reported
Silveira[74]	2013	*Enterococcus faecalis*	Not reported	Combination with alexidine demonstrates no additional bactericidal beneficial attributable to NAC.
Hernandez-Romero[75]	2013	*Aggregatibacter actinomycetemcomitans*	100 mg/mL	The combination of rifampicin (1 μg/mL) and NAC (200 mg/mL) demonstrates superior antibiofilm activity: it not only inhibits biofilm formation but also eradicates biofilms at 4 - 8 h post-inoculation.
Quah[76]	2012	*Enterococcus faecalis*	pH = 7, >200 mg/mL; pH = 9, 200 mg/mL; pH = 11, 1.56 mg/mL	Not reported

MIC: minimum inhibitory concentration; NAC: N-acetylcysteine

应,使蛋白失活或变性,从而导致细胞形态改变。此外,NAC可能通过竞争性抑制变异链球菌对半胱氨酸的利用,加速细胞内谷胱甘肽耗竭,降低抗氧化防御能力干扰细胞糖代谢。

NAC能够干扰生物膜的初期附着及破坏成熟生物膜结构[82]。变异链球菌的初期黏附依赖唾液黏蛋白及菌体表面黏附分子[83]。NAC分子中的巯基能够断裂唾液黏蛋白及菌体表面黏附分子间的二硫键，从而抑制菌体黏附。对于成熟生物膜，NAC同样通过降解基质中二硫键破坏生物膜的结构完整性，从而抑制其稳定性和耐药性（图1）[81-82]。



N-acetylcysteine (NAC) disrupts disulfide bond cross-linking between macromolecular compounds in the biofilm, making the biofilm looser and more water-soluble, thereby promoting the disintegration and detachment of mature biofilms. Figure 1 was generated using Google Gemini (Google LLC, Mountain View, CA, USA) and subsequently edited in Adobe Illustrator CC (Adobe Inc., San Jose, CA, USA)

Figure 1　N-acetylcysteine antibiofilm mechanism

图1　N-乙酰半胱氨酸抗生物膜机制

目前探索NAC防龋途径的研究主要是将NAC作为功能组分加入粘接材料中，增加其抗菌性，以降低正畸患者托槽周围牙釉质脱矿风险[84]。这些研究主要以体外研究为主，通过观察单一变异链球菌在材料表面的生长情况评价其抗菌性，对真实复杂的口腔菌群生态代表性不足；同时存在材料中NAC释放动力学研究、材料的长期稳定性及耐久性评价不足等缺点。

3.2　牙周病

牙周病的发生不仅是特定病原菌感染的结果，更是宿主免疫炎症反应与口腔微生物群落之间相互作用失衡的结果，过度的免疫应答是导致牙周支持组织破坏的关键因素[85-87]。NAC通过其抗菌、抗炎、抗氧化及骨保护等多重作用，在牙周病防治中展现出多方面的潜力。NAC可直接抑制牙周致病菌如伴放线聚集杆菌、中间普氏菌的生长及生物膜形成[72, 75]，其机制可能与NAC断裂细菌蛋白及胞外基质中的二硫键有关，从而破坏细胞结构并促进生物膜溶解。过度的炎症与氧化应激是驱动牙周炎进展的关键因素[88]。NAC能够抑制NF-κB信号通路的活化，下调促炎细胞因子的表达，从而减轻脂多糖对人牙周膜成纤维细胞的炎症损伤[89]。在抗氧化方面，NAC不仅能直接中和ROS，降低牙周炎组织中的氧化负荷[90]，在糖尿病大鼠牙周炎模型中，经NAC处理后，牙周组织内破骨细胞数量减少且形态异常，而成骨细胞活性却有所增强，推测NAC可通过调节氧化应激影响骨代谢，减少牙周炎相关的牙槽骨吸收[91]；NAC可通过激活核因子E2相关因子这一关键的抗氧化转录因子，上调超氧化物歧化酶、过氧化氢酶等抗氧化酶的表达，系统性地增强机体的内在防御能力[92]。

在一项探索NAC作为漱口水对实验性龈炎预防与治疗效果的随机对照临床试验[ISRCTN（International Standard Randomised Controlled Trial Number）Registry：ISRCTN31352091]中发现，

1.25%NAC对龈炎的预防和治疗作用弱于0.2%氯己定组，虽优于安慰剂组但效果不显著[93]。该研究中，NAC治疗受限的主要原因是其自身的气味影响了受试者的耐受性，1.25%浓度已接近受试者对NAC漱口水的耐受极限。后续研究可通过优化掩味技术，以提高NAC的有效作用浓度。近年来的材料学与纳米递送研究发现，单独使用NAC治疗牙周炎时，持续用药至第4周出现了疑似促进牙槽骨吸收的现象。而将NAC封装于ROS响应纳米颗粒中，可在高ROS环境下触发材料降解并释放NAC，实现对牙周炎ROS微环境的可控调节。持续用药至第4周时，该递送系统仍能有效抑制牙槽骨丢失，提示过度清除ROS可能不利于牙槽骨修复。因此，未来更具前景的研究方向是构建可将ROS调控至有利于组织修复浓度范围内的可控药物递送系统[94]。

3.3　牙髓根尖周病

根管治疗失败的主要原因是根管系统内持续的微生物感染，其中，粪肠球菌因其强大的生物膜形成能力与耐药性，成为最主要的病原菌之一[95-97]。研究表明，NAC抑制粪肠球菌的MIC范围为0.78～200 mg/mL[67, 69, 70, 76, 82]，对粪肠球菌的抗菌活性受pH影响，酸性或者中性条件下MIC可达200 mg/mL，这与碱性环境能够促进NAC巯基解离，增强NAC与细菌蛋白质的反应活性有关[76]。NAC抑制粪肠球菌生物膜的作用机制同样是通过巯基断裂生物膜二硫键，使致密、黏稠的生物膜基质解聚、结构崩解，变得松散、易脱落[82]。

联合用药研究也显示，NAC具有潜在的协同效应，200 mg/mL NAC与2%氯己定联合使用对粪肠球菌的抑菌作用明显大于单独使用[71]。在牙髓再生性治疗中，NAC与左氧氟沙星联合使用可显著降低离体牙根管模型中粪肠球菌数量，其效果强于氢氧化钙，进一步提示协同作用的存在[67]。此外，NAC与纳米银颗粒联合应用可显著增强抗菌效果，使纳米银对大肠杆菌的MIC降低约16倍[68]。推测NAC能够破坏生物膜完整性，增加其他抗菌剂如氯己定、左氧氟沙星对细胞的渗透性，提升药物在生物膜内部的浓度，增强抑菌作用[67]。

NAC的局部用药方式包括根管冲洗液与封药糊剂。研究发现NAC作为根管冲洗液使用时，短时间内对成熟粪肠球菌生物膜的抑制作用不及传统根管冲洗药物[82]；而作为根管封药糊剂时，NAC能够显著降低粪肠球菌生物膜内的活菌比例，其效果优于氢氧化钙糊剂[32]。此外，封药7 d后，NAC降低根管内脂多糖的作用亦较氢氧化钙更为显著[48]。目前，NAC在牙髓根尖周病治疗领域的研究仍存在明显不足：以体外研究为主，缺乏临床研究证据；多数研究集中于粪肠球菌，菌群代表性有限；此外，不同研究中NAC的使用浓度、作用时间等关键参数尚不统一。

3.4　NAC对感染性口腔黏膜炎的影响

白色念珠菌是一种常见的机会致病菌，主要寄生于口腔、消化道和阴道等部位[98-100]。当宿主的免疫力下降或微生态失衡时，白色念珠菌大量繁殖并侵入黏膜，从而引发感染[101]。白色念珠菌是引起口腔念珠菌病、假膜性口炎、义齿性口炎的主要致病菌。研究表明，NAC抑制白色念珠菌的MIC为8～25 mg/mL，浓度差异可能由菌株差异引起，临床分离株MIC稍高于标准株[64, 66, 73]。

谷胱甘肽是白色念珠菌生长所必需的物质，其耗竭导致细胞内活性氧堆积，诱发氧化应激，诱导细胞凋亡，抑制白色念珠菌生长[102]。NAC抑菌的机制可能涉及干扰白色念珠菌胞内谷胱甘肽的合成，进而诱导氧化应激并触发凋亡[66]。研究显示，经NAC处理后，白色念珠菌胞内氧化应激水平较对照组升高1.75倍，膜联蛋白-V阳性细胞比例显著增加，提示凋亡过程被激活[66]。NAC其结构与半胱氨酸相似，在高浓度下，其可与半胱氨酸竞争性结合谷胱甘肽合成途径中的限速酶γ-谷氨酰半胱氨酸合成酶，抑制γ-谷氨酰半胱氨酸的合成，从而减少了细胞内谷胱甘肽的合成。

白色念珠菌的酵母—菌丝双向转换和生物膜形成是其致病的关键步骤。NAC处理可导致白色念珠菌菌丝形态消失。低浓度NAC虽促进菌体生长，但不增加菌丝的比例；高浓度NAC则完全抑制菌丝的形成，提示NAC可能通过靶向调控菌丝形成相关关键基因来实现这一效应[66, 73]。此外，NAC分子中的巯基可断裂白色念珠菌胞外基质中的二硫键，减少胞外基质的生成并促进其溶解，从而抑制生物膜的成熟[73]。

目前，关于NAC对感染性黏膜炎的研究主要集中于白色念珠菌感染，多通过体外抗菌实验观察NAC的抗菌作用，而对其抗菌机制的探讨仍显不足。此外，NAC的抗菌剂量及联合用药方案尚不统一，相关剂型研究也较为缺乏。

4 小　结

NAC凭借其抗菌、抗炎、抗氧化及调节细胞功能等多重生物学活性，在龋病、牙周病、牙髓根尖周病及感染性口腔黏膜炎等多种口腔感染性疾病的防治中展现出潜在应用价值。NAC不仅能有效抑制变异链球菌的生长并破坏其生物膜结构；还可抑制中间普氏菌、伴放线聚集杆菌等牙周病致病菌，通过下调炎症通路、激活内源性抗氧化防御以及发挥牙槽骨保护作用来缓解牙周组织破坏。此外，NAC与氯己定等药物联用可产生协同效应，通过破坏细菌结构和生物膜形成来抑制粪肠球菌；同时，其对白色念珠菌的生长、生物膜形成及酵母—菌丝双向转换亦具有抑制作用。

尽管现有研究已证实NAC在口腔感染性疾病防治中的潜力，但证据主要来源于体外研究，人体研究数据不足，限制了NAC在口腔疾病中转化应用的确定性。未来研究可致力于深入阐明NAC在复杂口腔微环境中的分子作用机制，开展局部用药制剂及相关药物动力学研究，并通过体内实验和临床试验验证其有效性与安全性。随着相关研究不断深入，NAC有望成为口腔感染性疾病多学科防治策略中的重要组成部分。

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参考文献

[1] Nakatsu L, Lopez JR, Garcia CM, et al. Comparison of two-bag and three-bag acetylcysteine regimens in the treatment of paracetamol poisoning: a systematic review and meta-analysis[J]. Clin Toxicol (Phila), 2025, 63(3): 155-165. doi: 10.1080/15563650.2025.2456116.

[2] Lewis JC, Lim M, Lai L, et al. Evaluation of N-acetylcysteine dose for the treatment of massive acetaminophen ingestion[J]. Clin Toxicol (Phila), 2022, 60(4): 507-513. doi: 10.1080/15563650.2021.1984503.

[3] Sahasrabudhe SA, Terluk MR, Kartha RV. N-acetylcysteine pharmacology and applications in rare diseases-repurposing an old antioxidant[J]. Antioxidants (Basel), 2023, 12(7): 1316. doi: 10.3390/antiox12071316.

[4] Lizzo G, Migliavacca E, Lamers D, et al. A randomized controlled clinical trial in healthy older adults to determine efficacy of glycine and N-acetylcysteine supplementation on glutathione redox status and oxidative damage[J]. Front Aging, 2022, 3: 852569. doi: 10.3389/fragi.2022.852569.

[5] Albeltagy RS, Dawood SM, Mumtaz F, et al. Antioxidant capacity of N-acetylcysteine against the molecular and cytotoxic implications of cadmium chloride leading to hepatotoxicity and vital progression[J]. Environ Sci Pollut Res Int, 2023, 30(9): 23237-23247. doi: 10.1007/s11356-022-23823-x.

[6] Zhou W, Qu M, Yue Y, et al. Acetylcysteine synergizes PD-1 blockers against colorectal cancer progression by promoting $TCF1^{+}PD1^{+}CD8^{+}$ T cell differentiation[J]. Cell Commun Signal, 2024, 22(1): 503. doi: 10.1186/s12964-024-01848-8.

[7] Azarmehr Z, Poshtareh F, Shafiei N, et al. The neuroprotective effect of N-acetylcysteine by regulating inflammation and expression of TNF-α and ERK gene expression in the rats exposed to different doses of cadmium[J]. Mol Biol Rep, 2025, 52(1): 666. doi: 10.1007/s11033-025-10777-9.

[8] Gouda AR, El-Bassiouny NA, Salahuddin A, et al. Repurposing of high-dose N-acetylcysteine as anti-inflammatory, antioxidant and neuroprotective agent in moderate to severe traumatic brain injury patients: a randomized controlled trial[J]. Inflammopharmacology, 2025, 33(6): 3307-3316. doi: 10.1007/s10787-025-01706-0.

[9] Manoharan A, Whiteley G, Kuppusamy R, et al. Combating biofilm formation and bacterial killing: N-acetylcysteine's efficacy against *Pseudomonas aeruginosa* in urinary catheters[J]. Biofilm, 2025, 10: 100296. doi: 10.1016/j.bioflm.2025.100296.

[10] Josef M, Abdellatif MM, Abdelmonem R, et al. Invasomes and nanostructured lipid carriers for targeted delivery of ceftazidime combined with N-acetylcysteine: a novel approach to treat *Pseudomonas aeruginosa*-induced keratitis[J]. Pharmaceutics, 2025, 17

(9): 1184. doi: 10.3390/pharmaceutics17091184.

[11] Wang R, Li B, Dong M, et al. Targeting oxidative damage in diabetic foot ulcers: integrative strategies involving antioxidant drugs and nanotechnologies[J]. Burns Trauma, 2025, 13: tkaf020. doi: 10.1093/burnst/tkaf020.

[12] Karakoç E, Halaçlı SO, Hanelçi RH, et al. N-acetylcysteine stimulates organelle malfunction in endometriotic cells *via* IFN-gamma signaling[J]. Sci Rep, 2025, 15(1): 15120. doi: 10.1038/s41598-025-00195-z.

[13] Fang YQ, Ding H, Li T, et al. N-acetylcysteine supplementation improves endocrine-metabolism profiles and ovulation induction efficacy in polycystic ovary syndrome[J]. J Ovarian Res, 2024, 17(1): 205. doi: 10.1186/s13048-024-01528-8.

[14] Zhou D, Yang Y, Chen J, et al. N-acetylcysteine protects against myocardial ischemia-reperfusion injury through anti-ferroptosis in type 1 diabetic mice[J]. Cardiovasc Toxicol, 2024, 24(5): 481-498. doi: 10.1007/s12012-024-09852-7.

[15] Sun M, Lu Z, Chen WM, et al. N-acetylcysteine therapy reduces major adverse cardiovascular events in patients with type 2 diabetes mellitus[J]. Atherosclerosis, 2025, 402: 119117. doi: 10.1016/j.atherosclerosis.2025.119117.

[16] Pan X, Su Z, Huang Z, et al. N-acetylcysteine (NAC) ameliorates ethanol-induced oxidative stress, neuroinflammation, and cognitive dysfunction in APP/PS1 mouse model[J]. Transl Psychiatry, 2025, 15(1): 435. doi: 10.1038/s41398-025-03496-z.

[17] Sun Y, Liu C, Liang Y, et al. Mitophagy activation by N-acetylcysteine protects against Mic60 deficiency-induced auditory neuropathy[J]. Neurosci Bull, 2026, 42(3): 630-648. doi: 10.1007/s12264-025-01485-2.

[18] Yang YS, Maddock RJ, Zhang H, et al. N-Acetylcysteine effects on glutathione and glutamate in schizophrenia: a preliminary MRS study[J]. Psychiatry Res Neuroimaging, 2022, 325: 111515. doi: 10.1016/j.pscychresns.2022.111515.

[19] Koonsiripaiboon P, Ruamtawee W, Simasingha N, et al. Efficacy of N-acetylcysteine *vs* dexamethasone in preventing postembolization syndrome post-transarterial chemoembolization in hepatocellular carcinoma: a randomized controlled trial[J]. World J Gastroenterol, 2025, 31(31): 109630. doi: 10.3748/wjg.v31.i31.109630.

[20] Shu J, Li P, Huang X, et al. Solid – liquid equilibrium modeling and analysis of acetylcysteine in 12 pure solvents[J]. J Chem Eng Data, 2023, 68(12): 3435-3443. doi:10.1021/acs.jced.3c00458.

[21] Primas N, Lano G, Brun D, et al. Stability study of parenteral N-acetylcysteine, and chemical inhibition of its dimerization[J]. Pharmaceuticals (Basel), 2023, 16(1): 72. doi: 10.3390/ph16010072.

[22] Valent I, Bednárová L, Schreiber I, et al. Reaction of N-acetylcysteine with Cu^{2+}: appearance of intermediates with high free radical scavenging activity: implications for anti-/ pro-oxidant properties of thiols[J]. Int J Mol Sci, 2022, 23(11): 6199. doi: 10.3390/ijms23116199.

[23] Chen J, Hwang DW, Chen YW, et al. MRI detection of hepatic N-acetylcysteine uptake in mice[J]. Biomedicines, 2022, 10(9): 2138. doi: 10.3390/biomedicines10092138.

[24] Fayed MS, Brooks J, Seaquist ER, et al. Population pharmacokinetic model of N-acetylcysteine during periods of recurrent hypoglycemia in healthy volunteers[J]. Clin Pharmacol Drug Dev, 2023, 12(12): 1234-1240. doi: 10.1002/cpdd.1338.

[25] Sun J, Zhang X, Wang L, et al. Phase I study of the pharmacokinetics and safety of single and multiple doses of intravenous N-acetylcysteine in healthy Chinese subjects[J]. Eur Rev Med Pharmacol Sci, 2023, 27(24): 12103-12111. doi: 10.26355/eurrev_202312_34808.

[26] Wang J, Zhang W. Pharmacokinetics and bioequivalence of acetylcysteine granules among Chinese healthy volunteers under fasting and postprandial conditions[J]. Clin Pharmacol Drug Dev, 2026, 15(2): e1605. doi: 10.1002/cpdd.1605.

[27] Pedre B, Barayeu U, Ezeriņa D, et al. The mechanism of action of N-acetylcysteine (NAC): the emerging role of H_2S and sulfane sulfur species[J]. Pharmacol Ther, 2021, 228: 107916. doi: 10.1016/j.pharmthera.2021.107916.

[28] Gray KM, Tomko RL, Baker NL, et al. N-acetylcysteine for youth cannabis use disorder: randomized controlled trial main findings [J]. Neuropsychopharmacology, 2025, 50(5): 731-738. doi: 10.1038/s41386-025-02061-y.

[29] Emara SM, Fahmy SF, AbdelSalam MM, et al. Effect of high-dose N-acetyl cysteine on the clinical outcome of patients with diabetic peripheral neuropathy: a randomized controlled study[J]. Diabetol Metab Syndr, 2025, 17(1): 79. doi: 10.1186/s13098-025-01624-9.

[30] Lei TY, Chuan LF, Xing XQ, et al. Anaphylactoid reactions to acetylcysteine treatment in wild mushroom poisoning patients in Yunnan, China[J]. Clin Toxicol (Phila), 2025, 63(7): 458-465. doi: 10.1080/15563650.2025.2509723.

[31] Humphries C, Pettie J, Agboola B, et al. Scottish and newcastle antiemetic protocol (SNAP) 12-hour acetylcysteine regimen for paracetamol overdose reduces anaphylactoid reactions without compromising hepatic protection in all age groups: a secondary analysis[J]. Emerg Med J, 2025, 43(1): 3-7. doi: 10.1136/emermed-2024-214533.

[32] Calefi PHS, de Azevedo Queiroz I, Alcalde M, et al. Comparison of the physicochemical properties, antimicrobial action, and cytotoxicity of ambroxol hydrochloride, N-acetylcysteine, and calcium hydroxide pastes[J]. Eur Endod J, 2022, 7(3): 217-222. doi: 10.14744/eej.2022.30306.

[33] Abrami M, Biasin A, Tescione F, et al. Mucus structure, viscoelastic properties, and composition in chronic respiratory diseases[J]. Int J Mol Sci, 2024, 25(3): 1933. doi: 10.3390/ijms25031933.

[34] Duong K, Moss E, Reichhardt C. Solid-state NMR compositional analysis of sputum from people with cystic fibrosis[J]. Solid State Nucl Magn Reson, 2024, 134: 101975. doi: 10.1016/j.ssnmr.2024.101975.

[35] Rogliani P, Manzetti GM, Gholamalishahi S, et al. Impact of N-acetylcysteine on mucus hypersecretion in the airways: a systematic review[J]. Int J Chron Obstruct Pulmon Dis, 2024, 19: 2347-2360. doi: 10.2147/COPD.S474512.

[36] Cui KW, Myung DJ, Fuller GG. Tear film stability as a function of tunable mucin concentration attached to supported lipid bilayers [J]. J Phys Chem B, 2022, 126(33): 6338-6344. doi: 10.1021/acs.

jpcb.2c04154.

[37] Jin H, Chen X, Ji F, et al. Changes in tear cytokine and lactoferrin levels in postmenopausal women with primary acquired nasolacrimal duct obstruction complicated with obstructed meibomian gland dysfunction[J]. BMC Ophthalmol, 2025, 25(1): 29. doi: 10.1186/s12886-025-03866-7.

[38] Gunning JA, Limesand KH. Chronic phenotypes underlying radiation-induced salivary gland dysfunction[J]. J Dent Res, 2024, 103(8): 778-786. doi: 10.1177/00220345241252396.

[39] Eghtedari Y, Oh LJ, Di Girolamo N, et al. The role of topical N-acetylcysteine in ocular therapeutics[J]. Surv Ophthalmol, 2022, 67(2): 608-622. doi: 10.1016/j.survophthal.2021.07.008.

[40] Bøgh HL, Stanislaus S, Kjærstad HL, et al. Associations between levels of oxidative nucleoside damage and cardiovascular risk in patients newly diagnosed with bipolar disorder and their unaffected relatives[J]. Transl Psychiatry, 2022, 12(1): 327. doi: 10.1038/s41398-022-02095-6.

[41] Koutakis P, Hernandez H, Miserlis D, et al. Oxidative damage in the gastrocnemius predicts long-term survival in patients with peripheral artery disease[J]. NPJ Aging, 2024, 10(1): 21. doi: 10.1038/s41514-024-00147-3.

[42] Cao X, Sumed Y, Phannika T, et al. Biomarker changes before and after the 2024 peak burning period in healthy, diabetic, and hypertensive residents of Chiang Mai, Thailand[J]. Front Public Health, 2025, 13: 1535448. doi: 10.3389/fpubh.2025.1535448.

[43] Li YL, Wang G, Wang BW, et al. The potential treatment of N-acetylcysteine as an antioxidant in the radiation-induced heart disease[J]. Cardiovasc Diagn Ther, 2024, 14(4): 509-524. doi: 10.21037/cdt-24-19.

[44] Yilmaz H, Mercantepe F, Tumkaya L, et al. The potential antioxidant effect of N-acetylcysteine on X-ray ionizing radiation-induced pancreas islet cell toxicity[J]. Biochem Biophys Res Commun, 2023, 685: 149154. doi: 10.1016/j.bbrc.2023.149154.

[45] Zheng J, Zhang W, Ito J, et al. N-acetyl-l-cysteine averts ferroptosis by fostering glutathione peroxidase 4[J]. Cell Chem Biol, 2025, 32(5): 767-775.e5. doi: 10.1016/j.chembiol.2025.04.002.

[46] Mapamba DA, Sabi I, Lalashowi J, et al. N-acetylcysteine modulates markers of oxidation, inflammation and infection in tuberculosis[J]. J Infect, 2025, 90(2): 106379. doi: 10.1016/j.jinf.2024.106379.

[47] Eligini S, Munno M, Modafferi G, et al. N-acetylcysteine, N-acetylcysteine amide, and thioredoxin mimetic peptides regenerate mercaptoalbumin and exhibit antioxidant activity[J]. Antioxidants (Basel), 2024, 13(3): 351. doi: 10.3390/antiox13030351.

[48] Khoury RD, Abu Hasna A, Gagliardi CF, et al. Antimicrobial and anti-endotoxin activity of N-acetylcysteine, calcium hydroxide and their combination against *Enterococcus faecalis*, *Escherichia coli* and lipopolysaccharides[J]. PeerJ, 2024, 12: e18331. doi: 10.7717/peerj.18331.

[49] Soleimani P, Nekoonam S, Zafari F, et al. Effects of the combination of melatonin and N-acetylcysteine on the inflammatory response in a rat model of cerebral ischemia[J]. IBRO Neurosci Rep, 2025, 19: 83-90. doi: 10.1016/j.ibneur.2025.06.004.

[50] Asgharzadeh J, Derakhshan L, Asgharzadeh N, et al. N-acetylcysteine reduces the hepatic complications of social isolation stress through modulation of interleukin 1 and 6 gene expression and liver enzymes in mice[J]. Sci Rep, 2025, 15(1): 23166. doi: 10.1038/s41598-025-01557-3.

[51] 邱心一, 宋璐彤, 任双双, 等. 活性氧响应的纳米颗粒对炎性环境下牙龈成纤维细胞功能的影响及机制[J]. 口腔疾病防治, 2024, 32(4): 257-265. doi: 10.12016/j. issn. 2096-1456.2024.04.003.
Qiu XY, Song LT, Ren SS, et al. Effect and mechanism of reactive oxygen species-responsive nanoparticles on the regulation of human gingival fibroblast function and inflammation induced by lipopolysaccharide[J]. J Prev Treat Stomatol Dis, 2024, 32(4): 257-265. doi: 10.12016/j.issn.2096-1456.2024.04.003.

[52] Sadowski M, Zawieja E, Chmurzynska A. The impact of N-acetylcysteine on lactate, biomarkers of oxidative stress, immune response, and muscle damage: a systematic review and meta-analysis[J]. J Cell Mol Med, 2024, 28(23): e70198. doi: 10.1111/jcmm.70198.

[53] Ahmed R, Elekhnawy E. Unveiling the potential antibacterial action of acetylcysteine for managing *Staphylococcus aureus* wound infections: *in vitro* and *in vivo* study[J]. World J Microbiol Biotechnol, 2025, 41(4): 134. doi: 10.1007/s11274-025-04333-7.

[54] Pazarci Ö, Hümeyra Taşkin Kafa A, Taş A, et al. Assessment of the antimicrobial and antibiofilm activity of the combination of N-acetyl cysteine and carvacrol against *Staphylococcus aureus*, the most common orthopedic infectious agent[J]. Microb Pathog, 2024, 196: 106934. doi: 10.1016/j.micpath.2024.106934.

[55] Alam MI, Paget T, Moosa NY, et al. Liposomal drug delivery against *Helicobacter pylori* using furazolidone and N-acetyl cysteine in augmented therapy[J]. Pharmaceutics, 2024, 16(9): 1123. doi: 10.3390/pharmaceutics16091123.

[56] Mapamba DA, Sauli E, Mrema L, et al. Impact of N-acetyl cysteine (NAC) on tuberculosis (TB) patients-a systematic review[J]. Antioxidants (Basel), 2022, 11(11): 2298. doi: 10.3390/antiox11112298.

[57] Zuo XS, Wang QY, Wang SS, et al. The role of N-acetylcysteine on adhesion and biofilm formation of *Candida parapsilosis* isolated from catheter-related candidemia[J]. J Med Microbiol, 2024, 73(7): 001848. doi: 10.1099/jmm.0.001848.

[58] Subiksha K, Jena A, Sarangi P, et al. Comparative evaluation of antibacterial efficacy of N-acetylcysteine, aegle marmelos, and chitosan as intracanal medicaments against *Enterococcus faecalis* biofilm - an *in vitro* study[J]. J Conserv Dent Endod, 2024, 27(12): 1246-1250. doi: 10.4103/JCDE.JCDE_588_24.

[59] De Angelis M, Mascellino MT, Miele MC, et al. High activity of N-acetylcysteine in combination with beta-lactams against carbapenem-resistant *Klebsiella pneumoniae* and *Acinetobacter baumannii*[J]. Antibiotics (Basel), 2022, 11(2): 225. doi: 10.3390/antibiotics11020225.

[60] Valzano F, Boncompagni SR, Micieli M, et al. Activity of N-acetylcysteine alone and in combination with colistin against *Pseudomonas aeruginosa* biofilms and transcriptomic response to N-

acetylcysteine exposure[J]. Microbiol Spectr, 2022, 10(4): e0100622. doi: 10.1128/spectrum.01006-22.

[61] Llamosí M, Sempere J, Coronel P, et al. Combination of cefditoren and N-acetyl-l-cysteine shows a synergistic effect against multidrug-resistant *Streptococcus pneumoniae* biofilms[J]. Microbiol Spectr, 2022, 10(6): e0341522. doi: 10.1128/spectrum.03415-22.

[62] da Silva AM, Murillo DM, Anbumani S, et al. N-acetylcysteine effects on extracellular polymeric substances of *Xylella fastidiosa*: a spatiotemporal investigation with implications for biofilm disruption[J]. Int J Antimicrob Agents, 2024, 64(5): 107340. doi: 10.1016/j.ijantimicag.2024.107340.

[63] Hamed S, Emara M, Tohidifar P, et al. N-Acetyl cysteine exhibits antimicrobial and anti-virulence activity against *Salmonella enterica*[J]. PLoS One, 2025, 20(1): e0313508. doi: 10.1371/journal.pone.0313508.

[64] Hamed S, Emara M. Synergistic antifungal and antiviral activity of metal and metal oxide nanoparticles combined with N-acetyl cysteine against *Candida albicans*, adenovirus, and SARS-CoV-2" [J]. Bratislava Med J, 2025, 126(9): 2129-2139. doi: 10.1007/s44411-025-00223-4.

[65] Shen Y, Li P, Chen X, et al. Activity of sodium lauryl sulfate, rhamnolipids, and N-acetylcysteine against biofilms of five common pathogens[J]. Microb Drug Resist, 2020, 26(3): 290-299. doi: 10.1089/mdr.2018.0385.

[66] Nunes TSBS, Rosa LM, Vega-Chacón Y, et al. Fungistatic action of N-acetylcysteine on *Candida albicans* biofilms and its interaction with antifungal agents[J]. Microorganisms, 2020, 8(7): 980. doi: 10.3390/microorganisms8070980.

[67] Rastegar Khosravi M, Khonsha M, Ramazanzadeh R. Combined effect of levofloxacin and N-acetylcysteine against *Enterococcus faecalis* biofilm for regenerative endodontics: an *in vitro* study[J]. Iran Endod J, 2019, 14(1): 40-46. doi: 10.22037/iej.v14i1.21245.

[68] Hamed S, Emara M, Shawky RM, et al. Silver nanoparticles: antimicrobial activity, cytotoxicity, and synergism with N-acetyl cysteine[J]. J Basic Microbiol, 2017, 57(8): 659-668. doi: 10.1002/jobm.201700087.

[69] Ulusoy AT, Kalyoncuoğlu E, Reis A, et al. Antibacterial effect of N-acetylcysteine and taurolidine on planktonic and biofilm forms of *Enterococcus faecalis*[J]. Dent Traumatol, 2016, 32(3): 212-218. doi: 10.1111/edt.12237.

[70] Moon JH, Choi YS, Lee HW, et al. Antibacterial effects of N-acetylcysteine against endodontic pathogens[J]. J Microbiol, 2016, 54(4): 322-329. doi: 10.1007/s12275-016-5534-9.

[71] Palaniswamy U, Lakkam SR, Arya S, et al. Effectiveness of N-acetyl cysteine, 2% chlorhexidine, and their combination as intracanal medicaments on *Enterococcus faecalis* biofilm[J]. J Conserv Dent, 2016, 19(1): 17-20. doi: 10.4103/0972-0707.173186.

[72] Moon JH, Jang EY, Shim KS, et al. *In vitro* effects of N-acetyl cysteine alone and in combination with antibiotics on *Prevotella intermedia*[J]. J Microbiol, 2015, 53(5): 321-329. doi: 10.1007/s12275-015-4500-2.

[73] Mahmoud Abd El-Baky R, Mohamed Mohamed Abo El Ela D, Fadl Mamoud Gad G. N-acetylcysteine inhibits and eradicates *Candida albicans* biofilms[J]. Am J Infect Dis Microbiol, 2014, 2(5): 122-130. doi: 10.12691/ajidm-2-5-5.

[74] Silveira LFM, Baca P, Arias-Moliz MT, et al. Antimicrobial activity of alexidine alone and associated with N-acetylcysteine against *Enterococcus faecalis* biofilm[J]. Int J Oral Sci, 2013, 5(3): 146-149. doi: 10.1038/ijos.2013.58.

[75] Hernandez-Romero C, Hernandez-Delgadillo R, Galindo-Rodríguez S, et al. Rifampicin and N-acteylcisteyne inhibit oral bacterial growth and biofilm formation[J]. Pharma Innov, 2013, 2(3): 16-23.

[76] Quah SY, Wu S, Lui JN, et al. N-acetylcysteine inhibits growth and eradicates biofilm of *Enterococcus faecalis*[J]. J Endod, 2012, 38(1): 81-85. doi: 10.1016/j.joen.2011.10.004.

[77] Tian S, Ding T, Li H. Oral microbiome in human health and diseases[J]. mLife, 2024, 3(3): 367-383. doi: 10.1002/mlf2.12136.

[78] Mazurel D, Brandt BW, Boomsma M, et al. *Streptococcus mutans* and caries: a systematic review and meta-analysis[J]. J Dent Res, 2025, 104(6): 594-603. doi: 10.1177/00220345241303880.

[79] Moon J, Seo K, Kwon JS. Novel two-stage expansion of *Streptococcus mutans* biofilm supports EPS-targeted prevention strategies for early childhood caries[J]. NPJ Biofilms Microbiomes, 2025, 11(1): 65. doi: 10.1038/s41522-025-00699-6.

[80] Sekiya M, Ikeda K, Yonai A, et al. F-type proton-pumping ATPase mediates acid tolerance in *Streptococcus mutans*[J]. J Appl Microbiol, 2023, 134(4): lxad073. doi: 10.1093/jambio/lxad073.

[81] Rasmussen K, Nikrad J, Reilly C, et al. N-Acetyl-l-cysteine effects on multi-species oral biofilm formation and bacterial ecology[J]. Lett Appl Microbiol, 2016, 62(1): 30-38. doi: 10.1111/lam.12513.

[82] Choi YS, Kim C, Moon JH, et al. Removal and killing of multispecies endodontic biofilms by N-acetylcysteine[J]. Braz J Microbiol, 2018, 49(1): 184-188. doi: 10.1016/j.bjm.2017.04.003.

[83] Inostroza C, Berríos P, Orellana I, et al. How force drives pathogenicity: mechanoregulation of *Streptococcus mutans* adhesion to collagen[J]. Crit Rev Microbiol, 2025: 1-17. doi: 10.1080/1040841X.2025.2584074.

[84] Wahab A, Ganiger C, Pawar R, et al. Anti-microbial and microleakage properties of orthodontic cement[J]. Bioinformation, 2024, 20(10): 1368-1373. doi: 10.6026/9732063002001368.

[85] Baima G, Arce M, Romandini M, et al. Inflammatory and immunological basis of periodontal diseases[J]. J Periodontal Res, 2025. doi: 10.1111/jre.70040.

[86] Duran-Pinedo A, Solbiati JO, Teles F, et al. Longitudinal host-microbiome dynamics of metatranscription identify hallmarks of progression in periodontitis[J]. Microbiome, 2025, 13(1): 119. doi: 10.1186/s40168-025-02108-8.

[87] Mo S, Jang JS, Lee SH, et al. Single-cell transcriptome analysis reveals periodontal ligament fibroblast heterogeneity with distinct IL-1β and RANKL expression in periodontitis[J]. Mol Cells, 2024, 47(4): 100059. doi: 10.1016/j.mocell.2024.100059.

[88] Patil RT, Dhadse PV, Salian SS, et al. Role of oxidative stress in periodontal diseases[J]. Cureus, 2024, 16(5): e60779. doi: 10.7759/cureus.60779.

[89] Jiang Y, Yang P, Li C, et al. Periostin regulates LPS-induced apoptosis *via* Nrf2/HO-1 pathway in periodontal ligament fibroblasts[J]. Oral Dis, 2023, 29(5): 2188-2204. doi: 10.1111/odi.14189.

[90] Chu Y, Xu Y, Yang W, et al. N-acetylcysteine protects human periodontal ligament fibroblasts from pyroptosis and osteogenic differentiation dysfunction through the SIRT1/NF-κB/Caspase-1 signaling pathway[J]. Arch Oral Biol, 2023, 148: 105642. doi: 10.1016/j.archoralbio.2023.105642.

[91] Toker H, Ozdemir H, Balcı H, et al. N-acetylcysteine decreases alveolar bone loss on experimental periodontitis in streptozotocin-induced diabetic rats[J]. J Periodontal Res, 2012, 47(6):793-799.

[92] Yang Y, Ren D, Peng B, et al. Promotion of inflammatory response in mice with diabetes periodontitis: regulation of forkhead box protein M1 silencing to mediate activator protein-1 *via* reactive oxygen species production[J]. Cytojournal, 2024, 21: 72. doi: 10.25259/Cytojournal_143_2024.

[93] Al-Kamel A, Al-Hajj WA, Halboub E, et al. N-acetyl cysteine versus chlorhexidine mouthwashes in prevention and treatment of experimental gingivitis: a randomized, triple-blind, placebo-controlled clinical trial[J]. Clin Oral Investig, 2019, 23(10): 3833-3842. doi: 10.1007/s00784-019-02813-3.

[94] Qiu X, Yu Y, Liu H, et al. Remodeling the periodontitis microenvironment for osteogenesis by using a reactive oxygen species-cleavable nanoplatform[J]. Acta Biomater, 2021, 135: 593-605. doi: 10.1016/j.actbio.2021.08.009.

[95] Godoi-Jr EP, Bronzato JD, Francisco PA, et al. Microbiological profile of root canals indicated for endodontic retreatment due to secondary endodontic infections or for prosthetic reasons[J]. Clin Oral Investig, 2023, 27(5): 2049-2064. doi: 10.1007/s00784-023-04947-x.

[96] Sharma J, Jhamb S, Mehta M, et al. Prevalence of *Enterococcus faecalis* in refractory endodontic infections: a microbiological study [J]. J Conserv Dent Endod, 2025, 28(5): 462-467. doi: 10.4103/JCDE.JCDE_871_24.

[97] Manoil D, Cerit EE, Fang H, et al. Profiling antibiotic susceptibility among distinct *Enterococcus faecalis* isolates from dental root canals[J]. Antibiotics (Basel), 2023, 13(1): 18. doi: 10.3390/antibiotics13010018.

[98] Schille TB, Sprague JL, Naglik JR, et al. Commensalism and pathogenesis of *Candida albicans* at the mucosal interface[J]. Nat Rev Microbiol, 2025, 23(8): 525-540. doi: 10.1038/s41579-025-01174-x.

[99] Karajacob AS, Azizan NB, Al-Maleki ARM, et al. *Candida* species and oral mycobiota of patients clinically diagnosed with oral thrush [J]. PLoS One, 2023, 18(4): e0284043. doi: 10.1371/journal.pone.0284043.

[100] Delavy M, Sertour N, Patin E, et al. Unveiling *Candida albicans* intestinal carriage in healthy volunteers: the role of micro- and mycobiota, diet, host genetics and immune response[J]. Gut Microbes, 2023, 15(2): 2287618. doi: 10.1080/19490976.2023.2287618.

[101] Patel M. Oral cavity and *Candida albicans*: colonisation to the development of infection[J]. Pathogens, 2022, 11(3): 335. doi: 10.3390/pathogens11030335.

[102] Wangsanut T, Pongpom M. The role of the glutathione system in stress adaptation, morphogenesis and virulence of pathogenic fungi [J]. Int J Mol Sci, 2022, 23(18): 10645. doi: 10.3390/ijms231810645.

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